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Contamination and Potential Risks of Heavy Metals in the Sediments of the Chari and Logon Rivers in N'Djamena, Chad

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Abstract

The pollution of sediments by inorganic pollutants requires particularly important attention because of their toxicity, their persistence in the environment and their bioaccumulation by animal and plant life. The pollution of sediments by inorganic pollutants requires particularly important attention because of their toxicity, their persistence in the environment and their bioaccumulation by animal and plant living beings. This study focuses on the pollution of sediments of the Chari and Logon rivers in the city of N'Djamena by heavy metals. The objective of this study is to evaluate the degree of contamination, the geo-accumulation index and the degree of the Pollutant Loading Index of some heavy metals (Pb, Cr, Cu, Mn and Cd) and iron in the sediments of the sampled sites. The average concentrations of heavy metals and iron in the sediments are: Pb (10.00 ± 00 µg/Kg to 126 ± 16.52 µg/Kg); Cr VI (0.13 ± 00 mg/Kg to 0.21 ± 00 mg/Kg); Cd (trace); Cu (0.08 ± 0.02 mg/kg to 3.23 ± 0.64 mg/kg); Fe (0.25 ± 0.00 mg/kg to 5.79 ± 0.00 mg/kg); and Mn (0.2 ± 0.00 mg/Kg to 1.1 ± 0.00 mg/Kg); in order of highest to lowest abundance: Fe > Mn > Cd > Cu > Cr VI > Pb for the Logon; Fe > Cu > Mn > Cd > Cr VI > Pb for the Chari and Fe > Mn > Cu > Cd > Cr VI > Pb for the Confluent. The contamination factors for all heavy metals range from no contamination to low contamination for the sediments analyzed. The geo-accumulation indices indicate that the sampled sites are not polluted. The same is true for Er and RI which confirm an absence of ecological risks in the analyzed sediments.

Keywords

Heavy Metals, Contamination Factor, Geo-Accumulation Index, Ecological

Risk Index, Chari and Logone Rivers in Chad

1. Introduction

The Chari and the Logon are the rivers that surround the city of N'Djamena on the southern side and play the role of the receptacle of wastewater, urban and industrial effluents as well as erosion and runoff water [1]. These inputs are a priori a source of various types of pollutants whose dispersion in the environment is of great interest to the scientific community [2]. Among these pollutants, heavy metals present in the earth's crust are released by the alteration and erosion of rocks [3] [4] [5]. The rivers ensure several functions such as transport, irrigation, source of fish but also the production of domestic water [6]. In compliance with different standards and scientific objectives, several ecological functions of rivers have been evaluated and studied considering water quality [7] [8], hydrological process [9] [10], animal population dynamics [11], sediment quality [12] and aquatic flora [13] [14].

Heavy metals are known to be non-biodegradable and persistent for long periods of time in both aquatic and terrestrial environments [15] [16] [17] [18]. Heavy metals present in an aquatic environment accumulate in the sediments and only a small proportion remains in the water [19]. From an ecological point of view, toxicity is evaluated according to the mobility of heavy metals and depends on several parameters such as the dynamic conditions that fix the metal, the type of chemical bonding and the properties of the metal [20].

This work focuses on heavy metal contamination that can easily impact human health. Specifically, it is necessary to determine the concentrations of Pb, Cr, Cu, Cd, Mn and Fe in the Chari and Logon rivers and to evaluate their pollution level and ecological risks. The knowledge of heavy metal levels will allow the prediction of diseases to which the people living on the study site will be exposed as well as the probable environmental disorders.

2. Material and Methods

2.1. Description of the Study Area

The Chari River (1200 km long) and its main tributary, the Logon (950 km long), constitute the main hydrographic network in Chad (**Figure 1**). The confluence of these two rivers at N'Djamena cumulates the waters that flow into Lake Chad. These two rivers have passed through all the major cities of southern Chad, supporting all human activities related to the use of surface water (irrigated crops, discharge of urban and industrial liquid effluents, dumping of household and industrial waste, etc.). The rains water the watersheds of these rivers from May to September in the south of the country, which results in a rise in water levels which reaches its peak in September at N'Djamena. Then the water empties into Lake Chad to reach low water from March to June in

N'Djamena [10]. In the Sahelian part of the country where N'Djamena is located, two seasons are shared unequally throughout the year. There is a dry season that lasts a little less than nine (9) months while the rainy season lasts a little more than three (3) months. The river regime respects this rainfall variation with a pronounced flooding of the rivers during the rainy season (July to September). There is a long period of low water proportional to the duration of the dry season (October to June) [10] [11].

The Chari and Logon rivers are under the influence of the humid Sudanian climate in the south and the dry Sahelian climate in N'Djamena.

