Contamination and Risk Assessment of Heavy Metals in Stream Sediments of Bambui Area, Western Cameroon

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***Abstract*: The Bambui area is located at the foot of the Bamenda Mountains, which is part of the Cameroon Volcanic Line (CVL). The study area consists of different rock types such as alkali basalt, trachyte, rhyolite and ignimbrite with a granitic basement of the Pan Africa Fold belt. The main objective of this work was to assess the contamination and risk pose by heavy metals in stream sediments of Bambui area. Heavy metal in the representative stream sediment samples collected were determined using inductively coupled plasma-mass spectrometer (ICP-MS). Elevated levels of Co, Cr, Cu, Mn, Ni, Pb, Th, V, Zn, La, Fe and Ti could be attributed to geological and anthropogenic metal input sources in the area. Assessment of contamination factor, degree of contamination, modified degree of contamination, enrichment factor, ecological risk factor and potential ecological risk index showed that the sediments had a low to high ecological risk index. Pollution load index (0.78-1.60), geo-accumulation load index (1.73-5641.91) and anthropogenic metal input (0-5.25) indicate heavy metal contamination in the study area. Geological origin, agricultural practices, municipal waste disposal and animal manure were identified as the major sources of heavy metals in the stream sediments of the study area.**

***Keywords*: Bambui area, Heavy metal, stream sediment, risk assessment, contamination, Cameroon**

I. INTRODUCTION

Heavy metals pollution from municipal solid waste, agricultural practices, sewage, road traffic emissions and other human inputs has become a serious problem due to their long-term accumulation and toxicity. Heavy metals are environmental pollutants that affect various environmental compartments in nature. The environment is exposed to a variety of pollutants through the aquatic environments and affects the ecosystems. This is because they are often major reservoirs of many pollutant [1], [2]. Heavy metals contamination poses is a serious threat to the aquatic system due to its toxicity, profusion, abundance, environmental persistence and subsequent levels of accumulation in the aquatic environment [3], [4], [5]. Sediment is widely used as an environmental indicator to assess metal contamination in the watercourse [4], [6]. In generally, sediments provide useful information about the state of environmental and geochemical pollution [7]. The presence of trace elements in the sediments is widely reported, and both abiotic and biological processes influence the distribution and circulation of sediments [8].

Heavy metals come from geogenic and anthropogenic sources in the natural environment. In general, anthropogenic sources such as industrial wastewater, household waste, sewage and municipal wastewaters are rich in high levels of metals such as As, Cd, Cr, Co, Cu, Fe, Hg, Mn, Ni, Pb, and Zn [9] at high concentration, it is highly toxic and harmful to human health. Heavy metals are harmful when their bioaccumulation exceeds that released into various environmental compartments. Heavy metals entering sediments have a negative impact on river ecosystems due to their high toxicity, resistance to degradation and bioaccumulation [10]. Because river sediments are one of the most important environmental indicators, they can be used to measure pollution levels in natural waters. Stream sediment can be used to measure the pollution levels in natural waters [4]. Today, metal pollution has become a major problem in many rapidly developing countries such as Cameroon [11], [12]. Disposal of household waste, biosolids and raw waste water from various industrial and agricultural resources into open water and rivers has created a dire situation in Cameroon [11], [5], [13], [12]. Waste disposal, biosolids and intense agricultural practices are the main anthropogenic activities that have contributed to increase levels of heavy metals in soils and stream sediments of urban town and cities in Cameroon. Bambui area is one of the most rapidly emerging municipalities in Bamenda, Cameroon with a-lot of small factories for soap production, food processing, mechanical workshops, oil exchange services, traffic releases, intense agricultural practices, wastewater irrigation and the used of animal manure (excreta) which generates huge amounts of waste and heavy metals [11], [14]. This waste is drained into soils or water systems that supply the wetlands and flat areas mostly used for the cultivation of crops and vegetables consumed all over the country. These crops and vegetables have the potential of metal uptake from waste water irrigation and soils in the study area which is detrimental to the population through food chain. The purpose of this study is to assess the metal levels, as well as the degree of metal contamination in stream sediments based on pollution indicators.

II. GEOLOGICAL SETTING

A. *Regional Geology*

The Bambui area is located at the southwestern part of the Pan-African fold belt in Cameroon. This fold belt is linked to the Trans-Saharan belt of western Africa and to the Brasiliano Orogen of NE Brazil (Fig. 1a). The Pan-African fold belt is incompletely covered by basalts and trachytes of Tertiary to Recent age. In Cameroon, the Pan-African fold belt consists of 3 domains [15], [16] (Fig. 1b): The Yaoundé domain (YD) is located at the northern edge of the Congo craton (Fig 1b). It is generally made of Neoproterozoic epicontinental or passive marginal deposits [17. This domain was latterly recrystallized during the 630–610 Ma amphibolite- to granulite-facies metamorphism during nappe tectonics, which thrust the Archean Congo craton southward [18], [19], [20]. The Yaoundé domain is associated with high-K calc-alkaline granitoids harmonious with a subduction-related magmatism [15], [27]. The Adamawa-Yade domain (AYD) which contains the present study area, is located between the Tchollire-Banyo shear zone to the north and the Sanaga shear zone to the south (Fig. 1b). It consists of Archean and Paleoproterozoic crust [21], [22], the northern part of the Central African Orogen [21], [23]. The Adamawa-Yade domain is associated with Neoproterozoic metasedimentary rocks intruded by 640–560 Ma syn-, late- and post-collisional calc-alkaline, high-K calc alkaline to shoshonite and alkaline granitoids [24]. The emplacement of these granitoids is controlled by 640–610 Ma crustal thickening episode, and 610–585 Ma wrench tectonic regime [25] .The Northwestern Cameroon Domain (NWC) is located west of the Tchollire-Banyo Shear Zone (TBSZ Fig. 1b), it is considered as an early 750–650 Ma continental magmatic arc [26]. The domain includes Neoproterozoic volcano-sedimentary schists and orthogneisses intruded by Pan-African pre-, syn-late, and post-tectonic granitoids that derived from partial melting of the lower crust [27], [28].

B. Local Geology

The Bambui area is located in the southwestern part of the Pan-African fold belt in Cameroon. The southwestern part of the Pan-African fold belt consists of Mount Oku, Mount Bamenda and Mount Bamboutos [31] (Fig. 2a, b). The Bambui area lies between the Bamenda Mountains (at the foot of the Bamenda Mountains) and the Oku Mountains (Fig. 2b) which are part of the Cameroon volcanic line (CVL). The Cameroon volcanic line is a late Cretaceous alignment with recent intraplate volcanic massifs

