Published by Avanti Publishers

**The Global Environmental Engineers**

ISSN (online): 2410-3624

# Assessment of the Pollution of Soils Utilized for Growing Edible Plants in the DR Congo

Fabien Ilunga Mpanga and Michel Shengo Lutandula*

*Department of Chemistry, Inorganic Chemistry Unit, Faculty of the Sciences, University of Lubumbashi, P.O. Box 1825, Likasi Avenue, City of Lubumbashi, Haut-Katanga Province, the Democratic Republic of the Congo*

## ARTICLE INFO

*Article Type*: Research Article

*Keywords*:
Health risks
Mining activities
Contaminated soils
Edible plants growing
Environment pollution

*Timeline*:
Received: October 21, 2021
Accepted: March 28, 2022
Published: April 28, 2022

*Citation:* Mpanga FI, Lutandula MS. Assessment of the Pollution of Soils Utilized for Growing Edible Plants in the DR Congo. Glob. Environ. Eng. 2022; 9: 12-32.

*DOI*: https://doi.org/10.15377/2410-3624.2022.09.2

## ABSTRACT

This research was carried out with the aim to assess the pollution that threatens agricultural soils in urban areas in the Haut-Katanga region (DR Congo) by searching for heavy metals in the arable soil bordering the Kimpulande drain, in the nearby of the Shituru commune, the City of Likasi. This drain has been utilized since the 1930s by the Gécamines, the largest state-owned mining company in the country, to dispose of wastewaters from the copper and cobalt industry. The population living in Shituru utilizes the arable soil bordering the Kimpulande drain to grow edible plants. Based on the results from physicochemical analysis of soil samples from the first 40 centimeters and the determination of the spatial distributions of pH, electrical conductivity, and concentrations of selected heavy metals (Cu, Co, Cd, and Fe), it was concluded that the study area is composed of an alkaline soil (pH = 7.54) of which the average electrical conductivity is about 700 μS/cm. Unlike average concentrations of cobalt and iron, those of copper and cadmium have similar behavior, given that their average values decrease with soil depth. Besides, the soil utilized for urban agriculture of edible plants is polluted on the surface by cadmium (> 3 mg/kg) and copper (> 40 mg/kg). It is contaminated in depth by cadmium (> 1 mg/kg) and cobalt (from 20 up to more 100 mg/kg). This is not the case for copper and iron, given that their concentrations remained smaller compared to the limits set by the quality standards (QS) applicable to soils for agricultural use. Given the toxicity related to the presence in the arable soil of heavy metals to high concentrations, it was deduced that the Shituru in-force agricultural practices might result in the population's exposure to serious health problems. Consequently, the urban agriculture of edible plants on arable soils threatened by mineral pollution must be prohibited to protect the population's health.

---

*Corresponding Author
Email: shengolutandulamichel@yahoo.fr
Tel: +243842186336/ +243995084289

# 1. Introduction

In the Haut-Katanga region of DR Congo, and in particular, in the city of Likasi, where large production units of copper and cobalt had been built by the Gécamines [1], there is constant concern about the mineral pollution that threatens the agricultural soil and water [2-4], with numerous misdeeds on flora and fauna as well as on the quality of human life [5-9]. Indeed, very rudimentary methods have been utilized in the past to manage mineral wastes [10], with the discharge into watercourses of metal-laden liquid effluents emanating from metallurgical plants and ores concentrators [4, 5, 11, 12]. These practices date back to the period prior to the adoption by the DRC of the 2002 Mining Code. They contributed to the environmental pollution worsening, with great harm to human health and wildlife [5, 11-13], highlighting a new type of risks and hazards related to the country's mining and metallurgical industry [8, 14, 15]. Around the world, there are a great number of environmental pollution cases and especially the soils contaminated by heavy metals [8, 15].

According to [16], mining and smelting of ores operations are major activities involved in environmental pollution by heavy metals and metalloids in DR Congo [12]. This illustrates the situation experienced by the population in the City of Likasi, where agricultural soils are threatened by mineral pollution [18]. Indeed, in this city, located 120 km from Lubumbashi, which is the Haut-Katanga's capital, the dwellings in the commune of Shituru are located near the drain of Kimpulande utilized for the evacuation of industrial liquid effluents [17, 18]. At present, the Gécamines is not the only mining company in which the liquid discharges transit by the Kimpulande drain (Figure **1**) before pouring themselves into the Lufira River. The same river, in turn, feeds the Tshangalele Lake, which also receives wastewaters discharged by the newly installed mining companies, in mixture with percolates and runoff water rich in metals coming from tailings stored at Kimpulande and elsewhere, via the rivers Likasi, Panda and Buluo [18].