We used a GARMIN 72H handheld GPS to record the geographic coordinates of the sampling points. These coordinates are shown in Table 1.

Table 1. Coordinates of sampling points.

Logon - Sediment	S1: 11.98215˚N and 15.02281˚E S2: 12.05114˚N and 15.05987˚E
Chari - Sediment	S1: 12.0902˚N and 15.1155˚E S2: 12.08039˚N and 15.10585˚E
Confluent - Sediment	S1: 12.11235˚N and 14.9919˚E S2: 12.11419˚N and 14.99150˚E

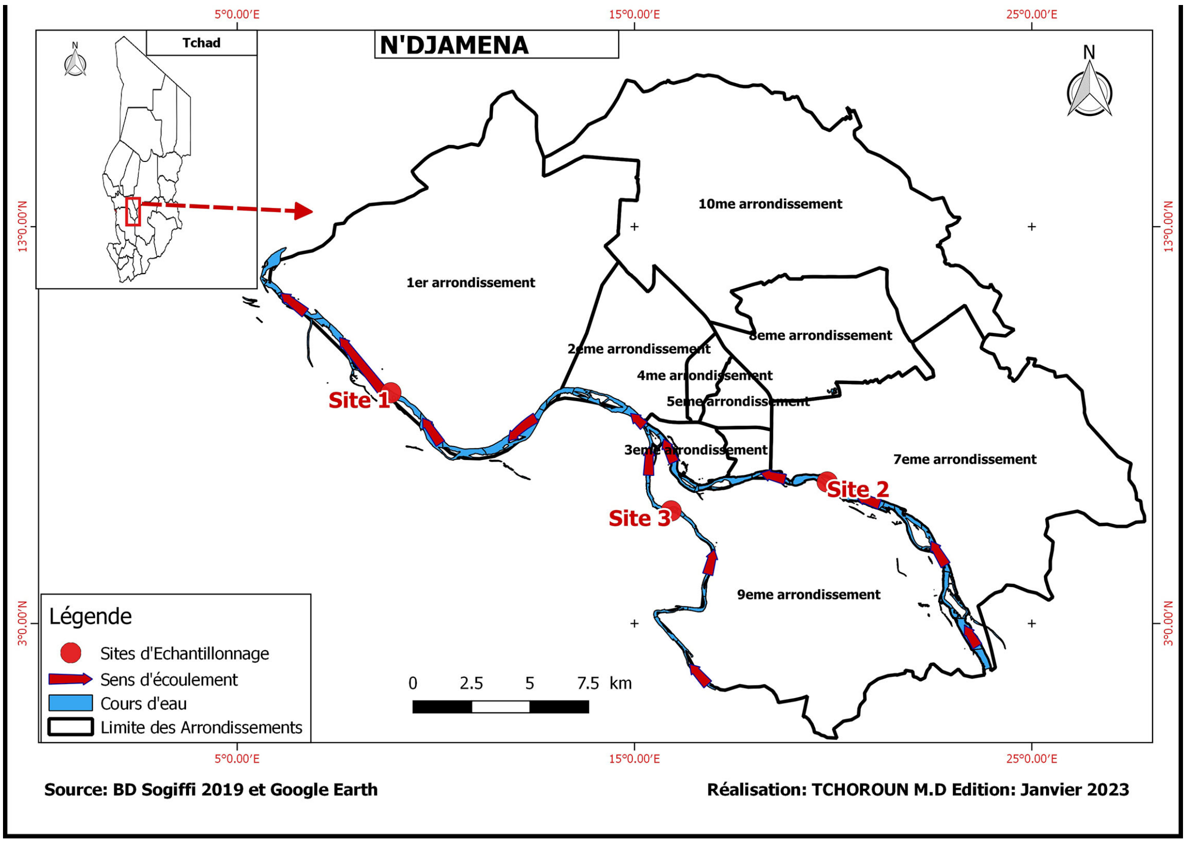

Figure 1. Overview of the study site.

2.2. Maintaining the Integrity of the Specifications

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2.3. Sampling

The sampling points of the Chari and Logon rivers were chosen according to their accessibility and their position along the rivers. The physico-chemical and chemical parameters are determined from seasonal sampling (end of low water in June and end of high water in December) carried out at sites along the Chari and Logone rivers and at the Chari-Logone confluence. For this purpose, the sampling of the first series (S1) was carried out in summer, during the low water level (in June 2020) and the sampling of the second series (S2) in winter, before the low water level (in December 2020) in three points. A GARMIN GPS (GPS 72H) was used to take geo-spatial coordinates.