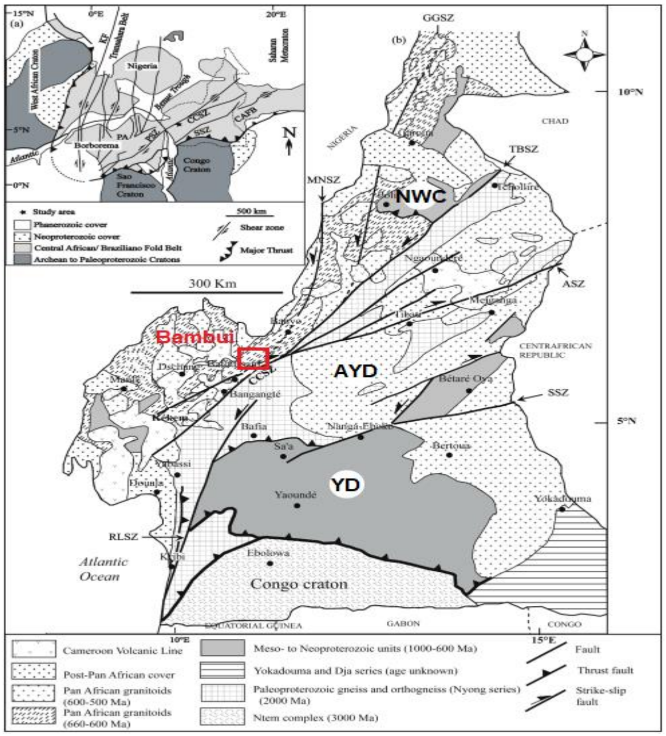

Fig. 1(a) Reconstitution map of the Pan-African NE Brazilian and West African domains showing the continuity between the Sergipano and North Equatorial ranges after [29]. 1(b) Geological map of Cameroon showing the Pan-African fold belt [18]. CCSZ = Central Cameroon Shear Zone, SSZ = Sanaga Shear Zone, TBSZ = Tchollire-Banyo Shear Zone, RLSZ = Rocher du Loup Shear Zone, ASZ = Adamawa-Yade Shear Zone, GGSZ = GodeGormaya Shear Zone, MNZ = Mayo Nolti Shear Zone. Insert showing the location of Cameroon in the pre-drift reconstruction [30]. PA = Patos shear zone, KF = Kandi Fault, PSZ = Pernambuco shear zone, (YD) Yaoundé domain, (AYD) Adamawa Yade domain, (WCD) Northern domain and plutonic complexes that extend from the Gulf of Guinea to the interior of northern Central Africa [32], [33], [34] Mount Oku and Mount Bamenda are among the main volcanic massifs along the CVL and sits on a basement of Pan-African granite-gneisses (~ 600 Ma), migmatites and biotite diorites [35], [36], (Fig. 2a, 2b). The CVL is characterized by alignment of oceanic and continental volcanic massifs, and orogenic plutonic complexes. The continental sector of the CVL is made up of massifs amongst which is Bamenda Mountains. The Bamenda Mountains is one of the most important volcanoes of the Cameroon Line in North-West Cameroon [37], [31]. Mounts Bamenda (600 km2) is the fourth largest massif in volume in the continental sector of the plutonic-volcanic Cameroon line and lies mid-way between Mount Bamboutos to the southwest and Mount Oku to the northeast [31]. Bamenda Mountains consists of volcanic rocks (alkali basalt, trachyte, rhyolite, and ignimbrite) with age ranging from 22 Ma to present and granito-gneissic basement of Pan-African ages [31], [37]. Bamenda Mountains is characterized by two elliptic calderas that include Santa-Mbu and Lefo caldera [38]. The radiometric dating gives ages ranging from the current to 17.4

Ma for the basaltic lavas and from 18.98 Ma to 27.40 Ma for the felsic lavas [38]. Bambui area is a continuation of the Bamenda highlands that stretches through Sabga dorsal to the Boyo hill. Bambui area is made up of four villages; Bambili, Bambui, Kedjom-Ketinguh and Kedjom-Keku. Most of the population in these villages depends on agriculture for livelihood as many villagers practice intense agriculture with the used of phosphate fertilizers, animal manure, agrochemicals, pesticides, fungicides and waste water irrigation for high crop yield without the knowledge of the negative impact into the environment. The study area is also recognised for indiscriminate dumped of municipal and household solid waste, effluents into stream and rivers without proper treatment, runoff from mechanical workshop and oil exchange services into streams and river which are detrimental to benthic organisms and human health.

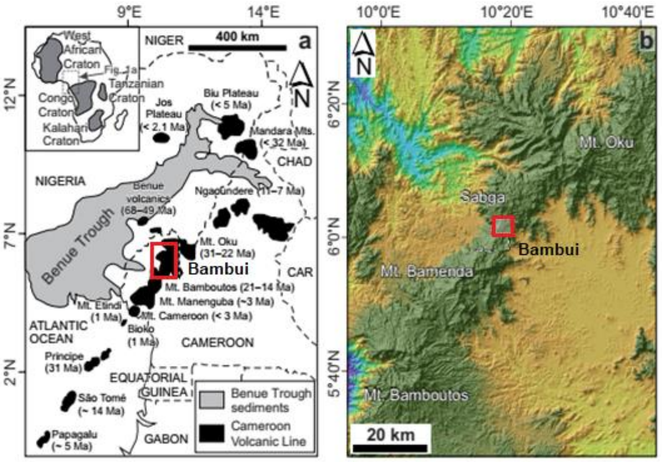

Fig. 2 Location of the Bambui area within the Cameroon Volcanic Line (CVL): a) Main volcanic systems of the Cameroon Volcanic Line; b) Location of the study area between the Mount Bamenda and Mount Oku

III. MATERIALS AND METHODS

Description of Study Area

Bambui area is found in the grass field zone of Cameroon; precisely in Tubah Sub-division of the Northwest Region of Cameroon. Bambui area is located between latitudes 4°50’ and 5°20’N and longitudes 10°35’ and 11°59’E. Bambui area is bordered to the North by Belo in Boyo Division, to the North West by Bafut, to the South and South East by Ndop and Balikumbat in Ngoketungia Division and to the West by Nkwen in Bamenda III Sub-division. Bambui area is characterized by the humid tropical climate of highland with two seasons, rainy season ranging from mid-March to October with an average precipitation of 1670mm of rain and a short dry season which starts from November to February with average precipitation of 80mm, favourable for agricultural practices. The area is usually well drained due to the abundant rivers and streams that drain into river Mezam. The vegetation is mostly grassland with shrubs and has been modified. Most zones have been changed into woodland by the planting of eucalyptus trees to reduce the erosion rate and reduce the risk of landslides.

Sample Collection and Analysis

Fieldwork was carried out in December 2020 where the four villages that make up the Bambui area were sampled. This four villages are potential areas of pollution due to anthropogenic activities such as intensive agricultural practices, settlements, bathing and laundry sites refuse, indiscriminate dumped of garbage, batteries and abandoned car parts, municipal and household solid waste into streams and the use of agrochemicals in crop cultivation on the wetlands and farms located along stream and river valleys which might be sources of heavy metals in the study area. A total of 25 sediment samples (about 30Kg each) were collected and quartered manually. Panning was carefully done at the spot for at least 15-20 minutes to collect the concentrates and transferred into a polythene bag immediately following the procedure used by [5]. Spacing between the samples was fixed at 450m. Locations of sampling sites were determined using Global Positioning System (GPS). Sediment samples were collected from a depth of 0–50 cm deep to avoid high contents of Fe-Mn oxide and humus with the use of an auger and stainless-steel shovel. Among the quartered 25 samples, fourteen sediment concentrate (about 50g each) were selected (spacing of 1km between them): five samples each from Kejom-Keku (KK) and Bambili (BB) and two samples each from Kejom-Ketinguh (KG) and Bambui (BU). The samples were air-dried in a dry and dust-free place at room temperature in the laboratory of The University of Bamenda. The dried sediment samples were ground manually to a fine powder in an agate mortar using a pestle and sieved through a 2mm sieve to remove any large organic matter or gravel. The powder samples are then place in a polythene bags for chemical analysis. The fine sediment samples (1.5g) was digested with aqua regia (0.6 ml concentrated HNO_3 and 1.8 ml concentrated HCl) for 1 hours at 90ºC. The sample is then cooled and diluted to 10 ml with deionized water and homogenized [50]. The digested samples were then analysed for heavy metals content by Inductively Coupled Plasma-Mass Spectrometer (ICP-MS- Aqua Regia) after digestion of the samples. Digestion and ICP-MS analysis of samples were done at Activation Laboratories (ACTLABS) Ltd., Ontario in Canada. The quality assurance procedures and precautions were ensured for the reliability of the results. Precautions were taken to avoid contamination during drying, grinding, sieving and storage. Glass wares were washed with liquid soap and rinsed properly and reagents were of analytical grades. Deionized water was used throughout the study. The analysis of blanks, randomisation of sample numbers and the use of in-house reference materials and sample triplicates, provided a measure of trueness of analytical results and precision. Laboratory controls of known concentrations and spiked samples of known concentrations were employed for quality control.