**Figure 1:** View of the Kimpulande tailings park in Shituru and a portion of the channel for liquid effluents discharge towards Lufira River.

Unaware of the danger related to the pollution of mineral origin that daily threatens human health and wildlife [4, 11, 13, 18], residents from the Shituru commune practice urban agriculture and utilize the surrounding soil for growing edible plants. As acknowledged by many authors [9, 18-21], farming practiced around urban centers is a major source of fresh crop. This is the case of vegetables consumed daily by the population in the City of Likasi. However, no one is interested in the quality of the soils on which those vegetables are grown. There is a concern that the consumption of vegetables is grown on polluted soils could result in health problems [19, 20, 22]. As admitted by [22], heavy metal contamination of soils is looked at today as a global challenge [9, 23-28] that requests both governments and scientific communities to join their efforts to remedy it [18]. Indeed, it is in the interest of public members and governments that vegetables grown on soils suspected to undergo mineral pollution be consumed safely [9, 27].

Unfortunately, hydrometallurgical operations performed at plants owned by the Gécamines, as is the case for those of the newly built plants, have generated solid wastes and liquid effluents of which the poor management has resulted in the spread of pollutants that threaten the soil and water in the City of Likasi [7, 10-12, 18]. Indeed, it is important recognizing that the fault lies more with the Congolese state, which had not quickly organized itself to regulate the management of mineral wastes during several decennia of copper ores mining and processing that have enabled the country to classify itself in the past among the world biggest producers [29] as it is the case today. It was necessary to wait until 2002 and later on in 2018 for the legislator to provide mining operators with guidelines for the environmentally friendly management of mineral wastes and their accompanying liquid effluents [12]. Now that the damage has been done both to fauna and flora, it remains only for each Congolese to manage this heavy environmental liability intelligently. The latter is in connection with adopted mineral ores processing practices, in view increasing the output of copper and cobalt [10].

This research has been carried out to assess the pollution of mineral origin in the soil bordering the Kimpulande drain, given that it is utilized by the population living in the Shituru commune for growing edible plants. In parallel, the spatial distribution of heavy metals of our interest (Cu, Co, Cd, Fe) and those of the pH and the electrical conductivity in the soil were determined. The findings of this research will be utilized for warning the population and the local authorities on health risks incurred due to in-force practices in the urban agricultural done in the City of Likasi. To achieve the objective pursued by this research, each targeted heavy metal has been analysed in soil samples via atomic absorption spectrophotometry. The obtained data have been mathematically processed using Matlab 7.1 software to establish the spatial distribution of each heavy metal. The same has been done for the pH and the electric conductivity of the soil through indirect instrument measurements in a prepared soil-water suspension.

# 2. Materials and Methods

## 2.1. Research Area Description

The study area is composed of a 200 m$^2$ terrain (Figure **2**) located along the Kimpulande drain in the commune of Shituru of the city of Likasi. In Shituru, a major part of the population practices the urban agriculture of cabbages, tomatoes, carrots, onions, cucumbers, amaranths, squash and cassava leaves, etc., as an additional source of income [30].