Sediment samples were collected at the three and same sites (Chari, Logone and Confluent) in June 2020 and then in December 2020 following the procedures described in [12]. Sampling at each sampling point was done at a depth of 0 - 15 cm, in three closely spaced catches; thus samples of 250 mg to 500 mg per site are placed in polyethylene packages, tied, labeled, and then transported to the Laboratory water and environment of the University of N'Djamena. The samples were mixed and homogenized to form a representative sample. At each sampling point, the physical parameters were determined based on the methods of U. S EPA [12].

2.4. Analysis Methods

2.4.1. Chemical and Physico-Chemical Analysis of Samples

1) Determination of pH

The sediments were suspended in bidistilled water at a liquid/solid ratio (L/S) of 10 ml/g [13]. The pH measurements were performed using a portable multimeter (brand ECOSCAN pH 6). The electrode was immersed in the sediment suspensions. The pH is expressed as a function of the concentrations of hydronium ions present [3].

2) Treatment and digestion of sediment samples for heavy metal analysis

The extraction of heavy metals was carried out by wet digestion with the disodium dihydrate salt of Ethylenediaminetetraacetic acid (EDTA). This solution was prepared according to the method proposed by the European Community Reference Bureau (BCR) [14] [15].

Preparation of the EDTA solution according to the BCR procedure

In a 400 ml beaker, 3.723 g of EDTA and 77 g of CH_3COONH_4 were introduced. Distilled water was added to dissolve and then a commercial solution of CH_3COOH was added to adjust the pH = 7 before gauging at 1000 ml [16].

Method: 4 g of sediment was introduced into a 50 mL centrifuge tube to which 40 mL of the EDTA solution buffered at pH = 7 was added. The whole was shaken for 2 hours and then filtered through whattman paper No. 40 [15] [16]. The filtrate passed over a cellulose membrane was read with a Hach DR 6000 spectrophotometer (Brand HACH Lange GmbH).

Finally, heavy metals such as Pb, Cr, Cu, Mn, Cd as well as iron (Fe) were determined directly using a standardized program of the spectrophotometer Hach DR/6000 [17] [18].

2.4.2. Evaluation of the Level of Contamination of Sediments

✧ **Geo-accumulation index *Igeo***

This index is used to assess the degree of contamination of sediment as described in the work of Rubio *et al.* [19] [20]. The geo accumulation index was calculated as follows:

$Igeo = \log 2\left(\frac{C_n}{1.5B_n}\right)$ with "C_n" the concentration of the heavy metal in the sediment sample; "B_n" the geochemical background value of element n; "1.5" the matrix correction factor of the geochemical background [21] [22].

According to Leila Sahli [23], the *Igeo* values are categorized into seven (7) classes defining the level of pollution:

- class 0: unpolluted (*Igéo* ≤ 0);
- class 1: unpolluted to low (*Igeo* = 0 to 1);
- class 2: moderate pollution (*Igeo* = 1 to 2);
- class 3: moderate to heavy pollution (*Igeo* = 2 to 3);
- class 4: strong pollution (*Igeo* = 3 to 4);
- class 5: strong to extreme pollution (*Igeo* = 4 to 5);
- class 6: extreme pollution (*Igeo* ≥ 6).

✧ **Contamination factor *CF* and average contamination index (I_m)**

The contamination factor is commonly used to determine the level of contamination of sampled sediments. It is defined as in "Equation (1)":

$$CF = \frac{C_m(\text{sample})}{C_m(\text{geochemical background})} \tag{1}$$

where "C_m sample", concentration of the metal in the sample and "C_m geochemical background", the geochemical background of the element.

According to AdjeKoudjo [24], the *FC* is subdivided into four (4) classes:

- class 1: low contamination (*FC* < 1);
- class 2: moderate contamination (1 ≤ *FC* < 3);
- class 3: considerable contamination (3 ≤ *FC* < 6);
- class 4: very high contamination (*FC* ≥ 6).

The average contamination index (I_m) was calculated by the following formula in "Equation (2)":

$$I_m = \frac{1}{n}\sum CF \tag{2}$$

where n is the number of elements analyzed and CF the contamination factor.

There is contamination from $I_m > 2$ [24] [25].

✧ **Pollution Load Index (PLI)**

The pollution load index is an important index for comparing contamination levels between sampling points [26]. The pollution load index of the Chari and Logone rivers will be determined by the formula of Rabee [27] and Mekuria [26] in "Equation (3)":

$$PLI = \left(CF_1 \times CF_2 \times \cdots \times CF_n\right)\frac{1}{n} \tag{3}$$

With "CF_1, CF_2, …, CF_n", the contamination factors of each element, "n", the number of heavy metals in the study. According to Rabee, the sediment is considered polluted if its $PLI > 1$; therefore the sediment is unpolluted if $PLI < 1$ [27] [28].