Data Analysis

Descriptive and multivariate statistical techniques were used to evaluate the sediment data set. Correlation analysis was used to evaluate relationships between the variables and factor analysis (FA) was used to differentiate natural and anthropogenic origins of metals in sediment samples of the study area. Data collected was analysed using Statistical Package for Social Science (SPSS 16.0) software and Microsoft Office Excel.

I. RESULTS AND DISCUSSION

A. *Heavy Metals Content in Stream Sediments*

The concentrations of heavy metals in sediments from the Bambui area are shown in Table II. The sediments contain high level of Mn (690– 2550 ppm, average = 1580 ppm), La (77– 1780 ppm average = 442 ppm), Cr (79 – 589 ppm average = 273.9 ppm), V (59 – 157 ppm average = 103 ppm) and Th (18.8 – 200 ppm average = 98 ppm) far exceeds the recommendation for the Upper Continental Crust proposed by [39]. The concentration of some transition metals such as Cu (7.40– 168 ppm, average = 32.5 ppm), Ni (20.02 – 146 ppm average = 54.12 ppm), Zn (41 – 147 ppm, average = 93.21 ppm) is moderate while the values of Pb (11 – 63.1 ppm average = 29.13 ppm), Co and (11.9 – 39.5 ppm, average = 23.91 ppm) are low and also elevated compared to the contents of the Upper Continental Crust. The high content of these metals may be due to intense weathering of the source rocks, agricultural practices, residential development, garbage, waste water irrigation and industrial emission in Bambui area. Comparing the average values of metals in various samples, it can be seen that the concentration of Mn, Th, La, Cr, V, Pb and Zn concentrations are higher than those of other metals (Fig 3). This shows that the high concentration of Mn, Th, La, Cr, V, Pb and Zn in the sediments cannot be clearly explained by geogenic influence alone, but have other anthropogenic origins. The high average content of these metals may be due to intense weathering of the source rocks, agricultural practices, household and industrial emission, phosphate fertilizer, municipal waste and sewage sludge in the Bambui area [40], [5]. The content of metals such as Ga (3 – 14 ppm), Hg (0.02 – 0.07 ppm), Al (0.53-1.82 ppm), Sc (2.9-6.7ppm) are very low (except Ba: 17 – 304 ppm; average = 92.21 ppm which is slightly elevated). The low mean content of theses metals is due to leaching of the source rocks during weathering [5]. The results indicate that metal levels found in sediments of Bambui area can negatively impact aquatic ecosystems and human health through the food chain.

The Pearson’s correlation matrix (Table III) mostly show positive correlations meanwhile, Ba/Th, Ga/Th, Al/Ti and Th/Zn show negative correlation. Generally positive correlation between elements ($r^2 > 0.5$) could be attributed to parent rock (geologic unit), agricultural activities (used of phosphate fertilizers, pesticides, fungicide and animal manure) and municipal solid waste which are probably governed by the same or similar physicochemical processes [41]. The strong correlations between some elements observed in this study signify that these elements come from the same source. The correlation of Co/Cr, Ni, V, Cr/Ni, Mo/Ni, Zn, Ni/V, Co/Fe, Mo/Fe, V/Fe is a reflection of their transition metal relationship and could be related to a mafic origin in relation with basaltic rocks in the study area [31], [37]. The correlations between Ga/Zn indicate the relationship between chalcophile elements in the study area. The correlations between Ba/Th, Ga/Th and Ga/ Al may be associated with an acidic origin, probably due to the presence of rhyolite, Ignimbrites and trachyte [31], [37] in the research area.

Table IV. Heavy Metals Concentrations (In Pmm) In Stream Sediments Of Bambui Area

Elements	BB01	BB02	BB03	BB04	BB05	BU01	BU02	KG01	KG02	KK01	KK02	KK03	KK04	KK05
Al	1.07	1.42	0.71	1	1.74	0.53	2.28	2.17	1.82	1.15	1.23	0.58	0.7	0.6
Fe	8.96	10.5	7.66	7.32	9.51	7	13.2	5.99	7.9	12.8	7.38	11.2	7.38	6.32
Ti	1.35	1.3	2.03	1.63	1.63	1.47	2.16	1.38	1.54	1.66	0.702	2.2	1.81	1.42
Ba	182	304	35.8	85.1	99.7	27.5	44.8	48.9	166	105	52.2	40.8	17	28.2
Co	20.3	22.2	31	20.4	39.5	16.5	36.7	27.6	17	28	14.1	30.9	18.6	11.9
Cr	244	299	106	513	589	159	593	517	191	122	188	79	147	87
Cu	10.6	10.9	10.8	28.1	13.7	7.8	17.5	10.7	22	168	14.5	10.2	123	7.4
Ga	10	11	4	7	11	4	14	13	9	13	9	8	6	3
Hg	0.02	0.04	0.02	0.02	0.01	0.01	0.02	0.01	0.03	0.02	0.07	0.03	0.02	0.02
Mn	2160	2550	2360	1260	1310	1310	1400	932	1930	1910	1500	1470	690	1340
Mo	3.5	8.5	2.2	1.7	4	0.9	8.5	3.4	4	4.4	5.2	1.6	2.6	1
Ni	65	67.9	33.8	44.6	146	32.3	114	66.6	47.2	31.6	26.5	37.6	24.4	20.2
Pb	33.9	35.2	31.2	23.2	54.1	16.3	9.3	10.5	11.3	43	55.1	6.6	63.1	15
Sc	3.9	5.9	6	5.2	7.5	4.7	6.7	2.9	5.9	4.2	7.1	4.2	3.1	3.9
Th	30.5	25.1	200	20.9	79	200	52.5	55.5	23.7	126	200	18.8	140	200

V	84	88	87	84	157	85	147	111	73	144	72	146	105	59
Zn	121	147	59	79	98	49	126	97	109	124	100	97	58	41
La	231	149	1010	126	267	739	88	197	77	393	1780	85	392	649

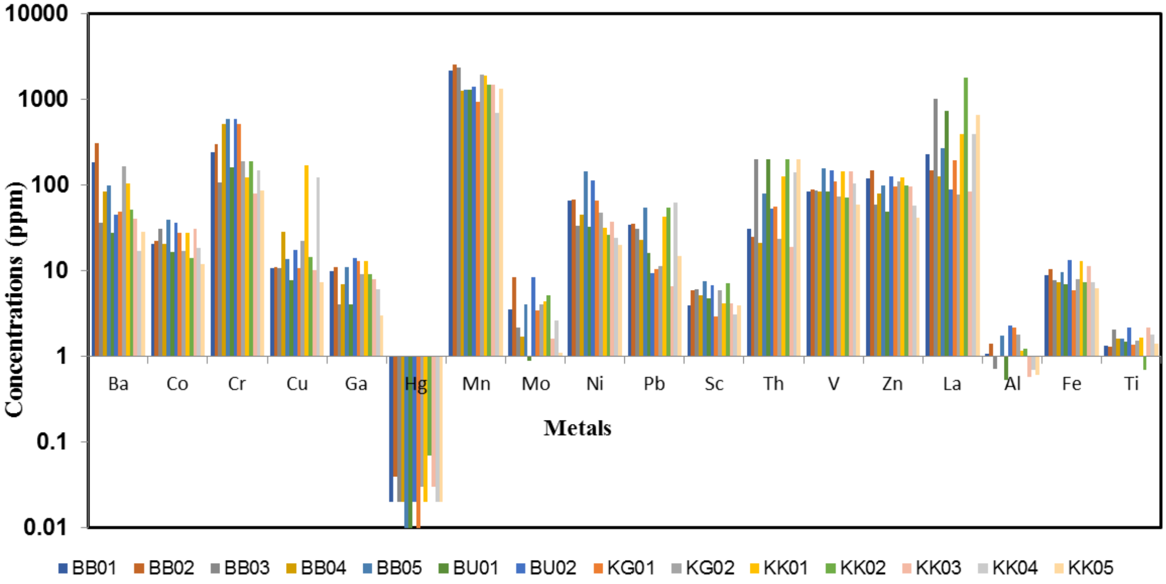

Fig. 3 Enrichment/depletion plot of heavy metals in stream sediments of Bambui area

