Research Article

Trace Element Soil Quality Status of Mt. Cameroon Soils

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The concentrations of Cu, Co, Zn, Ni, V, and Cr in topsoils at six sites located along the lower slopes of Mt. Cameroon were assessed for their potential toxicity to humans and the ecosystem. Soils were collected from horizons down to a depth of 70 cm and analysed for trace element concentration by ICP-MS technique. The Dutch soil quality standards which use %clay/silt and organic matter content to derive target values were used to assess the contamination levels of the soils. The content of these soils was also compared to the United Kingdom ICRL “soil trigger” values. Zinc and Cu values were persistently below the normal value (A) and occurred in the lower elevation, the region of extreme weathering, while Cr and V values were above the intervention (C) values. The high content of Cr in common fertilisers poses a potential risk in toxicity in the higher elevations experiencing lower weathering rates, where soil Cr levels are elevated.

1. Introduction

Many trace elements are essential macro- and micronutrients for humans, plant growth, and the maintenance of healthy ecosystems. Micronutrients like Cu, Mn, Se, and Zn can be toxic at high concentrations in the soil. Trace elements unknown to be essential to plant growth, such as barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), and nickel (Ni), are toxic at high concentrations or under certain environmental conditions in soils. One of the major factors controlling soil trace element content is the parent rock material. Soils vary across landscapes and rock weathering and other soil-forming processes may result in the addition or removal of these elements from the soil. High background concentrations of trace elements, whether from natural or anthropogenic sources, could result in mobilization and release into surface and subsurface waters and subsequently incorporation into the food chain. Soil factors such as organic matter, type and amount of clay, pH, and cation exchange capacity (CEC) influence the quantity of trace elements available for mobilization and release or sorption in a soil [1].

Regulations to protect humans and the environment from toxicities and deficiencies related to trace elements are primarily based on soil quality reference values which are

being developed in many countries. Many countries that have not developed their own formal guidelines follow the “Dutch standard” to support decision-making in assessing and monitoring soil quality. The Dutch are improving their soil quality in light of new scientific work particularly with regard to the impact of listed substances on living species and ecosystems [2]. Two values are particularly important in decision-making in regulating trace metals in soils. These are the target value (the A-value, the normal or natural level) and the intervention value (the C-value the clean-up level) [3]. Cameroon has not started working on soil standards; consequently, any level of information that can serve as indicators remains of immense importance in the fertile areas of Mt. Cameroon for reasons such as (i) identification of particular elements for further research on TE (trace elements) and health and (ii) identification of target soils (spatial) for further studies. The present study examines the potential risks associated with selected trace elements in the Mt. Cameroon region. The bulk concentration of selected trace metals (Cu, Co, Cr, Ni, Zn, and Pb) in surface soils in Mt. Cameroon is compared with world averages, ICRL (UK) “trigger” values for open space, and the Dutch standard for assessing soil contamination.

FIGURE 1: Map of Mt. Cameroon region showing the various sampling sites, elevation, and isohyets [23].

2. Materials and Methods

2.1. Study Area. The study area lies on the lower slopes of the south-southeastern flank of Mt. Cameroon volcano, which is located within latitudes 4°00'–4°13' N and longitudes 9°00'–9°30' E (Figure 1). Mt. Cameroon belongs to

the Cameroon volcanic line (CVL), an intraplate volcanic alignment extending from the Gulf of Guinea into the African continent. The flanks of the volcano are dominated by cones, some of which are breached due to lava effusion. The plain located to the east of the volcano consists of post-Cretaceous sediments and Quaternary alluvium (Figure 1). The climate

of the SSE slopes of Mt. Cameroon is humid tropical one, characterized by a pronounced dry season (mid-November to March) and wet season (mid-March to November) [4]. The combination of high relief (4095 m) and proximity of the sea leads to strong local climatic contrasts. Mean annual temperatures decrease from 26 to 29°C at sea level to 0°C at the top of the edifice, and this large temperature drop is associated with a decrease in rainfall. Extremely high rainfall is recorded on the southwestern flank where it can reach 12,000 mm/year. Lower rainfall occurs on the southeastern flank because it is partially sheltered from oceanic influence (e.g., 1800 mm/year at Ekona).