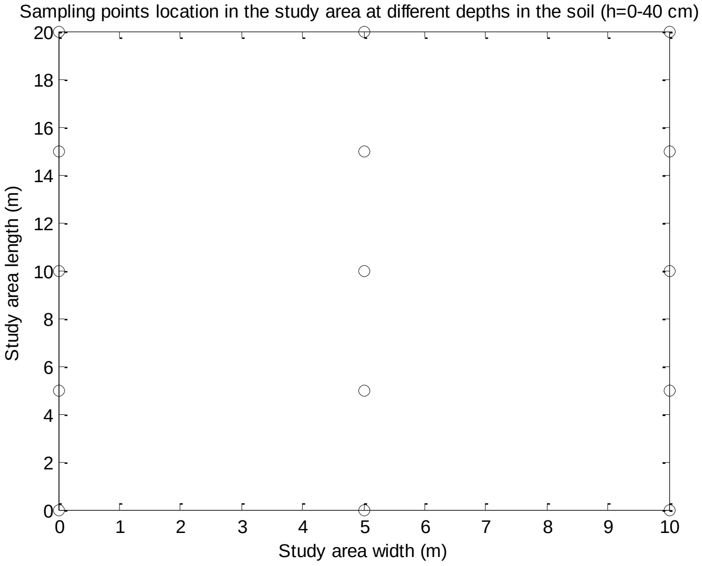

**Figure 2:** Soil sampling points location in the study area.

## 2.2. Soil Sampling Procedure

A set of 60 samples composed of the soil from the study area (20 m x 10 m) were subjected to physicochemical analyses. Sampling was conducted, from May to June 2019, after subdividing the study area into eight square-shaped sub-areas (Figure **2**), each of 25 $m^2$ (5 m x 5 m), and samples were collected at the summits of each one of the sub-areas. Thus, a steel pipe of 15 cm as the interior diameter and 50 cm as the length was utilized for the soil sampling by driving it deeply into the study area by means of a hammer until a depth of 40 cm. Once the desired depth was reached, the pipe was removed and emptied of its contents, which were divided into three fractions composed of surface soil (0 cm), intermediate soil (20 m), and depth soil (40 cm). Each fraction of the collected soil (300 up to 400 g) was placed in a plastic bag prior to preparing sub-samples intended for physicochemical analyses.

### 2.3. Sub-Samples Preparation

The preparation of sub-samples intended for analyses was conducted using the procedure described by [31]. It consisted in transferring the soil samples on a plastic tray for spreading them so that a thickness of less than 1 cm is obtained [32], followed by their air-drying for 72 hours when avoiding to expose them to direct sunlight. After the drying, any foreign material (organic matters, charcoal, shells and plant seeds, etc.) were removed, and the total sample weight was determined (200 g) before sieving at less than 2 mm [31, 32]. The oversize particles were divided using a lab roller mill to prepare a matter composed of particles with the size less than 2 mm [31]. Subsequently, the ground samples were subdivided into subsamples by means of a riffle divider to obtain 50 g of dry soil with a particle size that is less than 2 mm. Each soil sub-samples (50 g) was ground again using a disc pulveriser until a fine powder was obtained. That powder was homogenized and sieved using a 100-µm sieve's aperture before being bagged and labeled in view, indicating its location in the study area already divided into 8 square-shaped sub-areas.

### 2.4. Samples Physicochemical Analyses

These analyses consisted of determining the pH and electrical conductivity of soil samples using a consort C933-type multi-parameter analyser. They also enabled the dosage of copper, cobalt, cadmium, and iron by atomic absorption using an Analytikdjena AAS 300 spectrophotometer.

Concerning the pH measurement, an air-dried sample of soil (20 g) was placed in a 250 mL beaker containing 100 mL of deionised water, that is, in a ratio of 1:5. The obtained mixture was stirred to the speed of 180 rpm for 120 minutes at room temperature to prepare a soil-water suspension [31]. Indeed, a Fischer Scientific-type magnetic agitator enabled preparing that suspension in which an SP10B general-purpose electrode +ATC (Pt. 1000), connected to the Consort C933 apparatus, was introduced in view of measuring the pH [32]. The electrode, as mentioned above, was first rinsed with distilled water and calibrated using buffer solutions of different pH (4, 7, and 10) provided by Consort Belgium.

As for the measurement of the electric conductivity, it was performed using the same soil-water suspension [31, 32]. In this case, an SK10B general-purpose electrode +ATC (Pt. 1000), connected to the same Consort C933 analyser, was utilized after being calibrated using a 3M saturated solution of KCl (as a standard solution) also provided by Consort Belgium.