✧ **Ecological Risk Index (*ERI*)**

This index is used to assess the ecological risk of sediments. It is replicated by other authors to determine the ecological risk of contaminants such as metals in soil and sediment [29] in "Equation (4)":

$$ERI = \sum\nolimits_{i=1}^{i} E_r^i \tag{4}$$

With the "Equation (5)":

$$E_r^i = T_r \times FC \tag{5}$$

where ERI is the ecological risk index; T_r is the toxic reaction factor; CF is the contamination factor; E_r is the potential ecological risk of each metal.

The toxic reaction factors T_r of the trace elements studied (Cd, Cu, Cr, Pb) according to AouaCoulibaly [29] are respectively 30; 5; 2; 5.

The values of ecological risks of sediments according to Leila [24] are given in the following **Table 2**.

2.4.3. Statistical Analyses

Descriptive statistical analyses are used for metal concentrations, *Igeo*, *CF*, *PLI*, and *RI*. Pearson correlation and multivariate analysis are performed to evaluate

Table 2. Characterization of potential ecological risk (E_r) and ecological risk index (*ERI*).

E_r Value	Potential Ecological Risk	*RI* Value	Ecological Risk Index
$E_r < 40$	Low	$RI < 95$	Low
$40 \le E_r < 80$	Moderate	$95 \le RI < 190$	Moderate
$80 < E_r < 160$	Considerable	$190 \le RI < 380$	Considerable
$160 \le E_r < 320$	High	$380 \le RI$	Very High
$E_r \ge 320$	Very high		

the sources of heavy metals and the groups of sampling sites. Indeed, the Bravais-Pearson correlation and multivariate analysis are used to calculate or measure a trend between an explanatory variable X and a variable to be explained. The linear correlation coefficient, measures both the strength and direction of an association. Varying from −1 to +1, it is 0 when there is no association. The closer this coefficient is to −1 or +1, the stronger the association between the two variables, until it is perfect.

3. Results

3.1. Conductivity and pH of Sediments in the Chari and Logon Rivers

pH is a physico-chemical parameter that influences the accumulation of heavy metals in sediments. Table 3 presents the statistical variations of pH and conductivity of the different sediments.

3.2. Heavy Metal Content in Sediments

In general, seasonal fluctuations in concentrations are irregular. Heavy metal and iron concentrations are shown in Tables 4(a)-(c).

3.3. Evaluation of Heavy Metal Contamination

3.3.1. Contamination Factor (*CF*) and Average Contamination Index (I_m)

The contamination factor and the degree of contamination are used to determine the level of contamination of the sediments in the present study. The contamination factor is calculated according to the above formula. The results of this assessment are shown in Table 5.

These results allowed us to plot the following histograms to better observe the variations in Figure 2.

3.3.2. Ecological Risk Index [29] [30] [31] [32]

The seasonal potential risk factors (E_r) and Ecological Risk Index (*ERI*) values of trace elements in sediments are recorded in Table 6.

Table 3. Geographical coordinates, pH and conductivity of sediments by season.

Statistics of temporal variations				
Parameters	pH		EC (µS/cm)	
	S1	S2	S1	S2
Minimum	5.99	7.15	11.16	714
Maximum	7.33	7.26	129	1036
Mean	6.453	7.19	55.38	893.33
Standard deviation	0.75	0.044	64.18	164.1

S1: June series; S2: December series.

Table 4. (a) Heavy metal concentrations in Logon River sediments; (b) Heavy metal content of sediments in the Chari; (c) Sediment heavy metal concentrations in the Confluence.

(a)

Logon-sediment					
Geographic coordinates	S1: 11.98215˚N 15.02281˚E	S2: 12.05114˚N 15.05987˚E	Annual average		
Parameters	Mean S1	Mean S2		Back-ground	WHO (2009) µg/kg
Pb (µg/kg)	126 ± 16.52	10 ± 0.00	68 ± 58.77	20.00	15 - 50
CrVI (mg/kg)	0.17 ± 0.00	0.16 ± 0.001	0.16 ± 0.002	90.00	50
MnII (mg/kg)	0.3 ± 0.00	0.4 ± 0.00	0.35 ± 0.05	850.00	20 - 50
Cd (mg/kg)	trace	nd	trace	0.3	5
Cu (mg/kg)	3.23 ± 0.64	0.08 ± 0.02	1.65 ± 1.62	45.00	2000
Fe (mg/kg)	0.25 ± 0.00	5.79 ± 0.005	3.02 ± 2.77	46000	

(b)

