International Journal of Scientific Research and Management (IJSRM)
||Volume||12||Issue||12||Pages||1838-1844||2024||
Website: https://ijsrm.net ISSN (e): 2321-3418
DOI: 10.18535/ijsrm/v12i12.ec07

Analysis of the Degree of Soil Contamination by Metallic Trace Elements Used During the Establishment of an Industrial Company in the Fields of Electricity, Electronics, and Automotive Mechanics: Study of the Kachoma District in the City of Kipushi/Haut-Katanga (DR Congo)

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Abstract
The objective of this research was to assess the level of soil pollution in the Kachoma district located around the former discharge basin (dike 1) of the Générale desquarries et des mines/Kipushi (Gécamines/Kipushi). The samples were taken from two sites (OUA 1 and the cell five years) using a manual auger at a depth of 20 cm to 40 cm and packaged in a plastic bag before being analyzed in the laboratory. The Cu, Co, Ni, Pb, and Zn content was determined by an Inductively Coupled Plasma (ICP) spectrometer. The results showed that the soils sampled in the two cells were largely polluted by Cu, Zn, Pb, Mn, and Co. It is, therefore, imperative to see how to remedy the soil pollution of the Kachoma district.

Keywords: Kachoma, Metallic trace elements, Pollution Index, Soil

1. Introduction

Soil is a living space for humans, animals, plants, and microorganisms. It accumulates and makes available to them most of the elements essential to life (air, water, nutrients, etc.) [1]. In addition to its food function, soil can also be an effective environmental filter by purifying the water that passes through it of various pollutants that can contaminatethefoodchainandgroundwater[2]. However, human and industrial activities can significantly alter the quality of the soil and, therefore, have adverse effects on humans, animals, plants, and microorganisms [3].

When metallic trace elements are toxic, they destroy aquatic biotopes and can be metabolized throughout the food chain and, therefore, present risks to the health of local populations [4].

We report that in the Democratic Republic of Congo, uncontrolled mining often results in the pollution of soils and certain waterways [5]. Very often, industrial mining discharges and the fallout from atmospheric discharges are the main sources of contamination of metallic trace elements in the vast expanses of the soils of the Katangese copper arc (DR Congo) [6]. Hence the importance of carrying out the physico-chemical characterization of the soil in order to determine the level of pollution in metallic elements. The physico-chemical characterization of the soil,therefore,makesitpossibletodeterminethequalityof this soil from its pH, its porosity, its density, its humidity, and its chemical composition [7].

This study assesses the degree of soil pollution in the Kachoma district in the city of Kipushi, in the south-east of the Democratic Republic of Congo.

