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ORIGINAL ARTICLE

Distributions of Trace Metals and Radionuclides Contamination in Alluvial Sediments from the Lobé River in Cameroon

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Abstract
The spatial and vertical distribution of heavy metals (Fe, Ni, Cr, Co, Sc and V) and radionuclides (Th and U) and the sediment characteristics of Lobé River, south–west Cameroon were assessed in this study to determine the possible source of pollutants and evaluate the level of pollution. Cores sediments were analyzed to measure grain size parameters, organic matter and geochemical composition. To understand the vertical distribution, tree strata were chosen (surface, middle and bottom). The main constituent of studied sediment is sand (82.06%). In these sediments, low content was recorded for organic matter (2.87%). The average concentration (mg/kg) of selected elements are in the order Fe (23,112.84) > Cr (447.62) > Ni (109.93) > V (47.04) > Th (23.70) > Co (7.74) > Sc (5.10) > U (2.78). The maximum concentration of most selected chemical elements was recorded in the middle, followed by surface and bottom, respectively. Enrichment factor (EF > 1.5), Geo-accumulation index (Igéo > 0) and contamination factor (CF > 1) revealed a moderate to severe pollution of Cr, Ni and Th in all strata. The pollution load index (PLI) show that surface and middle sediments (1.08 and 1.14, respectively) are polluted, while bottom sediments (0.88) are unpolluted. Pearson correlation, cluster analysis and component principal analysis confirmed that heavy metals (Fe, Sc, V, Cr, Ni and Co) have common anthropogenic sources where grain size parameters (sand, silt and clay) were associated with them while radionuclides (Th and U) have a natural source. The presence of human activities such as household wastes, intensive agriculture and the result of the processing of the industries products could be possible sources of the anthropogenic pollution, threatening for the environmental related issues in the region.

Keywords Heavy metals and radionuclides · Spatial and vertical distributions · Pollution indices · Stream sediment · Lobé River

1 Introduction

Washed soil is usually deposited as sediment in streams. The aquatic ecosystems are easily damaged by eroded soil and other contaminants from natural and anthropogenic sources (Kaushik et al. 2009; Hanif et al. 2016). Because of the adsorption, hydrolysis and co-precipitation of metal ions, large amounts of heavy metals are deposited in sediment, whereas only a small proportion of free metal ions remain in solution in the water column. Indeed, Bartoli et al. (2012) reveal that, far less than 1% of pollutants remain dissolved in the water, whereas more than 99% are stored in the sediments. Heavy metals, soil nutrients and chemical pollutants become attached through disposal of liquid effluents, fertilizers and pesticides (Sun et al. 2018; Zhou et al. 2018; Armstrong-Altrin et al. 2019; Jiang et al. 2019) and terrestrial runoff and chemicals originating from various urban, industrial and agricultural activities (Xiao et al. 2013; Zahra et al. 2014; Mimba et al. 2018; Al-Hadithy et al. 2018; Chen et al. 2019). These pollutants reduce the usefulness and

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enjoyment of the environment to people downstream and damage aquatic life in streams, lakes and estuaries (Chairman 1991).

The interest of the radionuclides and the assessment of the impacts of these radioactive elements on soils, soil microbiota, edible plants and humans has been increasing constantly (Shtangeeva et al. 2018) . Radioactive elements like ^{232}Th and ^{238}U with their decay products are present in most environmental matrices and can be transferred to living bodies by different pathways which can lead to the sources of exposure to man (Harmsen and Haan 1980). Uranium and Thorium occur generally in low concentrations in rocks, soils and waters. Thorium is surprisingly abundant in the Earth's crust, being almost three times more abundant than uranium (Vinogradov 1959; Talibudeen 1964; Klement 1965; Baranov and Morozova 1971; Unscear 1977). It has been observed that felsic rocks (granite) contain higher amounts of U and Th compared to mafic rocks such as basalt and andesites (Rogers and Adams 1969; Harmsen and Haan 1980; Armstrong-Altrin et al. 2018; Armstrong-Altrin 2020). Results of the uranium distribution in rocks and sediments could indicate higher concentration in sediments and further support the possible effect of fertilizers as an additional source of uranium (Sahoo et al. 2011; Mandeng et al. 2019). For these reasons, it has been necessary to monitor those natural radionuclides in weathered soil samples to assess the possible hazards.

The developed practice of intensive agriculture and the result of the processing of its products in the Lobé watershed and its surroundings can affect environment. It is important to give a current environmental status of sediments for a potential monitoring of this environment. The aim of this study is to assess the spatial and vertical distributions of heavy metals and radionuclides in Lobé river sediments, to determine the possible source of pollutants and to evaluate the level of pollution.

2 Materials and Methods

2.1 Study Area

Lobé River is located in the south of Cameroon with the river Niété as main tributary. Lobé River is one of the main rivers in Cameroon's coastal river basin and is 130 km long. Lobé River takes its rise in the Ntem massif and joins the Atlantic Ocean by an estuary with spectacular falls. The hydrographic network is dendritic and the catchment basin of the Lobe with an area of about 1940 km^2 is, therefore, an exoreic basin (Fig. 1a). This zone is under the influence of a warm and humid oceanic equatorial climates with little differentiated seasons, with average rainfall around 2919 mm/year (Gaston Lienou et al. 2008). Average temperatures are stable, around 25 °C, while the relative humidity is maintained at values above 70% for most of the year.

The basement of South Cameroon is made up of two complexes (Fig. 1b): the Ntem Complex and the Nyong Complex. The Lobe watershed lies NW to the Ntem Complex, which partially represents the Congo Craton. The Ntem complex is divided into three units: Ntem, Nyong and Ayina and consists of charnockites, monzogranites, syenogranites, TTGs (tonalites, trondhjemites, granodiorites), syenites, Banded Iron Formation (BIF), green rocks, migmatites and gneisses (Maurizot et al. 1986; Toteu et al. 2001; Shang et al. 2007). The Nyong complex represents the Cameroonian part of the west central African chain described by Feybesse et al. (1998); Binam Mandeng et al. (2018). It consists of TTGs, anorthosites, charnockites, gneisses, migmatites, eclogites, metagabbros, quartzites and BIFs (Toteu et al. 2001; Lerouge et al. 2006). The alteration of these rocks favors the formation of ferralitic and hydromorphic soils. Ferralitic soils generally consist of kaolinite, gibbsite, hematite, goethite, quartz and some accessory minerals such as rutile, muscovite, illite, smectite and magnetite. Hydromorphic soils consist of smectites, kaolinite, illite and accessory minerals such as zircon, rutile and muscovite (Ndjigui et al. 2018; Zogo Mfegue et al. 2021).

2.2 Sampling and Analytical Methods

Sampling was collected (April 2019) from the alluvial terrace of the Lobe and Niete Rivers from up (Lob 1, Nie 1, Nie 2 and Nie 3) to downstream (Lob 2, Lob 3 and Lob 5). Seven cores were collected using an Uwitec Corer Sampler hammer. A tube is driving into the alluvium by gravity or vibrations, by raising and dropping weights connected to hammer with a cable (Guesdon et al. 2014; Chougong et al. 2021). To study the vertical distribution tree strata were chosen (surface, middle and bottom). Only the first stratum was defined for every core (surface: 0–10 cm); due to the variability of core lengths, the middle and the bottom strata was defined arbitrarily in different cores. These sediment cores were subsampled at different intervals (every 10 cm), air-dried and prepared for analyses. Grain size distribution was determined following the Robinson-Köln's pipetting standard method in Faculty of Agronomy and Agricultural Sciences (FASA) in Dschang, Cameroon (e.g. Ndjigui et al. 2014; Ekoa Bessa et al. 2018, 2021). To determine the total organic matter content (TOC), 20 g of samples were ground to pass through a 2 mm sieve and further fine ground to pass through a 0.5 mm sieve, TOC was determined by chromic acid digestion and spectrophotometric analysis (Heanes 1984). Powdered samples, 0.2 g (crushed, sieved with a 0.080 mm sieve) was mixed with 1.5 g $LiBO_2$. The mixture was dissolved in 100 ml 5% HNO_3. The intensity of metal concentration of Fe, Ni,