Chari-sediment					
Geographic coordinates	S1: 12.0902˚N 15.1155˚E	S2: 12.08039˚N 15.10585˚E	Annual average		
Parameters	Mean S1	Mean S2		Back-ground	WHO (2009) µg/kg
Pb (µg/kg)	112.33 ± 30.61	10 ± 0.00	61.16 ± 54.13	20.00	15 - 50
CrVI (mg/kg)	0.21 ± 0.005	0.13 ± 0.00	0.17 ± 0.03	90.00	50
MnII (mg/kg)	0.8 ± 0.00	1.1 ± 0.00	0.95 ± 0.15	850.00	20 - 50
Cd (mg/kg)	trace	Nd	trace	0.3	5
Cu (mg/kg)	1.02 ± 0.06	0.09 ± 0.01	0.55 ± 0.46	45.00	2000
Fe (mg/kg)	0.30 ± 0.02	5.34 ± 0.05	2.82 ± 2.52	46000	

(c)

Confluence-sediment					
Geographic coordinates	S1: 12.11235˚N 14.9919˚E	S2: 12.11419˚N 14.99150˚E	Annual average		
Parameters	Mean S1	Mean S2		Back-ground	WHO (2009) µg/kg
Pb (µg/kg)	55.66 ± 1.15	10 ± 0.00	32.83 ± 22.84	20.00	15 - 50
CrVI (mg/kg)	0.14 ± 0.00	0.19 ± 0.01	0.16 ± 0.02	90.00	50
MnII (mg/kg)	0.2 ± 0.00	0.8 ± 0.00	0.5 ± 0.3	850.00	20 - 50
Cd (mg/kg)	trace	Nd	trace	0.3	5
Cu (mg/kg)	55.66 ± 1.15	10 ± 0.00	32.83 ± 22.84	45.00	2000
Fe (mg/kg)	0.14 ± 0.00	0.19 ± 0.01	0.16 ± 0.02	46000	

S1: first series (June); S2: second series (December).

Table 5. Contamination Factor (*CF*) [24] [25].

Rivers	Sites	*FC*_Pb	*FC*_Cr	*FC*_Mn	*FC*_Cd	*FC*_Cu	*FC*_Fe	I_m	*PLI*
Logon	S1	6.3×10^{-3}	$1.8\ 10^{-3}$	3.5×10^{-4}	Nd	0.0717	5.424×10^{-6}	0.013	0.0033
	S2	5×10^{-4}	1.7×10^{-3}	4.7×10^{-4}	Nd	0.0017	1.25×10^{-4}	0.0007	0.002
Chari	S1	0.0056	2.7×10^{-3}	9.4×10^{-4}	Nd	0.022	6.52×10^{-6}	0.0052	0.0035
	S2	0.0005	0.0014	1.29×10^{-3}	Nd	0.002	7.9×10^{-5}	0.00087	0.0022
Confluent	S1	2.7×10^{-3}	3.1×10^{-3}	2.3×10^{-4}	Nd	0.015	6.08×10^{-6}	0.0035	0.0023
	S2	5×10^{-4}	4.2×10^{-3}	9.41×10^{-4}	Nd	2.6×10^{-3}	7.93×10^{-5}	0.00138	0.0027

Table 6. Seasonal potential risk factors (E_r) and ecological risk index (*ERI*) for sediments.

Potential risk factor E_r				
Statistics	Cu	Cr	Pb	RI
Low water period in June (S1)				
Minimum	0.075	0.0036	0.0135	0.0921
Maximum	0.3585	0.0062	0.0315	0.3962
Mean	0.181	0.005	0.0243	0.21
Winter period in December (S2)				
Minimum	0.0085	0.0028	0.0025	0.0138
Maximum	0.013	0.0084	0.0025	0.0239
Mean	0.0105	0.0146	0.0025	0.0276

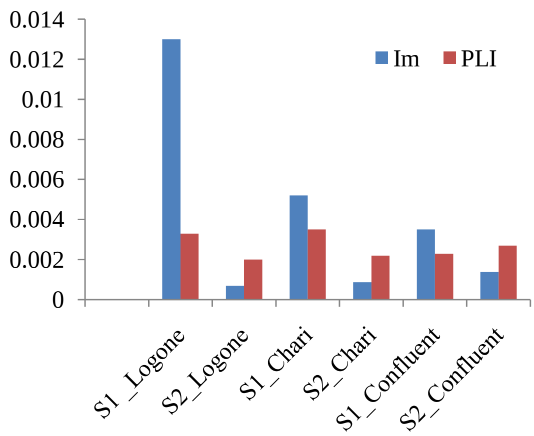

Figure 2. I_m and *PLI* of river sediments.

3.3.3. Geo-Accumulation Index (*GAI*) of Sediments [16] [19] [21]

The geo-accumulation index values are recorded in Table 7.

