



Research Journal of
**Environmental
Toxicology**

ISSN 1819-3420



Academic
Journals Inc.

www.academicjournals.com



Research Article

Background Concentrations of Potentially Harmful Elements in Soils of the Kette-Batouri Region, Eastern Cameroon

¹B.T. Edith-Etakah, ²M. Shapi, ¹J. Penaye, ³M.E. Mimba, ³S.C. NguemheFils, ²D.S. Nadasan, ^{2,4}T.C. Davies and ²M.A. Jordaan

¹Centre for Geological and Mining Research, B.P. 333, Garoua, Cameroon

²Faculty of Natural Sciences, Mangosuthu University of Technology, 511 Mangosuthu Highway, Umlazi, KwaZulu Natal Province, Republic of South Africa

³Laboratory of Image Processing, B.P. 4110, Yaoundé, Cameroon

⁴Department of Geology, University of Nigeria, Nsukka, Nigeria

Abstract

Background: Alluvial and bedrock gold mining as well as ore processing are predominant activities prevalent in the Kette-Batouri Region. These activities cause soil pollution by way of the accumulation and distribution of toxic, potentially harmful elements (PHEs). For the first time, the migration patterns and toxicity potential of PHEs in the soil of the gold mining district of the Kette-Batouri region is demonstrated. The data were sought as background information necessary for the design of suitable pollution monitoring schemes along with the development of guidelines for performing such monitoring. **Materials and Methods:** A total of 30 surface soil samples were collected and analysed for a selected number of PHEs by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). **Results:** Concentration ranges obtained (mg kg^{-1}) for total PHE were: Cu (4-15), Zn (5-18), Ni (3-17), Co (0.5-10), Mn (40-564), V (31-263), Cr (13-123), Fe (9000-127300) As (1-9), Pb (1.5-26) and Cd (0.25). Statistical analyses showed that the mean concentrations were mostly lower than reference background values. The highest in PHE concentrations were obtained only for Cr and V, at sectors of farmlands that are directly adjacent to the mining localities. Basic and multivariate statistical analyses (principal component analysis/varimax rotated component analysis) were performed to reduce the multi-dimensional space of variables and samples, thus defining two distinct sets of PHE associations as tracers of natural and anthropogenic influences. These associations, viz., (Cu-Pb-Ni-As-Cr-Fe-V) and (Zn-Co-Mn), accounted for 76.93% of the total variance. **Conclusion:** Geoaccumulation indices show that the soils in Kette-Batouri are unpolluted to moderately polluted. However, calculated Pollution Load Indices (PLI) indicated a slight deterioration of site quality, which requires further investigation. The effectiveness of the accrued dataset for monitoring PHEs pollution in the area and for strengthening other aspects of future ecological risk assessment campaigns is demonstrated.

Key words: Potentially harmful elements (PHEs), soils, pollution indicators, nutritional illnesses

Received: October 28, 2016

Accepted: November 28, 2016

Published: December 15, 2016

Citation: B.T. Edith-Etakah, M. Shapi, J. Penaye, M.E. Mimba, S.C. NguemheFils, D.S. Nadasan, T.C. Davies and M.A. Jordaan, 2017. Background concentrations of potentially harmful elements in soils of the Kette-Batouri region, Eastern Cameroon. Res. J. Environ. Toxicol., 11: 40-54.

Corresponding Author: M.A. Jordaan, Faculty of Natural Sciences, Mangosuthu University of Technology, 511 Mangosuthu Highway, Umlazi, KwaZulu Natal Province, Republic of South Africa

Copyright: © 2017 B.T. Edith-Etakah *et al.* This is an open access article distributed under the terms of the creative commons attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Following the dawn of the environmental epoch in Africa almost four decades ago, a plethora of pollution studies have been conducted in the continent's major mining countries to evaluate Potentially Harmful Element (PHE) distribution in farmlands, in order to assess their levels of pollution¹. Literature on the subject is quite comprehensive in illustrating examples of studies describing the fluxes and pollution potential of heavy metals in cultivable soils in Africa²⁻⁷. A number of these studies have employed different quantitative indices such as Enrichment Factor (EF), Pollution Load Index (PLI) and geo-accumulation index (I_{geo}) to estimate levels of heavy metal pollution and their variation within various soil compartments. These studies are important, because exposure to excess PHEs over a long period of time is often chronic and toxic to most organisms through food chain transfer⁷.

Soil pollution due to natural processes can be substantial. One important natural process that can lead to toxic metal accumulation is weathering. Weathering of rocks such as black shale and basic igneous rocks with high background concentrations of specific elements can lead to the dispersion of pollution trails over extensive areas of cultivable lands⁸.

Anthropogenic sources of soil pollution, in contrast are associated with rapid and uncontrolled urbanization and industrialization. These sources include effluent from the agricultural industry, manufacturing and construction activities, burning of fossil fuels, vehicle emissions and ore mining and smelting processes. An example is the study carried out in Douala, Cameroon, which showed that above-background concentrations of toxic elements have accumulated in soils as a result of the discharge of urban effluent generated by industrial activities⁹.

Eastern Cameroon has a long history of gold mining. The gold mining and ore processing activities in alluvial gold workings have been recognised as major sources of PHE contamination in the soil³. In the Kette-Batouri region, in particular, this kind of mining has been practiced for over 70 years. Effluent from abandoned workings, mine waste emanating from heaps of overburden, fragments from waste rock dumps and tailings, all contribute to the formation of Acid Mine Drainage (AMD) which infiltrates into the soil. Potentially harmful elements can accumulate to phytotoxic levels, especially in low pH soils and can subsequently reduce plant growth and enter the food chain when plants are

consumed by animals¹⁰. Yet, in the Kette-Batouri region, the real extent of pollution and its effects on surrounding agro-ecosystems, all the way to the food chain, have received limited attention to date by geochemists, biochemists and public health practitioners. These specialists have the important role of providing valuable input in efforts to trace PHEs uptake by food crops, determine the bio-accumulation characteristics and its interaction in the food chain. As a consequence economic issues arise as there is a huge potential that gold mining holds in the transformation of Cameroon's economy, which has, in recent times, triggered numerous research efforts in aspects pertaining to the nature and occurrence of the gold ore.

The study area is situated in the Kadey Division, Eastern region of Cameroon, along the Equatorial Rainforest Belt. This Division has a surface area of 15 884 km² and comprises seven sub-divisions or districts: Batouri, Kentzou, Kette, Mbang, Ndebele, Nguelebok and Ouli. The study area extends from the Kette sub-division in the North (4°57'40.04"N and 14°33'45.35"E) to Batouri, the Divisional Headquarters (4°25'59.84"N and 14°22'00.49"E) and covers a ground distance of about 85 km and a total cross-sectional area of approximately 3,600 km² (covered by a previous geological reconnaissance survey) (Fig. 1). The area is influenced by a hot and humid equatorial climate of the classic Guinean type, marked by the alternation of two rainy seasons and two dry seasons. The mean annual rainfall is between 1500 and 2000 mm and an average temperature range of 22.8-24.7°C. Such a combination of factors (hot, wet and humid) favors rapid and prolonged weathering and the formation of typical red or yellow lateritic soils, which are again subjected to leaching under conditions of low pH and low organic matter content. Patches of hydromorphic soils are found in the shallows and are mainly sandy or sandy-clay in texture. Despite having soils of apparently high agricultural potential, very few food crops are grown in the region. In addition, there is widespread microbial activity.

Taking all the above facts into consideration, this study aimed at exploring the following, namely: (1) To establish the distribution patterns and migration characteristics of eleven selected PHEs (Cu, Zn, Pb, As, Mn, Cr, V, Co, Ni, Fe and Cd) in the vicinity of the mining localities of the Kette-Batouri region, using quantitative indicators and (2) To assess the level of soil contamination for informing land use decisions and for better targeting intervention measures for environmental diseases related to excessive intake of PHEs through the food chain.