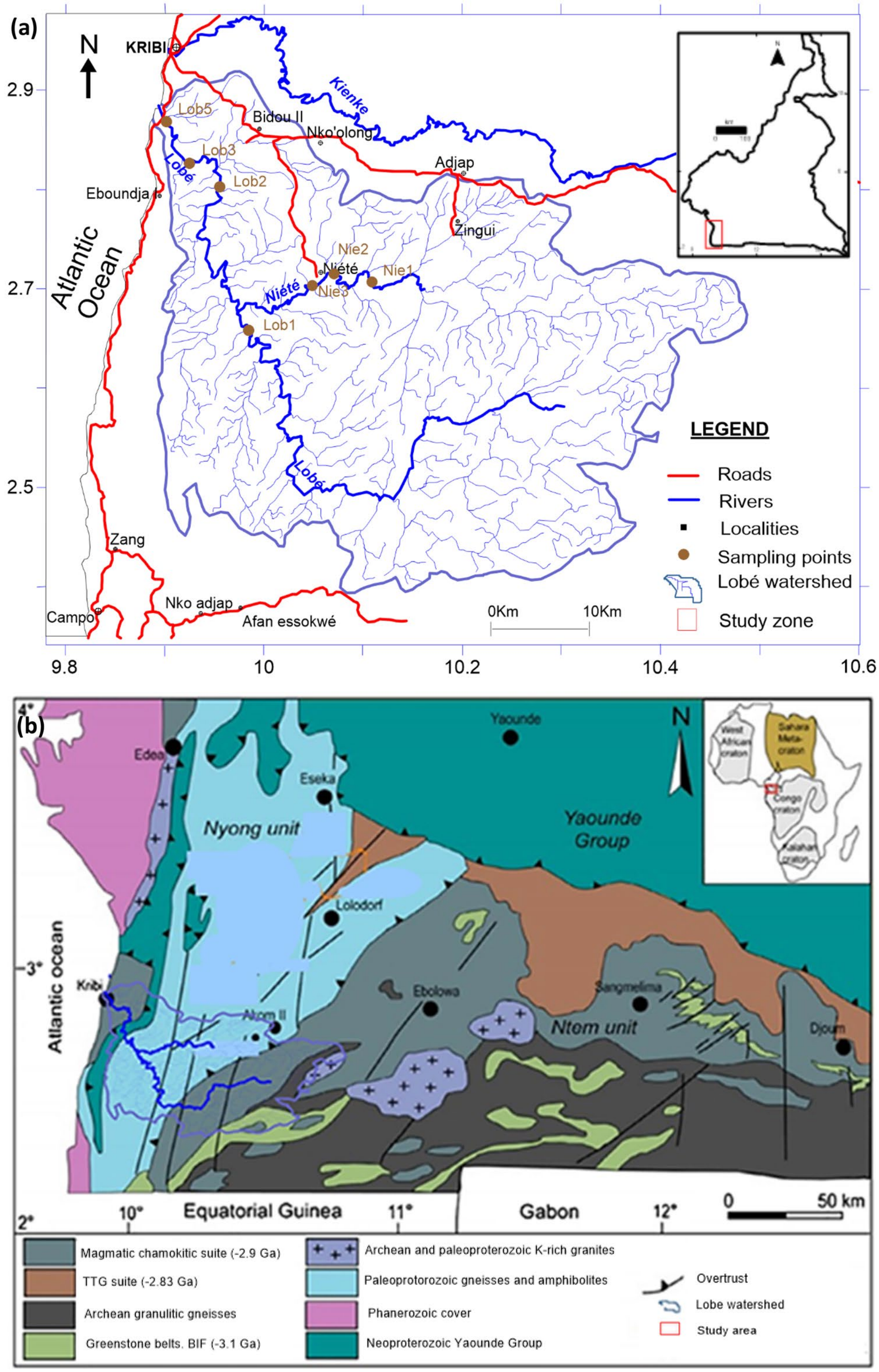

Fig. 1 Study area location: **(a)** Simplified map of Lobe River watershed showing coring sites (Lob1-5 and Nie1-3). **(b)** Geological map of the South Cameroon (from Toteu et al. 2001)

Cr, Co, Sc, V, Th and U was resolved into air/acetylene fire utilizing the Inductively Coupled Plasma-Mass spectrometry (ICP-MS) using the pulp at ALS (Australian Laboratory Services), Vancouver (Canada). Analytical doubts vary from 0.1 to 0.5% for traces of metal.

2.3 Pollution Indices and Ecological Risk Assessment

The sediment quality guidelines offer a simple, comparative means for evaluating the risk of contamination in an aquatic ecosystem (Ke et al. 2017). Heavy metals (Fe, Ni, Cr, Co, Sc and V) and radionuclides (Th and U) were selected based on spatial and vertical concentrations, toxicity and other methods used by various authors (Müller 1969; Hakanson 1980; Tomlinson et al. 1980). Table 1 lists pollution indices and their classification levels.

2.3.1 Enrichment Factor (EF)

The probable sources (natural or anthropogenic) of elements in sediments were determined by enrichment factor (EF). The EF of elements is express by the equation of Wang et al. (2008)

$$EF = \left(C_n/Fe\right) sample / \left(C_n/ Fe\right) background$$

C_n is the concentration of element "n" and the background value is that of Upper Continental Crust (McLennan 2001). Iron (Fe) is considered as the normalizing metals for the following reasons: Fe is associated with fine to medium solid elements; its geochemistry is comparable to that of many heavy metals; and its natural concentration in the study area tends to be uniform (Bhuiyana et al. 2010; Rahman et al. 2019).

2.3.2 Geo-accumulation Index (Igeo)

Geo-accumulation index was used to understand the current environmental status and the metal contamination with respect to natural background. It relies on the chemical data to evaluate the level of pollution. Müller (1969) defined the following equation to determine Igeo values.

$$Igeo = Log2\,(C\,sample\,/\,1.5\,B\,sample)$$

C is the considered contents (mg/kg) of metal in the sample sediment, B represents chemical background concentration (mg/kg) of an element in the background sample and the factor 1.5 is introduced to reduce the effects of probable dissimilarities in the background values, which may be assigned to lithogenic effects.

2.3.3 Contamination Factor (CF) and Pollution Load Index (PLI)

The contamination factor and pollution load index were used to determine the contamination status of the sediment (Hakanson 1980; Tomlinson et al. 1980).

$$CF = \left(\frac{C_{metal}}{C_{background}}\right)$$

C_{metal} represents the pollutant concentration in the sediment and $C_{background}$ refers to metal background values.

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \times \ldots \cdots \times CFn,}$$

n is the number of metals, while CF denotes the factor of contamination.

2.4 Statistical Analysis

A multivariate statistical analysis was performed at significant level of $P < 0.05$ to study the interrelationship among the chemical elements, grain size distribution and organic matter. Pearson correlation analysis was conducted to determine the relationship among these variables. Cluster

Table 1 Classes of pollution indices and contamination levels used in this study

EF		Igeo		CF		PLI	
Classes	Sediment quality	Classes	Sediment quality	Classes	Sediment quality	Classes	Sediment quality
EF < 1.5	Natural	Igeo ≤ 0; 0	Unpolluted	CF < 1	Low contamination	PLI < 1	No pollution
EF > 1.5	Anthropogenic	Igeo = 0–1; 1	Unpolluted to moderately polluted	CF = 1–3	Moderate contamination	PLI > 1	Polluted
EF < 1	No enrichment	Igeo = 1–2; 2	Moderately polluted	CF = 3–6	Considerable contamination		
EF = 1–3	Minor enrichment	Igeo = 2–3; 3	Moderately to strongly polluted	CF > 6	High contamination		
EF = 3–5	Moderate enrichment	Igeo = 3–4; 4	Strongly polluted				
EF = 5–25	Moderately severe enrichment	Igeo = 4–5; 5	Strongly to very strongly polluted				
EF = 25–50	Very severe enrichment						
EF > 50	Extremely severe enrichment						

EF the enrichment factor (Wang et al. 2008); Igeo: the geo-accumulation index (Müller 1969); *CF* the contamination factor (Hakanson 1980; Tomlinson et al. 1980); *PLI* the pollution load index (Tomlinson et al. 1980) analysis (AC) was applied to provide information about the grouping of variables based on similarity. Results are shown in a dendrogram that graphically illustrates the hierarchical cluster. Principal component analysis (PCA) was employed to infer the hypothetical source of heavy metals (Salati and Moore 2010).

3 Results and Discussion

3.1 Grain Size Distribution and Organic Matter

Grain size distribution has been carried out to determine the content of sand, silt and clay (%) in Lobé and Niété sediments (Table 2, Fig. 2). The results show that sand is the main constituent at all the sampling locations, which ranges from 51 to 99%. Silt is the second most constituent, with 2 to 47% content. The least concentrated constituent is clay which varied from 1 to 2%. The average sand, silt and clay percentages in the sediment are, respectively, 80.57, 17.86 and 1.86% from surface, 81.60, 16.60 and 1.80% middle and 84, 15 and 2.55% bottom. These results are similar to those observed along the Vaigai River, Tamil Nadu, India (Ramasamy et al. 2014). In Fig. 2, the vertical evolution of sands is inversely proportional to that of silts; Suresh et al. (2011) documented a similar observation in Ponnaiyar River sediment.

Organic matter content in sediments ranges from 0.38 to 4.83% (Table 2). Like grain size distribution, these values are recorded in the bottom stratum. The average organic matter percentages in the sediment are 2.87% from surface, 3.19% from middle and 1.29% from the bottom. The comparison of these values from those of Narayana and Rajashekara (2010) in Sharavathi River, India (ranging from 1.8 to 4.7%) and Aytas et al. (2012) in two different rivers of Turkey namely Maritza and Tundja (ranging from 0.82 to 7.80% and 1.05 to 6.67%, respectively) show low levels of organic matter in the Lobé and Niété sediments, although the geological context is not the same as in this study. Moreover, Ramasamy et al. (2014) and Narayana and Rajashekara (2010) noted that high levels of organic matter in sediments shift the pH to a highly acidic condition, which facilitates the fixation of high concentrations of metals and radionuclides in sediments.

3.2 Distribution of Metals and Radionuclides

3.2.1 Spatial Distribution *(Surface)*

The distribution of heavy metals (Fe, Ni, Cr, Co, Sc, V) and radionuclides (Th and U) of Lobé and Niété surface sediments is presented in Fig. 3. The average concentration (mg/kg) of these elements in the upper surface sediments decreased as Fe (22,360.82) > Cr (714.29) > Ni (125.61) > V (43.86) > Th (20.37) > Co (8.47) > Sc (4.43) > U (2.61) (Table 2). Comparison of average

Table 2 Heavy metals and radionuclides concentrations (mg/kg) of Lobé and Niété sediments

	Metal concentration (mg/Kg)						Radioactive element concentration (mg/Kg)		Grain seize distribution (%)			Organic matter (%)
Elements	Fe	Ni	Cr	Co	Sc	V	Th	U	Sand	Silt	Clay	
Surface												
Average ($n = 7$)	22,360.82	125.61	714.29	8.47	4.43	43.86	20.37	2.61	80.57	17.86	1.86	2.87
Minimum	19,653.14	45.00	140.00	6.20	3.00	31.00	5.60	1.00	73	10	1	1.65
Maximum	27,136.72	506.00	1540.00	12.90	7.00	72.00	58.60	5.70	88	25	2	3.97
Middle												
Average ($n = 5$)	29,053.08	133.60	300.00	8.50	6.00	55.68	28.30	2.88	81.60	16.60	1.80	3.19
Minimum	17,764.76	53.00	190.00	5.90	4.00	32.40	6.50	1.20	67	6	1	1.34
Maximum	39,655.98	325.00	460.00	12.50	8.00	78.00	54.40	4.50	93	31	2	4.06
Bottom												
Average ($n = 7$)	17,924.62	70.57	328.57	6.24	4.86	41.57	22.41	2.84	84.00	15.00	1.29	2.55
Minimum	7273.76	24.00	60.00	2.20	2.00	27.00	7.70	1.40	51	2	1	0.38
Maximum	29,864.38	189.00	960.00	13.90	8.00	68.00	62.10	4.30	99	47	2	4.83
Total average ($n = 19$)	23,112.84	109.93	447.62	7.74	5.10	47.04	23.70	2.78	82.06	16.49	1.65	2.87
Minimum	16,692.35	43.00	190.00	5.75	3.33	31.80	6.60	1.23				
Maximum	30,890.17	340.00	845.00	13.10	7.50	63.25	39.78	3.68				
UCC	35,000	44	83	17	13.6	107	10.7	2.8				

