

Contribution to the Assessment of the Impact of Mining Activities on Water Resources and Sediments in the Ubangi Basin: Case of the Moboma Commune (Bagandou)

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Abstract: Recently, the problems posed by chemical contaminants, in particular metallic trace elements (TMEs), in the environment, have aroused the interest of the scientific community, because the protection of the environment requires knowledge of the fate of these contaminants and their effects on the living beings that depend on them. Their presence in environmental matrices is often caused by human activities, particularly agriculture, livestock farming, industry and transport. In the region of the Lobaye prefecture, in the south-west of the Central African Republic, gold and diamonds have been mined for decades in an artisanal manner using inadequate methods and environmentally unfriendly substances such as mercury and cyanide. The aim of this study is to determine the trace metal content of the water and sediments in the study area in order to predict the environmental and health risks associated with their use. Water and sediment samples were taken at 16 sites, 6 boreholes, 10 watercourses and a control well, and their concentrations in metals such as Cd, Cu, Hg, Ni, Pb and Zn were analysed by inductively coupled plasma mass spectrometry (ICP-MS). The results obtained reveal a significant contamination of these waters and underline a significant variability of the concentrations of the TMEs according to the metal analysed and the type of water, on the semi-mechanised exploitation site at DIKEKELE, the concentration of mercury is 8 µg/l higher than the standard of 1 µg/l. The sediments are composed of a majority of Quartz at about 80% on average and 20% overall of kaolinite and muscovite and contain a high proportion of Cr, Pb, Cu, Co and Ni and a low proportion of Hg.

Keywords: TMEs, Environmental Risks, Quartz, Cadmium, Spectrometry

1. Introduction

The mining sector is a pillar of the Central African Republic's economy. Diamond and gold mining contribute 4% of the gross domestic product, and almost half of the total value of the country's exports. Industrial diamond mining dates back to the 1930s. The advent of the country's independence in 1960 was marked by a rapid expansion of mining activity and the decline of industrial mining. Today artisanal mining dominates the mining sector, producing all the gold and over

98% of the diamonds [20]. The first identified testimony is that of L. BRUSTIER who, in 1912, recognised indications of gold in the upper basin of the Kouango (now the Ouaka River) north of Bambari [12, 15]. It was not until 1921 that a campaign focused on gold prospecting was launched in the Bangassou region by the "Syndicat des Mines de l'Oubangui". In 1938, P. MENNERET took out permits south of Mbaïki and discovered the Moboma deposit in April, which was put into production in November of the same year. Other human activities, such as mining, affect the freshwater basins through the use of water for ore processing and the discharge of

effluents [17, 9, 36]. The flooding of tunnels creates reservoirs that can potentially be used as a water resource. However, this water is often too mineralised to be directly usable as a drinking water supply, and in some extreme cases is a source of significant environmental contamination [17]. Therefore, protection must remain the primary goal of society, which implies a full commitment to the protection of natural resources, including water resources, and communities in mining areas [7, 8]. Respecting and enforcing these actions will ensure that the race to extract gold does not turn into a nightmare of poisoned waterways. In the face of these major challenges to community water supply, the protection of ecological systems and knowledge of the quality of water resources in the mining area remains a priority [24].

The aim of this assessment is to determine the impacts of mining activities for better qualitative and quantitative management of water resources. This study will make it possible to assess the levels of trace metals (TMEs) in the water in the Moboma region (Bagandou) in order to determine

the environmental and health risks associated with their use. More specifically, the aim is to (1) determine the degree of contamination of the water by TMEs, (2) compare them with regulatory standard values, and (3) predict the risks associated with their agricultural use or consumption. The exploitation sites present themselves by a wild and very disorderly emergence of pits and quarries as well as dung beetle galleries. In addition, there is erosion and sedimentation as mineral development disturbs the rock and soil during the construction and maintenance of roads, open pits and in mine waste. Without adequate prevention and control strategies, soil erosion can lead to discharge into streams, rivers and lakes [24, 22]. Excessive discharge of sediment can block rivers, smother vegetation, destroy fauna, flora and aquatic life.

Study area

Our study area is located in the commune of Moboma, in the prefecture of Lobaye, in the southwest of the Central African Republic (Figure 1).

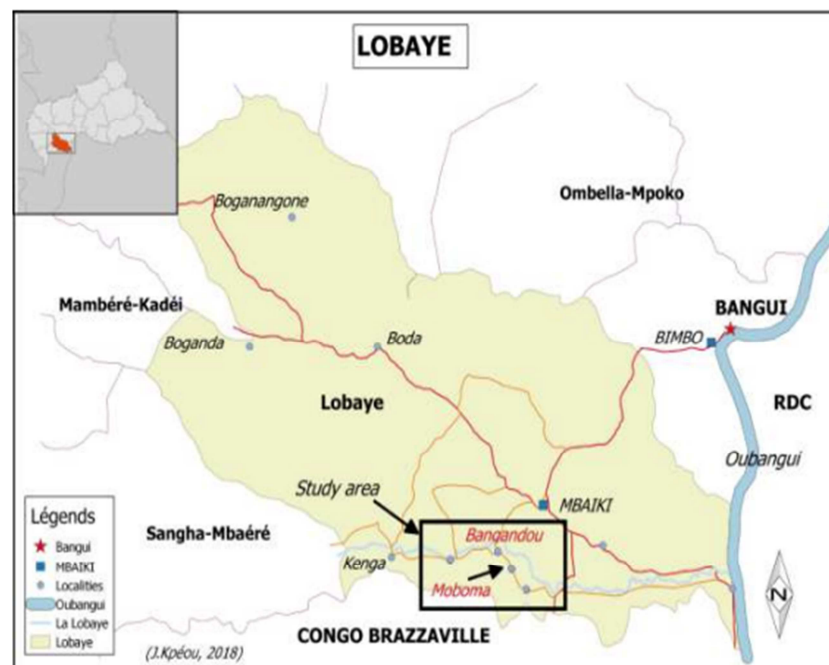


Figure 1. Study area.

It is located between 3°66' and 3°85' North latitude and between 17°65' and 18°98' East longitude. The commune of Moboma is bounded [11, 29]:

- 1) To the West by the prefecture of Sangha-Mbaéré,
- 2) To the East by the Oubangui River,
- 3) To the North by the prefecture of Ombella-M'poko,
- 4) To the South by the Republic of Congo.

2. Materials and Method

2.1. Materials

After a first phase of reconnaissance of the structures to be sampled in the field by the laboratory team, during the campaign, 16 points were sampled including boreholes (06),

and river water (10) in May during low water and in September during high water. The following in situ analyses were carried out on each water point sampled:

- 1) pH (pH meter WTW 340i);
- 2) Electrical conductivity and temperature (WTW 340i conductivity meter);
- 3) Alkalinity (HACH Alkalinity Kit).