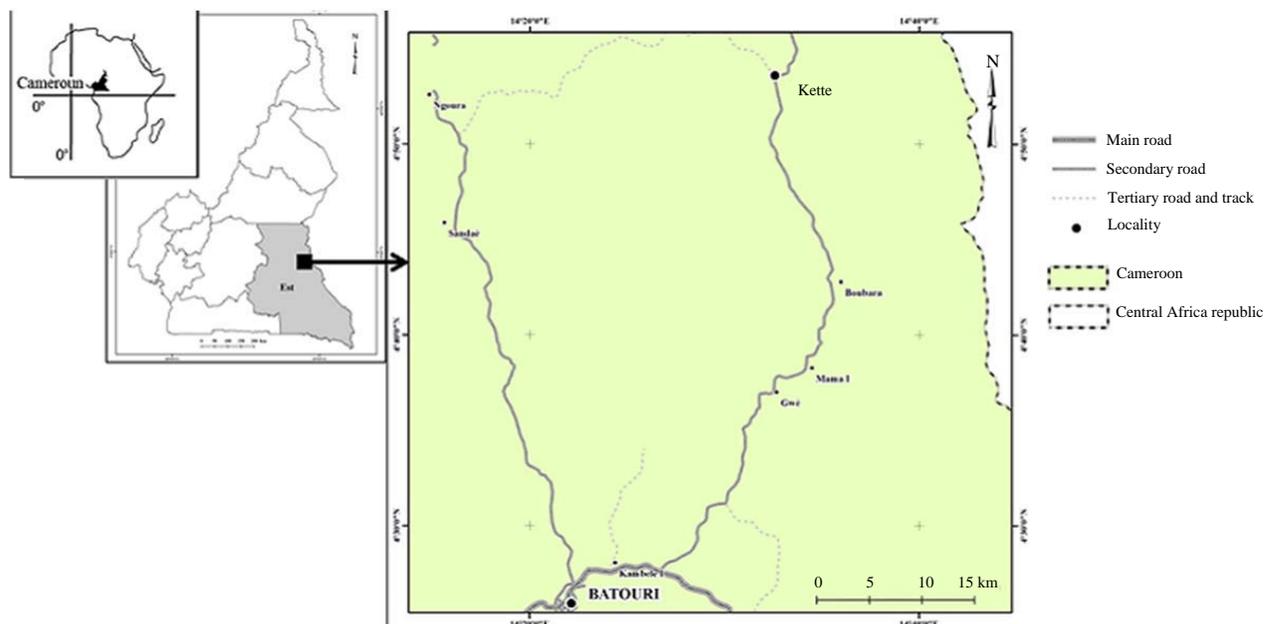


Fig. 1: Location of the Kette-Batouri region

MATERIALS AND METHODS

Sampling technique and sample preparation: Surface soil samples were collected from arable lands around mining localities at the Kette-Batouri region. Two composite soil samples were taken from each of the farms and 28 samples from mine sites and along road cuts. The 28 samples were collected in pairs, with each sample pair taken 15 m on either side away from the road cut. This sampling frame was designed with a view to capturing the impact of PHE pollution derived from mining activities on food chains and other ecosystem components stemming largely from alluvial gold mining activities on potential farmlands located close to mine settings and road cuts. Composite and single sample triplicates were collected for quality control purposes. At collection points, a 1 × 1 m pit was dug to a depth of 40 cm and approximately 250 g of bulk sample collected at 30 cm depth using a clean trowel. For the composite sampling, four holes were made at the corners of a square, 20 × 20 m in dimension, in accordance with ICGP 259 recommendations¹¹. Subsamples were homogenized and quartered on a plastic sheet using a clean trowel. All samples were stored in labelled Kraft paper envelopes and accurately determined (GPS) locations recorded.

Sample preparation at the Hydrological Laboratory of the Institute of Mining and Geological Research (IRGM) at

Nkolbisson in Yaounde, comprised the following steps: The soil samples were oven-dried (30°C) to constant weight and left to attain ambient (room) temperature. They were then lightly disaggregated but not pulverized and sieved through a 500 µm (0.5 mm) stainless steel mesh. No granulometric analysis was carried out. However, a number of studies have determined that metals in the coarse-grained soils are mainly derived from parent materials and metals in the fine fraction are mostly anthropogenic¹²⁻¹⁴. It is also known that enrichment of PHEs in urban soils takes place mostly in the clay and silt sized fractions and pose health risks. The high specific surface area and charge of fine particles are the probable factors that account for the high contamination levels seen in the fine fraction. The size fraction analyzed in this study (500 µm) encompasses all particles below medium sand (USDA classification) and includes the clay and silt sized particles that are the likely loci for anthropogenic enrichment of PHEs.

A fraction of 0.5 g of the sieved sample was digested with aqua regia, cooled and diluted with deionised water. Digested samples were analyzed for their PHEs content by the ICP-OES technique at the ACME Laboratories in Vancouver, Canada using the Spectro Arcos ICP-OES Model equipped with the CCD optic system, capable of covering a wavelength range of 130-770 nm. Elements present below the detection limit of the ICP-OES instrument were assigned a concentration of 0 ppm and were not considered further during data synthesis.

Analytical quality assurance assessment: A very strict quality control mechanism is installed by ACME. The fundamental parameters to ensure the acceptability of the performance of the ICP-OES method validation, viz., selectivity, accuracy, precision, sensitivity, reproducibility and instrument stability were all within acceptable limits. The analysis of blanks, randomisation of sample numbers and the use of in-house reference materials and sample triplicates, provided a measure of background noise, trueness of analytical results and precision. The ACME's in-house reference materials are prepared and certified against the internationally certified reference material, CANMET, which has a similar matrix (baseline trace element concentration) as the studied soils. Representative analyses were externally verified at other commercial laboratories. Soil samples with unusually high results of the elements studied were re-analyzed wherever possible. The limits of detection for all 11 elements studied are given in Table 1.

Data analysis: The analytical data were subjected to various evaluation methods for pollution potential using the following three pollution indicator parameters: Enrichment Factor (EF), geo-accumulation index (I_{geo}) and Pollution Load Index (PLI). These parameters were considered to provide realistic estimates of the extent of contamination that has impacted the soils in the study region^{2,3,6}.

A major objective of this evaluation was to provide a basis for determining if soils around and away from the mining locations contained elevated concentrations of PHEs relative to ambient conditions. The term 'Ambient conditions' [synonymous with "Local background" (LB)] is defined as concentrations of PHEs in soils in the vicinity of a site but which are unaffected by site-related activities¹⁵⁻²⁰. In this study, these activities are mainly mining and ore-processing.

It is evident that background values and realistic mandatory guidelines would be hard to assign without a more extensive soil sampling data collection. Therefore comparisons of soil PHE contents with respect to background were made with reference to average PHEs content of shale¹⁷. Soil quality was evaluated with reference to soil quality guideline values given in the 'Canadian Soil Quality Guidelines for Protection of Environmental and Human Health Document' (CSQGD)¹⁸.

Enrichment factor: The Enrichment Factor (EF) is calculated following Adakpoh⁵. The EF normalizes the measured PHEs

Table 1: Detection limits for 11 elements in Kette-Batouri soils using the Spectro Ciros Vision ICP-OES instrument

Elements	Detection limits (mg kg ⁻¹)	Upper limits (mg kg ⁻¹)
As	0.10	10,000
Cd	0.01	2,000
Co	0.10	2,000
Cr	0.50	10,000
Cu	0.01	10,000
Fe	0.01%	40%
Mn	1.00	10,000
Ni	0.10	10,000
Pb	0.01	10,000
V	2.00	10,000
Zn	0.10	10,000

content with respect to a sample's reference metal²¹⁻²³, such as Fe, Al or Zn. The EF of a heavy metal in the soil is calculated as:

$$EF = [C_{\text{metal}}/C_{\text{normalizer}}]_{\text{soil}}/[C_{\text{metal}}/C_{\text{normalizer}}]_{\text{control}}$$

where, C_{metal} and $C_{\text{normalizer}}$ are concentrations of heavy metal and normalizer, respectively, in the soil and in the control. In this study, the background concentrations in soils derived from rocks of average shale composition²¹ was adopted as control in the EF calculations and A1 used as the normalizer. The EF value is used to distinguish the magnitude of contamination resulting from either the natural or anthropogenic influence²⁴.

Contamination factor: The Contamination Factor (CF) is calculated according to Hakanson⁴, using the following formula:

$$CF = C_m(\text{sample})/C_m(\text{background})$$

where, $C_m(\text{sample})$ is the concentration of a given metal at a contaminated site and $C_m(\text{background})$ is the concentration of a given element in a control or background sample. It provides a measure of the degree of overall contamination of surface layers in a sampled site. The CF is defined according to 4 categories, ranging from: Low contamination ($CF < 1$) to moderate contamination ($1 \leq CF < 3$), to considerable contamination ($3 \geq CF < 6$), to very high contamination ($CF > 6$)¹⁶.