Mt. Cameroon soils are formed from lavas, pyroclastic flows, and lahars transported as mudflows from the top of the volcano. Several authors (e.g., Fitton et al. [5] and Suh et al. [6]) report the bulk-rock composition of the rocks of Mt. Cameroon to fall within the TAS (total alkalis versus silica) field of basalt, basanite-trachybasalt, phonotephrite, and basaltic trachyandesite. These studies also report that Mt. Cameroon magmas are of intraplate-type, with characteristically high concentrations of the high-field-strength elements Ti, Nb, and Ta [6]. The primary minerals are mainly plagioclase (dominance of anorthite over albite) and ferromagnesian minerals (pyroxene (mainly augite), olivine, and iddingsite).

The present study extends our previous work on the behaviour of elements during rock weathering in six soil profiles located at different elevations along the SSE slopes of Mt. Cameroon [7]. These soil profiles are found at elevations of 1017 m at Buea (BUA), 944 m at Borstal (BOR), 458 m at Ekona (EKA), 298 m at Mutengene (MUT), 84 m at Limbe (LBE), and 30 m at Bakingili (BAK). At these elevations, the environmental factors are judged to be different with MAP values decreasing with elevations from >8,000 to 3,000 mm. These soil profiles were developed from the alteration of pyroclastic deposits in the deepest units of the profiles.

2.2. Soil Sampling and Analysis. Top soils developed on basaltic rocks representing different stages of soil development were sampled from six sites including Buea town, Mutengene, Limbe, Ekona, Bakingili, and Borstal denoted as BUA, MUT, LBE, EKA, BAK, and BOR, respectively, throughout the text. A total of eleven disturbed soil samples were collected from the soil horizons up to a depth of 70 cm. The samples were air-dried for over 12 hrs and stored in plastic bags. Roots and litter were removed and samples lightly crushed with fingers and in a ceramic mortar and pestle to loosen soil aggregates. Samples were then weighed and adequately mixed, quartered, and stored in plastic bags in plastic sample boxes. All samples were air-dried and sieved through a 2 mm sieve and routine analysis was run on the fine fraction.

Eleven processed soil samples (including two duplicates) of about 15 mg (<2 mm fraction) were shipped to Acme Laboratory, Ontario, Canada, for routine geochemical analysis of trace elements: Cu, Co, Cr, Ni, Zn, Pb, and V. An aliquot of each horizon was analyzed by inductively coupled plasma atomic emission spectrometry (ICP-AES) following

a lithium metaborate/tetraborate fusion acid digestion which ensured that the entire sample was dissolved, thus making it possible to solubilize the trace and major oxides including SiO₂. Total carbon (analysed by Acme Laboratory, Canada) was determined by infrared adsorption using Leco CS200 after igniting at >1650°C. The results are attributed to the mineralisation of organic matter since the parent material does not contain carbonate minerals. Organic matter was calculated as % organic matter = 1.7 × % organic carbon. All eleven processed soil samples (<2 mm fraction) were sent to the Soil Laboratory, University of Dschang, Cameroon, for physicochemical analysis. Particle-size distribution was determined by dry sieving and the pipette method. After shaking with a dispersing agent, sand was fractionated by dry sieving and the clay and silt fractions were fractionated by the pipette method [8]. Measurements of pH were made in water and in 1 M KCl in a 1:2.5 soil:water suspension. Cation exchange capacity (CEC) was determined using the ammonium acetate method [8].

2.3. Calculations. There is no uniform procedure for setting contamination thresholds for heavy metals in soils. This complexity arises from several factors; that is, different metal origins and different metal species will not be equally mobile or bioavailable and the intended use of the site may require different levels of concentration. Adsorption of metals is generally acknowledged to be directly proportional to soil pH and this has been observed for various adsorbing soil components and differing soil types [9]. Threshold concentrations are generally given for specific conditions, commonly pH.

In the United Kingdom, the Interdepartmental Committee on the Redevelopment of Contaminated Land [10] trigger concentrations of metals in contaminated soils have been the guide to acceptable threshold levels for those posing a hazard to human health, such as As, Cd, Cr, Pb, Hg, and Se, and those that may be phytotoxic but are not normally hazardous to humans, such as B, Cu, Ni, and Zn [10].

The Dutch standard for soil contamination is based on two values which are particularly important in making decisions on the regulation of heavy metals in soils. These are the target value (the A-value, the normal or natural level) and the intervention value (the C-value, the clean-up level) [3]. Soil assessment for the derivation of these values considers two major soil parameters, %clay/silt and organic matter content.