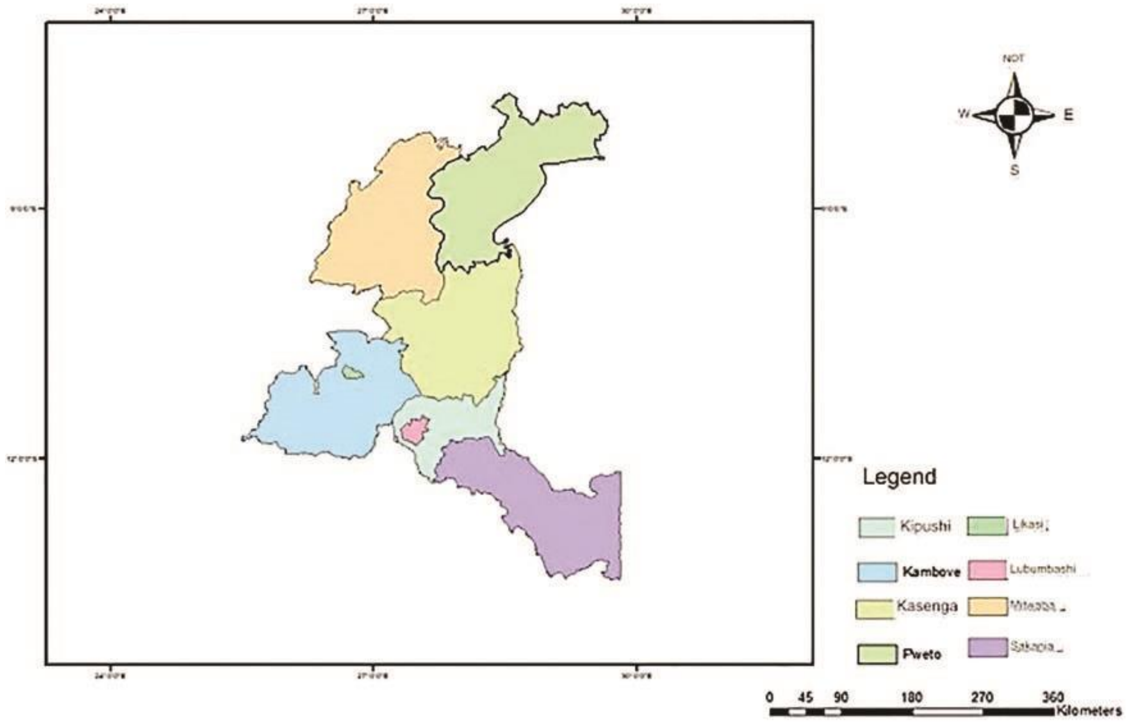

Fig. 1. Geographical map of the regions of the province of Haut-Katanga.

2. Materials and Methods

2.1. Study Area

Our investigations were carried out in the Kachoma district located in the city of Kipushi. The territory of Kipushi is located in the southwest of the former Province of Katanga in the Democratic Republic of Congo (Fig. 1). It is made up of several small villages and centered on the mining and border town of Kipushi. The territory covers two chiefdoms and one sector (the chiefdoms of Kaponda and Kinama, and the sector of Bukanda). In terms of geographical coordinates, the territory of Kipushi is located at 28° 10 E longitude, 12° 30 S latitude.

2.2. Materials and Methodology

To assess the level of pollution in the Kachoma district of the city of Kipushi, we used a set of materials to take and analyze soil samples.

The samples were taken from the sides of the roads (Fig. 2). Given the direction of the wind from the former Gécamines/Kipushi discharge basin (dyke 1), we took two samples in the OUA one cell and three in the cell five years. We used a mobile GPS for the geolocation of manual augers for taking samples, plastic packaging, and a notepad.

The samples taken were analyzed at the Chemistry laboratory of the Congolese Control Office of Lubumbashi (OCC/Lubumbashi). The heavy metals were analyzed by an analytical technique with inductively coupled plasma (Inductively Coupled Plasma or ICP), and the other parameters, such as (pH and the rate of humidity) analyzes were carried out in the analytical chemistry laboratory at the faculty Polytechnique of the University of Lubumbashi, for this we used some materials such as; a pH meter, beakers, an oven, and a desiccator.

2.3. Analysis of Meteorological Data

The dispersion of pollutants depends on weather conditions. This dispersion takes place essentially in the compartments of the environment. The meteorological factors that intervene either directly or indirectly in the transport and dispersion of pollutants are temperature, precipitation, and humidity [8]. These parameters influence the presence of pollutants in a soil [9]. The climate of Kipushi is Cwa6 in the Köppen climate classification: warm temperate with dry winters and hot summers. The averageannualtemperatureis20°C,withminimumsof8°C and maximums of 32°C [10].

Kipushi's primary average hourly wind direction varies throughout the year. The wind often comes from the west, from January 1 to February 20, with a humidity rate of 39%. The rest of the year, the wind often comes from the east with a humidity rate of 96% (Fig. 3).
The temperature range throughout the year is 7.1°C. It should be noted that it is during the rainy season that there is the infiltration of pollutants into the soil due to leaching water, while during the dry season, there is the phenomenon of wind erosion [11]. The water balance is given by (1):

$$\textit{Precipitation} = \textit{evapotranspiration} + \textit{runoff} + \textit{transpiration} \quad (1)$$

Monthly potential evapotranspiration can be calculated using Thorn thwaite'sformula. The purpose of this method is to account for water inflows and losses in a catchment area or at the level of a region over more or less long periods.