A series of samples were taken for different chemical analyses:

3 x 30 ml bottles filtered through 0.45μ for the determination of cations (then acidification with HNO₃), anions and trace elements (then acidification with ultra-pure HNO₃) respectively. On each borehole and well, the measurements and samples were taken after sufficiently

renewing the water in the column of the structure when the equipment allowed it. Finally, we took sediment samples using a corer for mineralogical and chemical analysis [30].

Sediment sampling.

Sediments were collected by coring. The corers were sunk

vertically over the smallest possible area in order to avoid the heterogeneity of the terrain. In order to preserve the possible anoxia of the sediments, the tubes are sealed at the top with a lid and at the bottom with a Teflon piston. Immediately after sampling, the cores are then cut out on site.

Table 1. Geographical coordinates of sampling points.

Code	Name	Nature	Group	Latitude	Longitude	Altitude (m)
1E	LOBAYE PONT SCAD	R10	1	3°39'48,8"	17°59'12,7"	364
2E	MOSSORO TI YI (DIKEKELE)	R7	1	3°44'11,8"	17°53'38,4"	376
3E	FORAGE NGOUMA	F3	2	3°43'14,9"	17°45'35,8"	456
4E	RIVIERE NGOUMA	R5	1	3°43'55,2"	17°43'55,2"	420
5E	FORAGE MOBOMA	F5	2	3°41'52,9"	17°55'22,2"	401
6E	RIVIERE MOBOMA (AVAL)	R8	1	3°41'38,5"	17°53'34,8"	389
7E	FORAGE KENGA II	F4	2	3°43'36,5"	17°41'41,3"	417
8E	FORAGE BOBEKITI	F1	2	3°45'44,1"	17°50'04,4"	543
9E	RIVIERE KOUNGUE	R1	1	3°50'25,1"	17°50'19,0"	424
10E	RIVIERE LOTEMO	R9	1	3°38'54,9"	17°54'20,1"	397
11E	FORAGE LOTEMO	F6	2	3°38'32,8"	17°54'56,9"	411
12E	RIVIERE LOMBE	R4	1	3°45'15,0"	17°47'53,0"	399
13E	LOBAYE BAC	R3	1	3°47'16,9"	17°50'35,0"	379
14E	RIVIERE KENGA	R6	1	3°43'40,7"	17°42'27,2"	404
15E	RIVIERE KOUNGUE NDOLOBO	R2	1	3°49'52,1"	17°50'26,7"	419
16E	FORAGE LOMBO I	F2	2	3°44'52,4"	17°50'20,2"	528

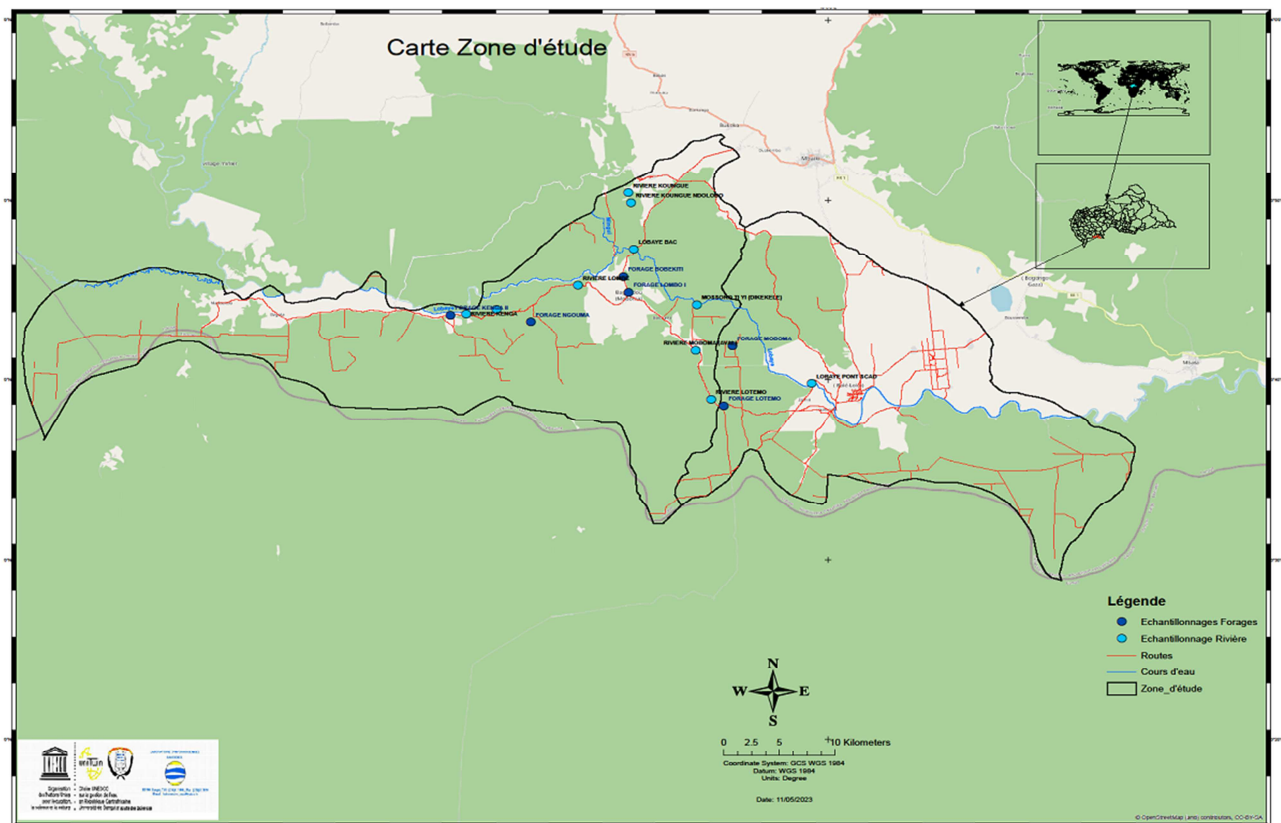


Figure 2. Geo-sampling map of the study area (Commune of MOBOMA and BALE LOKO).

2.2. Methods

This section covers the processing and analyses applied to the study of the water and sediment samples taken. Several methods were used for the physical, chemical and mineralogical analyses of the water and sediment samples.

2.2.1. Sediment Size Distribution

Sediment Preparation

In the laboratory, we dried the sediment samples in a laminar flow hood, an environment free of contamination. Then the samples were sieved at different mesh sizes. The particles were divided according to their particle size into

three categories. Fine ($F1 < 63\mu\text{m}$), medium ($63 < F2 < 224\mu\text{m}$) and coarse ($F3 > 224\mu\text{m}$) fractions.