4. Discussions

4.1. Conductivity and pH of Sediments in the Chari and Logon Rivers

The pH values (Table 1) vary between 5.99 and 7.33 with an average value of 6.45 ± 0.75 during the low water period (S1) before the rains (June) and from

Table 7. Geo-accumulation index (*GAI*) of sediments.

Rivers	Series	Sediment Geo-accumulation Index					
		*Igeo*_Pb	*Igeo*_Cr	*Igeo*_Mn	*Igeo*_Cd	*Igeo*_Cu	*Igeo*_Fe
Logon	S1	−7.895	−9.633	−12.053	Nd	−4.385	−18.074
	S2	−11.55	−9.72	−11.638	Nd	−9.72	−13.54
Chari	S1	−8.065	−9.38	−10.638	Nd	−6.048	−17.811
	S2	−11.55	−10.02	−10.178	−nd	−9.55	−13.657
Confluent	S1	−9.074	−9.913	−12.638	Nd	−6.591	−17.91
	S2	−11.55	−9.472	−10.638	Nd	−9.135	−14.206
	Fd.Geo	20	90	850	0,3	45	46,000

Fd.Geo: value of the geochemical background of the earth's crust (Turkian and Wedepohl, 1961).

7.15 to 7.26 with an average of 7.19 ± 0.04 at the end of the river flood (December) (S2). There is no significant difference between the pH means (p = 0.342) with a higher pH during the low water period (June). There is a more even distribution at the end of the flood (December). The analysis of the pH values shows an acidic (5.99) to neutral (7.33) trend during low water. This trend would be influenced on the one hand by the nature of the soil but much more by the withdrawal of water which could dilute the acidity. It is suggested that the decomposition of aquatic plants and litter as well as erosion during the previous flood and urban effluents would produce an acidification in this period of heat by contribution of nitrogen in the form of ammonium [33]. At the end of the flood, homogeneity of pH is observed along the path of the rivers and a neutral trend (7.15 to 7.26). This finding would be influenced by the presence of water as an ion dilution factor.

Conductivities vary from 11.16 µS/cm to 129 µS/cm with an average of 55.38 ± 64.18 during low water (S1). They vary from 714 µS/cm to 1036 µS/cm for an average of 893.33 ± 164.1 µS/cm at the end of the flood. These conductivity values are typical of continental freshwater sediments that vary from 100 µS/cm to 1000 µS/cm and are significantly higher than the values obtained by Adje *et al.* (2021) [24] in the lake of the Nangbeto hydroelectric dam in Togo. The values obtained are relatively low compared to those obtained by Leila *et al.*, (2014) [23] in the Boumerzoug basin in Algeria. These high values observed in December reflect a rather high mineralization due to urban and industrial discharges, runoff from agricultural fields.

4.2. Heavy Metal Content in Sediments

Pb concentrations vary from 55 µg/kg to 143 µg/kg, with an average of 98 ± 36.68 µg/kg in June and a homogeneous value of 10 µg/kg in December (**Tables 4(a)-(c)**. The levels recorded during low water are clearly higher than those recorded in December. This homogeneity of Pb levels after the flood is similar to the homogeneity of pH during this period. This is similar to the heterogeneity of pH values during low water. The WHO limit being 50 mg/kg [34]. On average, the values obtained in our study are low compared to those obtained by Adje *et al.*, (2021) [24] in Lake Nangbeto in Togo (0.11 - 76.70 mg/kg) but also to those obtained by Mekuria *et al.*, (2020) [26] in Little Akaki River in Ethiopia. Similarly, the results obtained by Banu *et al.*, (2013) [35] are much higher than our results (28.30 - 36.4 mg/kg) and also those recorded by Rabee *et al.*, (2011) (8 - 59 µg/g) [27]. The values obtained by Muhammad *et al.*, (2020) [36] in Weihe River in China are much higher.

For Cr VI, the concentrations vary from 0.02 mg/kg to 0.04 mg/kg in S1 (low water in June) for a mean of 0.031 ± 0.009 µg/kg. They vary from 0.136 mg/kg to 0.166 mg/kg in S2 for an average of 0.171 ± 0.009 mg/kg (**Tables 4(a)-(c)**). A relative homogeneity of Cr levels at the sites attests to a contribution mainly from natural sources with a slight contribution at the Chari-Logon site exposed to the cumulative urban and industrial effluents of the entire city of N'Djamena. The WHO limit is 1 mg/kg to 5 mg/kg [34].

Cd concentrations ranged from 0.12 mg/kg to 0.19 mg/kg with an average of 0.16 ± 0.024 mg/kg (**Tables 4(a)-(c)**). Measurements were consistent across sampling locations. This small variation in concentrations over the sampling period is consistent with a natural source. However, a slight increase at the Chari sampling point suggests an anthropogenic contribution from the discharge of urban waste and effluents, as well as runoff from agricultural areas where fertilizers are used. These levels are below the WHO limit of 1 mg/kg to 3 mg/kg [34].