2.4. Sampling

The sampling strategy results from a statistical approach, i.e., random sampling [12]. As part of this research, we dug holes of the sampling points of 20 cm to 40 cm to collect the samples.

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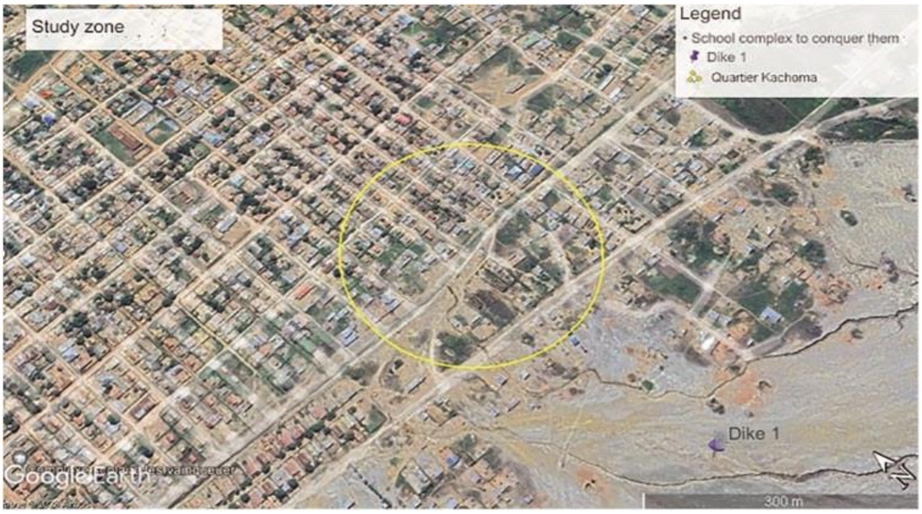

Fig. 2. Aerial view of the Kachoma neighborhood located in Kipushi territory.

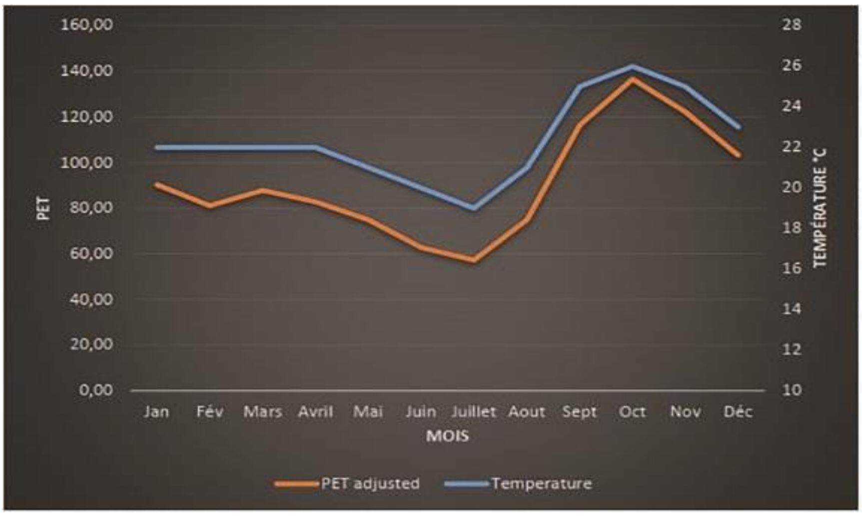

Fig. 3. Variation in monthly potential evapotranspiration and temperatures (Kahilu *et al*., 2020).

2.5. Physico-Chemical Analyzes

The physico-chemical analyzes made it possible to determine the metallic trace elements contained in the soil of the Kachoma district, and to evaluate the mobility and the bioavailability of the metallic trace elements (ETM). The main parameters analyzed are copper, cobalt, nickel, manganese, lead, zinc, humidity, organic matter content, and pH. We have chosen the AFNOR NF U 44-041 standard, used in French legislation and by the Directorate GeneralfortheEnvironmentoftheEuropeanCommission to assess the quality of polluted soils [13].

2.6. Data Processing

The data collected was processed with Microsoft Excel 2016 software.

3. Results and Discussion

3.1. Results of Physico-Chemical Analyzes

Theresultsofthephysico-chemicalanalysisarereported in Tables I and III.