Mineralogical study of fine fractions

The X-ray diffraction (XRD) method is based on the constructive interference of monochromatic X-rays in a crystalline sample. Crystalline substances containing a lattice of atoms can diffract the incident X-rays and generate an interference pattern [27]. The resulting pattern can be analysed to obtain information about the atomic or molecular structure of the material, and hence the identity of the phase.

2.2.2. Sediment Analysis

The sediments are observed with a scanning electron microscope (SEM), the ESEM model, QUANTA 200 FEI, was used in order to observe and photograph the surface of the grains. Elemental analysis of the support surface was done before dye adsorption using the ESEM/EDS technique (ESEM, Quanta-200-FEI) and driven by the QUANTA-400 software.

2.2.3. Trace Metal Analysis (TME) in Sediments

In a Teflon etching tube, approximately 0.2g of dry sediment (F3) is weighed with 10 ml of 50% concentrated hydrofluoric acid (HF) (Prolabo) and 5 ml of supra pure nitric acid (Merck, 65%). This tube is heated to 140°C for approximately 48 hours. This first stage solubilises the majority of the carbonates, aluminosilicates, sulphides, certain oxides and organic compounds. In a second step and after evaporation of the solution, the residue is mineralised using a mixture of 6 ml of hydrochloric acid (Merck, supra pure, 33%) and 2 ml of nitric acid (Merck supra pure, 65%). This mixture is heated to 120°C until the solid residue is completely dissolved. The latter solution is then evaporated almost completely (0.5ml); then 20 ml of milli-Q water is added to rinse the walls of the tube and solubilise the metals adsorbed on them. The solution is then filtered through a

cellulose acetate membrane (Swinnex, Millipore) with a pore size of 0.45 μm to remove the remaining carbon particles. The diluted dissolution liquid is assayed with ICP-OES and ICP-MS, each controlled by a microprocessor.

2.2.4. Total Mercury Analysis on the AMA 254

The AMA 254 mercury analyser is an atomic absorption spectrometer used for mercury analysis. It is intended for the direct quantification of mercury in solid or liquid samples without the need for sample pre-treatment (mineralisation, etc.). Using the mercury vapour formation technique, exceptionally high sensitivity is achieved independent of the sample matrix. The microprocessor-controlled 254 Mercury Analyser and the analysis accessories (balance, micropipette, spatula etc.). The sample is deposited in a nickel scoop (50 μl for liquid sample or 50mg for solid sample), which has been tared. The scoop is then installed on the scoop holder, which will allow it to be automatically introduced into the decomposition/calcination oven. A temperature rise to 750°C, under a current of oxygen, ensures the drying of the matrix, its decomposition and its calcination. The decomposition products and the mercury are carried by the oxygen flow through the catalytic furnace, heated to 550°C, continuously. At the exit of this second furnace, the mercury vapour is trapped on a quartz tube filled with gold coated sand (Timmerman trap). The whole system is purged for 45 seconds, then the Timmerman trap is heated to release the mercury. The measurement is made in a double absorption cell. The signal given by the detector is processed by software.

3. Results and Discussion

3.1. Physico-Chemical Parameters

Surface water

a) Evolution of water Temperature

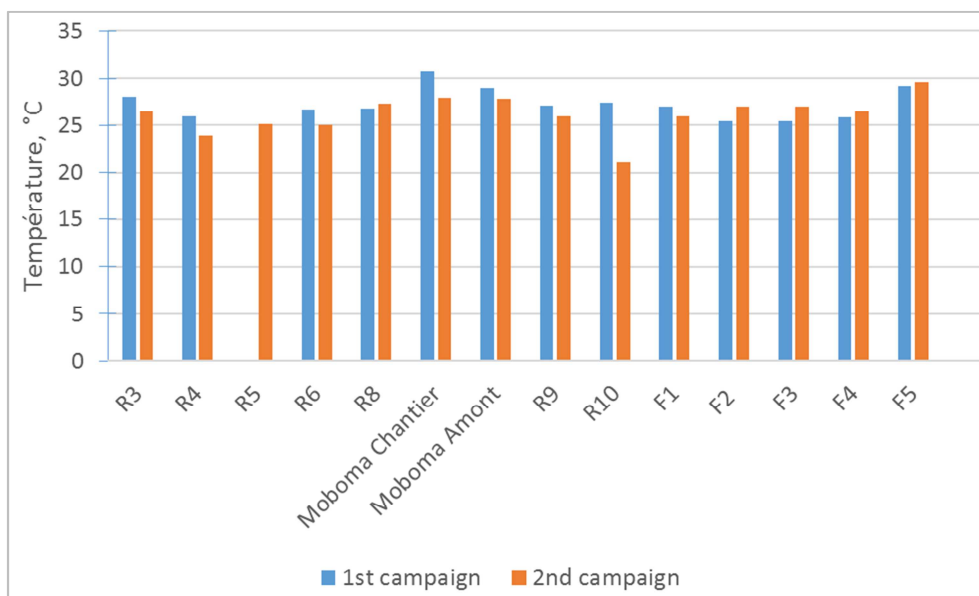


Figure 3. Evolution of water temperature.

Temperature is one of the physical parameters that plays a very important role in biogeochemical processes, and

varies between 21.1 and 30.8°C with an average of 27.5°C. These values reflect the effect of daily solar radiation on the equipment of the catchment areas and water bodies. These high temperatures favour the

development of microbiological activity, which is often the cause of pollution and oxidation-reduction processes of oxides and hydroxides [31].

b) *Evolution of pH.*

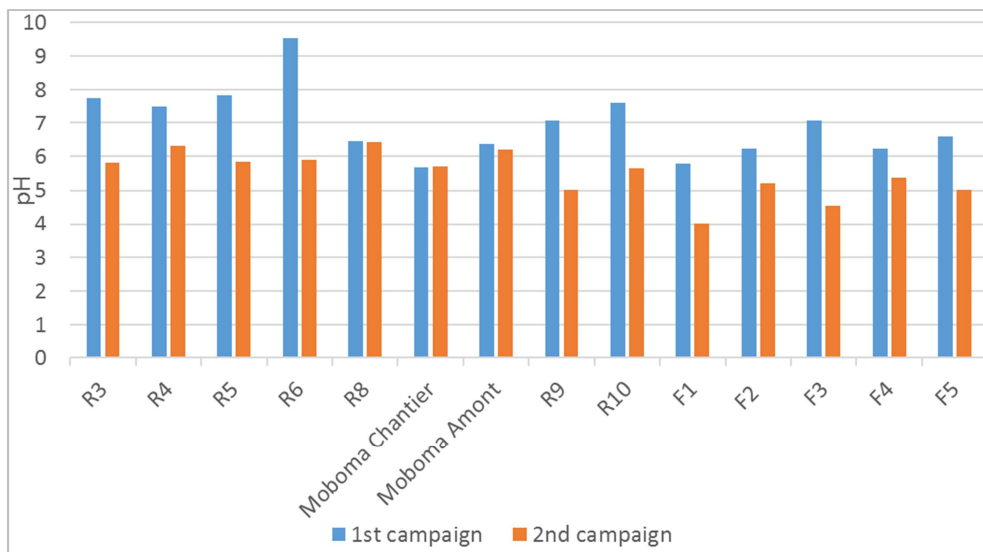


Figure 4. Evolution of the pH of water.