As for the spectrophotometric dosage of heavy metals of our interest (Cu, Co, Cd, and Fe), it was conducted using an aqueous solution prepared through the soil samples dissolution with aqua regia. A 0.5 g aliquot of each soil sample was placed into a 250 mL beaker and attacked with a solution composed of 50 mL of concentrated hydrochloric acid (36%), 10 mL of concentrated nitric acid (65%), 4 mL of concentrated $HClO_4$ (85%) and 2 drops of concentrated hydrofluoric acid (70%), all of them provided by Merck Germany. The obtained soil-acid mixture was heated until the liberation of white smoke before being allowed to cool. Afterward, 5 mL of concentrated HCl (36%) was added to the cooled mixture that had been reheated until boiling for 10 minutes, followed by the addition of 20 mL of distilled water. The resulting solution was transferred to a 100 mL volumetric flask, with the volume adjusted until the mark using distilled water. Afterward, the solution was homogenized and diluted by pipetting 5 mL of the stock solution into a 100 mL flask to which distilled water was added until the flask’s mark. The newly prepared solution was subjected to the spectrophotometric analysis of metals of our interest.

### 2.5. Obtained Data Mathematical Processing Procedure

The mathematical processing of the data provided by physicochemical analyses of soil samples (60) was performed using Matlab 7.1 software. The aim was to establish the spatial distributions of heavy metals concentrations as well as the pH and the electric conductivity in the soil of the study area. The spatial distribution of each studied parameter was analysed in view to describe its behavior in the study area soil to determine if it has brought about the pollution or not when comparing the measured concentration to limits defined by quality standards applicable to agricultural soil. The spatial distribution allowed us to visualize variations in the concentration of given heavy metals in the study soil area and determine whether they may be considered as pollution cases or not. It also enabled searching for a relationship between the electrical conductivity and variations in the pH as well as showing how they influence the heavy metals chemical speciation (Cu, Co, Cd, and Fe) present in the soil under consideration. Indeed, as stated by [33], it is not the total concentration of a given metal that determines the toxicity risk related to its presence, but rather the form in which it may be in the soil, that is, as a free metal ion or as a metal-ligand complex as well as physicochemical and biological processes it may be exposed to [33, 34].

# 3. Results and Discussions

The results presented and discussed in this section are related to physicochemical analyses of soil samples and the mathematical processing of data they have provided to establish the spatial distribution of each studied parameter.

## 3.1. Physicochemical Analyses of the Soil Samples

These analyses of the soil samples sampled at different depths of the study area enabled obtaining the results given in Table **1**.

The obtained results reveal, at first glance, that the soil mean pH is equal to 7.54, that is, slight alkalinity. As for the mean value of the electrical conductivity of the soil, it is almost equal to 700 µS/cm. This means a great presence in the soil water of free chemical entities capable of assuring the electric current circulation. It can be assumed that these chemical species could be present as dissolved matters but in sufficient quantities so that the electric conductivity is far lower than values that would render the soil unfit for agricultural use [37]. As for copper and cobalt, their average concentrations in the soil are between 16 and 17 mg/kg, contrary to cadmium and iron, for which the concentrations average 1.34 and 7.52, respectively. It is clear that, considering the obtained results (Table **1**), the average concentrations of copper in the soil do not surpass the maximum limits set by different soil quality standards referred to in this research. However, this is not applicable to the concentration of cobalt, of which the value in the soil reveals a pollution of mineral origin [36]. It is important to note that a few years ago, the results given by chemical analyses conducted on samples of liquid effluents, taken in an area more expansive than that of this research study area, reported the presence of large concentrations of copper and cobalt [18].

As for the average cadmium concentration, it is found in some spots lower than the limits set by among the strictest agricultural soil quality standards. The same average concentration is also higher than the limits set by other soil quality standards, revealing the pollution of mineral origin. This does not apply to the concentration of iron, of which the mean value is well below the limit set for agricultural soils (see Table **1**).

If only the surface's soil quality is considered, it can be seen that the average values of the electrical conductivity and average concentrations of copper, cobalt, and iron remain below the limits laid down by the soils quality standards for agricultural use. This is not the case for the cadmium concentration, given that its average value far exceeds all the limits laid down by different soil quality standards this research is referencing to (see Table **1**). It is important to keep in mind that in the surface soil, the average pH is equal to 7.58, which value enables classifying the soil under consideration as slightly alkaline one.