The results show that the concentrations of metallic trace elements in the soils vary according to the sampling sites(Fig. 3).Thesoilpollutionindexiscalculatedfromthe average of the ratios of the concentrations of metals in the samples compared to the limit values of the French standardAFNORNFU44-041.Theselimitvaluescorrespond to the supposedly tolerable levels in the soil [13]. This soil pollution index (PI) is calculated, for the case of our work, by the equation (Table II): $PI = (Cu/100+Co/30+Ni/50+Mn/90+Pb+Zn/300)/6$ (2) where *PI* greater than 1 corresponds to polluted soil.

3.2. Copper Concentration

The laboratory results clearly show that the copper content in the soil samples from the Kachoma district is

TABLE I: Results of Analyzes of Metallic Trace Elements Contained in the Soils of the Kachoma District

Site	Sample	Cu (mg/kg)	Co (mg/kg)	Ni (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
OUA 1	S 1	8120	140	40	510	4340	4170
OUA 1	S 2	4700	170	34	730	2010	3190
Cell 5 years	S 3	6120	120	42	770	130	3150
Cell 5 years	S 4	5010	150	27	700	2150	5210
Cell 5 years	S 5	4170	130	46	650	1310	5190
	SD	100	30	50	90	100	300

much

Note: S: Sample, SD: Sandard AFNOR NF U 44-041.

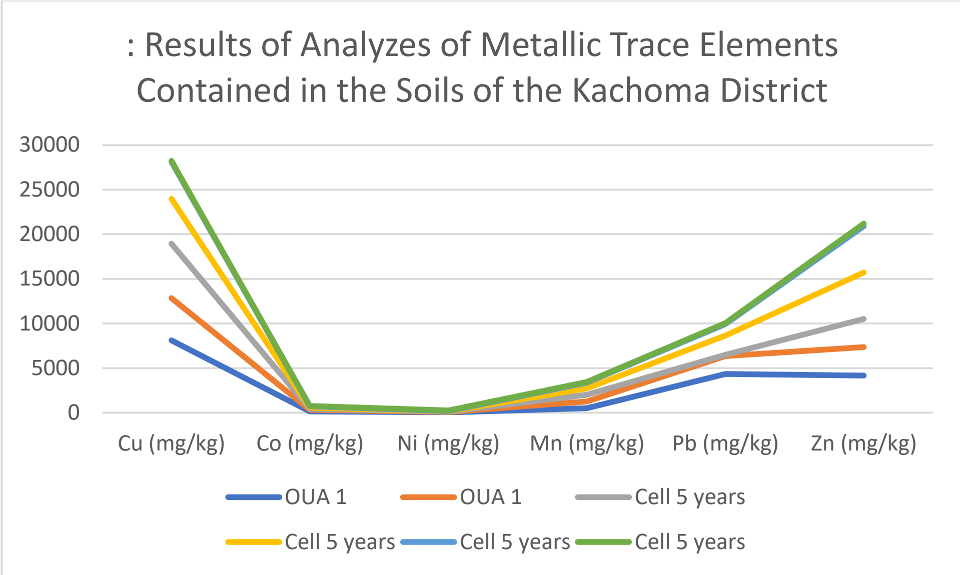

TABLE II: Soil Pollution Index of the Kachoma District

Site	Pollution index
OUA 1	30.615
Cell 5 years	19.09
LM	1

Note: LM: limit value of the pollution index for polluted soil.

TABLE III: Results of the Physico-Chemical Analyzes of the Soils of the District

TH (%)	pH	MO (%)
3.51	6.26	5.2
4.5	6.41	6.79
10.09	6.67	13.19
8.09	6.1	10.15
15.64	6.17	16.42

Note: TH (%): humidity level; MO (%): percentage of organic matter.

higher than that of the other metallic trace elements. It exceeds the limit values proposed by the AFNOR NF U 44-041 standard. It varies from 4170 mg/kg to 8120 mg/kg. This indicates that the soil in the Kachoma district is heavily polluted with copper, the content of which, in all the samplesanalyzed,iswellabovethelimitvalueof100mg/kg providedforbytheAFNORNFU44-041standard.These results are in agreement with those observed by other researchers [14], [15]. The high concentration of copper in this soil is due to the migration of copper from the basin to the Kachoma district facilitated by the diffusion of the wind.