The pH is an indicator of the acidity or basicity of water on a scale of 0 to 14, 7 being the neutral pH [30]. It conditions a large number of physico-chemical balances. The pH of groundwater in general depends on the aquifers that contain it; it is acidic for groundwater from silica-rich geological

formations and basic for groundwater from carbonate geological formations [10, 29, 32]. In our study, we note that the pH varies between 6.46 and 9.52 for surface water and 4 to 7.06 for boreholes, which is normal.

c) *Evolution of conductivity*

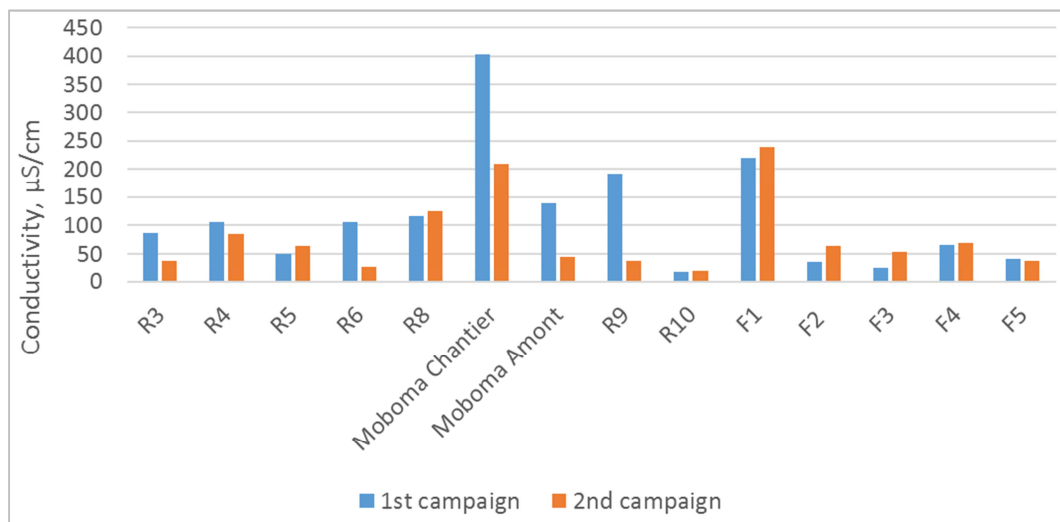


Figure 5. Evolution of the electrical conductivity of the water.

It can be seen that the borehole water is poorly mineralised, with the exception of boreholes F1, with a value of between 220 and 239. The increase in conductivity is perhaps due to the return of the rainy season with the infiltration of meteorite water into the water table and runoff carrying substances

(mineral salts) into the water as well as the rainfall of the soil. Finally, the Maboma mine site has the highest conductivity [28], with a value of 403 µS/cm, which raises some questions. On the whole, these waters are poorly mineralised.

d) *Evolution of Turbidity*

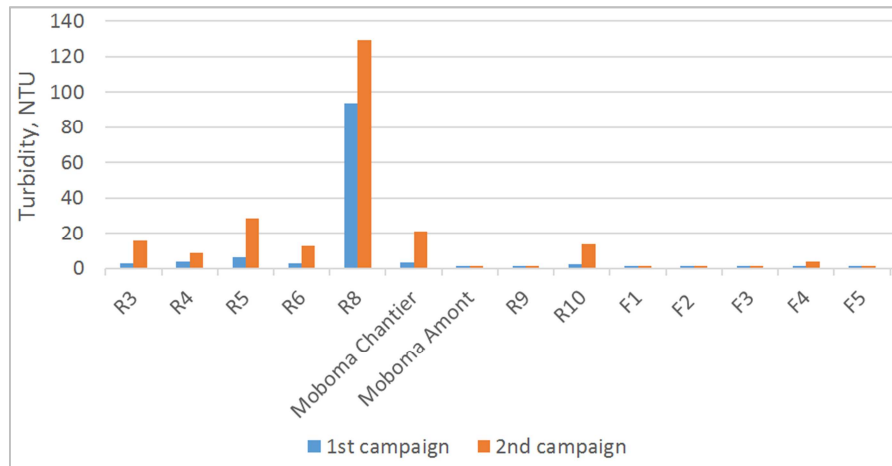


Figure 6. Evolution of Turbidity.

Turbidity characterises the presence of cloudiness in water caused by suspended particles and is generally low or non-existent in groundwater except in karstic terrain. Turbidity is

on the whole acceptable except for some peaks recorded during the rainy season at the level of the watercourses.

e) Evolution of suspended solids.

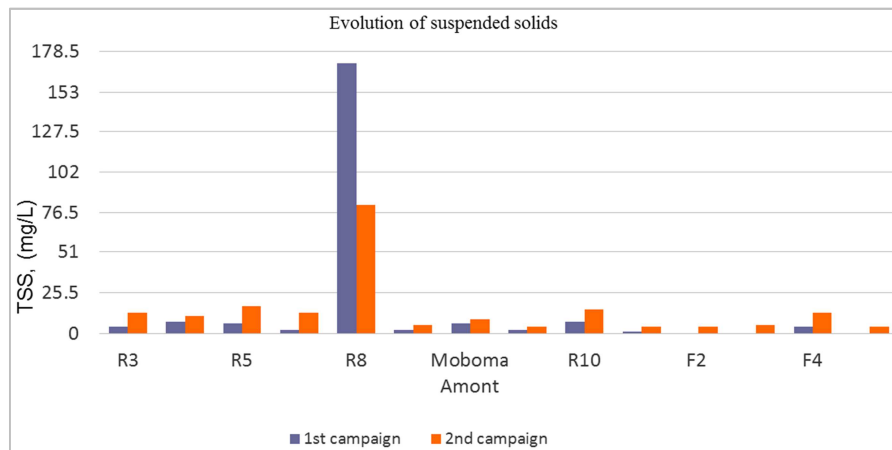


Figure 7. Evolution of Suspended Solids.

There is a good correlation between suspended solids and turbidity for the different points sampled. The river R8 is located upstream of the DIKEKELE mining site and is impacted by its mining activities.

f) Evolution of the iron concentration.