Table V. Correlation matrix of metals in stream sediments of Bambui area

Variables	**Ba**	**Co**	**Cr**	**Cu**	**Ga**	**Hg**	**Mn**	**Mo**	**Ni**	**Pb**	**Sc**	**Th**	**V**	**Zn**	**La**	**Al**	**Fe**	**Ti**
Ba	**1**																	
Co	-0.05	**1**																
Cr	0.10	**0.52**	**1**															
Cu	-0.08	0.01	0.25	**1**														
Ga	0.38	**0.53**	**0.58**	0.18	**1**													
Hg	0.22	-0.37	-0.28	-0.10	0.05	**1**												
Mn	**0.70**	0.04	-0.27	-0.14	0.08	0.27	**1**											
Mo	**0.55**	0.31	0.42	0.01	**0.73**	0.37	0.36	**1**										
Ni	0.24	**0.72**	**0.81**	-0.27	**0.60**	-0.29	-0.00	**0.51**	**1**									
Pb	0.08	-0.03	-0.07	0.48	0.02	0.28	-0.02	0.13	0.02	**1**								
Sc	0.20	0.31	0.34	-0.34	0.17	0.39	0.32	0.49	**0.50**	0.19	**1**							
Th	**-0.55**	-0.33	-0.48	0.13	**-0.58**	0.11	-0.13	-0.34	-0.46	0.31	0.01	**1**						
V	-0.13	**0.86**	0.39	0.31	**0.59**	-0.32	-0.20	0.25	**0.58**	0.05	0.11	-0.32	**1**					
Zn	**0.72**	0.35	0.34	0.06	**0.86**	0.30	0.48	**0.81**	0.46	0.02	0.29	**-0.66**	0.36	**1**				
La	-0.35	-0.37	-0.39	-0.07	-0.38	0.57	0.03	-0.13	-0.42	0.40	0.27	**0.81**	-0.41	-0.36	**1**			
Al	0.27	0.44	**0.75**	-0.13	**0.81**	-0.02	-0.02	**0.68**	**0.70**	-0.15	0.34	-0.48	0.33	**0.62**	-0.33	**1**		
Fe	0.27	**0.60**	0.13	0.32	**0.61**	0.03	0.33	**0.59**	0.39	-0.01	0.27	-0.38	**0.71**	**0.68**	-0.36	0.26	**1**	
Ti	-0.30	**0.62**	0.04	0.14	-0.02	-0.53	-0.06	-0.10	0.18	-0.33	-0.09	-0.23	**0.57**	-0.09	**-0.52**	-0.06	0.46	**1**

r^2= 0.50-0.69 (moderate correlation), r^2= 0.70-0.79 (strong correlation) and r^2= 0.80-0.99 (very strong correlation)

B. *Factor Analysis*

The factor analysis method is applied to determine the latent factors that control the distribution of metals and the sources of contamination (natural, anthropogenic, or both) on a specific region. In the evaluation of the factors, varimax rotation with Kaiser normalization that maximizes the variances was used.

According to the [42] criterion, the factors with eigenvalues >1 were taken into consideration for evaluations. Table VI presents a five factors model cumulatively accounting for 80.08% in the study area.

The elements in factor groups with the factor loading scores > 0.50 were interpreted to identify their possible sources. Five factors identified in Bambui area include: (i) Factor 1 (Cr, Ga, Ni, Al) accounts for 20.31% of the total variability contains Ga and Ni, and two lithophile element (Al and Cr). The high loading of the elements by this factor indicates high mobility within the environment rich in lithophile and Al may be associated with alumina silicate minerals in the source rock of the study area. (ii) Factor 2 (Co, V, Fe, Ti) accounts for 15.99%% of the total variability is made up of transition metals. These factors may be related to the presence of basic minerals in the parent rock (Basalt). (iii) Factor 3 (Cu, Pb) which accounts for 10.42% of the total variability, consists of predominantly by chalcophile elements and is a sulphide phase. (iv) Factor 4 (Hg, Sc Th, La) accounts for 11.81% of the overall variability. It is primarily a silicate phase, as it is saturated with lithophile elements. Factor 4 also reflect a lithological controlled. (v) Factor 5 (Ba, Mn, Mo, Zn) account for 21.54% of the total variability reflects the enriched environment of transition metal associations. The strong loading of Ba (0.91) may be due to the presence of feldspars in the rocks (rhyolite, Ignimbrites and trachyte) of the study area.

Table III. Varimax Rotated Factor Analysis With Kaiser (1958) Normalization

Variable	F1	F2	F3	F4	F5
Ba	0.118	-0.200	-0.052	-0.171	**0.915**
Co	0.445	**0.832**	-0.068	-0.013	0.026
Cr	**0.908**	0.116	-0.123	-0.117	-0.024
Cu	-0.214	0.220	**0.794**	-0.153	0.006
Ga	**0.708**	0.256	0.240	-0.153	0.461
Hg	-0.090	-0.327	0.101	**0.536**	0.423
Mn	-0.269	0.081	-0.282	0.178	**0.759**
Mo	0.516	0.145	0.153	0.187	**0.657**
Ni	**0.810**	0.402	-0.158	0.009	0.133
Pb	0.029	-0.077	**0.768**	0.471	0.073
Sc	0.357	0.197	-0.260	**0.655**	0.301
Th	-0.411	-0.145	0.135	**0.582**	-0.466
V	0.374	**0.821**	0.234	-0.130	-0.022
Zn	0.435	0.176	0.107	-0.090	**0.838**
La	-0.257	-0.304	0.074	**0.872**	-0.204
Al	**0.858**	0.064	-0.046	-0.079	0.232
Fe	0.110	**0.747**	0.156	-0.032	0.526
Ti	-0.124	**0.783**	-0.090	-0.356	-0.193
Eigenvalue	6.793	3.578	2.227	1.963	1.484
Varibility (%)	20.31	15.994	10.422	11.814	21.542
Cumulative %	20.316	36.310	46.732	58.546	80.089

C. Evaluation of Heavy Metal Contamination

In this study, various pollution indicators were used to determine the level of heavy metal contamination in stream sediments of Bambui area.

1) Contamination Factor (CF), Degree of Contamination (Cd) and Modified Degree of Contamination (mCd)

The contamination factor (CF) is calculated using the method presented by [43], [44]. CF is defined as:

$$\text{CF} = \frac{\text{Concentration of metal in the sample}}{\text{Background concentration of metal}}$$

The CF values are interpreted as follows: low contamination at CF < 1; moderate contamination at 1 < CF < 3, considerable contamination at 3 < CF < 6, and very high contamination at CF > 6, according to [44]. Table VII presents the results of CF of heavy metals in stream sediments of the study area. Ba, Cu, Ga, Hg, Sc and Al are slightly contaminated (CF < 1), Co, Cr, Cu (BB04), Hg (KK02), Mn, Mo, Ni, Pb, V, Zn and Fe are moderately contaminated (CF = 1 - 3). Cr (BB04, BU02, KG01), Mo (KK01, KK02, BU02 and BB02) and Ti (BB01 and BB02) are considerably contaminated (CF = 3 - 6) and Th, La and Ti are highly contaminated CF > 6) within the study area.

Degree of Contamination (Cd) is a cumulative indicator calculated as the sum of individual contamination factors (Cd). It represents the sum of all the CF values for all the sampling sites. This was suggested by [45] as follows:

$$Cd = \sum_{i=1}^{8} CF.$$

The Cd is expressed as Cd < 6 = low, 6 < Cd < 12 = moderate, 12 < Cd 24 = considerably high, and Cd > 24 = high. The Cd varies between 28.50 (KK03) to 100.01 (KK02) in the study area (Table VIII). It is in the order: KK02 > BB03 > BU01 > KK01 > KK05 > KK04 > BB05 > BU02 > BB03 > KG01 > BB01 > BB04 > KG02 > KK03 and the value ranges from 28.50 to 100. The entire study area is characterised by a high Cd (Cd > 24) in stream sediments.