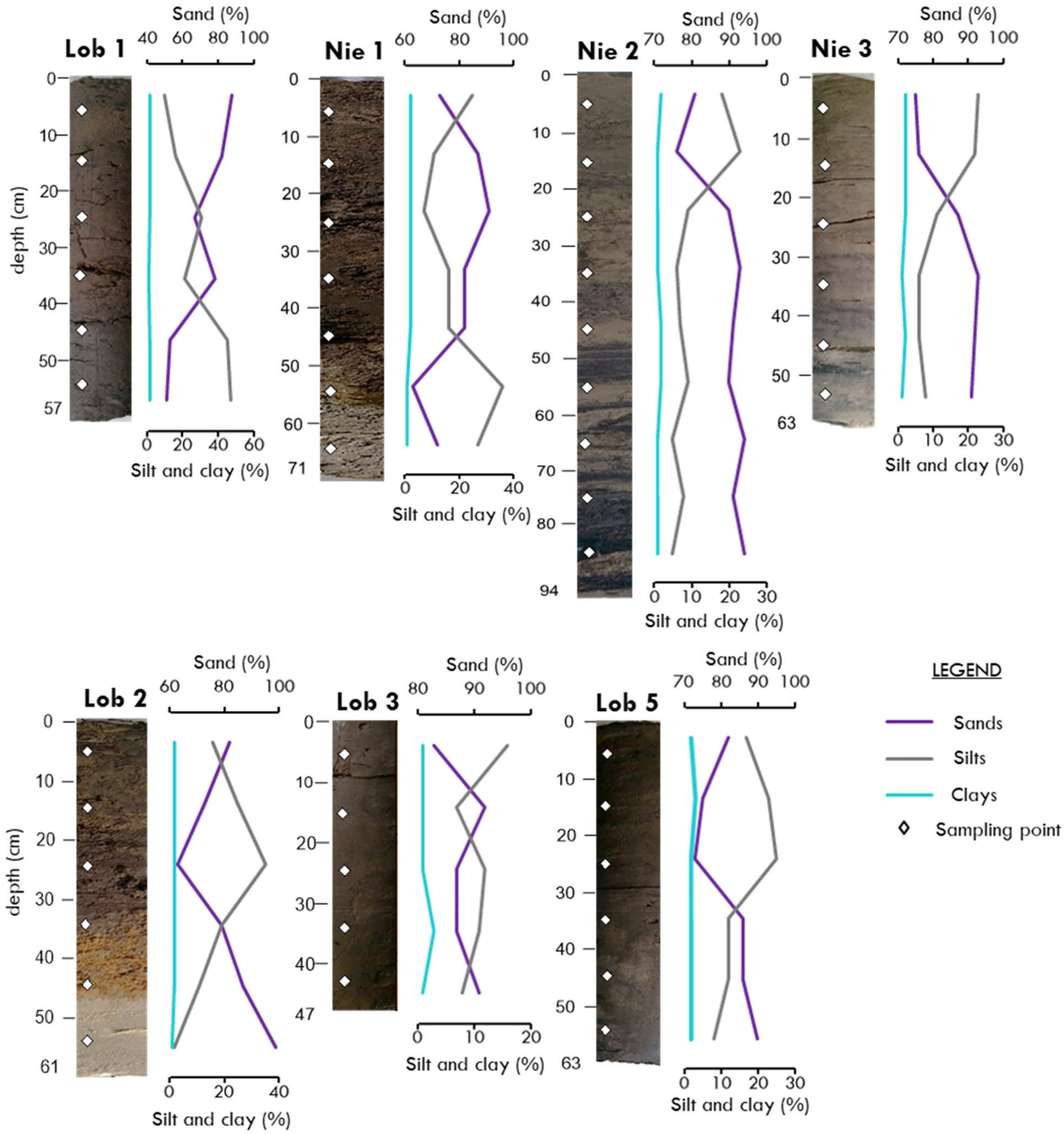

Fig. 2 Core sediments variation in grain size distribution

concentrations of these elements shows that Ni, Cr and Th are higher than the Upper Continental Crust (UCC) reference values (McLennan 2001) while the remaining are less. Variation in metal concentrations in sediments is the result of the variability of source rock composition, sediment texture, redox reactions, adsorption/desorption, sediment transport, mineral sorting and anthropogenic activity (Selvaraj et al. 2004; Ramos-Vázquez and Armstrong-Altrin 2019). Indeed, the high levels of Ni, Cr and Th could be attributed to the pollutant load derived through various discharges from agricultural activities (Ekoa Bessa et al. 2018; Tehna et al. 2020).

Iron is believed to be the most abundant element in the earth's crust. Ranging from 19,653.14 to 27,136.72 mg/kg, the highest value was recorded at Lob 2 (27,136.72 mg/kg). The average value of Fe in the present study is 22360.82 mg/kg; all of each value are lesser than the UCC reference value (35,000 mg/kg).

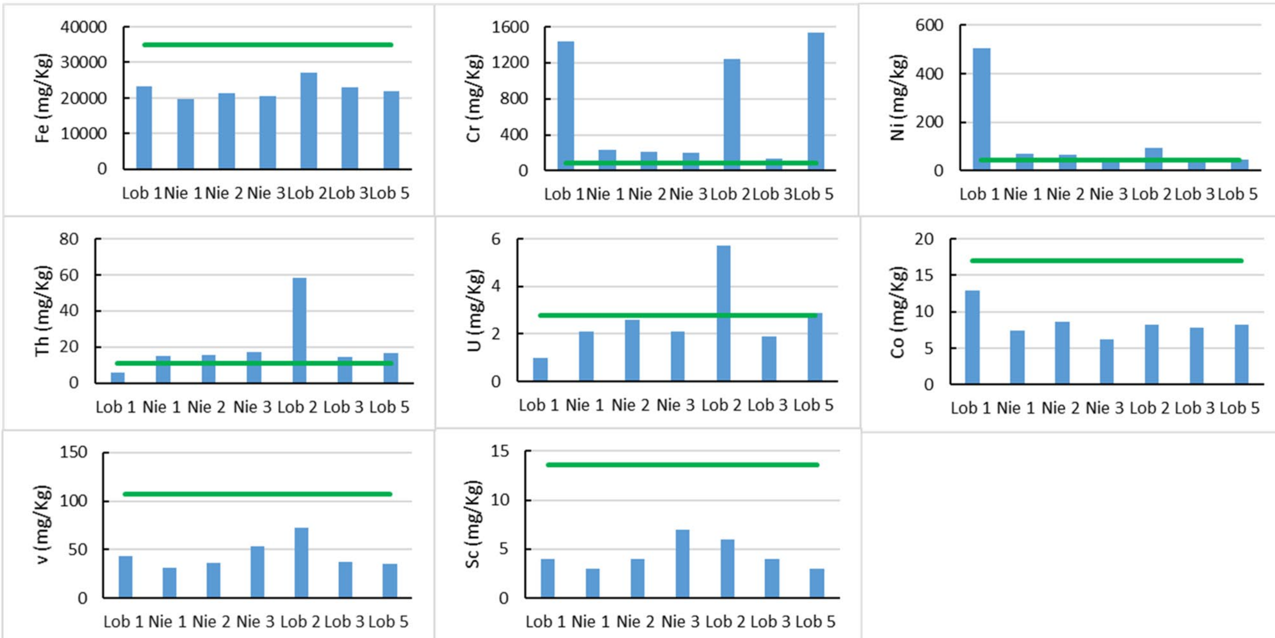

Fig. 3 Distribution of heavy metals and radionuclides of Lobé and Niété surface sediments; the horizontal green line represents the UCC reference values (McLennan 2001)

The levels of chromium in air, water and soil are generally low and form through natural processes and human activities. In water, chromium will be absorbed into sediment and become immobile and strongly attached to soils particles (Reimann and Caritat 1998). Chromium is more toxic to invertebrates than to fish, it is not known to accumulate in the bodies of fish but high concentrations can damage their gills (Moore and Ramamoorthy 1984). The Cr content in this study is about 140 to 1540 mg/kg, with an average of 714.29 mg/kg and at all sampling sites, the Cr content is higher than the UCC reference value (83 mg/kg). This element is irregularly distributed along the River, with highest values (more than 1200 mg/kg) recorded at Lob 5, Lob 1 and Lob 2, whereas the remaining had low values (under 400 mg/kg).

The larger part of all nickel compounds that are released to the environment will be absorbed into sediment or soil particles and became immobile, it is not known to accumulate in plants or animals (Chau and Kulikovsky-Cordeiro 1995). Nickel can also end in surface water when it is a part of wastewater streams. The highest value of Ni in Lobé and Niété sediments was recorded at Lob 1 (506 mg/kg) while the rest are less than 100 mg/kg. Ranging from 45 to 506 mg/kg, the average content of Ni in the present study is 125.61 mg/kg. All of these values are higher than the UCC reference value (44 mg/kg).

Thorium is found in small amounts in most rocks and soils. Very little of this element circulates through the environment due to the highly insolubility of thorium oxides (Reimann and Caritat 1998; Sahoo et al. 2011). Ranging from 5.6 to 58.6 mg/kg, the average value content of Th in present samples is 20.37 mg/kg and all samples have higher value than the UCC reference value (10.7 mg/kg) except Lob 1.

Although uranium is radioactive like thorium, it is not particularly rare. It is found in small amounts in rocks, soil, air and water in varying concentrations that are usually very low. Uranium is not likely to accumulate in fish or vegetables because of its water-solubility, which determines its mobility in the environment, as well as its toxicity (Domingo 2001). The mean concentration of U is 2.61 mg/kg, ranging from 1 to 5.7 mg/kg. The highest value is recorded at Lob 2, is the only one that exceeds the UCC reference value (2.8 mg/kg).