**Table 1: Physicochemical characteristics of soil samples.**

| Sample Location Coordinates | | | Studied Physicochemical Parameter | | | | | |
|---|---|---|---|---|---|---|---|---|
| X (m) | Y (m) | Z (m) | pH | EC (µS/cm) | Cu (mg/kg) | Co (mg/kg) | Cd (mg/kg) | Fe (mg/kg) |
| 0 | 0 | 0 | 7.58 | 752.13 | 40.08 | 5.37 | 16.00 | 2.00 |
| 5 | 0 | 0 | 7.42 | 573.80 | 66.80 | 1.08 | 26.80 | 0.40 |
| 10 | 0 | 0 | 7.80 | 674.06 | 90.34 | 9.00 | 36.00 | 3.60 |
| 0 | 5 | 0 | 7.53 | 659.06 | 19.88 | 2.03 | 8.00 | 0.80 |
| 5 | 5 | 0 | 7.29 | 874.22 | 23.42 | 8.84 | 9.20 | 3.60 |
| 10 | 5 | 0 | 7.70 | 858.01 | 16.06 | 7.00 | 6.40 | 2.80 |
| 0 | 10 | 0 | 7.48 | 764.42 | 19.02 | 8.04 | 7.60 | 3.20 |
| 5 | 10 | 0 | 7.63 | 783.05 | 14.10 | 3.00 | 5.60 | 1.20 |
| 10 | 10 | 0 | 7.79 | 575.78 | 16.62 | 9.01 | 6.80 | 3.60 |
| 0 | 15 | 0 | 7.54 | 674,82 | 26.06 | 4.02 | 10.40 | 1.60 |
| 5 | 15 | 0 | 7.60 | 692.08 | 70.01 | 1.82 | 28.00 | 0.72 |
| 10 | 15 | 0 | 7.68 | 798.12 | 12.99 | 3.00 | 5.20 | 1.20 |
| 0 | 20 | 0 | 7.51 | 783.08 | 18.77 | 1.03 | 7.60 | 0.40 |
| 5 | 20 | 0 | 7.49 | 685.05 | 14.02 | 2.11 | 5.60 | 0.80 |
| 10 | 20 | 0 | 7.70 | 672.89 | 93.34 | 8.02 | 37.20 | 3.20 |
| Mean values in the soil (0 m) | | | 7.58 | 721.37 | 36.10 | 4.89 | 14.43 | 1.94 |
| 0 | 0 | 0.2 | 7.44 | 578.15 | 5.32 | 1.04 | 0.42 | 0.40 |
| 5 | 0 | 0.2 | 7.51 | 625.06 | 1.18 | 0.01 | 0.09 | 0.00 |
| 10 | 0 | 0.2 | 7.32 | 744.98 | 10.02 | 3.22 | 0.80 | 1.20 |
| 0 | 5 | 0.2 | 7.68 | 674.37 | 2.20 | 6.00 | 0.18 | 2.40 |
| 5 | 5 | 0.2 | 7.50 | 765.07 | 10.07 | 5.67 | 0.80 | 2.40 |
| 10 | 5 | 0.2 | 7.90 | 773.02 | 7.13 | 1.00 | 0.57 | 0.40 |
| 0 | 10 | 0.2 | 7.79 | 686.78 | 7.98 | 7.01 | 0.64 | 2.80 |
| 5 | 10 | 0.2 | 7.62 | 542.01 | 4.04 | 2.98 | 0.32 | 1.20 |
| 10 | 10 | 0.2 | 7.63 | 776.13 | 10.31 | 9.03 | 0.80 | 3.60 |
| 0 | 15 | 0.2 | 7.00 | 660.93 | 4.34 | 4.03 | 0.34 | 1.60 |
| 5 | 15 | 0.2 | 7.71 | 804.20 | 18.31 | 7.96 | 1.46 | 3.20 |
| 10 | 15 | 0.2 | 7.63 | 680.12 | 3.02 | 3.01 | 0.24 | 1.20 |
| 0 | 20 | 0.2 | 7.74 | 792.51 | 2.00 | 1.00 | 0.16 | 0.40 |
| 5 | 20 | 0.2 | 7.79 | 471.70 | 2.12 | 7.05 | 0.17 | 2.80 |
| 10 | 20 | 0.2 | 7.70 | 716.42 | 8.81 | 3.04 | 0.70 | 1.20 |
| 0 | 0 | 0.2 | 7.71 | 536.03 | 7.04 | 56.06 | 0.42 | 0.40 |
| Mean values in the soil (0.2 m) | | | 7.60 | 686.10 | 6.46 | 4.14 | 0.51 | 1.65 |