Modified degree of contamination helps in the assessment of overall heavy metal contamination in the sediment samples. It can be used to better estimate the value. It is calculated using the following formula:

$$\text{mCd} = \frac{\sum CF}{\text{n}}$$

Where CF is the contamination factor and n is the number of elements analyzed [45]. mCd values are interpreted as follows: mCd< 1.5 is nil to low, 1.5 <mCd< 2 is low, 2 <mCd< 4 is moderate, 4 <mCd< 8 is high, 8 <mCd< 16 is very high, 16 <mCd< 32 is extremely high and mCd> 32 is ultra-high contamination. mCd varies between 1.58 (KK03) to 5.56 (KK02) in the study area (Table IX). The mCd in the study area follow the order: KK02 > BB03 > BU02 > KK01 > KK05 > KK04 > BB05 > BU02 > BB02 > KG01 > BB01 > BB04 > KG02 > KK03 with values comprised between 1.58 to 5.56. Sample BB04, KK02 and KK03 are in the category of low contamination (mCd<1.5 - 2) accounting for 21.42% of the study area. Sample BB01, BB02, BB05, BU01, BU02, KG01, KK01 and KK04 are moderately contaminated (mCd = 2 - 4) accounting for 57.14% of the study area and sample BB03 and KK02 are classified as highly contaminated (mCd = 4 - 8) accounting for 14.28% of the study area, indicating serious anthropogenic input of heavy metals in stream sediments of the study area. This study suggests that proper focus should be taken on monitoring the point sources of metals entering the stream bed from nearby villages, and reduction of urban domestic sewage discharge, municipal waste and industrial effluent.

2) *Pollution Load Index (PLI), Geo-accumulation Index (Igeo) and Enrichment Factors (EF)*

The Pollution Load Index (PLI) is used to comprehensively assess the pollution effect of study metals. It is widely used to assess the degree of heavy metal pollution in sediments [45]. PLI is given according to [46] by the relation:

$$\text{PLI} = (\text{CF}_1 \times \text{CF}_2 \times \ldots\ldots \times \text{CF}_n)^{1/n}$$

Where n is the number of metals (18 in the present study), CF is the contamination factor. If PLI > 1, the sediments are polluted, if PLI < 1, there is no pollution and the PLI = 0 indicates perfection [47], [48].

PLIs calculated for each sample are shown in Table X. The PLI follow the trend: KK01 > BB05 > KK02 > BB02 >BU02 >BB01 > BB03 > KG02 >KK04 > KG01 > BB04 > BU01 > KK03 > KK05 in the study area. The PLI across the study area varies from 0.78 in sample KK05 to 1.60 in sample KK01. Sample BU01, KK03 and KK05 with PLI values 0.86, 0.85 and 0.78 are less than 1 indicating low pollution within this sampling sites accounting for 21.43% of the study area, while the rest of the sampling sites had PLI values greater than one (PLI >1) indicating that the study area is polluted, suggesting inputs from anthropogenic sources. The high level of PLI values observed eleven sampling sites accounting for 78.57% of the study area might be due to the effects of the various industrial and human activities such as discharge of industrial effluents, untreated sewage, municipal waste, storm water runoff with road site deposits, and vehicle of the studied area [5], [13], [12].

The Geo-accumulation index (Igeo) is introduced by [49] to assess the level of metal accumulation in the soils and have been used by several researchers for various studies [44]. It is mathematically expressed as follows:

$$\text{Igeo} = \log_2 \frac{Cn}{1.5 \times Bn}$$

Where, *Cn* = measured concentration of metal ion in sample; *Bn* = background concentration value for metals [39] and 1.5 represents the background matrix correction factor due to lithogenic effects. [49] classified Igeo into five groups as follows: Igeo < 0 = practically unpolluted, 0 < Igeo < 1 = unpolluted to moderately polluted, 1 < Igeo < 2 = moderately polluted, 2 < Igeo < 3 = moderately to strongly polluted, 3 < Igeo < 4 = strongly polluted, 4 < Igeo < 5 = strongly to extremely polluted and Igeo > 5 = extremely polluted.

According to [49] classification, Ba, Co, Cr, Ga, Hg, Ni, Sc, V, Zn and Al are in the class of practically unpolluted (Igeo < 0) in the study area (Table V; Fig. 4). Unpolluted to moderately polluted (Igeo = 0 - 1) refers to Mn, Mo, Pb (BB05, KK02 and KK04), Th and Fe. La and Ti are moderately polluted (Igeo = 1 - 2) in the study area. Moderately to strongly polluted (Igeo = 2 - 3) is attributed to Ti (KK01, KK03, KG02, BUO2, BB03 and BB05), strongly polluted (Igeo = 3 - 4) for La (BU01, KK01, KK04 and KK05) and Th (BB03, BU01, KK01, KK02, KK04 and KK05) while strongly to extremely polluted (Igeo = 4 - 5) in La (BB03 and KK02). Moderately to extremely polluted in Mn, Mo, Pb, Th, Fe, Ti and La in the study area is due to anthropogenic activities such as, grazing, urbanization, pigment, glazes, industrialization, indiscriminate dumped of household effluents in streams, assorted electronic waste deposition, municipal waste, application of phosphate fertilizers, animal excreta, and sewage sludge discharge in various streams and rivers.

Table XI. Contamination factor, Degree of contamination, Modified degree of contamination and pollution load index of heavy metals in stream sediments of Bambui area

Elements	Ba	Co	Cr	Cu	Ga	Hg	Mn	Mo	Ni	Pb	Sc	Th	V	Zn	La	Al	Fe	Ti	Cd	mCd	PLI
BB01	0.29	1.17	2.65	0.38	0.57	0.40	2.79	3.18	1.38	1.99	0.28	2.90	0.87	1.81	7.45	0.13	2.54	5.40	36.19	2.01	1.21
BB02	0.49	1.28	3.25	0.39	0.63	0.80	3.29	7.73	1.44	2.07	0.42	2.39	0.91	2.19	4.81	0.17	2.97	5.20	40.44	2.25	1.45
BB03	0.06	1.79	1.15	0.39	0.23	0.40	3.05	2.00	0.72	1.84	0.43	19.05	0.90	0.88	32.58	0.09	2.17	8.12	75.83	4.21	1.14
BB04	0.14	1.18	5.58	1.00	0.40	0.40	1.63	1.55	0.95	1.36	0.37	1.99	0.87	1.18	4.06	0.12	2.07	6.52	31.37	1.74	1.05
BB05	0.16	2.28	6.40	0.49	0.63	0.20	1.69	3.64	3.11	3.18	0.54	7.52	1.62	1.46	8.61	0.21	2.69	6.52	50.96	2.83	1.55
BU01	0.04	0.95	1.73	0.28	0.23	0.20	1.69	0.82	0.69	0.96	0.34	19.05	0.88	0.73	23.84	0.07	1.98	5.88	60.35	3.35	0.86
BU02	0.07	2.12	6.45	0.63	0.80	0.40	1.81	7.73	2.43	0.55	0.48	5.00	1.52	1.88	2.84	0.28	3.74	8.64	47.34	2.63	1.43
KG01	0.08	1.60	5.62	0.38	0.74	0.20	1.20	3.09	1.42	0.62	0.21	5.29	1.14	1.45	6.35	0.27	1.70	5.52	36.87	2.05	1.08
KG02	0.27	0.98	2.08	0.79	0.51	0.60	2.49	3.64	1.00	0.66	0.42	2.26	0.75	1.63	2.48	0.22	2.24	6.16	29.18	1.62	1.11
KK01	0.17	1.62	1.33	6.00	0.74	0.40	2.46	4.00	0.67	2.53	0.30	12.00	1.48	1.85	12.68	0.14	3.63	6.64	58.64	3.26	1.60
KK02	0.08	0.82	2.04	0.52	0.51	1.40	1.94	4.73	0.56	3.24	0.51	19.05	0.74	1.49	57.42	0.15	2.09	2.81	100.10	5.56	1.41