3. Results and Discussion

Results of soil physical properties and trace element concentration are shown in Table 1. BAK has the highest content of organic matter followed by BOR. The soils are generally acidic with BOR being the most acidic with a pH of ~3.88. EKA the most weathered soil [7] has the highest clay content followed by BUA. Trace element concentration is ranked as follows: Cr > V > Zn > Cu > Co > Ni > Pb. The high concentrations of Cr and V can be attributed to the basaltic composition of the parent rock. Sato et al. [11] and Che et al. [12] measured high Ni, Cr, and V concentrations in some picritic rocks samples

TABLE 1: Physicochemical and trace element concentration of soils in the study area.

Site	Depth cm	O.M %	pH	CEC	Sand	Silt %	Clay	Cu	Co	Cr	Ni ppm	Zn	Pb	V
MUT	0-29	4.7	5.62	18.9	14	53	33	57.8	102	400	46.5	156.9	39	654
	29-76	2.05	5.15	17.9	13	46	41	46.2	51.6	200	39.4	101.7	18	584
BUA	0-33	5.19	5.58	20.6	5	51	44	142.1	109	700	106	160.1	13	561
	33-186	1.29	5.74	21.2	5	38	57	94.8	97.3	800	114	95.9	8.1	459
LBE	0-20	1.36	5.42	31	5	74	21	68	59.1	100	43.1	129.9	8.6	435
	20-70	0.16	5.2	22.6	19	56	25	63.9	51.3	100	48.3	136.9	6.1	477
EKA	0-170	2.36	4.93	16.2	5	35	60	68.1	98.5	600	48.3	90.2	9.9	530
BAK	0-10	14.7	5.12	38.5	3	70	27	145.3	94.9	800	177	178.3	19	487
	10-70	3.5	6.12	22.6	2	68	30	151.4	123	1100	192	170	16	633
BOR	0-21	6.23	3.88	20.4	32	56	12	136.5	67.7	200	83.6	151.1	15	418
	21-77	7.91	3.98	20.3	26	55	19	138.9	76.7	300	88.2	168.5	17	458

TABLE 2: Trace metal concentration in Mt. Cameroon soils compared to mean values for soils worldwide, ICRCL (UK) soil “trigger” concentrations (ppm).

Element	Av. soil conc. ^a	ICRCL (UK) soil “trigger” ^b	Soil conc. Mt. Cameroon ^c
Cu	24	50	46–145
Co	30	Na	67–101
Cr	67	1000	100–800
Ni	24	70	39–203
Zn	67	300	68–178
Pb	29	2000	5.3–39
V	100	—	418–654

(i) ^aKabata-Pendias and Pendias [24].(ii) ^bInterdepartmental Committee on the Redevelopment of Contaminated Land [10].(iii) ^cSurface soil concentration.

from the Mt. Cameroon region. Basalts are enriched in Fe-family elements (i.e., Ti, V, Co, and Ni), which are conserved during soil formation due to the preferential loss of more mobile major elements. Zhang et al. [13] observed an increase of Ti, V, and Cr with soil age, which in this case can be inferred from the weathering intensity, particularly in the most weathered profiles EKA and BUA. Che et al. [12] made similar observations for V and Cr in this area. The influence of weathering in the distribution of the Fe-family elements (Co, Cu, Cr, and Ni) is evident in BUA and BAK profiles. In the former, enrichment is associated with secondary mineral formation and the removal of more mobile elements while predominantly organic matter sequestration may account for the latter. The lower concentrations of these elements in the most weathered soil profiles, EKA and BUA, could explain leaching under excessive weathering [7]. In the low to moderately weathered profiles, MUT and LBE, these elements could be distributed predominantly in primary (particularly BOR) and secondary mineral phases or they may have been mobilised out of the soils due to the higher leaching conditions that exist in the lower altitudes. Zinc on the other hand is higher in the moderately weathered soils, MUT and LBE. The concentration of trace elements is compared worldwide and to ICRCL (UK) trigger values in Table 2.

Cobalt concentration varies from ~40 to 135 ppm. BAK, BUA, and BOR have the highest values. Cobalt concentrations for the topsoil samples are well below the intervention values and above the target values (Table 3). The geochemical behaviour of cobalt generally follows that of the iron-manganese system and its concentration in sediment and soil systems is mainly controlled by adsorption and coprecipitation reactions with manganese and iron oxide minerals [14].