3.3. Zinc Concentration

The concentration of Zinc is higher than the maximum value (300 mg/kg) proposed in international standards; it variesbetween3150mg/kgand5210mg/kg.Incomparison with the limit value proposed by the AFNOR NF U 44041 standard, the results obtained are around seventeen times higher than the acceptable threshold, which is in perfect agreement with the results of other researchers [16], [17]. However, these results are far superior to the results published by Haichan *et al*. [18] and those reported by Kabata-Pendias and Szteke [14].

3.4. Lead Concentration

The lead comes in the third position, and its concentration varies between 130 mg/kg and 4340 mg/kg. Its reference value is 100 mg/kg according to the AFNOR NF U 44-041 standard. The lead concentration values are higher than those obtained by other researchers [19], [20]. And are lower than those reported by Parizanganeh *et al*. [21].

3.5. Manganese Concentration

The concentration of manganese varies from 510 mg/kg to 770 mg/kg. Compared to the standard, which sets the limit value for manganese at 90 mg/kg [15], we see that this soil is loaded with manganese. The concentrations found in this study are lower than the values obtained by Tchanadema *et al*. [20]. This is explained by the fact that the metallic trace elements (ETM), which pollute the soils of the Kachoma district, come from mining discharges from 1 of Gécamines Kipushi.

3.6. Cobalt Concentration

Cobalt is the fifth pollutant of this soil by order of magnitude. Its concentration varies between 120 mg/kg and 170 mg/kg. These values are higher than the limit concentration set by the standard (30 mg/kg) [14]. This leads us to deduce that the soil in the Kachoma district is contaminated with cobalt. These values, although higher than those published by Kabata-Pendias and Mukherjee [22], are nevertheless in agreement with the results of Boukari [16].

3.7. Nickel Concentration

From the above, the soil of the Kachoma district is not polluted with Nickel, with the maximum concentration of Nickel being 46 mg/kg; this value is lower than the threshold limit of Nickel, which is set at 50 mg/kg. With regard to soil pollution in the Kachoma district by Nickel, the concentration values found in this study are lower than those found by Kabata-Pendias and Mukherjee [22].

3.8. Physico-Chemical Analyzes

It appears from (Table III) that the moisture content varies between 3.51% and 15.64%, respectively, of samples 1 to 5 (Ech1 to Ech5); on average, the moisture content is low at 8.37%. This is justified by the fact that the sampling was carried out during the dry season. The organic matter content varies between 5.2% to 16.42%, and the soil sampled has an acid character, the pH of which varies from 6.1 to 6.67.

3.9. Proposal of Some Soil Remediation Techniques in the Kachoma District

After evaluating the level of soil pollution in the Kachoma district, we will propose, in this paragraph, some means of soil remediation. To do this, we will start by reducing the degree of pollution by acting on the potential source of soil pollution in the district, which is the former Gécamines/Kipushi waste basin (dyke 1). To do this, we propose a physical containment of dyke 1 to prevent the diffusion of pollutants to the soils of the Kachoma district. Then, we propose to carry out phytostabilization to clean up the soil. It should be noted that phytostabilization is a highly recommended technique for depolluting soil in urban and peri-urban areas [10].

4. Conclusion

The objective of this study was to assess the concentration of metallic trace elements contained in the soils of the Kachoma district, located in the territory of Kipushi, in the Province of Haut-Katanga in the Democratic Republic of Congo. The results obtained show that the values of the concentrationsofmetallictraceelements(ETM)according to the metallic element and the sampling site. In addition to this, the pollution index of each site is greater than 1, which sufficiently shows that the soils of the Kachoma district are subject to multiple pollutions in metallic trace elements. The analyzsis of the samples shows that the soil is contaminated with copper, cobalt, manganese, lead, and zinc.

Conflict of Interest : The authors declare that they do not have any conflict of interest.

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