Cobalt is not often freely available in the environment; it tends to be produced as by-product of nickel and copper mining activities. However, when cobalt particles are not bound to soil or sediment particles the uptake by plants and animals is higher and accumulation in plants and animals may occur. The Co content in this study is about 6.20 to 12.90 mg/kg, with an average of 8.47 mg/kg and all of this value is less than the UCC reference value (17 mg/kg). Like Ni, the highest concentration of Co was recorded at Lob 1 (8.2 mg/kg).

Vanadium is never found unbound in nature. It occurs in carbon containing deposits such as crude oil, coal, oil shale and tar sands. Watering is an important way in which vanadium is redistributed around the environment because venedates are generally very soluble. It can be associated with algae, plants, invertebrates, fishes and many other species. Ranging from 31 to 72 mg/kg, the average value content of V in Lobé and Niété River sediments is 43.86 mg/kg and each of these values is less than the UCC reference value (107 mg/kg); Lob 2 recorded the highest value (72 mg/kg).

Scandium can rarely be found in nature, as it occurs in very small amounts. It is usually found only in two different kinds of ores, Thortveitite is the primary source and uranium mill tailings by-product also being an important source. The Sc content of Lobé and Niété sediments is about 3 to 7 mg/kg, with an average of 4.43 mg/kg. Like Fe, V and Co, Sc has all its values less than the UCC reference value (13.6 mg/kg). The highest concentration was recorded at Nie 3 (7 mg/kg).

3.2.2 Vertical Distribution

Vertical chemical elements assessment reflects the history of the deposition of these elements and helps to understand the characteristics of accumulation in various layers of the sediment.

3.2.3 Middle

The range of concentrations of the studied metals and radionuclides in the sampled strata of Lobé and Niété sediments are shown in Table 2 and Fig. 4. The average concentration (mg/Kg) of these metals and radionuclides in the middle section decreased, like the surface stratum as Fe (29,053.08) > Cr (300) > Ni (133.60) > V (55.68) > Th (28.30) > Co (8.50) > Sc (6) > U (2.88). Like the surface stratum, the comparison of average concentrations of these elements with UCC (McLennan 2001) also shows higher values of Ni, Cr and Th, while the remaining elements are lower.

Fe content ranges from 17,764.76 to 39,655.98 mg/kg, the average value of Fe in this stratum is 29053.08 mg/kg. All values are less than the UCC reference value (35,000 mg/kg). The Cr content is about 190 to 460 mg/kg, with an average of 300 mg/kg and at all sampling sites, the Cr content is higher than the UCC reference value (83 mg/kg) with highest values recorded at Nie 1. The highest value of Ni in Lobé and Niété sediment was recorded at Lob 1 and are higher than the UCC reference value (44 mg/kg). Ranging from 53 to 325 mg/kg, the average value of Ni is 133.60 mg/kg. Ranging from 6.50 to 54.40 mg/kg, the average value of Th is 28.30 mg/kg and all samples have higher value than the UCC reference value (10.7 mg/kg) except Lob 1; Lob 2 recorded the highest concentration. The average concentration of U is 2.88 mg/kg, ranging from 1.20 to 4.50 mg/kg. The highest value is recorded at Lob2. The Co content varies from 5.90 to 12.50 mg/kg, with an average of 8.50 mg/kg, where Lob 1 recorded the highest concentration, however, is less than the UCC reference value (17 mg/kg). Ranging from 32.40 to 78 mg/kg, the average value of V is 55.68 mg/kg and is lesser than the UCC reference value (107 mg/kg); Lob 2 recorded the highest value. The Sc content of Lobé and Niété sediments is about 4 to 8 mg/kg, with an average of 6 mg/kg. Like Fe, V and Co, Sc is lesser than the UCC

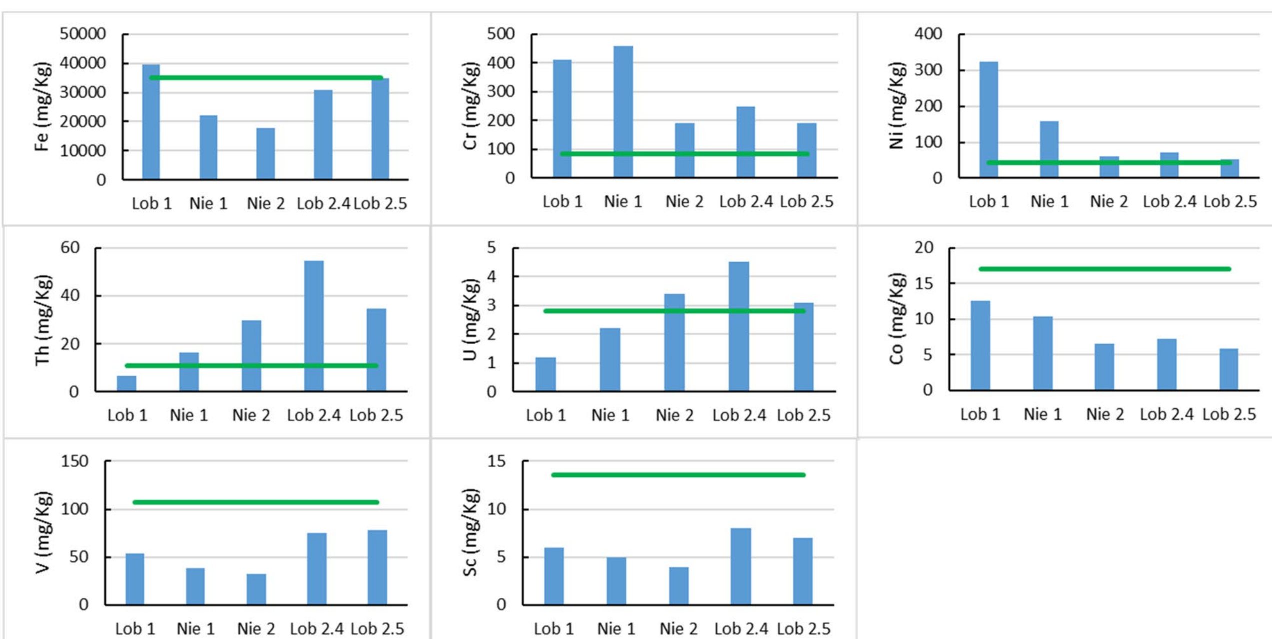

Fig. 4 Distribution of heavy metals and radionuclides of Lobé and Niété middle sediments; the horizontal green line represents the UCC reference values (McLennan 2001)

reference value (13.6 mg/kg) and Lob 2 recorded the highest concentration.

3.2.4 Bottom

The average concentration (mg/Kg) of Lobé and Niété sediments in the bottom stratum in decreasing order: Fe (17,924.62) > Cr (328.57) > Ni (70.57) > V (41.57) > Th (22.41) > Co (6.24) > Sc (4.86) > U (2.84) (Table 2; Fig. 5).

Fe content ranges from 7273.76 to 29,864.38 mg/kg, the average value in this stratum is 17924.62 mg/kg. With highest value recorded at Lob 1, all Fe values are less than the UCC reference value (35,000 mg/kg). The Cr content in this study is about 60 to 960 mg/kg, with an average of 328.57 mg/kg and at all sampling sites, the Cr content is higher than the UCC reference value (83 mg/kg). Lob 3 recorded the highest Cr value (960 mg/kg). Ranging from 24 to 189 mg/kg, the average value content of Ni is 70.57 mg/kg. The highest value of Ni in Lobé and Niété sediment was record at Lob 1. All of these Ni values are higher than the UCC reference value (44 mg/kg) except Nie 3 and Lob 2. With an average of 22.41 mg/kg, the Th content ranges from 7.70 to 62.10 mg/kg. Th content is higher than the UCC reference value (10.7 mg/kg) except Lob 1, where the highest concentration was recorded at Nie 2. The average concentration of U is 2.84 mg/kg, which ranges from 1.40 to 4.30 mg/kg, U content of these samples (Nie 1, Nie 2, Nie 3 and Lob 3) were higher than the UCC reference value (2.8 mg/kg). With 4.3 mg/kg, Nie 1 recorded the highest value. The Co content in this study varies from 2.20 to 13.90 mg/kg, with an average of 6.24 mg/kg, which is lesser than the UCC reference value (17 mg/kg). Lob 1 recorded the highest Co concentration. Ranging from 27 to 68 mg/kg, the average content of V in Lobé and Niété sediments is 41.57 mg/kg. Vanadium (V) contents are lesser than the UCC reference value (107 mg/kg), with highest value recorded at Lob 1. The Sc content is about 2 to 8 mg/kg, with an average of 4.86 mg/kg. Like Fe, V and Co, Sc has all of its values lesser than the UCC reference value (13.6 mg/kg). The highest Sc value was recorded at Lob 1 and Nie 3.

The general distribution of chemical elements in Lobé and Niété sediments are shown in Fig. 6. The average concentration (mg/Kg) in decreasing order: Fe (23,112.84) > Cr (447.62) > Ni (109.93) > V (47.04) > Th (23.70) > Co (7.74) > Sc (5.10) > U (2.78) (Table 2). The same observation was made in the previous strata and for the comparison of average concentrations, the same elements Ni, Cr and Th are higher than the UCC reference values (McLennan 2001).

In Lobé and Niété sediments, the average content of Fe is 23112.84 mg/kg. Lob 1 recorded the highest concentration (30,890.17 mg/kg) and all of each average value is less than the UCC reference value (35,000 mg/kg). Fe contents were similar to those found in the soil of the Betare-Oya, eastern Cameroon (Tehna et al. 2020). The basement of South Cameroon region (Feybesse et al. 1998; Shang et al. 2007) can explained these results through the alteration of these rocks which formed ferralitic and hydromorphic soils.