Copper concentration in the soils varies between 46 and 145 ppm. Compared to the ICRCL (UK) values (Table 2), some soils are above the trigger values. The results show the highest concentrations in BAK, BOR, and BUA which are likely in the form of Cu(II) and are bounded to fulvic acids [15]. Temminghoff et al. [16] reported that, at pH 6.6, >99% of Cu in soil solution was predicted by models to be bound to dissolved organic matter, decreasing to 30% at pH 3.9. In this study, soil pH values were as low as 3.89, implying acidic

conditions which according to such predictive models could enhance the release of Cu ions from organic complexing chelates. Copper concentrations are below the intervention values indicating that these soils are not contaminated. However, some soils are below the target values (MUT and EKA) required for their proper functioning.

Zinc concentrations vary from about 68 to 178 ppm. The highest concentrations are found at MUT, LBE, BAK, and BOR. Zn is likely associated with organic matter and Mn-Fe oxides. The concentration of Zn is below the ICRCL threshold value (Table 2). BUA and EKA soils show concentration values below the target values which are required for the proper functioning of soils (Table 3). Zinc is an essential plant nutrient especially for maize [17]. Zinc together with Cu is important in the production of animal feed because of their multifunctional role in the metabolism of animals [18]. Zinc deficiency is known to occur in the same soils where there is the greatest risk of Cu deficiency [17]. This condition is found in the EKA soils.

Chromium concentration varies from 800 to 100 ppm with an average of 400 ppm. Cr content is below the ICRCL trigger value. In BUA and BAK Cr content exceeds intervention values, inferring the possibility of contamination (Table 3). Although Cr is an essential micronutrient for animals, its role in plants has not been established. The chemical speciation of trace elements in the rhizosphere profoundly affects their solubility, mobility, and toxicity. In soils, Cr that is present in the +6 oxidation state (Cr(VI)) is more mobile, more readily bioaccumulated, and 100 to 1000 times more toxic when present in the +3 oxidation state (Cr(III)) [19]. Nickel concentration varies from 39 to 203 ppm. The highest concentrations are found in BUA and BAK. Compared to the ICRCL threshold, soils in BUA, BAK, and BOR can be potentially polluted. The concentrations of Ni in all the surface soils are well below the intervention values (Table 3), indicating the absence of contamination. With reference to the target values, EKA contents are below those required for proper soil functioning. Nickel is an essential micronutrient and has been shown to influence seed germination. The results show that Ni is comparatively highly mobile when compared to, for instance, Zn and Cu. This therefore can be of a higher risk to contamination of water resources.

TABLE 3: Target, intervention values, and concentrations in soils of metals. Target and intervention values for soils are expressed as the concentration in a standard soil (10% organic matter and 25% clay), Ministry of Housing, The Netherlands [3].

Site	Depth	Co			Cu			Zn			Ni			V			Cr		
		A	C	Mt. Cam.	A	C	Mt. Cam.	A	C	Mt. Cam.	A	C	Mt. Cam.	A	C	Mt. Cam.	A	C	Mt. Cam.
MUT	0-29	11	359	102	90	477	58	156	803	157	43	258	46	52	307	654	116	441	400
	29-76	13	382	52	98	517	46	176	906	102	51	306	39	61	364	584	132	502	200
BUA	0-33	14	479	108	107	564	142	190	976	160	54	324	106	65	386	561	138	524	700
	33-186	18	210	97	120	633	95	223	1147	96	67	402	114	80	479	459	164	623	800
LBE	0-20	8	240	59	68	360	68	115	592	130	31	186	43	37	221	435	92	350	100
	20-70	9	501	51	72	381	64	125	644	137	35	210	48	42	250	477	100	380	100
EKA	0-170	19	262	99	126	664	68	234	1201	90	70	420	48	84	500	530	170	646	600
	0-10	10	277	95	97	515	145	156	803	178	38	228	177	46	271	487	106	403	800
BAK	10-70	10	143	123	84	445	151	145	747	170	40	240	192	48	286	633	110	418	1100
	0-21	5	195	68	62	329	136	95	490	151	22	132	84	26	157	418	74	281	200
BOR	21-77	7	53	77	75	395	139	119	611	169	29	174	88	35	207	458	88	334	300

Notes:

A = target values: normal or natural levels;

C = intervention values: clean-up level.