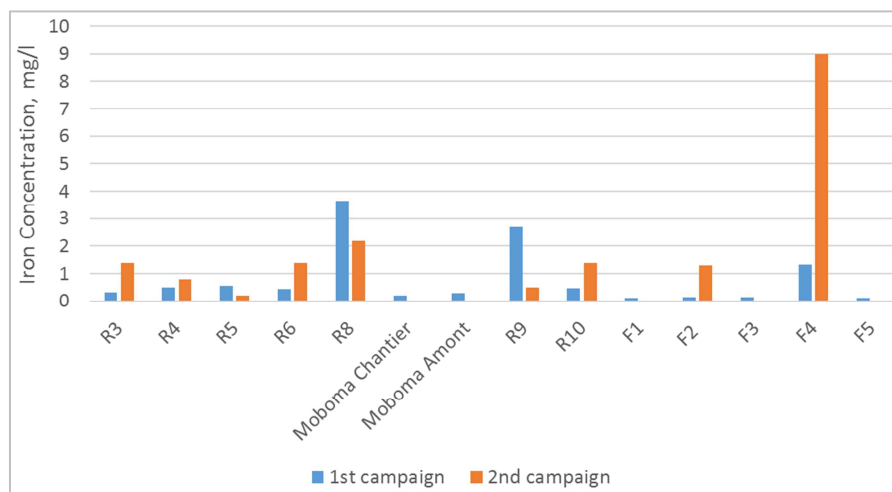


Figure 8. Evolution of iron concentration.

Iron is an essential element in the human diet, its origin in water is natural, it is abundant in rocks in the form of silicates, oxides and hydroxides, carbonates and sulphides. It is soluble in the form of ferrous ion (Fe^{2+}) and insoluble in the form of ferric ion (Fe^{3+}) [2, 5]. Its presence in water above 0.1 mg/l is troublesome as it gives the water a yellow to orange colour. In this study, it is noted that the majority of the points sampled have a concentration that exceeds the standards set by the regulations, which are 0.5 to 1 mg/l. We can cite the case of boreholes F4 with 9 mg/l, rivers R8 and R9 which have respectively 4 and 3 mg/l. As far as the rivers are concerned, this could be due to leaching of the soil during the rainy season.

g) Evolution of the concentration of heavy metals (Pb, Cd and Hg) in water

Lead is a natural product of the disintegration of uranium. Native Pb is rare, and due to its chalcophilic character it is associated with sulphide deposits; it is extracted from its main mineral source, galena (PbS) which contains 86.6% by

weight [21, 35] It is generated by natural activities through the leaching of carbonate rocks.

Cadmium does not exist in its native state. Its ore, greenockite, is very rare and unexploited. It is also present in lead and copper ores, as well as in natural phosphates [30, 33]. It comes from industrial discharges, waste incineration and fertiliser use [18, 19]. In this work, the average concentrations vary from 0.009 to 1.44 mg/l, which is not a cause for concern at present. Other elements such as arsenic, molybdate, cobalt, nickel, silver, aluminium, chromium, zinc and copper are present in infinitesimal quantities.

The water samples analysed contain a high proportion of lead, sometimes exceeding the standard of 3 $\mu\text{g/l}$.

We also note a fairly large quantity of mercury in the Lobaye River at the level of the semi-mechanised mining site at DIKEKELE, 8 $\mu\text{g/l}$ higher than the standard of 1 $\mu\text{g/l}$, but the mercury content is low upstream, This situation can be explained by the dilution effect of the Lobaye River.

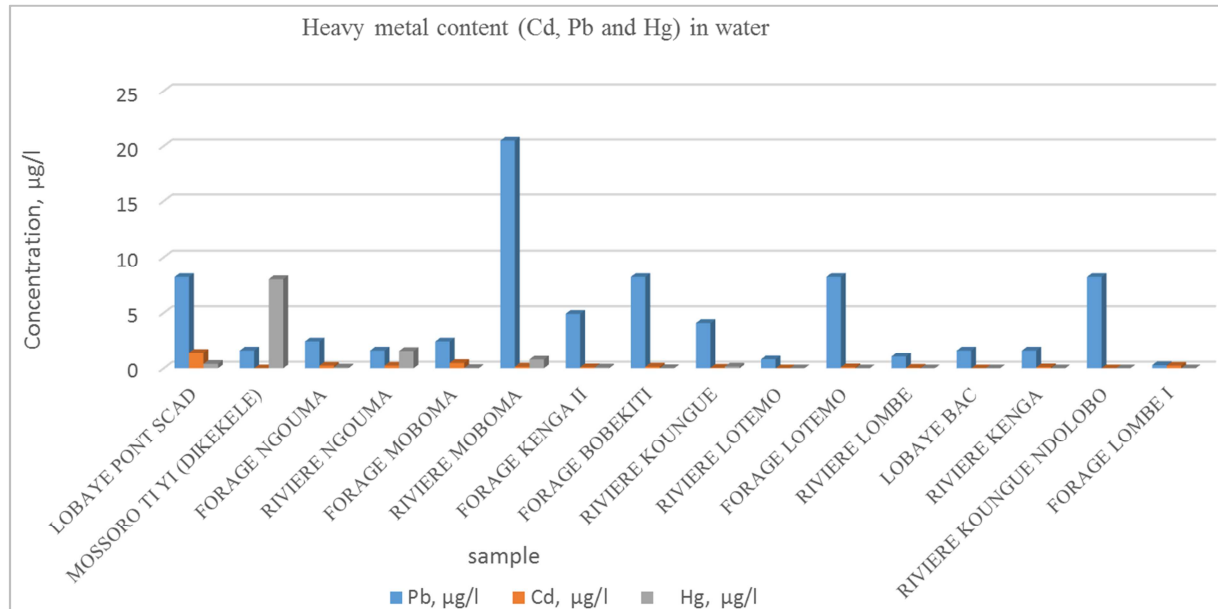


Figure 9. Heavy metal content (Cd, Pb and Hg) in water.

3.2. Chemical Characterisation of Sediments

After the study of the water, we were interested in the sediments that are likely to exchange pollutants with the water. First of all, we carried out an analysis of the sediments taken.

The scanning electron microscope (SEM) model ESEM, QUANTA 200 FEI, was used to observe and photograph the surface of the grains. The table shows the results of the analysis of 5 samples and the average content expressed as oxides.

Table 2. Analyses of 5 river sediments (and average analysis) after alkaline fusion.

sample,% by mass	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	K ₂ O	TiO ₂
1	78,82	14,17	3,33	0,18	0,29	1,11	1,41
2	68,16	13,80	12,97	0,17	0,55	0,77	2,34
3	92,84	3,43	3,05	0,04	0,01	0,32	0,31
4	63,06	24,12	8,22	0,33	0,02	1,55	2,70
5	38,99	26,57	28,32	0,26	0,27	2,47	2,63

The sediments are mainly composed of quartz (about 70%) and a small proportion of clay and iron compounds (illite or iron oxide).