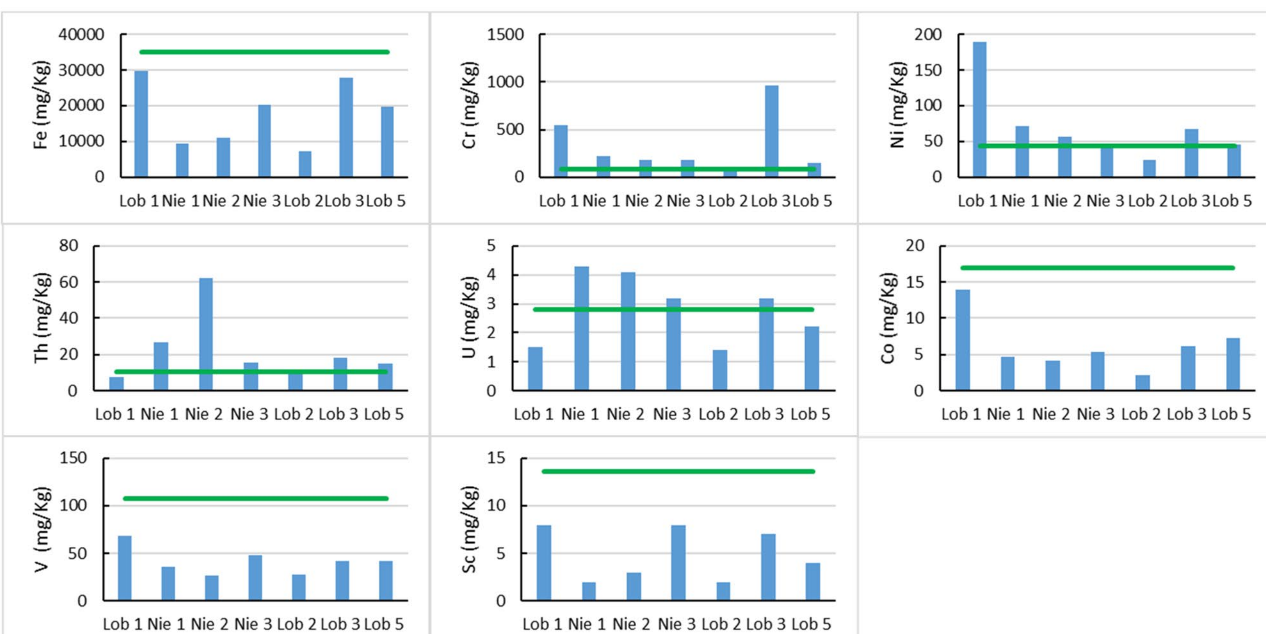

Fig. 5 Distribution of heavy metals and radionuclides of Lobé and Niété bottom sediments; the horizontal green line represents the UCC reference values (McLennan 2001)

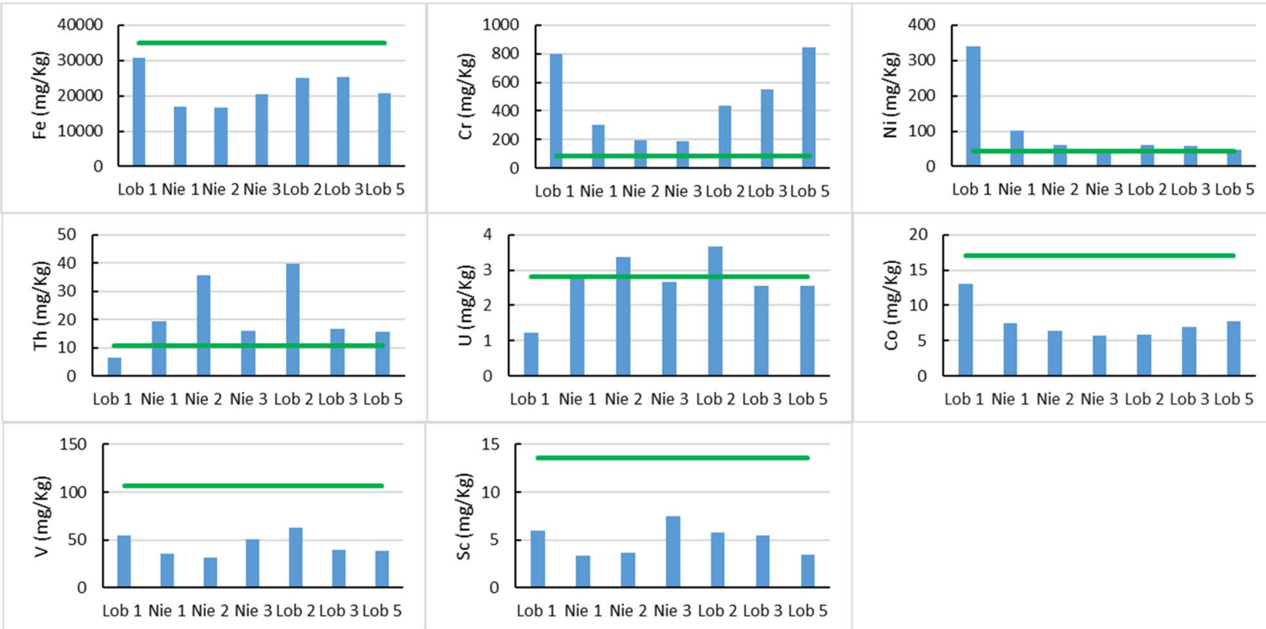

Fig. 6 Distribution of heavy metals and radionuclides of all samples in Lobé and Niété; the horizontal green line represents the UCC reference values (McLennan 2001)

The Cr average content in this study is 447.62 mg/kg and at all sampling sites has their average value higher than that of UCC reference value (83 mg/kg); Lob 5 recorded the highest average value (845 mg/kg). With similar values in tributaries from the southwestern coast of the Rio de la Plata estuary, Ronco et al. (2008) suggested that Cr levels in sediments could indicate historic levels of this metal pollution that still remains to the present.

The highest average value of Ni in Lobé and Niété sediments was record at Lob1 (340 mg/kg) while the rest are less than 100 mg/kg. This highest Ni concentration could be ascribed to its accumulation at the surface of sediments from deposition by agricultural activities (Cempel and Nikel 2006; Anaya-Gregorio et al. 2018; Ayala-Pérez et al. 2021). The average content of Ni is 109.93 mg/kg; all of these values are higher than the UCC reference value (44 mg/kg) except at Lob 5 (43 mg/kg). These values were similar to those recorded in Abiete-Toko gold district, Southern Cameroon (Mandeng et al. 2019).

The average content of Th in present samples is 23.70 mg/kg and all samples have higher contents than the UCC reference value (10.7 mg/kg) except Lob 1 (6.60 mg/kg). It can be explained by the fact that, felsic rocks with constitute the basement of South Cameroon region contains higher U and Th contents compared to mafic rocks (Rogers and Adams 1969; Harmsen and Haan 1980).

The average concentration of U is 2.78 mg/kg. The highest value is recorded at Lob 2 (3.68 mg/kg), which exceeded the UCC reference value (2.8 mg/kg). The addition of uranium to the soil through industrial activities, especially by the possible effect of fertilizers (Sahoo et al., 2011) could explain these high values. The U contents are higher than those recorded in Abiete-Toko gold district, Southern Cameroon (Mandeng et al. 2019), but lower than those observed in the Vale De Abrutiga uranium Mine, Central Portugal (Pinto et al. 2004).

The Co average content in the present study is 7.74 mg/kg and are lesser than the UCC reference value (17 mg/kg). Like Ni and Fe, the highest concentration of Co was recorded at Lob 1 (13.10 mg/kg). The level of this element is similar to those observed along the Saudi coastline of the Gulf of Aqaba (Al-Trabulsy et al. 2010), but lower than those reported for Moloundou swamp, eastern Cameroon (Ekoa Bessa et al. 2018) which can link to the high affinity of Co with iron and manganese oxyhydroxides present in that zone.

The average content of V in Lobé and Niété sediments is 47.04 mg/kg and are lesser than the UCC reference value (107 mg/kg); Lob 2 recorded the highest value (63.25 mg/kg). Same results were reported along the Saudi coastline of the Gulf of Aqaba (Al-Trabulsy et al. 2010) and in the soil of the Betare-Oya, eastern Cameroon (Tehna et al. 2020).

The Sc average content of Lobé and Niété sediments is 5.10 mg/kg. Like Fe, V and Co, Sc has all its values lesser than the UCC reference value (13.6 mg/kg). The highest concentration was recorded at Nie 3 (7.5 mg/kg).

In summary, the average concentrations of the studied metals and radionuclides of Lobé and Niété sediments

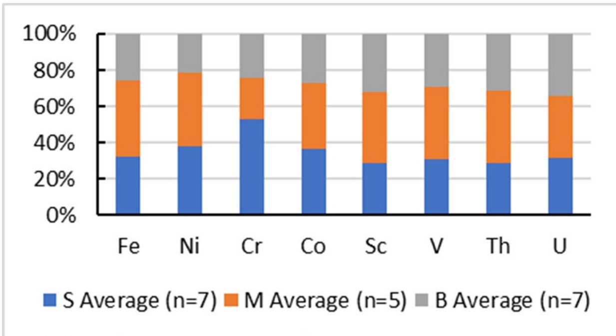

Fig. 7 Fractional contribution of each element to the total distribution (S: surface. M: middle and B: bottom)

were approximately evenly distributed among the three strata (Fig. 7). Cr content (714.29 mg/Kg) in the surface strata contributed half to the distribution of this element in this zone. In this surface stratum, Cr and Ni recorded the highest concentration. Among other elements, Cr, Th and U have their highest values at the middle stratum (Table 2; Fig. 7). The similar trends of the vertical profiles of heavy metals (middle > surface > bottom) suggest common sources of each metal and was also observed in sediment cores in the ship breaking area of Bangladesh (Hossain et al. 2021). Wang et al. (2015) also reported metal concentrations at the maximum in the middle layer. Nawrot et al. (2019) suggested that higher content of heavy metals in the middle layer denotes historical deposition of these metals in the sediment cores.

3.3 Assessment of Sediment Contamination

Numerous indices are available to infer the environmental risks associated with heavy metals in sediments, which are based on metal content, bioavailability and toxicity (Yang et al. 2009). For example, the enrichment factor (EF), the geo-accumulation index (Igéo) and the contamination factor (CF) for individual heavy metals and radioactive elements in sediments are calculated using the metal content and background values (Wang et al. 2008; Müller 1969; Hakanson 1980; Tomlinson et al. 1980). To evaluate the combined risk of multiple heavy metals in sediment, the pollution load index (PLI), has also been developed (Hakanson 1980; Tomlinson et al. 1980). A summary of the values obtained from the indices of metals and radioactive elements in Lobé and Niété sediments are listed in Table 3 and Fig. 8.