KK03	0.07	1.79	0.86	0.36	0.46	0.60	1.90	1.45	0.80	0.39	0.30	1.79	1.51	1.45	2.74	0.07	3.17	8.80	28.50	1.58	0.85
KK04	0.03	1.08	1.60	4.39	0.34	0.40	0.89	2.36	0.52	3.71	0.22	13.33	1.08	0.87	12.65	0.09	2.09	7.24	52.89	2.94	1.10
KK05	0.05	0.69	0.95	0.26	0.17	0.40	1.73	1.00	0.43	0.88	0.28	19.05	0.61	0.61	20.94	0.07	1.79	5.68	55.58	3.09	0.78

The Enrichment Factors (EF) of heavy metals are commonly used to assess anthropogenic contamination. EF values were calculated using the following equation [44].

$$\mathrm{EF} = \frac{(\mathrm{me/Fe2O3})_{\mathrm{sample}}}{(\mathrm{me/Fe2O3})_{\mathrm{samplebackground}}}$$

where (me/Fe_2O_3) sample) is the measured ratio of metal between iron oxide and (me/Fe_2O_3) sample background) unpolluted background ratio of metal of iron oxide. Five contamination categories were defined on the basis of the EF, which are EF < 1, EF < 2, 2 < EF <5, 5 < EF < 20 and EF = 20 < EF < 40 corresponding to no enrichment, minimal enrichment, moderate enrichment, significant and severe enrichment [44]. The EFs of heavy metals in the study area are shown in (Table VXII, Fig. 5). Lanthanum has the highest EF value (27.46) in sample KK02 (Kedjom-Keku), Th (10.64) is the second most abundant enriched element in sample KK05 and Ti (3.74) is the third most enriched element in sample BB03 (Bambili) in the study area. Ba, Co, Cr, Cu, Ga, Hg, Ni, Pb, Sc, V, Zn, Al and Fe show no enrichment (EF < 1) in all samples of the study area, except Cr (BB01 - BB05), Cu (KK01 and KK05), Mn, Mo, Pb (BB04, KK02 and KK04), Th and Ti (KK03) respectively, which was in the category of minimal enrichment (EF = 1 - 2). Cr in sample KG01 (Kedjom-Ketinguh), La in sample (BB01, BB05, KG01, BU01, BB03, KK01 and KK05), Ti in sample (BB03, BB04, KG01, KK04 and KK05) and Th in sample (BB03, KG01, KK04 and KK05) are generally moderately to significant enriched (EF = 2 - 20). La in sample KK02 (Kedjom-Keku) and Th in sample KK05are severely enriched (EF = 20 to more than 40). Moderately to severely enrichment of Cr, La, Th and Ti in the study area indicates its origin from the anthropogenic sources such as agricultural practices, domestic waste water, effluents from sewage sludge, garbage, assorted electronic wastes, household wastes, urban and agricultural runoff, fossils fuel, atmospheric deposition, animal excreta, pesticides, fungicides, herbicides and municipal wastes dumped in to streams and rivers of the study area. This finding suggests that stream sediments in the study area are more likely to contain reasonable amount of heavy metals.

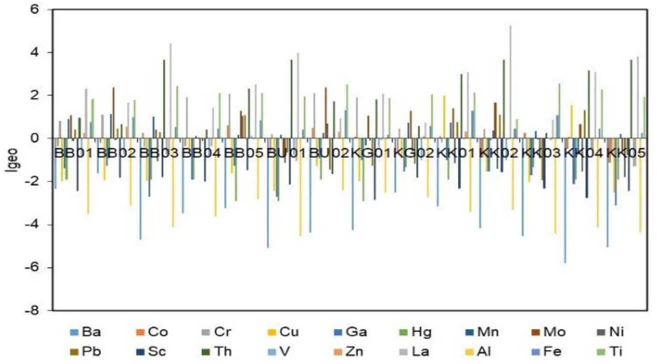

Fig. 4 Geo- accumulation index of heavy metals in stream sediments of Bambui area.

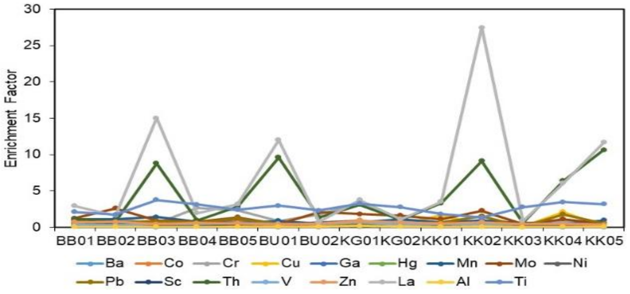

Fig. 5 Enrichment factor of heavy metals in stream sediments of Bambui area

3) Potential Ecological Risk Factor (Er), Potential Ecological Risk Index (PERI) and Anthropogenic Metal Input.

The potential ecological risk factor (Er) is an index that quantitatively expresses the potential ecological risk associated with a given single contaminant [45]. It is calculated as follows:

$$\mathrm{Er} = \mathrm{Tr}^{i} \times \mathrm{CF}^{i}$$

Where Tr^i is toxic response factor of a metal (Pb = 5, Zn = 1, Cd = 30, Cr = 2, Ni = 5, Hg = 40, Cr = 2, Cd = 30, As = 10 and Cu = 5).CF^i is the contamination factor. Five terminologies are used to define Er based on [46]. These are: Er< 40, low potential ecological risk; 40 <Er<80, moderate potential ecological risk; 80 <Er< 160, considerable potential ecological risk; 160 <Er< 320, high potential ecological risk and Er≥ 320, very high ecological risk.

Table V. Geo- accumulation index of heavy metals in stream sediments of Bambui area

Element	Ba	Co	Cr	Cu	Ga	Hg	Mn	Mo	Ni	Pb	Sc	Th	V	Zn	La	Al	Fe	Ti
BB01	-2.36	-0.35	0.82	-1.98	-1.39	-1.9	0.89	1.08	-0.11	0.41	-2.42	0.95	-0.79	0.26	2.31	-3.51	0.75	1.84
BB02	-1.62	-0.22	1.11	-1.94	-1.25	-0.9	1.13	2.36	-0.05	0.46	-1.83	0.67	-0.72	0.54	1.68	-3.1	0.98	1.79
BB03	-4.7	0.25	-0.81	-1.95	-2.71	-1.9	1.02	0.41	-1.06	0.29	-1.8	3.66	-0.74	-0.76	4.44	-4.1	0.53	2.43
BB04	-3.45	-0.34	1.89	-0.58	-1.9	-1.9	0.11	0.04	-0.66	-0.13	-2.01	0.4	-0.79	-0.34	1.43	-3.61	0.46	2.1
BB05	-3.23	0.6	2.09	-1.61	-1.25	-2.9	0.17	1.27	1.05	1.08	-1.48	2.32	0.11	-0.03	2.52	-2.81	0.84	2.12
BU01	-5.08	-0.65	0.24	-2.42	-2.71	-2.9	0.17	-0.87	-1.12	-0.64	-2.16	3.66	-0.77	-1.03	3.99	-4.52	0.4	1.97