Pollution load index: The Pollution Load Index (PLI) was calculated using the following formula²⁵:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \dots \times CF_N)^{1/N}$$

where, CF is the contamination factor, N is the number of metals studied, C_{metal} is the concentration of metal pollutant in

soil and $C_{\text{background}}$ is the background value of the metal. The PLI gives an estimate of the metal contamination status and the necessary action that should be taken in mitigating undesirable conditions.

Geoaccumulation index: The geoaccumulation index (I_{geo}) was introduced for determining the extent of metal accumulation in sediments²⁶ and has subsequently been applied to soils by various workers. The geo-accumulation index is mathematically expressed as:

$$I_{\text{geo}} = \frac{\log_2 C_n}{1.5B_n}$$

where, C_n is the heavy metal concentration in the soil samples and B_n is the background concentrations in soils derived from rocks of average shale composition²¹. The factor 1.5 is introduced to minimise the effect of possible variations in the background values that may be attributed to lithological variations imparted in the soils.

Calculation of correlation coefficients and principal components: Calculation of Correlation Coefficients (CC) and analysis of Principal Components (PC) were performed on the acquired geochemical data with the aid of the SPSS software package, version 17.0. The number of significant principal components was selected on the basis of the varimax orthogonal rotation with Kaiser normalization at Eigen values greater than 1.

Box and whisker plots: Box and whisker plots²⁷ were constructed to give a display that aids the visualisation of basic statistics for the concentrations of PHEs investigated in the soils of the Kette-Batouri region.

RESULTS AND DISCUSSION

The landscape comprises a peneplain which is rugged in some places, with gently rolling hills of average altitude between 600 and 900 m (Fig. 2, 3). Steep slopes are observed but these are much localised. The drainage system is dendritic (Fig. 2), a feature created by the lithology (granites) and

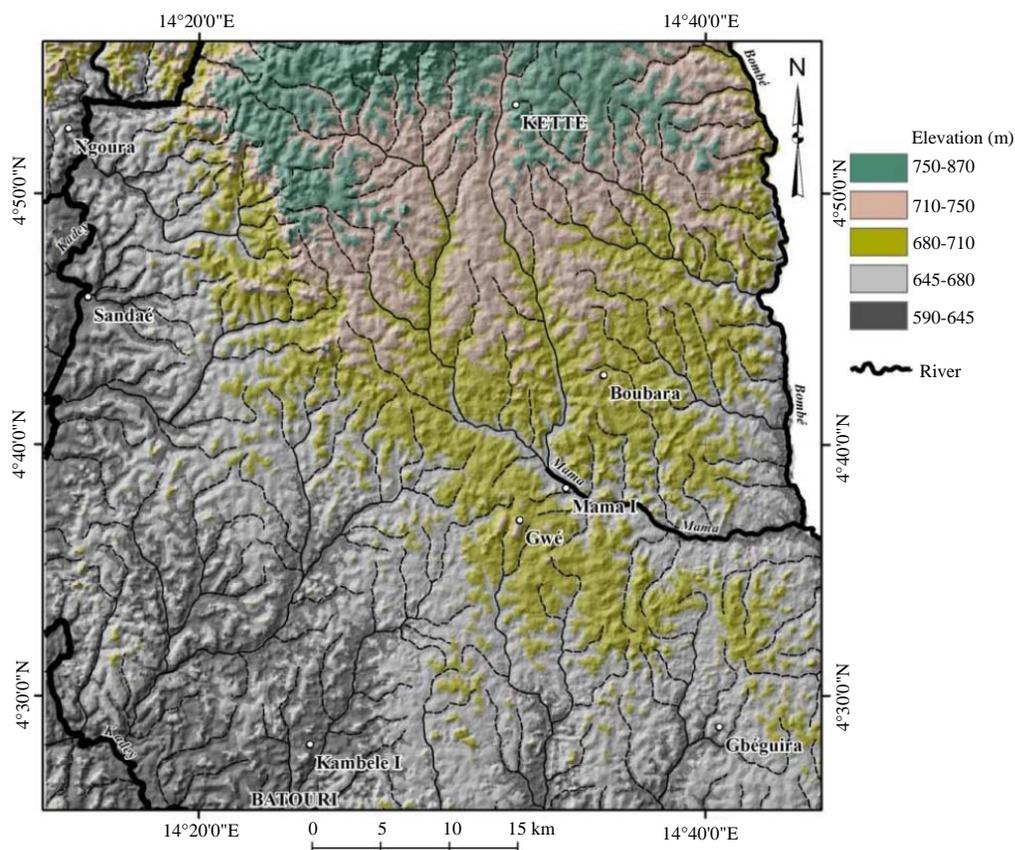


Fig. 2: Map showing the drainage pattern and relief of the Kette-Batouri region

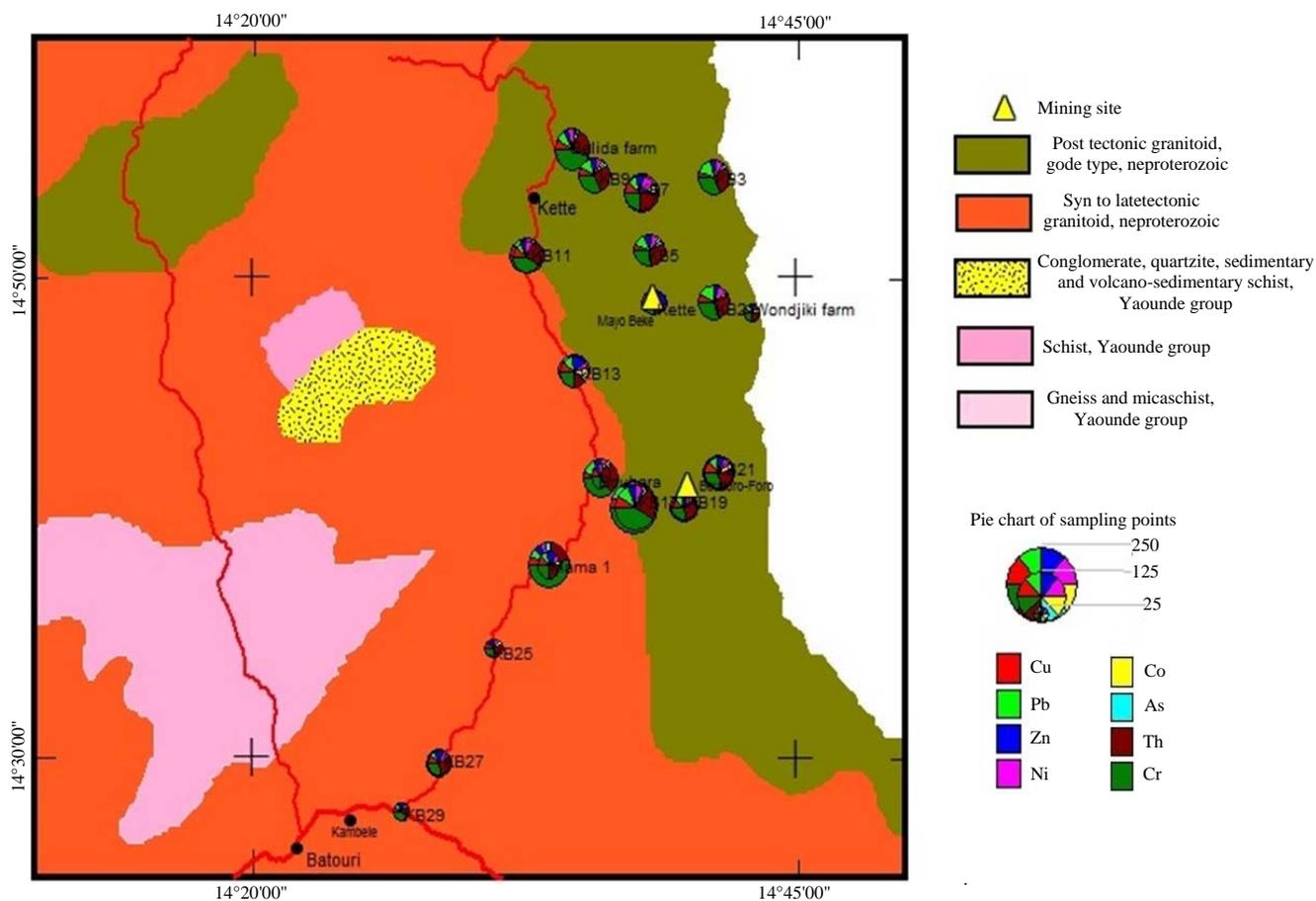


Fig. 3: Modified geological map of the Kette-Batouri region showing sampling points in the study area. Source: Toteu *et al.*¹³

associated structures. The most important river is the Kadey at Batouri. The mining process begins after the identification of a gravel bar or a gold vein, whereby the miners begin by clearing all foliage and trees that hinder access to the deposit. This process is then followed by drilling in a dry substrate to locate auriferous gravel. After separation of the gravel, it is washed on a table followed by the jiggling process to extract the mineral in its crude form. Gold is also collected by panning sediments from nearby streams and rivers. Pollution effects due to these artisanal mining activities have received limited research attention, although these activities have been shown to release huge concentrations of PHEs into the soil and both ground and surface water systems. Enormous pollution trails produced due to the improper disposal of mine waste are derived from materials such as tailings, desegregated rock and overburden; all of which contain noxious sulphide and iron minerals. In addition to geochemical effects, artisanal gold mining produces physical effects such as scarification. Pits dug

by the miners are often never refilled. At times, miners would have to divert a stream from its course in order to dig into its bed.