3.3.1 Spatial Distribution of Sediment Contamination *(Surface Section)*

Enrichment factor (EF) of metals is a robust tool in heavy metal pollution evaluation (Hakanson 1980). The average EF of metal contents in Lobé and Niété surface sediments (Table 3, Fig. 8a) reveals that Cr has highest value (13.47), respectively, followed by Ni (4.47), Th (2.98), U (1.46), Fe (1), Co (0.78), V (0.64) and Sc (0.51). Referring to Table 1, the EF of Cr, Ni and Th, are higher than 1.5, indicates that these elements originated from anthropogenic sources, may be through the use of fertilizers in agricultural activities. Indeed, Salati and Moore (2010) in Khoshk River, Shiraz, Southwest Iran reported high EF values for the urban area located near the farmlands. Moreover, a moderate

Table 3 Enrichment factor (EF), geo-accumulation index (Igeo), contamination factor (CF) and pollution load index (PLI) for heavy metals and radioactive elements in sediments of Lobé and Niété sediments

	Metal concentration (mg/Kg)						Radioactive element concentration (mg/Kg)		
EF									
Elements	Fe	Ni	Cr	Co	Sc	V	Th	U	
Surface($n=7$)	1	4.47	13.47	0.78	0.51	0.64	2.98	1.46	
Middle ($n=5$)	1	3.66	4.35	0.60	0.53	0.63	3.19	1.24	
Bottom ($n=7$)	1	3.13	7.73	0.72	0.70	0.76	4.09	1.98	
Igeo									
Elements	Fe	Ni	Cr	Co	Sc	V	Th	U	
Surface($n=7$)	−1.23	0.93	2.52	−1.59	−2.20	−1.87	0.34	−0.68	
Middle ($n=5$)	−0.85	1.02	1.27	−1.58	−1.77	−1.53	0.82	−0.54	
Bottom ($n=7$)	−1.55	0.10	1.40	−2.03	−2.07	−1.95	0.48	−0.56	
CF&PLI									
Elements	Fe	Ni	Cr	Co	Sc	V	Th	U	**PLI**
Surface($n=7$)	0.64	2.85	8.61	0.50	0.33	0.41	1.90	0.93	1.08
Middle ($n=5$)	0.83	3.04	3.61	0.50	0.44	0.52	2.64	1.03	1.14
Bottom ($n=7$)	0.51	1.60	3.96	0.37	0.36	0.39	2.09	1.02	0.88

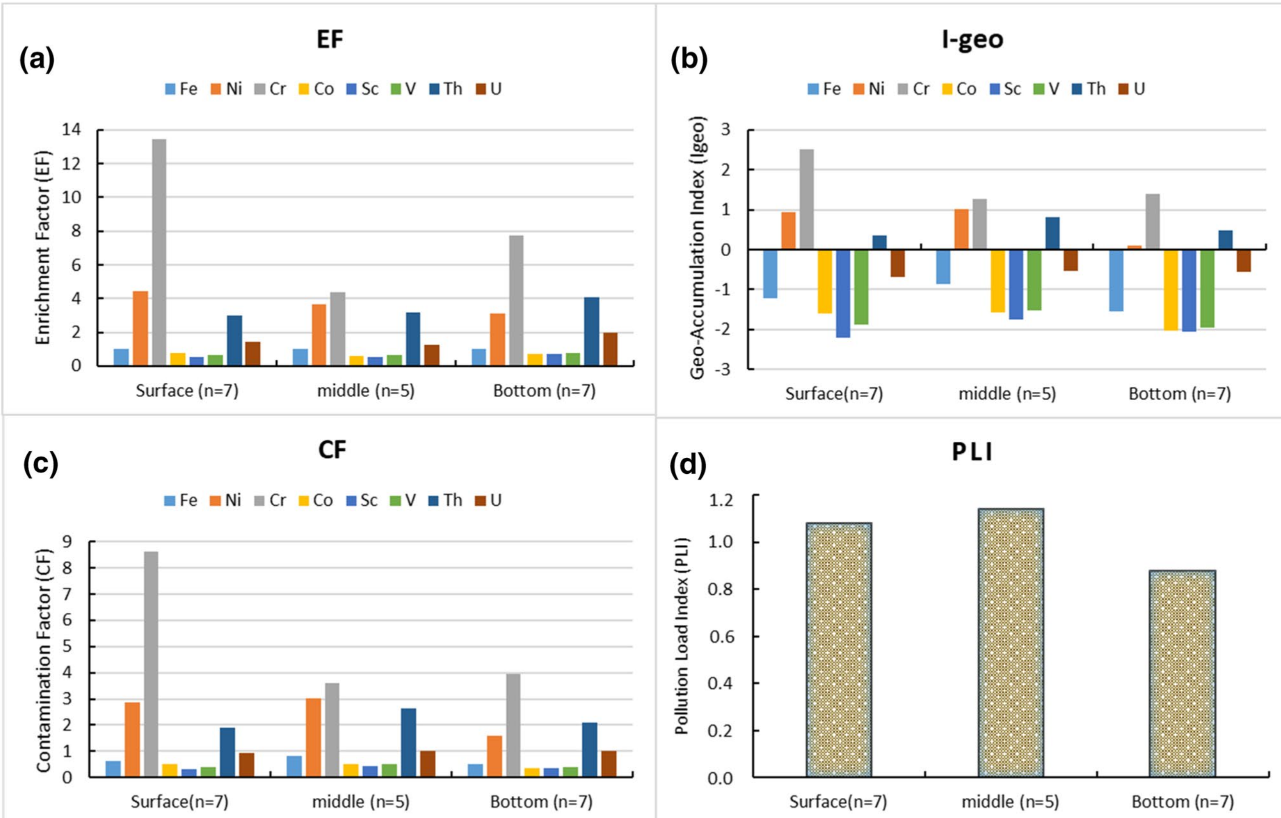

Fig. 8 Indices of **a** enrichment factor (EF); **b** geo-accumulation index (Igeo); **c** contamination factor (CF); **d** pollution load index (PLI); in Lobé and Niété sediments

enrichment (Th and Ni) and moderately severe enrichment (Cr) were noted. In Moloundou swamp, eastern Cameroon, Ekoa Bessa et al. (2018) also noted high EF value of Cr and attributed it to agricultural wastes and artisanal gold exploitation.

The geo-accumulation index (Igéo) is a quantitative measure of the degree of pollution in sediments (Müller 1969). The average Igeo values of selected elements in present samples in decreasing order are Cr (2.52) > Ni (0.93) > Th (0.34) > U (-0.68) > Fe (-1.23) > Co (-1.59) > V (-1.87) > Sc (-2.20) (Table 3, Fig. 8b). Based on Table 1, U, Fe, Co, V and Sc were, characterizing, respectively the sediments as unpolluted. Cr, Ni and Th represent the category polluted, where the category is moderate to strongly polluted. The high Cr Igeo values suggesting that the sediments retain Cr (Pinto et al. 2004).

To determine the contamination status of sediments, the contamination factor (CF) is calculated (Hakanson 1980; Tomlinson et al. 1980). The CF values in the Lobé and Niété surface sediments are Cr (8.61), Ni (2.85), Th (1.90), U (0.93), Fe (0.64), Co (0.50), V (0.41) and Sc (0.33) (Table 3, Fig. 8c). According to Table 1, some elements U, Fe, Co, V and Sc indicated a low contamination; Th and Ni presented a moderate contamination, while Cr (8.61) indicated a high contamination. In Abiete-Toko gold district, Southern Cameroon same value of Ni CF was observed, but the EF value of U is higher than those recorded in this study (Mandeng et al. 2019).

PLI gives an assessment of the overall toxicity status of the sample and is also an index of the combined contribution of the eight studied elements (Hakanson 1980; Tomlinson et al. 1980). Referring to Table 1, the PLI value of the surface sediment (1.08) indicated the polluted status of Lobé and Niété sediments (Table 3, Fig. 8d). Same value was recorded in Moloundou swamp, eastern Cameroon (Ekoa Bessa et al. 2018).

3.3.2 Vertical Distribution of Sediment Contamination (*Middle Section*)

The EF average of metals in Lobé and Niété middle section in decreasing order: Cr (4.35) > Ni (3.66) > Th (3.19) > U (1.24) > Fe (1) > (V 0.63) > Co (0.60) > Sc (0.53) (Table 3, Fig. 8a). This classification is almost similar to that of surface sediments, except for V, which is higher than that of Co. Referring to Table 1, the EF of Cr, Ni and Th are higher than

1.5, indicated that the source of these elements was from anthropogenic activities. The same observation was done in the surface strata but here, only a moderated enrichment for Cr, Th, and Ni is observed.

The Igéo average of selected elements in this stratum is decreasing like the EF values: Cr (1.27) > Ni (1.02) > Th (0.82) > U (-0.54) > Fe (-0.85) > V (-1.53) > Co (-1.58) > Sc (-1.77) (Table 3, Fig. 8b). Based on Table 1, U, Fe, Co, V and Sc are similar to the surface strata, characterizing restrictively the sediments as unpolluted. Cr, Ni and Th representing the category polluted, where the pollution is moderate.

In the Lobé and Niété Rivers middle section sediments the average CF values of Cr (3.61), Ni (3.04), Th (2.64), U (1.03), Fe (0.83), V (0.52), Co (0.50) and Sc (0.44) are similar as EF and Igeo (Table 3, Fig. 8c). According to Table 1, some elements Fe, Co, V and Sc indicated a low contamination while the rest presented moderate (Ni, Th and U) to considerable (Cr) contamination. Referring to Table 1, the PLI value of the middle sediment (1.14) indicated the polluted status of Lobé and Niété sediments like the surface section (Table 3, Fig. 8d).

3.3.3 Vertical Distribution of Sediment Contamination (*Bottom Section*)

In the bottom strata of the Lobé and Niété sediments, the EF average values are (Table 3, Fig. 8a) decreasing as: Cr (7.73) > Th (4.09) > Ni (3.13) > U (1.98) > Fe (1) > (V 0.76) > Co (0.72) > Sc (0.70). Except Th, which is higher than that of Ni, this classification is almost the same as that of middle section sediment. Referring to Table 1, the EF of Cr, Th, Ni and U are higher than 1.5, indicating that the source of these elements was from anthropogenic activities. The enrichment was minor (U), moderate (Th and Ni) and moderately severe (Cr).