BU02	-4.38	0.5	2.1	-1.26	-0.9	-1.9	0.26	2.36	0.69	-1.45	-1.64	1.73	0.01	0.32	0.92	-2.42	1.31	2.52
KG01	-4.25	0.08	1.9	-1.97	-1.01	-2.9	-0.31	1.04	-0.08	-1.28	-2.85	1.81	-0.39	-0.05	2.08	-2.49	0.17	1.88
KG02	-2.49	-0.61	0.46	-0.93	-1.54	-1.32	0.73	1.27	-0.57	-1.17	-1.83	0.59	-0.99	0.11	0.72	-2.74	0.57	2.03
KK01	-3.15	0.11	-0.17	2	-1.01	-1.9	0.71	1.41	-1.15	0.75	-2.32	3	-0.01	0.3	3.07	-3.41	1.27	2.14
KK02	-4.16	-0.88	0.44	-1.53	-1.54	-0.1	0.36	1.65	-1.41	1.11	-1.56	3.66	-1.01	0	5.25	-3.31	0.47	0.9
KK03	-4.52	0.25	-0.8	-2.04	-1.71	-1.32	0.33	-0.04	-0.9	-1.95	-2.32	0.25	0	-0.05	0.87	-4.39	1.08	2.55
KK04	-5.78	-0.48	0.09	1.55	-2.12	-1.9	-0.75	0.65	-1.53	1.3	-2.76	3.15	-0.47	-0.79	3.07	-4.12	0.49	2.27
KK05	-5.05	-1.12	-0.66	-2.5	-3.12	-1.9	0.2	-0.58	-1.8	-0.76	-2.42	3.66	-1.3	-1.29	3.8	-4.34	0.25	1.92

Table VXIII. Enrichment factor of heavy metals in stream sediments of Bambui area

Element	Ba	Co	Cr	Cu	Ga	Hg	Mn	Mo	Ni	Pb	Sc	Th	V	Zn	La	Al	Fe	Ti
BB01	0.11	0.46	1.04	0.15	0.23	0.16	1.10	1.25	0.54	0.79	0.11	1.14	0.34	0.71	2.94	0.05	0.40	2.13
BB02	0.16	0.43	1.09	0.13	0.21	0.27	1.11	2.60	0.49	0.70	0.14	0.80	0.30	0.74	1.62	0.06	0.33	1.75
BB03	0.03	0.83	0.53	0.18	0.11	0.18	1.40	0.92	0.33	0.85	0.20	8.78	0.41	0.41	15.01	0.04	0.89	3.74
BB04	0.07	0.57	2.69	0.48	0.19	0.19	0.78	0.75	0.46	0.66	0.18	0.96	0.42	0.57	1.96	0.06	0.65	3.14
BB05	0.06	0.85	2.38	0.18	0.23	0.07	0.63	1.35	1.15	1.18	0.20	2.79	0.60	0.54	3.20	0.08	0.12	2.42
BU01	0.02	0.48	0.87	0.14	0.12	0.10	0.85	0.41	0.35	0.48	0.17	9.61	0.44	0.37	12.02	0.03	0.34	2.97
BU02	0.02	0.57	1.72	0.17	0.21	0.11	0.48	2.07	0.65	0.15	0.13	1.34	0.41	0.50	0.76	0.07	0.44	2.31
KG01	0.05	0.94	3.31	0.23	0.44	0.12	0.71	1.82	0.84	0.36	0.12	3.11	0.67	0.85	3.75	0.16	0.46	3.25
KG02	0.12	0.44	0.93	0.35	0.23	0.27	1.11	1.62	0.45	0.30	0.19	1.01	0.34	0.73	1.11	0.10	0.27	2.75
KK01	0.05	0.45	0.37	1.65	0.20	0.11	0.68	1.10	0.19	0.70	0.08	3.31	0.41	0.51	3.50	0.04	0.15	1.83
KK02	0.04	0.39	0.98	0.25	0.25	0.67	0.93	2.26	0.27	1.55	0.24	9.11	0.36	0.71	27.46	0.07	0.56	1.34
KK03	0.02	0.56	0.27	0.11	0.14	0.19	0.60	0.46	0.25	0.12	0.09	0.56	0.47	0.46	0.86	0.02	0.78	2.77
KK04	0.01	0.51	0.76	2.10	0.16	0.19	0.43	1.13	0.25	1.78	0.11	6.38	0.52	0.41	6.05	0.04	0.98	3.46
KK05	0.03	0.38	0.53	0.15	0.10	0.22	0.97	0.56	0.24	0.49	0.16	10.64	0.34	0.34	11.69	0.04	0.60	3.17

The potential ecological risk index (PERI) is the sum of all the ecological risk factors of the metals under study, taking into account the cumulative effects of the metals under study [45]. It is calculated thus:

$$\mathrm{PERI} = (\mathrm{Er1} + \mathrm{Er2} + \mathrm{Er3} \ldots + \mathrm{Ern})$$

Where Er is the ecological risk factor and n is the number of elements studied. The following terminologies have been used for the PERI: PEERI < 150, low ecological risk; 150 <PERI < 300, moderate ecological risk; 300 < PERI < 600, considerable ecological risk and PERI ≥ 600, very high ecological risk. The Er and the PERI in the study area are presented in Table XIVI and Fig 6. The Er in Bambui area showed low potential ecological risk factor (Er< 40) for Co, Cr, Cu, Hg, Mn, Ni, Pb, V and Zn. Hg with value 56 in sample KK02 (Kedjom-Keku) have moderate Er (Er 40-80). Hence sediments of the presents study show low PERI. Moderate Er refers to Hg (KK02) in the study area. This could be attributed to agricultural practices, pesticides, fungicides, agricultural and domestic runoff and municipal wastes deposited into streams. The PERI across the study area varies between 30.01 in sample BU01 (Bambui) to 90.69 in sample KK02 (Kedjom-Keku) within the study area (Table XVI; Fig 6). The PERI is in the order: KK02 > KK01 > BB05 > BB02 > KK04 > BU02 > BB04 > BB01 > KG02 > KK03 > BB03 > KG01 > KK05 > BU01 and the values vary between 30.02 to 90.69, indicating low potential ecological risk index within the study area.

The anthropogenic metal input in tailings is derived from the following formula:

$$\text{Anthropogenic Input} = \frac{X-X_1}{X_1} \times 100$$

Where, x represents the average concentration of the metal in tailings, and x1 is the average background concentration of the metal. When anthropogenic input is <1, men they is not contribution from human activities and when anthropogenic input is >1, means it is from human activities within the ecosystem. The results of anthropogenic metal input show a variation from -1.73 for Co in sample KG01 (Kedjom-Ketinguh) to 5641.94 for La in sample KK02 (Kedjom-Keku) in the study area. Anthropogenic contribution to the study area refers to Co, Cr, Mn, Mo, Ni, Pb, Th, Zn, La, Fe and Ti (Table XVII; Fig 7). This may be attributed to the leaching of metals from garbage, solid waste heaps, domestic and agricultural runoff, municipal wastes, phosphate fertilizers, fungicides, pesticides, assorted electronic wastes water irrigation in the study area [50], [4], [41], [5], [13], [12]. These anthropogenic activities can generate heavy metals in stream sediment and water bodies that pollute the aquatic ecosystem within the study area. Therefore, proper focus should be taken to monitor the sources of metals entering the river and stream bodies from nearby towns and villages and reduction of urban domestic discharge, used of phosphate fertilizers, industrial effluent and municipal waste.