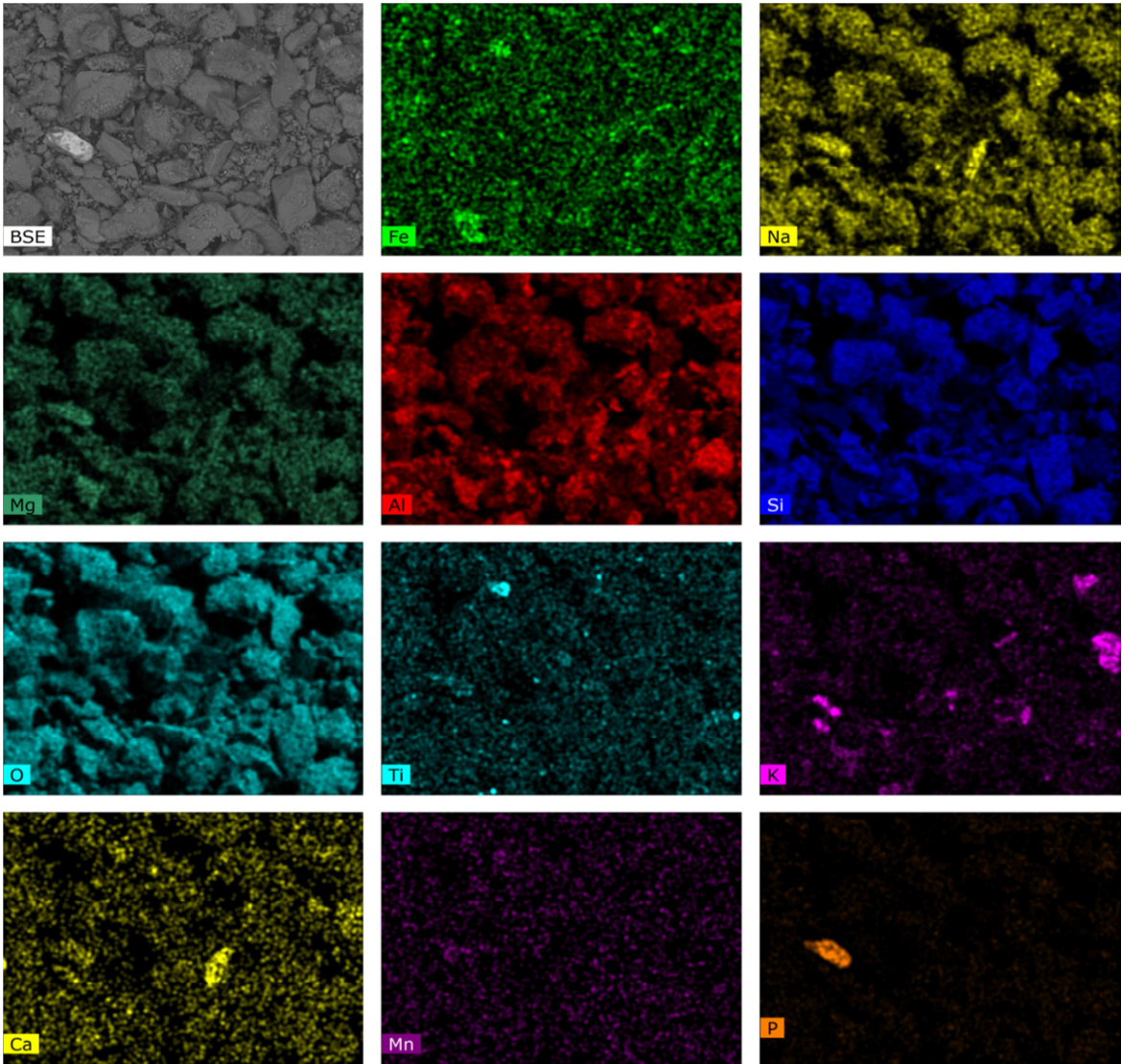


Figure 10. SEM image of sediment grains.

3.2.1. Sediment Particle Size Analysis

We obtained different particle sizes for each site: fine (F1<63µm), medium (63<F2<224 µm) and coarse

(F3 >224µm) fractions. The table below summarises the % of each of the fractions in the ten sediments analysed.

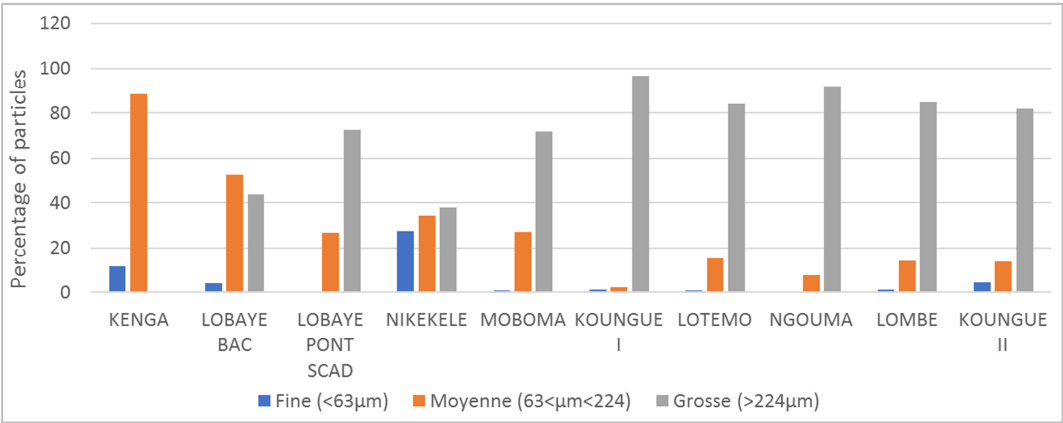


Figure 11. Particle size composition of the sediments.

Although present in small quantities compared to F3, fractions F1 and F2 will be studied throughout this work

because of their capacity to absorb metallic pollution.

3.2.2. Mineralogical Study of Fractions F1 and F2

The X-ray diffraction (XRD) method is a rapid and powerful technique for identifying and characterising materials; it is commonly used in many geosciences and physical sciences research departments and is widely used in industry [1, 6, 16]. It requires minimal sample preparation and interpretation of the resulting data is generally

straightforward. The main use of XRD is to identify the minerals present in a sample and quantify their relative proportions in a mixture. However, there are several other applications that can help characterise the crystal structure of a mineral [27, 32, 38].

The diffractograms were processed using MacDiff software and the quantifications were carried out using Highscore+ software. The results obtained are listed in the table below.