TABLE 4: Heavy metal concentration (mg kg^{-1}) in common fertilizer constituents concentration [25].

Element	Phosphate	Potassium	Farmyard
Cd	9–30	7–15	0.3–1.8
Cr (T)	1000	1000	12
Ni	300	80	17
Zn	5–1450	—	15–250

Lead concentration varies from 5.3 to 39 ppm. Lead accumulations arising from atmospheric deposition are highest in MUT, BAK, and BOR. Lead in these profiles is principally associated with organic matter. Present lead values in all profiles are exceedingly below those of the threshold. Atmospheric deposition of Pb linked to inputs from Saharan dust in this region at rates of up to 8% has been reported by Dia et al. [20]. In EKA it is possible that atmospheric Pb is mobilized as Pb-P. Vanadium in these soils exhibits very low mobility and as a consequence shows very high concentration in soils. The contents are consistently above the intervention values (Table 3). V is described as a new essential trace micronutrient in animal nutrition by Poulsen [21].

Intensive agricultural usage of these soils, for example, for plantation (palm, banana, and tea) and food cropping, requires large inputs of pesticides, fertilizers (N, P, and K), and micronutrients. These practices also provide another potential source of trace element contamination, that is, from impurities in commercial fertilisers. Fergusson [22] considers that the primary sources of Cd, Pb, and As that may contaminate soils are phosphate fertilisers. Table 4 shows heavy metal concentrations in some common fertiliser constituents. Considering that the Cr content is already high, the application of inputs with high Cr content can potentially contaminate the soil. Chromium is easily absorbed from the soil by corn, a crop that is intensively cultivated in this area of Cameroon, which means that our food supply is at risk of contamination if high Cr-inputs are used.

4. Conclusion

The concentrations of these elements in soils generally reflect those of the parent material, with the exception of Pb. Distribution of the latter is associated with anthropogenic activities particularly traffic. Potential soil deficiency is associated with highly mobile elements, that is, Zn and Ni, and is displayed in the most weathered soil, EKA. Cu deficiency is associated with soils under extreme leaching conditions, that is, MUT and LBE, located in the lower elevations with higher rainfall. Cr and V contents display some levels of contamination. The high content of Cr in common fertilisers may pose a potential risk in toxicity in the higher elevations where soil Cr levels are elevated.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

- [1] A. Slagle, J. Skousen, D. Bhumbra, J. Sencindiver, and L. McDonald, "Trace element concentrations of three soils in central appalachia," *Soil Survey Horizons*, vol. 45, no. 3, pp. 73–85, 2004.
- [2] P. R. J. Danneman and J. G. Robberse, "Ecotoxicological risks assessment as a base for development of soil quality criteria," in *Contaminated Soil '90*, F. Arendt, H. Hinsinfelt, and W. J. van den Brink, Eds., pp. 157–164, Kluwer Academic Publisher, Dordrecht, The Netherlands, 1990.
- [3] Ministry of Housing Netherland, "Physical planning and environmental conservation," Report HSE 94.021, 1994.
- [4] G. W. van Barneveld, "Agroclimatic conditions of West Africa and Cameroon," in *Proceedings of the 3rd International Forum on Soil Taxonomy and Agro-Technology Transfer*, H. Ikawa and G. Y. Tsuji, Eds., Benchmark Soils Project Technical Report 10, pp. 121–133, University of Hawaii, 1987.
- [5] J. G. Fitton, C. R. J. Kilburn, M. F. Thirlwall, and D. J. Hughes, "1982 eruption of Mount Cameroon, West Africa," *Nature*, vol. 306, no. 5941, pp. 327–332, 1983.
- [6] C. E. Suh, R. S. J. Sparks, J. G. Fitton et al., "The 1999 and 2000 eruptions of Mount Cameroon: eruption behaviour and petrochemistry of lava," *Bulletin of Volcanology*, vol. 65, no. 4, pp. 267–281, 2003.
- [7] V. E. Manga, C. E. Suh, C. M. Agyingi, and E. M. Shemang, "Mineralogy and geochemistry of soils developed along the slopes of Mt. Cameroon, West Africa," *Journal of African Earth Sciences*, vol. 81, pp. 82–93, 2013.
- [8] USDA-NRCS, "Soil survey laboratory methods manual," Soil Survey Investigations Report 42, Version 3.0. USDA-NRCS-National Soil Survey Centre, Washington, DC, USA, 1996.
- [9] B. J. Alloway, I. Thornton, G. A. Smart, J. C. Sherlock, and M. J. Quinn, "Metal availability," *Science of the Total Environment*, vol. 75, no. 1, pp. 41–69, 1988.
- [10] Interdepartmental Committee on the Redevelopment of Contaminated Land, *ICRCL 59/83 Guidance on the Assessment and Redevelopment of Contaminated Land*, Code EPTSSP187-5RH3, CEDP/EPTS, Romney House, London, UK, 2nd edition, 1987.
- [11] H. Sato, S. Aramaki, M. Kusakabe et al., "Geochemical difference of basalts between polygenetic and monogenetic volcanoes in the central part of the Cameroon volcanic line," *Geochemical Journal*, vol. 24, no. 6, pp. 357–370, 1990.
- [12] V. B. Che, K. Fontijn, G. G. J. Ernst et al., "Evaluating the degree of weathering in landslide-prone soils in the humid tropics: the case of Limbe, SW Cameroon," *Geoderma*, vol. 170, pp. 378–389, 2012.
- [13] G.-L. Zhang, J.-H. Pan, C.-M. Huang, and Z.-T. Gong, "Geochemical features of a soil chronosequence developed on basalt in Hainan Island, China," *Revista Mexicana de Ciencias Geológicas*, vol. 24, no. 2, pp. 261–269, 2007.