The Igéo average of selected elements in the bottom strata (Table 3, Fig. 8b) in decreasing order: Cr (1.40) > Ni (0.10) > Th (0.48) > U (-0.56) > Fe (-1.55) > V (-1.95) > Co (-2.03) > Sc (-2.07). Based on Table 1, U, Fe, Co, V and Sc were similar to surface and middle stratum, characterizing restrictively the sediments as unpolluted. Cr, Ni and Th representing the category polluted, where the pollution is moderate.

The variations in CF average values of Lobé and Niété bottom sediments (Table 3, Fig. 8c) are similar as EF: Cr (3.96), Th (2.09), Ni (1.60), U (1.02), Fe (0.51), V (0.39), Co (0.37) and Sc (0.36). According to Table 1, Fe, Co, V and Sc indicated a low contamination while the remaining elements presented moderate (Th, Ni, and U) to considerable (Cr) contamination.

The PLI value of the bottom sediment (0.88) indicated the unpolluted status of Lobé and Niété sediments (Table 1; Table 3, Fig. 8d); this observation is different to those in the surface and middle strata.

3.4 Statistical Analysis

To assess the relationships and interdependency among the sediment characteristics, a multivariate statistical analysis was used because of its value as a tool for reducing and organizing large data sets into groups with similar characteristics without losing much information. In the present study, a multivariate statistical analysis (Pearson correlation, cluster and principal component analysis) for each stratum was used to identify relationships among the variables. The measured heavy metals and radionuclides concentrations and sediment characteristics (grain size parameters and organic matter) were used in this multivariate analysis.

3.4.1 Pearson Correlation

The Pearson correlation coefficients of studied variables (element concentrations, grain size parameters and organic matter) in Lobé and Niété sediments are presented in Table 4. In surface sediments (Table 4a), Fe concentration was significantly positive correlated with Cr (0.53), V (0.77), Th (0.77) and U (0.70). Like Fe, Ni vs Cr (0.51), Ni vs Co (0.94), Cr vs Co (0.59), Sc vs V (0.81), V vs Th (0.84), V vs U (0.73) and Th vs U (0.97) showed a significant positive correlation. Fe, Ni, Cr and Co are significantly positively correlated with sand (0.58, 0.65, 0.62 and 0.80, respectively) and significantly negatively correlated with silt (-0.61, -0.70, -0.64 and -0.84, respectively). Clay and organic matter (OM) do not show a significant correlation with metals.

The middle strata show first a significant positive correlation between Fe vs Ni (0.51), Fe vs Sc (0.69), Fe vs V (0.71), Ni vs Cr (0.77), Ni vs Co (0.96), Cr vs Co (0.92), Sc vs V (0.95), Sc vs Th (0.59), V vs Th (0.56), Th vs U (0.98) and second, a significant negative correlation between Ni vs Th (-0.79), Ni vs U (− 0.86), Cr vs Th (− 0.69), Cr vs U (− 0.72), Co vs Th (− 0.79), Co vs U (− 0.83) (Table 4b). Sand was significantly negatively correlated with Fe (− 0.74), Ni (− 0.87), Cr (− 0.66) and Co (− 0.83) and significantly positively correlated with U (0.56). On the other hand, with same proportion, silt was positively correlated with same elements Fe (0.73), Ni (0.88), Cr (0.66) and Co (0.83) and negatively correlated with U (− 0.56). Similarly, Fe (0.70), Sc (0.71) and V (0.63) shows a positive correlation with clay. Organic matter is negatively correlated with V (-0.60) and positively correlated with Ni (0.88), Cr (0.66) and Co (0.83).

At bottom section (Table 4c), almost all elements, except Th and U were significantly positive correlated with each other. Ni, Co, V and Fe (clay only) were significantly positively correlated with silt (0.93, 0.82 and 0.77, respectively)

Table 4 Pearson correlation matrix of studied variables (chemical elements content, grain size parameters and organic matter) in Lobé and Niété sediments (a: surface. b: middle. c: bottom and d: all samples)

(a)	Fe	Ni	Cr	Co	Sc	V	Th	U	Sand	Silt	Clay	OM
Fe	1											
Ni	0.2	1										
Cr	**0.53**	**0.51**	1									
Co	0.29	**0.94**	**0.59**	1								
Sc	0.33	−0.11	−0.14	−0.32	1							
V	**0.77**	0.03	0.29	−0.07	**0.81**	1						
Th	**0.77**	−0.3	0.24	−0.27	0.48	**0.84**	1					
U	**0.7**	−0.4	0.28	−0.31	0.36	**0.73**	**0.97**	1				
Sand	**0.58**	**0.65**	**0.62**	**0.8**	−0.17	0.11	−0.04	−0.05	1			
Silt	**−0.61**	**−0.7**	**−0.64**	**−0.84**	0.12	−0.17	0.01	0.04	**−0.99**	1		
Clay	−0.1	0.2	0.39	0.14	0.13	0.21	0.15	0.21	−0.21	0.17	1	
OM	0.32	−0.25	−0.35	−0.14	−0.12	0.13	0.49	0.45	−0.13	0.13	−0.25	1
(b)	Fe	Ni	Cr	Co	Sc	V	Th	U	Sand	Silt	Clay	OM
Fe	1											
Ni	**0.51**	1										
Cr	0.12	**0.77**	1									
Co	0.33	**0.96**	**0.92**	1								
Sc	**0.69**	−0.11	−0.19	−0.17	1							
V	**0.71**	−0.21	−0.36	−0.32	**0.95**	1						
Th	−0.11	**−0.79**	**−0.69**	**−0.79**	**0.59**	**0.56**	1					
U	−0.32	**−0.86**	**−0.72**	**−0.83**	0.39	0.37	**0.98**	1				
Sand	**−0.74**	**−0.87**	**−0.66**	**−0.83**	−0.37	−0.22	0.41	**0.56**	1			
Silt	**0.73**	**0.88**	**0.66**	**0.83**	0.35	0.2	-0.42	**−0.56**	**−1**	1		
Clay	**0.7**	0.36	0.48	0.39	**0.71**	**0.63**	-0.04	−0.23	**−0.65**	**0.63**	1	
OM	−0.18	**0.63**	**0.72**	**0.75**	−0.35	**−0.6**	-0.44	−0.38	**−0.52**	**0.53**	−0.04	1
(c)	Fe	Ni	Cr	Co	Sc	V	Th	U	Sand	Silt	Clay	OM
Fe	1											
Ni	**0.63**	1										
Cr	**0.76**	0.46	1									
Co	**0.8**	**0.92**	0.45	1								
Sc	**0.9**	**0.51**	**0.59**	**0.65**	1							
V	**0.84**	**0.82**	0.43	**0.93**	**0.81**	1						
Th	−0.44	−0.23	−0.19	−0.39	−0.41	**−0.58**	1					
U	−0.29	−0.27	0.01	−0.4	−0.22	−0.41	**0.71**	1				
Sand	−0.47	**−0.93**	−0.29	**−0.84**	−0.36	**−0.79**	0.29	0.16	1			
Silt	0.44	**0.93**	0.28	**0.82**	0.34	**0.77**	−0.3	−0.17	−1	1		
Clay	**0.53**	**0.58**	0.05	**0.8**	0.29	**0.66**	−0.41	**−0.58**	**−0.55**	**0.53**	1	
OM	**0.85**	**0.66**	**0.64**	**0.75**	**0.75**	**0.65**	−0.01	−0.21	−0.39	0.36	0.49	1
(d)	Fe	Ni	Cr	Co	Sc	V	Th	U	Sand	Silt	Clay	OM
Fe	1											
Ni	0.37	1										
Cr	0.25	0.47	1									
Co	**0.62**	**0.76**	0.45	1								
Sc	**0.72**	0.07	0.02	0.3	1							
V	**0.74**	0.13	0.12	0.31	**0.8**	1						
Th	−0.05	−0.34	−0.04	−0.39	0.09	0.3	1					
U	−0.09	−0.46	0.07	−0.43	0.11	0.26	0.87	1				
Sand	−0.43	−0.27	−0.05	**−0.63**	−0.31	−0.4	0.24	0.18	1			
Silt	0.4	0.25	0.03	**0.61**	0.28	0.37	−0.25	−0.19	**−1**	1		
Clay	**0.56**	0.36	0.31	**0.62**	0.27	**0.5**	−0.1	−0.19	−0.48	0.45	1	
OM	**0.5**	0.2	0.1	**0.58**	0.4	0.2	0.07	−0.01	−0.38	0.36	0.24	1

and clay (0.58, 0.80, 0.66 and 0.53, respectively). Sand shows a significant negative correlation with Ni (-0.93), Co (− 0.84) and V (− 0.79) like clay with U (-0.58). Except Th and U, the remaining elements were positively correlated with organic matter.

The matrix of all studied samples (Table 4d) shows a significant positive correlation between Fe vs Co (0.62), Fe vs Sc (0.72), Fe vs V (0.74), Ni vs Co (0.76), Sc vs V (0.80) and Th vs U (0.87). Silt shows a significant positive correlation with Co (0.60) like clay with Fe (0.56), Co (0.62) and V (0.50), and organic matter with Fe (0.50) and Co (0.58). Sand shows a significant negative correlation with Co (− 0.63).

The relationship among selected elements indicated a common source in the area. According to Singh et al. (2017) in the River Ghaghara, a major tributary of the River Ganges in Northern India, positive relationship between Co, Cr, and Ni demonstrated a characteristic natural origin of these components in the waterway sediment while good correlation between each other could be suggested from common anthropogenic sources, and that they can be affected by possible additions.

3.4.2 Cluster Analysis

Cluster analysis is a technique that is used to provide important information about the grouping of variables based on similarity. Figure 9 represents the dendrograms of metals and radionuclides of Lobé and Niété sediments, grouped into three statistically significant clusters for all strata. In surface sediments (Fig. 9a), the first cluster includes Sc, V, Fe, Th and U; Cr is the only element of the second cluster while Ni and Co represent the third cluster. The first cluster of middle strata includes Cr, Ni and Co; Th and U form the second and the third integrates Fe, Sc and V (Fig. 9b). Bottom strata regroup Th and U in the first cluster, only Cr in the second like the surface and the remaining (Fe, Sc, Ni, Co and V) in the third cluster (Fig. 9c). Due to some differences obtained in each stratum, a dendrogram of all sample was done (Fig. 9d) and we noted that Th and U formed the first cluster. The second cluster included Fe, Sc and V while Cr, Ni and Co represent the third. This grouping revealed that elements belonging to the same cluster have similar source.