Baseline concentrations of the studied elements: Total concentrations of PHEs studied and derived basic statistics are summarized in Table 2. The box and whisker plots shown in Fig. 4 give a summary of the basic statistics. These plots were found to be useful for characterizing and comparing the geochemical distributions and for assessing the shape of distributions (e.g., whether they are positively or negatively skewed). Each of the plots encloses the middle 50% of the data distribution of the respective PHE by a box; where the median value is represented by a line and the notch represents the 95% confidence interval around the median value²⁸. If the median value lies close to the lower or upper limits of the box, the distribution is markedly skewed (Fig. 4). The lines (whiskers) are drawn from the lower and upper

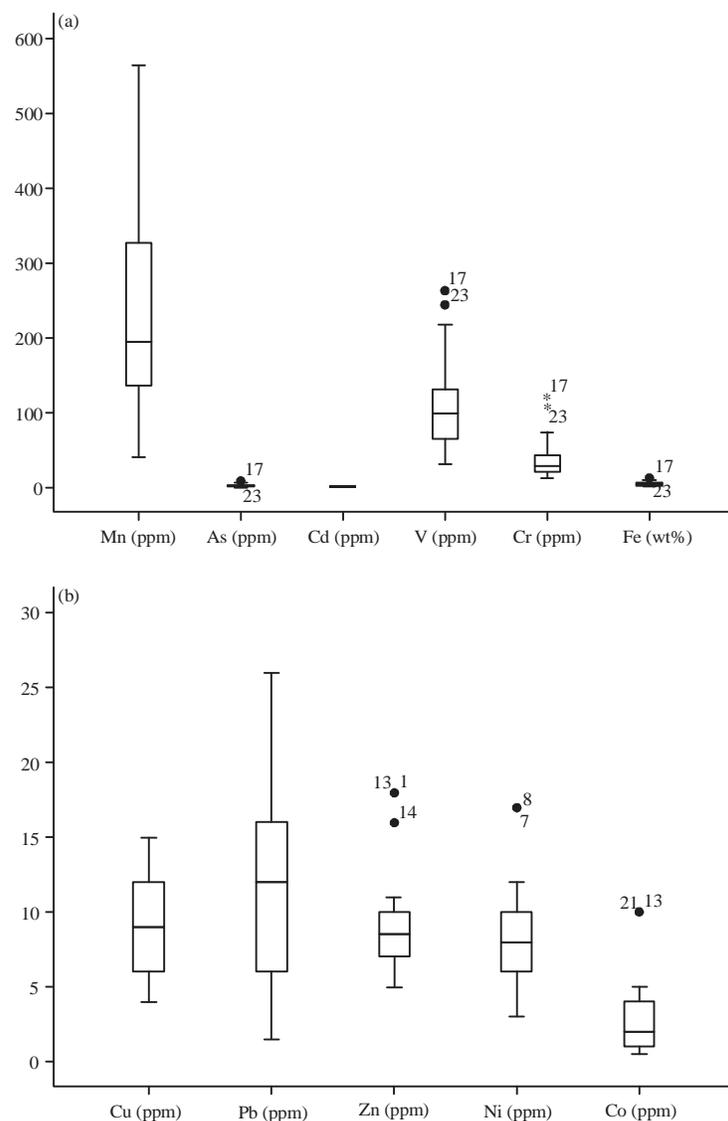


Fig. 4(a-b): Range of PHE concentrations in soils of the Kette-Batouri region shown as box and whisker plots

Table 2: Concentration of PHEs (mg kg^{-1}), Fe (wt%) in the soils of the Kette-Batouri region, derived basic statistics* and enrichment factors** determined for 11 PHEs in soils of the Kette-Batouri region, using their (PHEs) abundance in average shale as background values

*Element	Range	Median	Mean \pm 2SD	Skewness	**Average shale	Mean	Range
Cu (63)	4-15	9.00	9.370 \pm 2 (3.25)	0.1	45.00	0.6	0.2-1.4
Pb (70)	1.5-26	12.00	11.830 \pm 2 (6.80)	0.3	20.00	1.6	0.3-5.6
Zn (200)	5-18	3.00	9.100 \pm 2 (3.32)	3.3	95.00	0.3	0.08-1.3
Ni (50)	3-17	4.00	8.267 \pm 2 (3.64)	0.6	68.00	0.5	0.04-1.8
Co (40)	0.5-10	2.00	2.900 \pm 2 (2.86)	1.4	19.00	0.3	0.2-0.4
Mn	40-564	134.00	231.130 \pm 2 (135.01)	0.9	850.00	0.8	0.2-2.1
As (12)	1-9	2.00	2.100 \pm 2 (2.43)	1.0	13.00	0.5	0.1-1.8
V (130)	31-263	99.00	107.870 \pm 2 (57.74)	1.9	130.00	2.9	1.2-4.9
Cr (64)	13-123	29.00	36.767 \pm 2 (26.062)	2.1	90.00	1.1	0.5-3.1
Fe (wt%)	0.9-12.73	4.10	4.790 \pm 2 (2.93)	1.2	4.72	2.6	1.4-7.0
Cd (1.4)	0.25	0.25	0.250 \pm 2 (0)	-	0.30	2.6	0.9-6.3

*Values in first column are from the Canadian soil quality guidelines for protection of environmental and human health document (CSQGD)²², **Average shale values given by Turekian and Wedepohl²¹