- [14] J. D. Hem, C. E. Roberson, and C. J. Lind, "Study and interpretation of the chemical characteristics of natural water," U.S. Geological Survey Water Supply Paper 2254, US Geological Survey, Alexandria, Va, USA, 1985.
- [15] G. Sposito, *The Chemistry of Soils*, Oxford University Press, USA, 1989.
- [16] E. J. M. Temminghoff, S. E. A. T. M. van der Zee, and F. A. M. de Haan, "Copper mobility in a copper-contaminated sandy soil as affected by pH and solid and dissolved organic matter," *Environmental Science and Technology*, vol. 31, no. 4, pp. 1109–1115, 1997.
- [17] L. Knudsen, "Status of micronutrient demand of Danish crops," in *Essential Trace Elements for Plants, Animals and Humans*, G. Thorvaldsson and R. S. Jónsdóttir, Eds., NFJ Seminar no. 370, Reykjavík, Iceland, August 2005.
- [18] M. Korhonen, M. Rinne, and P. Huhtanen, "Effects of soil characteristics and fertiliser application on grass yield and chemical composition including mineral and trace element content—farm scale studies in Finland 1995–2004," in *Essential Trace Elements for Plants, Animals and Humans*, G. Thorvaldsson and R. S. Jónsdóttir, Eds., NFJ Seminar no. 370, Reykjavík, Iceland, August 2005.
- [19] F.-Y. Wu, W.-Y. Wu, H.-W. Kuo, C.-S. Liu, R.-Y. Wang, and J.-S. Lai, "Effect of genotoxic exposure to chromium among electroplating workers in Taiwan," *Science of the Total Environment*, vol. 279, no. 1–3, pp. 21–28, 2001.
- [20] A. Dia, C. Chauvel, M. Bulourde, and M. Gérard, "Eolian contribution to soils on Mount Cameroon: isotopic and trace element records," *Chemical Geology*, vol. 226, no. 3–4, pp. 232–252, 2006.
- [21] H. D. Poulsen, "Trace elements in animal nutrition," in *Essential Trace Elements for Plants, Animals and Humans*, G. Thorvaldsson and R. S. Jónsdóttir, Eds., NFJ Seminar no. 370, Agricultural University of Iceland, Reykjavík, Iceland, 2005.
- [22] J. E. Fergusson, *The Heavy Elements: Chemistry, Environmental Impacts and Health Effects*, Pergamon Press, New York, NY, USA, 1990.
- [23] M. F. Benedetti, A. Dia, J. Riotte et al., "Chemical weathering of basaltic lava flows undergoing extreme climatic conditions: the water geochemistry record," *Chemical Geology*, vol. 201, no. 1–2, pp. 1–17, 2003.
- [24] A. Kabata-Pendias and H. Pendias, *Trace Elements in Soils and Plants*, CRC Press, Boca Raton, Fla, USA, 3rd edition, 2001.
- [25] B. Alloway, Ed., *Heavy Metals in Soils*, Blackie Academic and Professional, Chapman and Hall, London, UK, 1995.