For Cu, the concentrations vary from 0.78 mg/kg to 3.92 mg/kg in S1 (low water level) for an average of 1.72 ± 1.18 mg/kg. These concentrations vary from 0.05 mg/kg to 0.2 mg/kg in S2 (end of flood) for an average of 0.098 ± 0.044 mg/kg (**Tables 4(a)-(c)**). Given the small variation in concentrations in this study, it would be risky to attribute this to an anthropogenic source because the rivers are not exposed to a similar source; hence the composition of riverbed sediments would be a plausible source.

For Mn, the concentrations range from 0.1 mg/kg to 1.1 mg/kg with an average of 0.43 ± 0.30 mg/kg in S2 and range from 0.1 mg/kg to 5.1 mg/kg with an average of 2.02 ± 2.15 mg/kg in S1 (**Tables 4(a)-(c)**). At S1, the concentration remained high at the sampling point on the Chari. This may point to a localized source but also to leaching from tree leaves from forests upstream of N'Djamena and plant debris.

Finally, Fe concentrations vary from 0.19 mg/k to 0.36 mg/kg for an average of 0.278 ± 0.05 mg/kg in S1. This variation is from 5.06 mg/kg to 5.40 mg/kg for an average of 5.26 ± 0.15 mg/kg in S2 (**Tables 4(a)-(c)**).

The Pearson correlation matrix for heavy metals in the Chari and Logon River sediments is shown in the following **Table 8**.

In order to achieve our objectives, we compared our results with others, which are shown in **Table 9**.

Table 8. Correlation matrix.

	pH	Cond.	Pb	Cu	Fe	Mn	Cr	Cd
pH	1							
Cond.	0.912	1						
Pb	0.670	0.306	1					
Cu	0.997*	0.877	0.725	1				
Fe	0.666	0.300	1.000**	0.721	1			
Mn	−0.674	−0.918	0.096	−0.615	0.102	1		
Cr	−0.477	−0.796	0.333	−0.408	0.338	0.971	1	
Cd	b	b	b	b	b	b	b	b

The confidence interval level is 95%; *The correlation is significant at the 0.05 level ($p < 0.05$); **The correlation is significant at the 0.01 level ($p < 0.01$); [b]Calculation is impossible, because at least one of the variables is a constant (in our case, [Cd] = 0).

Table 9. Comparison of average heavy metal concentrations (mg/kg) with other results.

Sources	Concentration of heavy metals in sediment						References
	Pb	Cr VI	Mn	Cd	Cu	Fe	
Sediments of Chari, Logone, Chad	53.99×10^{-3}	0.166	0.6	<0.025	0.873	2.601	Present study
Lake Nangbeto sediments, Togo	4.835	5.875	ND	0.055	10.645	ND	Adje *et al.*, 2021
N'zi River sediments, Ivory Coast	0.652	ND	ND	0.485	14.73		Ouattara *et al.*, 2021
Little Akaki River sediments, Ethiopia	129.68	109.51	ND	3.14	ND	ND	Mekuria *et al.*, 2020
Weihe River sediments, China	24.44	109.98	888.29	ND	52.37	ND	Muhammad *et al.*, 2020
OuedBoumerzouk sediments, Algeria	ND	ND	ND	0.44	43.61	ND	Dounia *et al.*, 2019
Sediments of the Ebrié Lagoon, Ivory Coast	118.88	ND	ND	0.75	54.02	ND	Irié Bi *et al.*, 2019
Lake Chad sediments, Nigeria	113.53	82.41	1208.09	1.825	19.37	62602.5	Jonathan *et al.*, 2016
Sediments of the BouRegreg Estuary, Morocco	128.05	21.49	ND	2.90	33.48	19517.50	Nadem *et al.*, 2015
Sediments of the Boumerzouk Basin, Algeria	66.23	46.82	ND	1.19	52.19	ND	Leila *et al.*, 2014
Turag River sediments, Bangladesh	32.78	43.02	ND	0.28	50.40	ND	Banu *et al.*, 2013
Tigris River sediment in Baghdad, Iraq	34.33	ND	265.16	0.736	29.33	ND	Rabee *et al.*, 2011
Sediment from Tsurumu River, Japan	40.8	102.9	ND	1.0	133.0	ND	Mohiuddin *et al.*, 2010

Given this comparison, the heavy metal contents obtained in our work are lower than those obtained by other researchers.