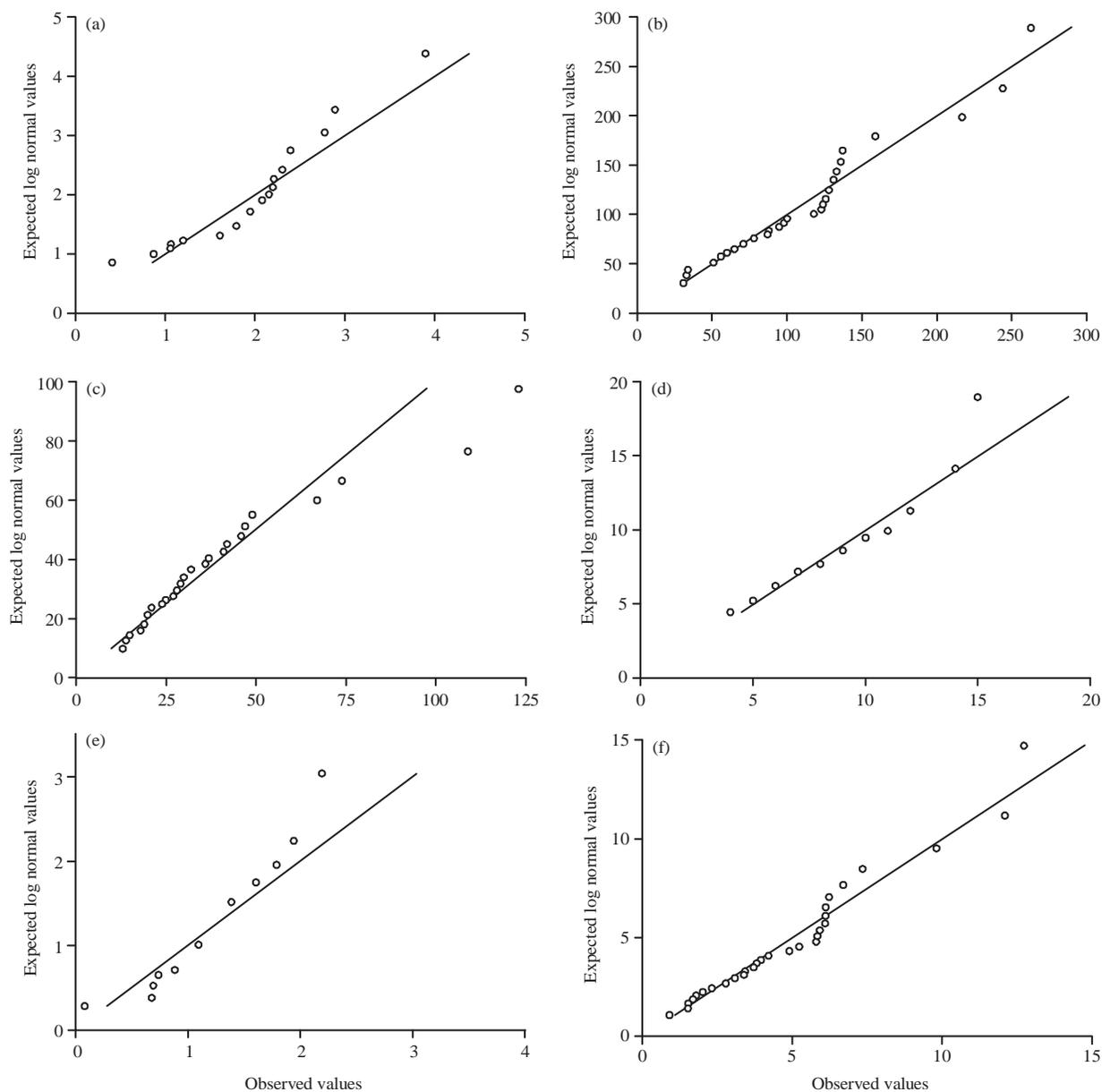


Fig. 5(a-f): Log normal probability plots for PHEs in soils of the Kette-atouri region, log normal Q-Q plot of (a) Zn, (b) V, (c) Cr, (d) Cu, (e) As and (f) Fe

quartiles to the smallest and largest point within the 1.5 interquartile ranges, respectively²⁸. The mean value is plotted as a point within the box.

Linear trends are formed when the metal concentrations are log-transformed and plotted on a normal probability diagram as shown in Fig. 5. Most of the PHEs in this study show lognormal or close to lognormal behavior (Fig. 5). When compared with background contents of these PHEs in average shale (Table 2), only Cr, Pb, Fe and V have values above the

reference backgrounds, supporting the later conclusion of moderate pollution (for these elements), that decreases significantly away from mine sites. Total concentrations of the PHEs: As, Co, Cu, Pb, Ni and Zn are up to several fold lower than the corresponding CSQGD values²⁹ for agricultural soils (Table 2). The only PHEs that showed higher values were Cr and V (highest values of 123 and 263 mg kg⁻¹, respectively). The higher values obtained for Cr and V are considered to represent localized contamination. As

Table 3: Pearson product-moment correlations between 10 PHEs in the soils of Kette-Batouri region (n = 30)

Elements	Cu	Pb	Zn	Ni	Co	Mn	As	V	Cr	Fe
Cu	1									
Pb	0.472**	1								
Zn	0.412*	0.341	1							
Ni	0.638**	0.595**	0.035	1						
Co	0.202*	0.079	0.476**	-0.016	1					
Mn	0.402**	0.237	0.472*	0.220	0.814**	1				
As	0.525**	0.698**	0.350	0.495**	-0.078	0.281	1			
V	0.594**	0.699**	0.181	0.646**	-0.184	0.164	0.863**	1		
Cr	0.562**	0.619**	0.119	0.492**	-0.291	0.091	0.860**	0.914**	1	
Fe	0.607**	0.694	0.166	0.693**	-0.180	0.227	0.886**	0.979**	0.913**	1

*Correlation significant at 0.05 level (two-tailed), **Correlation significant at 0.01 level (two-tailed)

expected, there is a general decrease in the concentration of these metals away from the mine sites.

The behaviour of the other chalcophile elements studied: As (1-9 mg kg⁻¹), Cu (4-15 mg kg⁻¹), Zn (5-18 mg kg⁻¹) is consistent with their release from sulphide-rich ores (by weathering and anthropogenic processes) and migration within a lateritic or sandy clay-textured soil (of low pH, low organic matter content and low sorption capacity)⁸. In addition, defecation from grazing animals increases the organic content of the soil (albeit to a limited extent) and this, coupled with the high clay content and high pH of soils (away from the mine site), causes the deposition of heavy metals³⁰.

Explanation of geochemical behaviour based on PHE enrichment indicators:

Based on values obtained for Contamination Factor (CF) and Pollution Load Indices (PLI), most of the soil samples analysed could be classed under 'Low contamination' for the PHEs studied. The CF values obtained were: Cu (0.2), Pb (0.6), Zn (0.1), Ni (0.1), Co (0.2), Mn (0.3), As (0.32), V (0.8), Cr (0.4), Fe (1.01), Cd (0.8) and PLI for Cu (1.2).

In this study the EF values (Table 2) were interpreted as follows: EF < 1 indicates no enrichment; the range 1-3 signifies minor enrichment, 3-5 is moderate, 5-10 is moderately severe, 10-25 is severe, 25-50 is very severe and >50 is extremely severe^{31,32}. The highest average EFs were recorded for Fe (2.6 ± 1.2) and Cd (2.6 ± 1.3), with some samples showing moderate to severe enrichment for Cd.

The high average EF value for Fe is consistent with its behaviour in association with a group of elements with chalcophile tendency viz., V, Cr, As, Ni, Pb and Cu. This element cohort is a factor in the principal component 1 ("Principal component analysis"). The high EF for Cd was not investigated further as supporting statistical data (correlation indices/principal component associations) were not available. However, sewage sludge disposal, fertilizer

application and agronomic activities may be considered as more important sources of Cd, in comparison to mining activities in the region.

To complement the results obtained on application of PHE contaminant indicators (CF and EF), geo-accumulation indices (I_{geo}) were also calculated³³. The calculated I_{geo} showed that 100% of the studied elements belong to class 1 (unpolluted to moderately polluted).

Pearson's product-moment correlation coefficient: The matrix of linear correlation coefficient is shown in Table 3. The correlation values (r) show a wide range of variation in the soils, from -0.291 (between Cr and Co) to 0.979 (between Fe and V). This suggests the interplay of multiple geochemical factors in the migration behaviour of the PHEs. Strong positive correlations ($r = 0.8-0.9$) between some pairs of PHEs (As and V, Cr, Fe, Mn and Co, Fe and Cr) indicate a geogenic relationship and origination from the same pollution sources, with similar pollution channels.

Cobalt showed a strong positive correlation with Mn ($r = 0.814$) but has a negative to a weakly positive correlation with the other elements studied. The strong correlation between Mn and Co may be attributed to an adsorption and co-precipitation effect. Binding of Co to Mn concretions is favoured by the presence in the soil of negatively charged Mn oxide (MnO₂) and Mn hydroxide [Mn(OH)₄] with their small crystal sizes and large surface areas.

The strong correlation between the other elements (As, Fe, Cr, Cu, Pb and V) suggests a chalcophile relationship (in sulphides) associated with the gold mineralization. These PHEs can substitute for each other in sulphide ore minerals and are released in the soils as a result of weathering of mineralized bedrock and quartz veins as well as through mining and ore processing activities. In the Batouri Gold district, gold occurs in quartz veins bearing pyrite and also in wall rocks bearing sericite²⁹ ("Nature and occurrence of gold").

The weaker correlations ($r = 0.6$) [(Pb, As, V, Cr, Fe and Cu) and (Cu, As, V, Cr, Fe)], on the other hand, reflect contamination from multiple sources, including direct hydraulic transport of toxic metal species in mine tailings and associated soils as well as probable limited inputs from fertilizer use and agronomic activities.

Principal component analysis: The relationship between the variables in soils of Kette-Batouri region is displayed in another format [based on principal components (PCs)] in Table 4 and is shown to be consistent with the links indicated in the correlation matrix (Table 3). Principal component analysis enhances subtle but significant single-element anomalies and helps discriminate between element associations that have different underlying factors controlling their distribution. Two PCs were extracted with respect to Eigen values greater than 1. The values in bold in Table 4 represent PC loadings >0.5 ; these were used in the determination of PCs. Principal component 1 (PC-1), the more important component, accounted for 55.49% of total variance and was mainly characterized by high levels of V, Fe, Cr, As, Ni, Pb and Cu. This component is lithogenic in origin, rather than anthropogenic. The compatible chalcogenides behaviour of these elements (Cr, As, Ni, Pb and Cu) in the sulphide minerals of the gold ore and their presence as lattice components in the associated heavy minerals (e.g., rutile: Cr, V and Fe) are the probable factors that determine their migration characteristics as well as their enrichment and enhanced pollution potential in the soil.