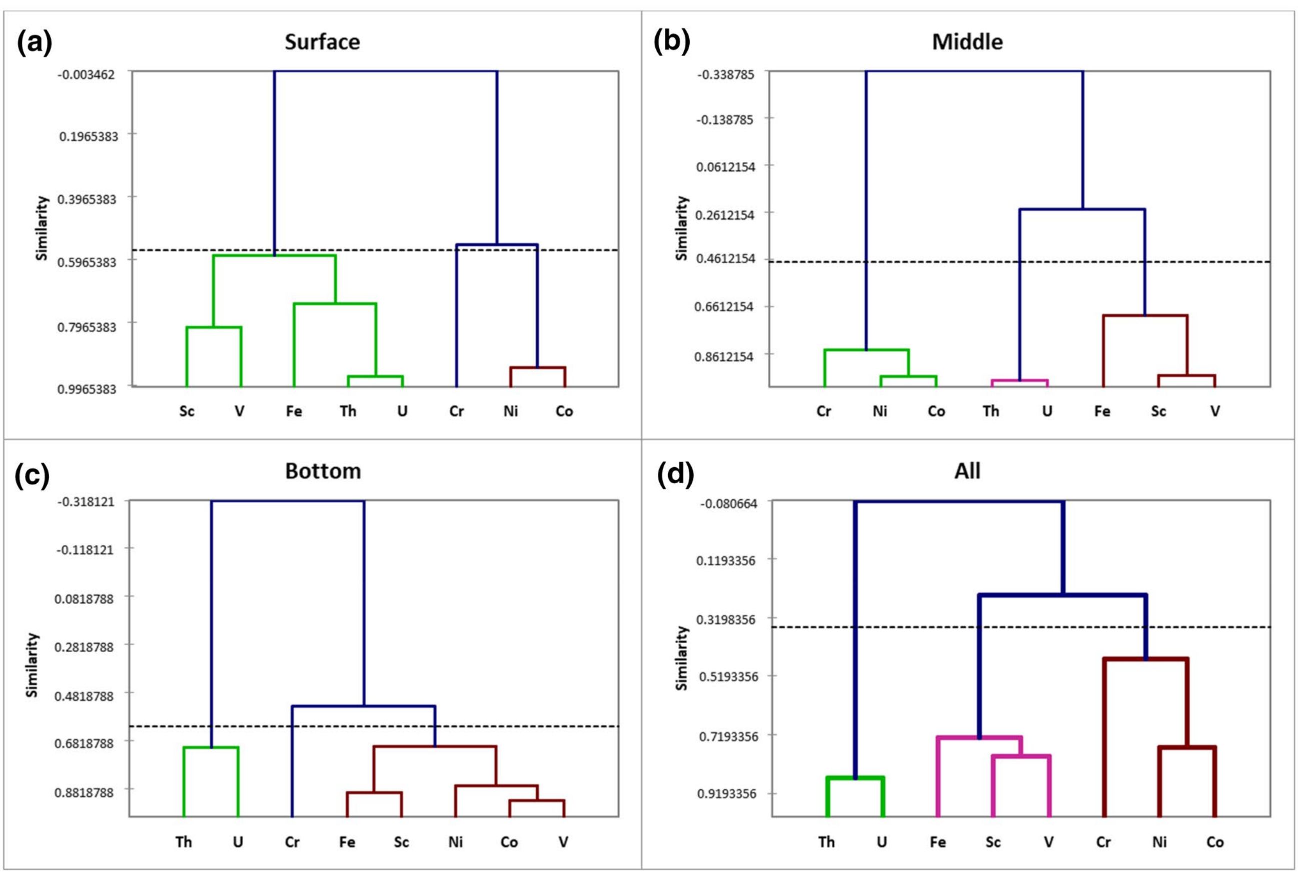

Fig. 9 Dendrograms of cluster analysis of the concentration of analyzed variable (chemical elements) in Lobé and Niété sediments

3.4.3 Principal Component Analysis

To sustain the association obtained from the Pearson correlation and cluster analyses, a principal component analysis (PCA) was performed with chemical elements, grain size parameters and organic matter as variables. In the analysis, the first three principal components accounted for nearly 72.99% of the total variance, and the variances of F1, F2 and F3 is 40.08, 20.92 and 12%, respectively. Two main groups are distinguished: the first integrating the component F1 and F3 and the second is represented by the component F2 (Table 5, Fig. 10). The first group includes Fe, Ni, Cr, Co, Sc and V, grain size parameters (Sand, silt and clay) and organic matter. We noted that except sand with a significant negative correlation, the rest are positively correlated to this group (Table 5, Fig. 10). According to the cluster analysis, this group integrated the second (Fe Sc and V) and the third (Cr, Ni and Co) clusters materialized by the Fig. 9d. Wang et al. (2008) in west-four Pearl River Estuary sediments, China, explained that Cr, Ni and Co come from the terrigenous detrital matter taken by the runoff, and the lithological characteristics of drainage area. This observation suggest that this group could be identified as "anthropogenic factor" while the second, made of Th and U (like also materialized by the first cluster) could be identified as "natural factor". As seen in Table 5 and Fig. 10, Sc and V could also be attributed to the second group.

4 Conclusions

This is the first study on spatial and vertical distribution and contamination assessment in sediment cores of Lobé River, south–west Cameroon. The study was carried out on heavy metals (Fe, Ni, Cr, Co, Sc and V) and radionuclides (Th and U) in sediment cores and to assess their contamination level in the environment through the EF, Igeo, CF and PLI values and source apportionments of these metals. The result of sediment characteristics analysis showed that sand is the main constituent. The river sediments recorded low levels of organic matter. The average concentration of selected elements decreased as Fe > Cr > Ni > V > Th > Co > Sc > U. Spatial and vertical distributions of chemical elements presented high concentration of Cr, Ni and Th which exceed the

Table 5 Correlation between variables (chemical elements contents, grain size parameters and organic matter) and factors

	Fe	Ni	Cr	Co	Sc	V	Th	U	Sand	Silt	Clay	OM
F1	**0.81**	**0.59**	0.34	**0.90**	**0.58**	**0.62**	−0.27	−0.30	**−0.77**	**0.75**	**0.72**	**0.56**
F2	0.31	−0.44	−0.07	−0.28	0.55	0.66	**0.82**	**0.83**	0.04	−0.06	0.03	0.17
F3	0.12	0.47	**0.77**	0.18	−0.09	0.01	0.18	0.14	0.49	−0.51	0.14	−0.04

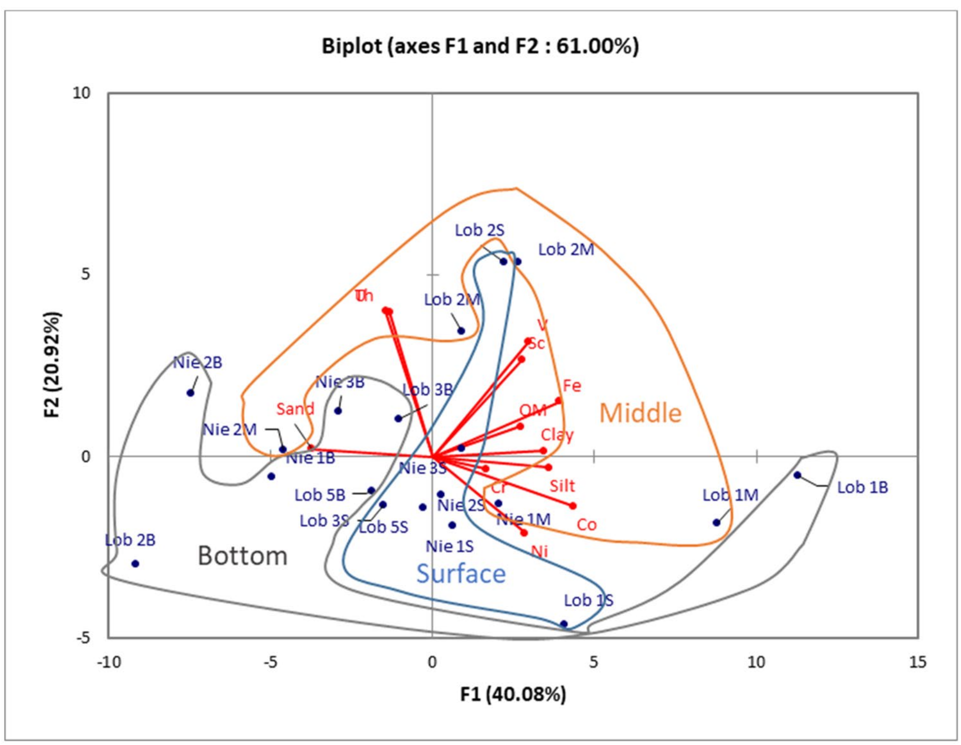

Fig. 10 Principal component analysis of studied variables (chemical elements contents, grain size parameters and organic matter) of Lobé and Niété sediments

average values. The maximum concentration of most studied metals was recorded in the middle stratum of sediment cores, followed by surface and bottom strata, respectively. Due to the human activities such as household wastes, intensive agriculture and the result of the processing of industries products, the highest concentrations of most chemical elements were recorded at Lob 1, Nie 2, Lob 2 and Lob 5. Pollution indices (EF, Igéo and CF) of Lobé sediments revealed a moderate to severe pollution of Cr, Ni and Th in all strata, with a low contamination of U at the bottom section. Several pollution indices show that surface and middle section sediments are polluted while bottom sediments are unpolluted. According to statistical analysis, heavy metals (Fe, Sc, V, Cr, Ni and Co) have common anthropogenic sources, whereas grain size parameters (sand, silt and clay) were associated with them while radionuclides (Th and U), which have a natural source. Through the contamination assessment in sediment cores of Lobé River of south–west Cameroon, this study provides environmental pollution related information over the study area, which is important for policy makers.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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