4.3. Evaluation of Heavy Metal Contamination

4.3.1. Contamination Factor (*CF*) and Average Contamination Index (I_m)

The results show that during the whole study period, the CF values are lower than 1 (Table 5): thus all the sediments are weakly contaminated or not contaminated. The results of our studies are very low compared to those obtained by Rabee *et al.*, (2011) in the sediments of Tigris River in Baghdad area as well as the work of Banu in the sediments of Turag River in Bangladesh [27]. Our results are also inferior to those obtained by Adje in the sediments of Nangbeto

Dam Lake in Togo [24] and to the results of Mekuria in the sediments of Little Akaki River in Ethiopia [26]. The same is true for the results of Leila in the sediments of the Boumerzouk Basin in Algeria showing heavy metal contamination [23]. The results obtained by Muhammad in the sediments of Weihe River (China) show contamination [36]. The results obtained in this study are clearly weaker than those obtained by Ouattara in the N'zi River in Côte d'Ivoire [36].

For both seasons, the Im values are lower than 2, which is the threshold for the onset of contamination, so the sediments studied do not suffer from metal quality degradation (**Figure 2**).

The Pollution Load Index (*PLI*) values in **Figure 2** are all below 1 ($PLI < 1$) (0.002 to 0.0035). These results are low compared to the results of Mekuria *et al.*, (2020) in Little Akaki River in Ethiopia [26] and Rabee *et al.*, (2011) in Tigris River in Baghdad [27]. This denotes that the sites are not polluted by heavy metals according to Banu *et al.*, (2013) [35].

4.3.2. Ecological Risk Index

The results of the evaluation of the ecological risk index in relation to the contamination of sediments in trace elements (Cu, Cr, Pb) show values of potential risk factors (E_r) that vary 0.0025 to 0.3585 for the three (3) elements (Cu, Cr, Pb) and over the two seasons (**Table 6**). These values lead to *IR* values ranging from 0.0138 to 0.3962 for both seasons. These potential risk factors imply low ecological risks in both June (low water) and December (winter) ($RI < 40$) [24].

The RI values (21.02 to 26.52) determined by Adje *et al.*, (2021) in the Lake of Nangbeto Dam in Togo are largely superior to our values obtained [24]. The RI values from our studies are much lower than those determined by Mekuria *et al.*, (2020) in the sediments of Little Akaki River in Ethiopia [26]. The results of Muhammad *et al.* (2020) (*RI*: 1.43 to 30.71) conclude low ecological risks in the Wheihe River (China) [36].

4.3.3. Geo-Accumulation Index (*GAI*) of Sediments [9] [14] [24]

For all elements are analyzed at all sites in **Table 7**, $Igeo < 0$ according to the classification of Rabee, (2011) [27]. This indicates the character of Non contamination or non pollution of sediments by these heavy metals. The Igeo obtained in our study are low in front of those obtained by Mekuria *et al.*, (2020) in the sediments of Little Akakiriver in Ethiopia [26], and also the results of Jonathan *et al.*, (2016) in the sediments of Lake Chad, Nigeria sector [21]. However, the results of the work of Leila *et al.*, (2014) in the Boumerzouk basin (Algeria) [23] as well as the work of Adjé *et al.*, (2021) in the Lake of Nangbéto dam (Togo) on heavy metals such as Cr, Cu and Pb are almost similar to our work [24]. The same conclusions are observed in the results of Banu *et al.*, (2013) in the sediments of Turag River (Bangladesh) [35] but also of Rabee *et al.*, (2011) in the sediments of Tigris River (Baghdad) [27]. The results obtained by Muhammad *et al.*, (2020) in Weihe River (China) are higher and show moderate pollution of Cu, Cr and Pb [36].

5. Conclusions

The results of this study show that the sediments of the Chari and Logon rivers have slightly acidic to very slightly basic pH values with very low mineralization.

The annual average concentrations of heavy metals in the sediments are unevenly distributed in time and space. Higher concentrations are recorded during low water for Pb and Cu, which would be due to a concentration and deposition of the quantities contained in the flood waters. However, Fe and Mn levels are high during winter, which is the result of recent inputs from runoff, agricultural leaching and anthropogenic activities. Cd and Cr levels are homogeneous over the two seasons; the result of a natural contribution of these metallic elements.

The evaluation of the degree of contamination of the sediments by heavy metals through the *CF*, the *Igeo*, the average contamination index (I_m), the *PLI* as well as the ecological risk index (*RI*) indicates an absence of contamination and a low ecological risk.

The quality of the sediments in the Chari and Logon rivers biotope is therefore considered acceptable according to this study. Where the sediments of the Chari and Logon rivers are suitable for market gardens, and necessary for human consumption.

However, the present study did not focus on PAH-type pollutants, chlorinated solvents, pesticides and pharmaceutical residues, which can cause considerable health and ecological risks.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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