Table 3. Element composition in% per fraction < 63 μm (fraction F1).

	Quartz	Kaolinite	Hématite	Géothite	Muscovite	Ilménite	Zircon
KENGA	100						
LOBAYE BAC	77	9	13	1			
LOBAYE PONT SCAD	89	10					1
NIKEKELE	65	5			30		
MOBOMA	36	4			59	1	
KOUNGUE I	82		2	5	11		
LOTEMO	82	6		2	9	1	
NGOUMA							
LOMBE	47	13			40		
KOUNGUE II	48	16			36		

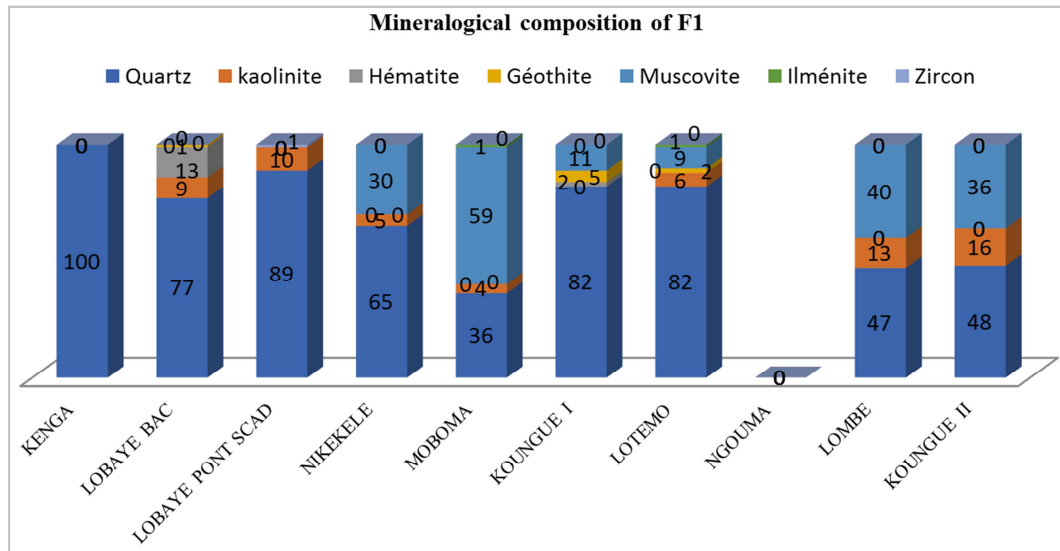


Figure 12. Mineralogical composition of the F1 fraction.

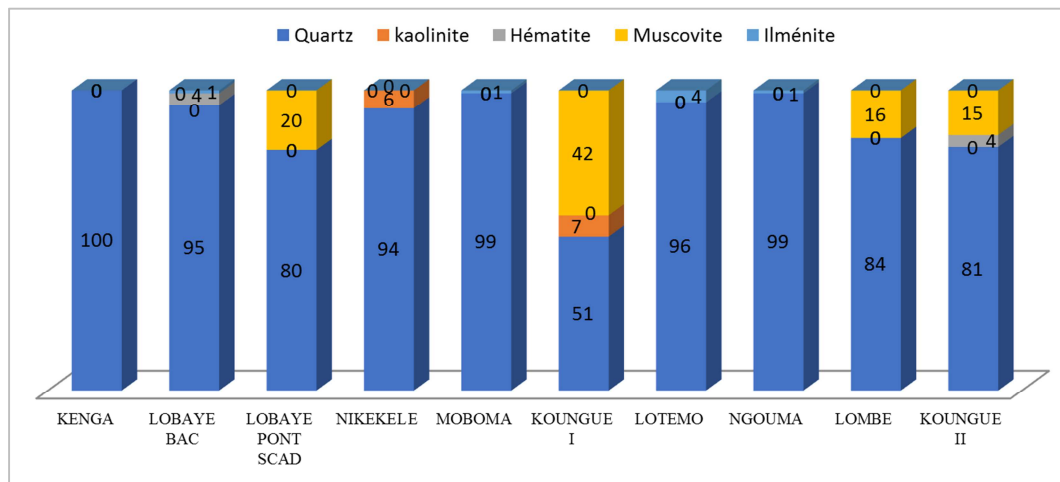


Figure 13. Mineralogical composition of the F2 fraction.

Table 4. Element composition in% by fraction $63 < \mu\text{m} < 224$ (Fraction F2).

	Quartz	Kaolinite	Hématite	Muscovite	Ilménite
KENGA	100				
LOBAYE BAC	95		4		1
LOBAYE PONT SCAD	80			20	
NIKEKELE	94	6			
MOBOMA	99				1
KOUNGUE I	51	7		42	
LOTOMO	96				4
NGOUMA	99				1
LOMBE	84			16	
KOUNGUE II	81		4	15	

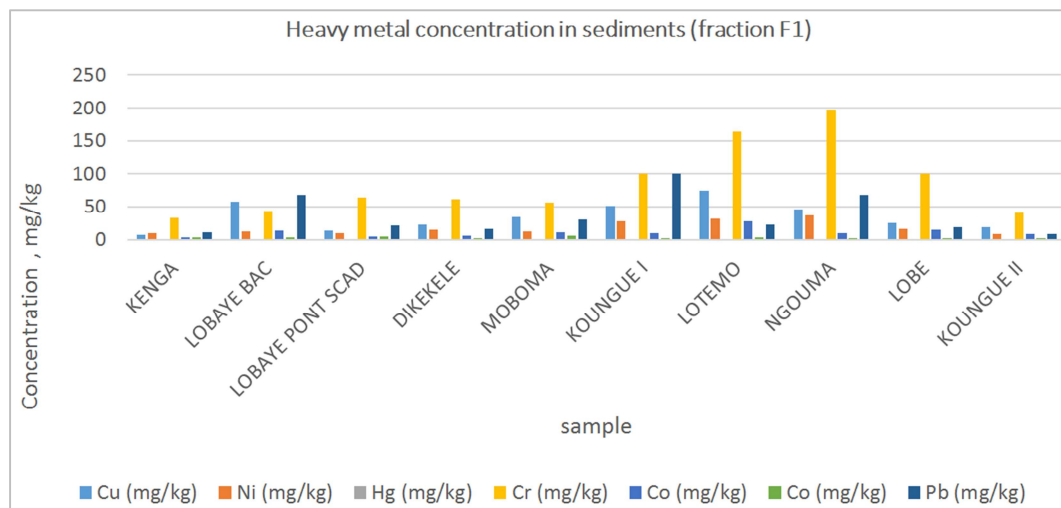
It can be seen that the majority of the sediments are composed of Quartz at about 80% on average and 20% overall of kaolinite and muscovite (equal share 10%). These results confirm the observation made with the SEM.