Principal component (PC-2) accounted for 21.44% of total variance with a cohort comprising: Mn, Co and Zn. This

component is anthropogenic and denotes concordant migration in the soil of this PHE association after the metals are released by mining, erosion and hydraulic transport processes. Geochemical mechanisms by which they bind to the finer-grained soil particles, causing moderate contamination, include adsorption, complexation and co-precipitation, in a largely acidic environment.

Spatial distribution of potentially harmful elements: The concentration and spatial distribution maps for PHEs drawn using the Surfer 17.0 software package are presented in Fig. 6. Concentrations of V, As, Cr, Fe and Zn show significant correlations as well as, distinct distribution patterns. Despite the generally steady decrease of PHE concentrations away from the mine sites, isolated areas located approximately 10-80 km away from the NE segment of the study area still show significantly enhanced concentrations for some PHEs (Cr, Pb, Fe and V), with reference to background values (Fig. 6). Large amounts of metals present in the mine wastes and associated soils provide a source for continuing dispersion both downstream and downslope (deposition of hydraulically transported mine tailings). This has resulted in a moderate degree of contamination of soils suitable for crop production.

Inferred link of PHEs contamination of soil to environmental health: The commonly established ingestion pathways, from the literature, for the PHEs in the study are: Food consumption, drinking water and ingestion of contaminated soil (mostly by children or as in 'Geophagy' the deliberate or sometimes inadvertent consumption of soil). Of the eleven PHEs studied, only Cr, Pb, Fe and V (above reference background), Cr and V (above CSQG values) and Fe and Cd (high average EF) show enhanced concentrations that would be statistically significant in any proposed risk assessment studies in the region. Possible health implications of the bioaccumulation and food chain entry of these PHEs are discussed for Cr³⁴⁻³⁶, Pb^{33,35-38}, Fe³⁹⁻⁴⁶, V⁴⁷⁻⁴⁹ and Cr^{50,51}.

This study has provided important background information for vulnerability assessment of sampled areas for future investigation and development planning in the Kette-Batouri region of Eastern Cameroon. Principal component analyses, correlation coefficients and other relevant statistics indicate dominant lithogenic control and subordinate anthropogenesis in the migration and accumulation of eleven PHEs. Initial results emphasize the

Table 4: Rotated component matrix of principal component analysis loadings for PHEs in the soils of the Kette-batouri region

Elements	Principal component (PC)		Communalities
	1	2	
Cu	0.656	0.420	0.607
Pb	0.777	0.242	0.662
Zn	0.149	0.749	0.584
Ni	0.747	0.103	0.569
Co	-0.210	0.904	0.865
As	0.870	0.202	0.798
Cr	0.919	-0.085	0.851
Mn	0.104	0.875	0.792
Fe	0.974	0.023	0.949
V	0.960	0.002	0.922
Eigen values	6.104	2.358	
Percentage of variance	55.490	21.440	
Cumulative (%)	55.490	76.930	

absence of large-scale soil contamination in areas located outside of a relatively small radius of the mine sites and suitability of these localities for agriculture is indicated. However, agricultural and agronomic activities are not intense in the study area at present and pollution from these extraneous sources (sources outside mining and ore processing) is considered to be of limited significance in risk assessment studies in the region.

A complete and detailed mapping of PHEs distribution in the soils, especially along certain defined

profiles, is also advocated. Although, total metal concentrations in soils can be an important factor in determining the uptake of metals into plants, it is realised that uptake can also be influenced by several other soil and plant factors. Factors, such as soil texture, pH, organic matter content and bio-availability/bio-accessibility characteristics, should be carefully investigated, before credible links can be established between PHE excesses in soils and environmental diseases in the study region.