Table XVIIII. Potential Ecological Risk Factor And Pollution Ecological Risk Index Of Heavy Metals In Stream Sediments Of Bambui Area

Samples	Co	Cr	Cu	Hg	Mn	Ni	Pb	V	Zn	PERI
BB01	5.87	5.30	1.89	16.00	2.79	6.91	9.97	1.73	1.81	52.27
BB02	6.42	6.50	1.95	32.00	3.29	7.22	10.35	1.81	2.19	71.74
BB03	8.96	2.30	1.93	16.00	3.05	3.60	9.18	1.79	0.88	47.68
BB04	5.90	11.15	5.02	16.00	1.63	4.74	6.82	1.73	1.18	54.17
BB05	11.42	12.80	2.45	8.00	1.69	15.53	15.91	3.24	1.46	72.50
BU01	4.77	3.46	1.39	8.00	1.69	3.44	4.79	1.75	0.73	30.02
BU02	10.61	12.89	3.13	16.00	1.81	12.13	2.74	3.03	1.88	64.20
KG01	7.98	11.24	1.91	8.00	1.20	7.09	3.09	2.29	1.45	44.24
KG02	4.91	4.15	3.93	24.00	2.49	5.02	3.32	1.51	1.63	50.96
KK01	8.09	2.65	30.00	16.00	2.46	3.36	12.65	2.97	1.85	80.04
KK02	4.08	4.09	2.59	56.00	1.94	2.82	16.21	1.48	1.49	90.69
KK03	8.93	1.72	1.82	24.00	1.90	4.00	1.94	3.01	1.45	48.77
KK04	5.38	3.20	21.96	16.00	0.89	2.60	18.56	2.16	0.87	71.61
KK05	3.44	1.89	1.32	16.00	1.73	2.15	4.41	1.22	0.61	32.77

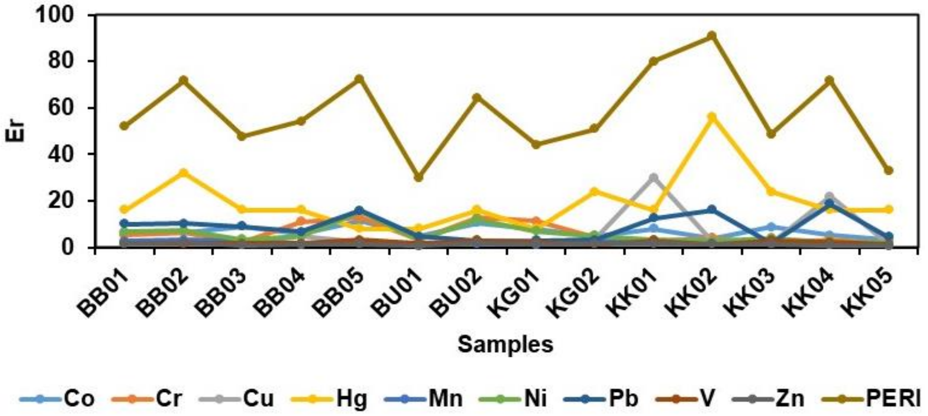

Fig. 6 Er and PERI of heavy metals in stream sediments of Bambui area

Table XVIIIIII. Anthropogenic Metal Input Of Heavy Metals In Stream Sediments Of Bambui Area.

Sample	Ba	Co	Cr	Cu	Ga	Hg	Mn	Mo	Ni	Pb	Sc	Th	V	Zn	La	Al	Fe	Ti
BB01	-70.83	17.34	165.22	-62.14	-42.86	-60.00	178.71	218.18	38.30	99.41	-72.14	190.48	-13.40	80.60	645.16	-86.87	153.82	440.00
BB02	-51.28	28.32	225.00	-61.07	-37.14	-20.00	229.03	672.73	44.47	107.06	-57.86	139.05	-9.28	119.40	380.65	-82.58	197.45	420.00
BB03	-94.26	79.19	15.22	-61.43	-77.14	-60.00	204.52	100.00	-28.09	83.53	-57.14	1804.76	-10.31	-11.94	3158.06	-91.29	117.00	712.00
BB04	-86.36	17.92	457.61	0.36	-60.00	-60.00	62.58	54.55	-5.11	36.47	-62.86	99.05	-13.40	17.91	306.45	-87.73	107.37	552.00
BB05	-84.02	128.32	540.22	-51.07	-37.14	-80.00	69.03	263.64	210.64	218.24	-46.43	652.38	61.86	46.27	761.29	-78.65	169.41	552.00
BU01	-95.59	-4.62	72.83	-72.14	-77.14	-80.00	69.03	-18.18	-31.28	-4.12	-66.43	1804.76	-12.37	-26.87	2283.87	-93.50	98.30	488.00
BU02	-92.82	112.14	544.57	-37.50	-20.00	-60.00	80.65	672.73	142.55	-45.29	-52.14	400.00	51.55	88.06	183.87	-72.02	273.94	764.00
KG01	-92.16	59.54	461.96	-61.79	-25.71	-80.00	20.26	209.09	41.70	-38.24	-79.29	428.57	14.43	44.78	535.48	-73.37	69.69	452.00
KG02	-73.40	-1.73	107.61	-21.43	-48.57	-40.00	149.03	263.64	0.43	-33.53	-57.86	125.71	-24.74	62.69	148.39	-77.67	123.80	516.00
KK01	-83.17	61.85	32.61	500.00	-25.71	-60.00	146.45	300.00	-32.77	152.94	-70.00	1100.00	48.45	85.07	1167.74	-85.89	262.61	564.00
KK02	-91.63	-18.50	104.35	-48.21	-48.57	40.00	93.55	372.73	-43.62	224.12	-49.29	1804.76	-25.77	49.25	5641.94	-84.91	109.07	180.80
KK03	-93.46	78.61	-14.13	-63.57	-54.29	-40.00	89.68	45.45	-20.00	-61.18	-70.00	79.05	50.52	44.78	174.19	-92.88	217.28	780.00
KK04	-97.28	7.51	59.78	339.29	-65.71	-60.00	-10.97	136.36	-48.09	271.18	-77.86	1233.33	8.25	-13.43	1164.52	-91.41	109.07	624.00
KK05	-95.48	-31.21	-5.43	-73.57	-82.86	-60.00	72.90	0.00	-57.02	-11.76	-72.14	1804.76	-39.18	-38.81	1993.55	-92.64	79.04	468.00

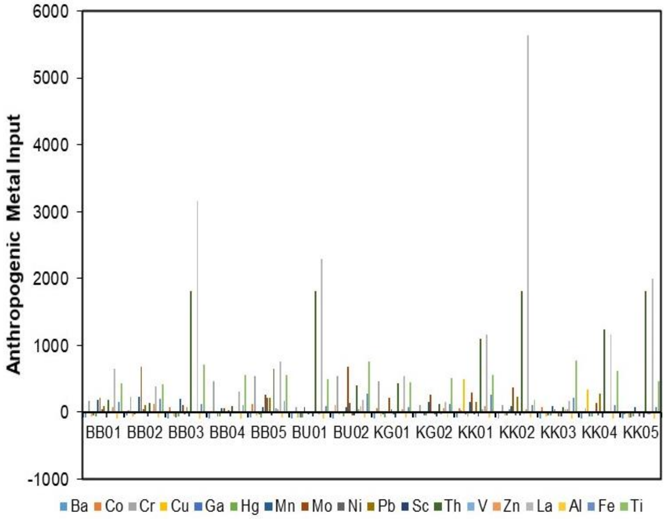

Fig. 7 Histogram of anthropogenic input of heavy metals in stream sediments of Bambui area.

V. CONCLUSIONS

This study aimed at investigating the contamination and risk pose by heavy metals in stream sediments of the study area. The mean concentrations of Co, Cr, Cu, Mn, Ni, Pb, Th, V, Zn, La, Fe and Ti are higher than the upper continental crust values. The strong positive correlations between some elements signify that these elements come from the same activities or geologic unit. The correlation of Co/Cr, Ni, V, Cr/Ni, Mo/Ni, Zn, Ni/V; is a reflection of their transition metal relationship. The PLI and Igeo showed that stream sediments are highly polluted by La, Th and Ti and moderately polluted by Mn, Mo, Pb and Fe. Er and PERI have low values in stream sediments of the study area indicating low potential ecological risk index. Anthropogenic input in the study area refers to Co, Cr, Mn, Mo, Ni, Pb, Th, Zn, La, Fe and Ti. This is due to leaching of metals from garbage, solid waste heaps, animal and human excreta, unplanned urbanization and haphazard industrialization, domestic and agricultural runoff, household effluents, municipal wastes, phosphate fertilizers, fungicides, pesticides, sewage sludge, fossils fuel, atmospheric deposition, assorted electronic wastes, plastics disposal and waste water irrigation.

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