3.3. Total Etching Results for Sediments F1 and F2: Heavy Metals

Fraction F1

Table 5. Composition des éléments en mg/kg par fraction $< 63 \mu\text{m}$.

Fraction F1	Cu (mg/kg)	Ni (mg/kg)	Hg (mg/kg)	Cr (mg/kg)	Co (mg/kg)	Cd (mg/kg)	Pb (mg/kg)
KENGA	7	10,35	0,03	33,2	3,400	3,6	11,2
LOBAYE BAC	58	12	0,08	44,03	14,000	2,8	68,1
LOBAYE PONT SCAD	13,44	9,4	0,1	64	4,000	4,4	21,1
DIKEKELE	22,34	14,82	0,05	61,4	5,300	1,6	16,6
MOBOMA	34	12	0,1	57	11,000	5,7	31,02
KOUNGUE I	51	27,53	0,2	101	10,000	1,8	100
LOTOMO	75	31,54	0,12	164,1	28,000	2,9	23
NGOUMA	46	37,1	0,04	197	10,000	2,5	68
LOBE	25	16,32	0,2	100	15,210	1,5	19
KOUNGUE II	19,15	8,25	0,14	41,13	9,000	1,8	8,32

**Figure 14.** Evolution of heavy metal concentration in sediments (fraction F1).

Fraction F2

Table 6. Element composition in mg/kg per fraction $63 < \mu\text{m} < 224$.

	Pb (mg/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Hg (mg/kg)	Ni (mg/kg)	Cu (mg/kg)
KENGA	4,31	0,57	1,440	13,23	0,01	2,6	2,15
LOBAYE BAC	27,1	0,87	5,000	24	0,02	4,4	22,3
LOBAYE PONT SCAD	5	0,81	-	14,3	0,01	2	3,15
DIKEKELE	12	1,0	4,000	44	0,03	11	16,41
MOBOMA	13	1,1	4,500	23,01	0,02	3	12,34
KOUNGUE I	115	1,9	12,000	69,2	0,1	20	57
LOTOMO	14,27	1,7	12,000	45,35	0,2	6	26,52

	Pb (mg/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Hg (mg/kg)	Ni (mg/kg)	Cu (mg/kg)
NGOUMA	16	1,3	7,530	46,42	0,01	4	16,42
LOBE	4,33	0,30	4,000	19	0,02	3	4,33
KOUNGUE II	22	0,75	3,520	51	0,05	8	13,1

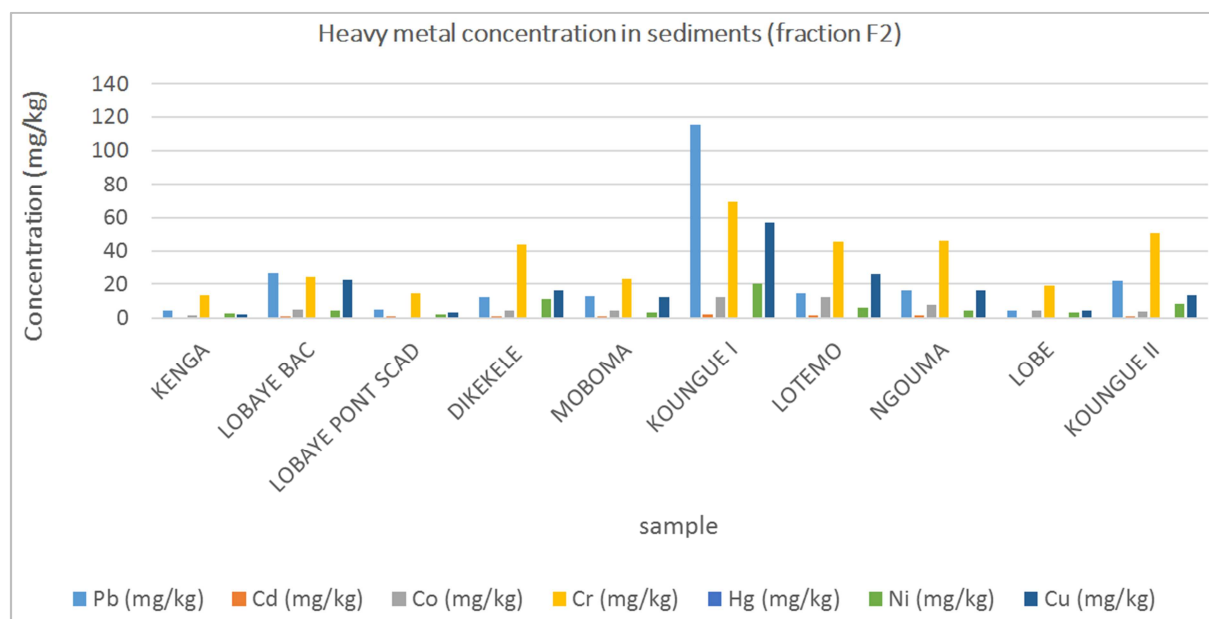


Figure 15. Evolution of heavy metal concentration in sediments (fraction F2).

Fractions F1 and F2 contain a high proportion of the following elements: Cr, Pb, Cu, Co and Ni. A small amount of mercury was found, which could lead to the suspicion that mercury is present in the water around these sampling points in the future.

4. Conclusion

The presence of heavy metals in water and sediments has become a major threat to the environment due to their persistence, non-biodegradable and toxic nature. Toxic metals such as Cd, Pb, Hg, Ni, and Cr are considered to be the most dangerous elements for the environment. Human activities such as mining and dumping of mine waste have played an important role in increasing the concentrations of these metals in the environment. The study of TME contamination in the gold zone in the region of has revealed the presence of several metals at different levels in the water and stream sediments of this locality. This pollution seems to have an anthropogenic origin. The comparison of the TME content in these waters revealed that the limit values for wastewater discharge into the natural environment were exceeded in Pb and Hg. In the sediments, the samples analysed contained high proportions of Cr, Pb, Cu, Co and Ni and low proportions of Hg. A fairly large quantity of mercury was also found in the Lobaye River at the level of the semi-mechanised mining site at DIKEKELE, which confirms the use of mercury by these mining companies. The mercury content is low downstream (Lobaye pont bac), which can be explained by the dilution effect of the Lobaye River. The work also enabled us to establish the level of contamination

(river, borehole and sediment) and finally the quality of the water during low and high rainfall periods. Also the clayey nature of the soil and the probable contamination induced by the Lobaye and its tributaries contribute significantly to this situation. Alternatively, in periods of high water, it should be noted that groundwater is also of average quality with a high concentration of suspended matter, turbidity and sometimes iron.

Conflict of Interests

The authors declare that they have no competing interest.

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