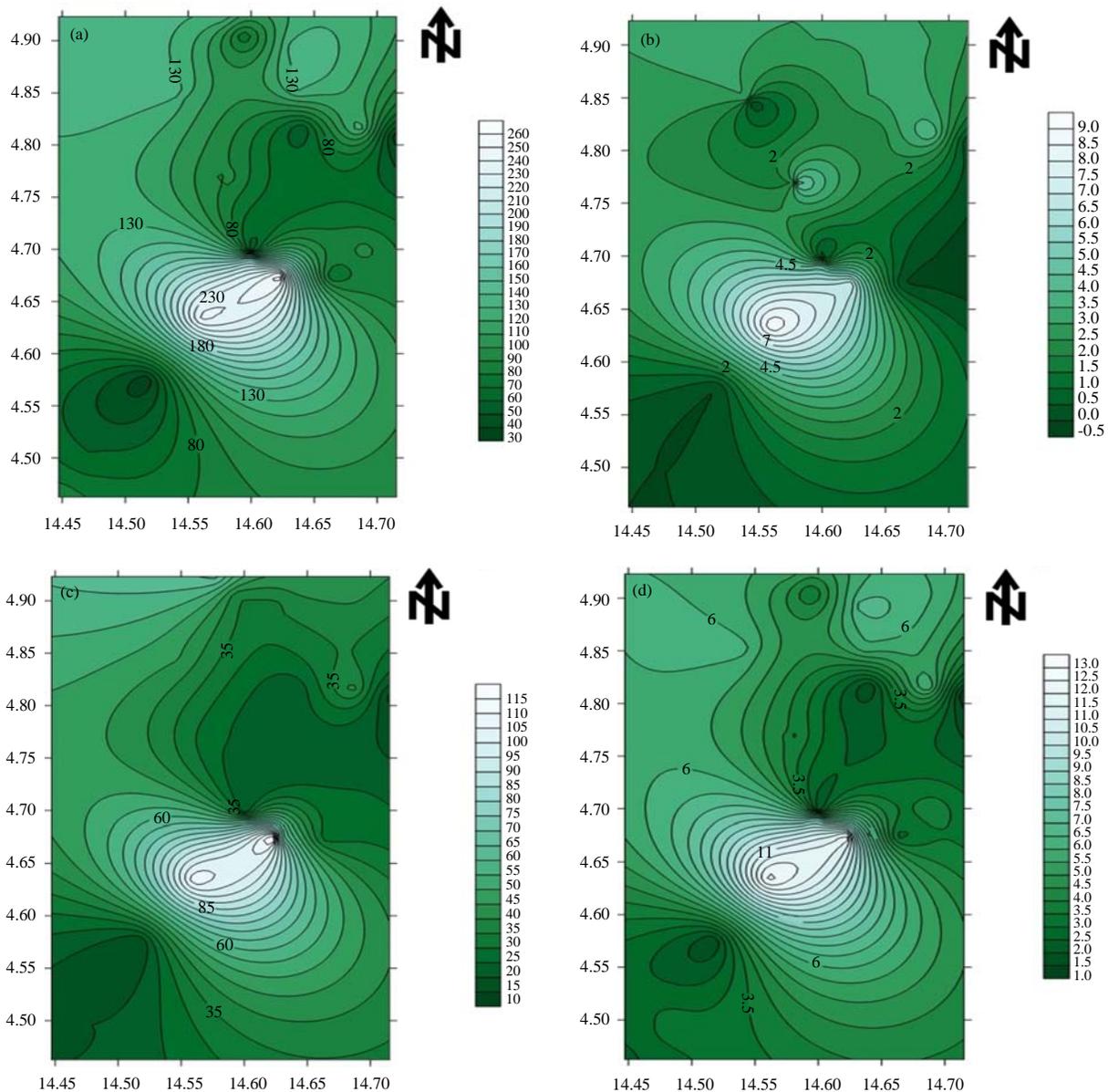


Fig. 6(a-h): Continue

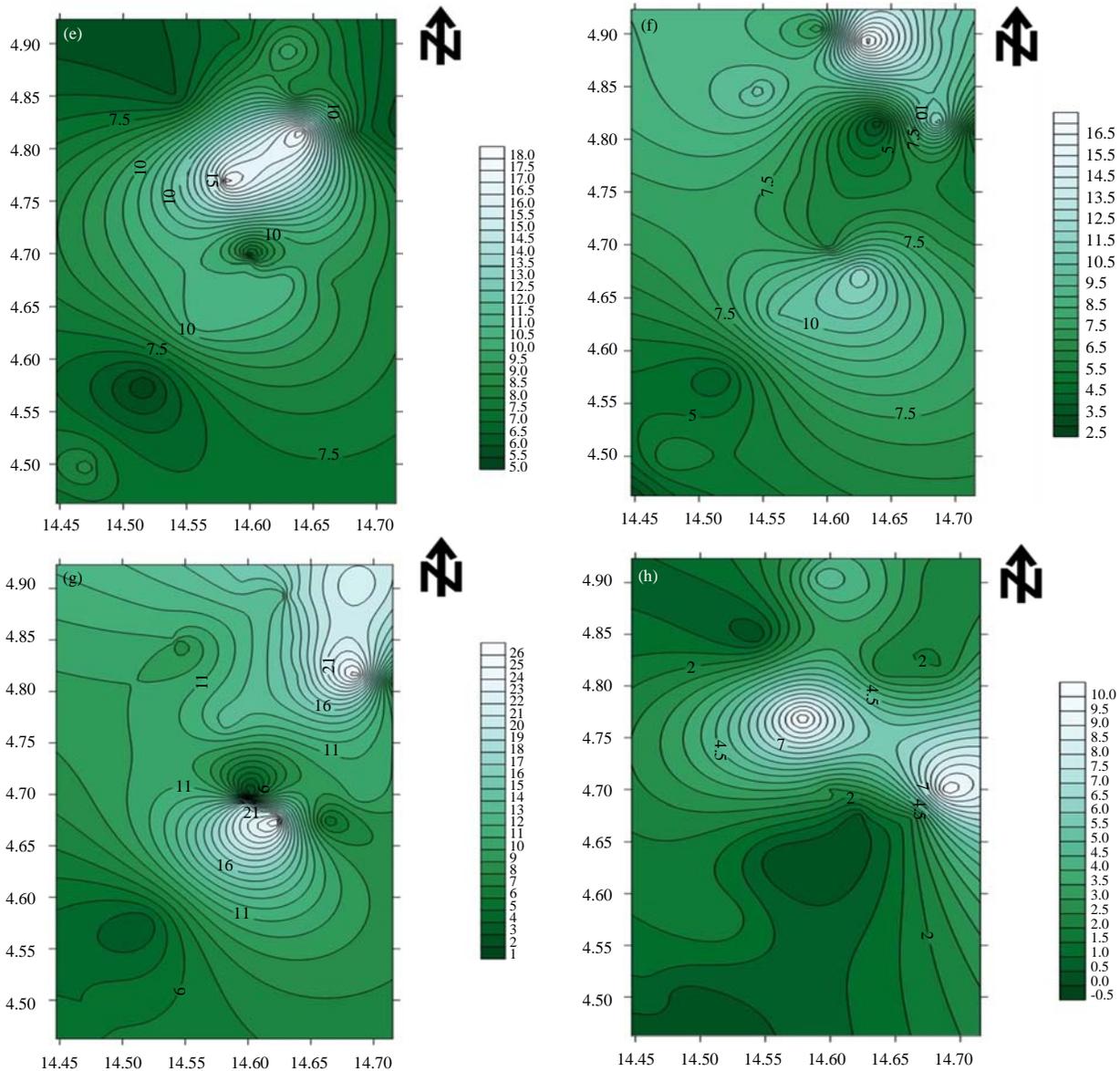


Fig. 6(a-h): Spatial distribution of (a) V, (b) As, (c) Cr, (d) Fe, (e) Zn, (f) Ni, (g) Pb and (h) Co in surface soils of the Kette-Batouri region. Element concentrations are in mg kg^{-1} , except Fe which is in wt%

CONCLUSION

The effects of soil environmental pollution caused by mining in the Kette-Batouri region were investigated, for the first time. This study has provided important background information for vulnerability assessment of sampled areas for future investigation and development planning in the Kette-Batouri region of East Cameroon. Principal component analyses, correlation coefficients and other relevant statistics indicate dominant lithogenic control and subordinate

anthropogenesis in the migration and accumulation of eleven PHEs. Initial results emphasise the absence of large-scale soil contamination in areas located outside of a relatively small radius of the mine sites and suitability of these localities for agriculture is indicated. Agricultural and agronomic activities are not intensive in the study area at present and pollution from these extraneous sources (sources outside mining and ore processing) is considered to be of limited significance in risk assessment studies in the region.

SIGNIFICANT STATEMENTS

The paper highlights for the first time the distribution of potentially harmful elements (PHEs), their migration patterns and toxicity potential for soils of the gold mining district of the Kette-Batouri. Though most of the primary gold mines have been abandoned, mining activities in this area are still of economic importance to the Eastern Cameroon region as the alluvial gold mining sector there is still very active. Pollution by PHEs largely from alluvial gold mining but also from effluents from abandoned workings, has long been of concern in the Kette-Batouri area but the extent of pollution and its effect on surrounding agro-ecosystems, all the way to the food chain, have received limited attention. The bioaccumulation of these PHEs in food crops can cause long-term cumulative health effects due to nutritional imbalances and other maladies when heavy metal concentrations in soils exceed Maximum Allowable Concentration (MAC) levels.

ACKNOWLEDGMENTS

This study was supported by funding from the 2013 Swedish International Development Agency (SIDA)/IGCP/UNESCO Project 606 grant. Further support for this study came from the Centre for Geological and Mining Research, Garoua, Cameroon as well as the Research Directorate and the Faculty of Natural Sciences of Mangosuthu University of Technology, South Africa. The professionalism shown by ACME Laboratories in Vancouver, Canada in performing analytical work of the highest quality is also gratefully acknowledged.

REFERENCES

1. Kribek, B., B. De Vivo and T. Davies, 2014. Special Issue: Impacts of mining and mineral processing on the environment and human health in Africa. *J. Geochem. Explor.*, 144: 387-390.
2. Kagambega, N., S. Sawadogo, O. Bamba, P. Zombre and R. Galvez, 2014. Acid mine drainage and heavy metals contamination of surface water and soil in southwest Burkina Faso-West Africa. *Int. J. Multi. Acad. Res.*, 2: 9-19.
3. Guan, Y., C. Shao and M. Ju, 2014. Heavy metal contamination assessment and partition for industrial and mining gathering areas. *Int. J. Environ. Res. Public Health*, 11: 7286-7303.
4. Hakanson, L., 1980. An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Res.*, 14: 975-1001.
5. Adaikpoh, E.O., 2013. Distribution and enrichment of heavy metals in soils from waste dump sites within imoru and environs, southwest Nigeria. *J. Environ. Earth Sci.*, 3: 45-54.
6. Likuku, A.S., K.B. Mmolawa and G.K. Gaboutloeloe, 2013. Assessment of heavy metal enrichment and degree of contamination around the copper-nickel mine in the Selebi Phikwe Region, Eastern Botswana. *Environ. Ecol. Res.*, 1: 32-40.
7. Matini, L., P.R. Ongoka and J.P. Tathy, 2011. Heavy metals in soil on spoil heap of an abandoned lead ore treatment plant, SE Congo-Brazzaville. *Afr. J. Environ. Sci. Technol.*, 5: 89-97.
8. Jung, M.C., 2008. Heavy metal concentrations in soils and factors affecting metal uptake by plants in the vicinity of a Korean Cu-W mines. *Sensors*, 8: 2413-2423.
9. Asaah, V.A., A.F. Abimbola and C.E. Suh, 2006. Heavy metal concentrations and distribution in surface soils of the Bassa industrial zone 1, Douala, Cameroon. *Arabian J. Sci. Eng.*, 31: 147-158.
10. Chaney, R.L., 1994. Trace Metal Movement in Soil-Plant Systems a Bioavailability of Biosolids. In: *Sewage Sludge: Land Utilization and the Environment*, Clapp, C.E. (Ed.). American Society of Agronomy, Madison, Wisconsin, ISBN: 9780891188131, pp: 27-31.
11. Darnley, A.G., A. Bjorklung, B. Bolviken, N. Gustavsson and P.V. Koval *et al.*, 1995. A Global Geochemical Database for Environmental and Resource Management: Recommendations for International Geochemical Mapping: Final Report of IGCP Project 259. UNESCO Publishing, Paris, ISBN: 9789231030857, Pages: 122.
12. Suh, C.E., B. Lehmann and G.T. Mafany, 2006. Geology and geochemical aspects of lode gold mineralization at Dimako-Mboscorro, SE Cameroon. *Geochem.: Explor. Environ. Anal.*, 6: 295-309.
13. Toteu, S.F., R.Y. Fouateu, J. Penaye, J. Tchakounte and A.C.S. Mouangue *et al.*, 2006. U-Pb dating of plutonic rocks involved in the nappe tectonic in southern Cameroon: Consequence for the Pan-African orogenic evolution of the central African fold belt. *J. Afr. Earth Sci.*, 44: 479-493.
14. Omang, B.O., C.V. Bih, A.N. Fon, V. Embui and C.E. Suh, 2014. Regional geochemical stream sediment survey for gold exploration in the upper Lom Basin, eastern Cameroon. *Int. J. Geosci.*, 5: 1012-1026.
15. Jung, M.C. and I. Thornton, 1996. Heavy metal contamination of soils and plants in the vicinity of a lead-zinc mine, Korea. *Applied Geochem.*, 11: 53-59.
16. Wang, H.H., L.Q. Li, X.M. Wu and G.X. Pan, 2006. Distribution of Cu and Pb in particle size fractions of urban soils from different city zones of Nanjing, China. *J. Environ. Sci. (China)*, 18: 482-487.
17. ECOMED Eastern Europe, 2012. Contaminated soil remediation. <http://www.ecomed-intl.com/contaminated-soil-remediation.html>

18. Li, Q., H. Ji, F. Qin, L. Tang, X. Guo and J. Feng, 2014. Sources and the distribution of heavy metals in the particle size of soil polluted by gold mining upstream of Miyun Reservoir, Beijing: Implications for assessing the potential risks. *Environ. Monit. Assess.*, 186: 6605-6626.
19. Lech, M. and P. de Caritat, 2007. Protocol for sampling in regional geochemical surveys: Lessons from pilot projects. *Geoscience Australia, CRC Leme Open File Report No. 229*, November 2007.
20. Ander, E.L., C.C. Johnson, M.R. Cave, B. Palumbo-Roe, C.P. Nathanail and R.M. Lark, 2013. Methodology for the determination of normal background concentrations of contaminants in English soil. *Sci. Total Environ.*, 454-455: 604-618.
21. Turekian, K.K. and K.H. Wedepohl, 1961. Distribution of the elements in some major units of the earth's crust. *Geol. Soc. Am. Bull.*, 72: 175-192.
22. CCME., 2007. Canadian soil quality guidelines for the protection of environment and human health. *Canadian Council of Ministers of the Environment (CCME)*, September 2007.
23. Mediolla, L.L., M.C.D. Domingues and M.G. Sandoval, 2008. Environmental assessment of an active tailings pile in the State of Mexico (Central Mexico). *Res. J. Environ. Sci.*, 2: 197-208.
24. Sutherland, R.A., 2000. Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. *Environ. Geol.*, 39: 611-627.
25. Tomlinson, D.L., J.G. Wilson, C.R. Harris and D.W. Jeffrey, 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgolander Meeresunters*, 33: 566-575.
26. Muller, G., 1969. Index of geoaccumulation in sediments of the Rhine river. *J. Geol.*, 2: 108-118.
27. Tukey, J.W., 1977. *Exploratory Data Analysis*. Addison-Wesley Publishing Co., Reading, MA., USA., ISBN-13: 9780201076165, Pages: 688.
28. Harris, J.R., L. Wilkinson and M. Bernier, 2001. Analysis of Geochemical Data for Mineral Exploration using a GIS-A Case Study from the Swayze Greenstone Belt, Northern Ontario, Canada. In: *Drift Exploration in Glaciated Terrain*, McClenaghan, M.B., P.T. Bobrowsky, G.E.M. Hall and S.J. Cook (Eds.). Geological Society of London, USA., ISBN: 9781862390829, pp: 165-200.
29. Vishiti, A., C.E. Suh, B. Lehmann, J.A. Egbe and E.M. Shemang, 2015. Gold grade variation and particle microchemistry in exploration pits of the Batouri gold district, SE Cameroon. *J. Afr. Earth Sci.*, 111: 1-13.
30. Adeyi, A.A. and N. Torto, 2014. Profiling heavy metal distribution and contamination in soil of old power generation station in Lagos, Nigeria. *Am. J. Sci. Technol.*, 1: 1-10.
31. Acevedo-Figueroa, D., B.D. Jimenez and C.J. Rodriguez-Sierra, 2006. Trace metals in sediments of two estuarine lagoons from Puerto Rico. *Environ. Pollut.*, 141: 336-342.
32. Chen, C.W., C.M. Kao, C.F. Chen and C.D. Dong, 2007. Distribution and accumulation of heavy metals in the sediments of Kaohsiung Harbor, Taiwan. *Chemosphere*, 66: 1431-1440.
33. Brochin, R., S. Leone, D. Phillips, N. Shepard, D. Zisa and A. Angerio, 2008. The cellular effect of lead poisoning and its clinical picture. *Georgetown Univ. J. Health Sci.*, 5: 1-8.
34. ATSDR., 2012. Toxicological profile for chromium. Agency for Toxic Substances and Disease Registry (ATSDR), September 2012, Atlanta, USA. <https://www.atsdr.cdc.gov/toxprofiles/tp7.pdf>
35. Eastmond, D.A., J.T. MacGregor and R.S. Slesinski, 2008. Trivalent chromium: Assessing the genotoxic risk of an essential trace element and widely used human and animal nutritional supplement. *Crit. Rev. Toxicol.*, 38: 173-190.
36. Singh, H.P., P. Mahajan, S. Kaur, D.R. Batish and R.K. Kohli, 2013. Chromium toxicity and tolerance in plants. *Environ. Chem. Lett.*, 11: 229-254.
37. CDCP., 2015. Lead. Centre for Disease Control and Prevention (CDCP). Atlanta, Georgia, USA. <http://www.cdc.gov/nceh/lead/>
38. Sharma, P. and R.S. Dubey, 2005. Lead toxicity in plants. *Braz. J. Plant Physiol.*, 17: 35-52.
39. Abhilash, K.P.P., J.J. Arul and D. Bala, 2013. Fatal overdose of iron tablets in adults. *Indian J. Crit. Care Med.*, 17: 311-313.
40. Bodek, I., W.J. Lyman, W.F. Reehl and D.H. Rosenblatt, 1988. *Environmental Inorganic Chemistry: Properties, Processes and Estimation Methods*. Pergamon Press, New York, ISBN: 9780080368337, Pages: 1280.
41. Chanarin, I., 1999. Nutritional Aspects of Hematological Disorders. In: *Modern Nutrition in Health and Disease*, Shils, M.E., J.A. Olson, M. Shike and A.C. Ross (Eds.). Williams and Wilkins, Baltimore, pp: 1419-1436.
42. Fraga, C.G. and P.I. Oteiza, 2002. Iron toxicity and antioxidant nutrients. *Toxicology*, 180: 23-32.
43. Fraga, C.G., 2005. Relevance, essentiality and toxicity of trace elements in human health. *Mol. Aspects Med.*, 26: 235-244.
44. Michibata, H., 2011. *Vanadium: Biochemical and Molecular Biology Approaches*. Springer Science and Business Media, Dordrecht, Netherlands, ISBN: 9789400709133, Pages: 228.
45. Powers, J.M. and G.R. Buchanan, 2014. Iron deficiency anaemia in toddlers to teens: How to manage when prevention fails. <http://contemporarypediatrics.modernmedicine.com/contemporary-pediatrics/content/tags/american-academy-pediatrics/iron-deficiency-anemia-toddlers-tee?page=full>
46. Wilson, L., 2015. Chronic acquired iron overload-A disease of civilisation. The Centre for Development, November 2015.

47. ATSDR, 2012. Toxicological profile for vanadium. Agency for Toxic Substances and Disease Registry (ATSDR), U.S. Department of Health and Human Services, Atlanta, GA.
48. Srivastava, A.K. and J.L. Chiasson, 1995. Vanadium Compounds: Biochemical and Therapeutic Applications. Kluwer Academic Publishers, Netherlands, Pages: 244.
49. WHO. and IPCS., 1992. Environmental health criteria document 134: Cadmium. World Health Organization (WHO), International Programme on Chemical Safety (IPCS), Geneva.
50. McLaughlin, M.J. and B.R. Singh, 1999. Cadmium in Soils and Plants: Summary and Research Perspectives. In: Cadmium in Soils and Plants, McLaughlin, M.J. and B.R. Singh (Eds.). Vol. 85, Chapter 10, Springer, New York, pp: 257-267.
51. Ciobanu, C., B.G. Slencu and R. Cuciureanu, 2011. Estimation of dietary intake of cadmium and lead through food consumption. *Revista Medico-Chirurgicala a Societatii de Medici si Naturalisti din Iasi*, 116: 617-623.