(Table 1) contd....

| Sample Location Coordinates | | | Studied Physicochemical Parameter | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| X (m) | Y (m) | Z (m) | pH | EC ( μS/cm) | Cu (mg/kg) | Co (mg/kg) | Cd (mg/kg) | Fe (mg/kg) |
| 5 | 0 | 0.4 | 7.72 | 757.90 | 4.99 | 23.14 | 0.64 | 22.40 |
| 10 | 0 | 0.4 | 7.39 | 847.84 | 4.06 | 70.32 | 0.40 | 9.24 |
| 0 | 5 | 0.4 | 7.10 | 744.36 | 5.89 | 13.00 | 0.32 | 28.12 |
| 5 | 5 | 0.4 | 7.72 | 659.04 | 3.11 | 72.21 | 0.48 | 5.20 |
| 10 | 5 | 0.4 | 7.64 | 705.81 | 10.06 | 14.10 | 0.24 | 28.88 |
| 0 | 10 | 0.4 | 7.34 | 679.02 | 11.00 | 26.02 | 0.80 | 5.64 |
| 5 | 10 | 0.4 | 7.49 | 762.41 | 9.23 | 49.89 | 0.88 | 10.40 |
| 10 | 10 | 0.4 | 7.32 | 515.03 | 7.06 | 33.30 | 0.72 | 20.00 |
| 0 | 15 | 0.4 | 7.56 | 833.90 | 6.11 | 91.02 | 0.56 | 13.32 |
| 5 | 15 | 0.4 | 7.40 | 715.32 | 7.89 | 93.17 | 0.48 | 36.40 |
| 10 | 15 | 0.4 | 7.23 | 626.17 | 4.04 | 16.92 | 0.64 | 37.24 |
| 0 | 20 | 0.4 | 7.81 | 695.05 | 9.97 | 17.00 | 0.32 | 32.60 |
| 5 | 20 | 0.4 | 7.19 | 608.80 | 8.21 | 49.31 | 1.35 | 8.52 |
| 10 | 20 | 0.4 | 7.02 | 678.32 | 5.00 | 1.03 | 0.80 | 6.80 |
| Mean values in the soil (0.4 m) | | | 7.44 | 691.00 | 6.91 | 41.77 | 0.62 | 18.97 |
| Total mean values in the soil | | | 7.54 | 699.50 | 16.49 | 16.93 | 1.34 | 7.52 |
| QS for an agricultural soil [20] | | | 5.5-6.8[f] | ND | 270[a] | 15.2 [29] | 0.48[a] | 5000[e] |
| | | | | | 150[b] | | 3.0[b] | |
| | | | | | 200[c] | | 1.0[c] | |
| | | | | | 100[d] | | 3.0[d] | |
| | | | | | 200[e] | | 1.0[e] | |

a: US QS; b: Canadian QS; c: Tanzanian QS; d: Australian QS; e: Maximum allowable limit, f: According to [31]; ND=Not defined.

By analysing changes in the pH and electrical conductivity in the soil, that is, when moving in the study area from the top layer to a depth of 40 cm, the average soil pH first increases until a depth of 20 cm. Beyond this depth, it displays a downward trend and becomes slightly alkaline until a depth of 40 cm is achieved (Figure **3**). This is not the same for average electrical conductivity. Indeed, its value firstly decreases until the depth of 20 cm before displaying an upward trend until a depth of 40 cm.

The behavior displayed by the electrical conductivity as a function of the soil depth could be explained by a variation in the number of chemical species capable of assuring the circulation of electricity brought about by a change in the pH. Indeed, the increase in the soil pH observed until the depth of 20 is achieved resulted in a decrease in the electrical conductivity, meaning that the soil has become slightly a bit more alkaline, presumably due to an increase in the number of hydroxyl ions compared to hydrogen ions of the soil water. An increase in alkalinity results in lowered ionic mobility [38] as well as the precipitation of ionic chemical species capable of carrying electricity in the soil water. As for the drop in the pH observed beyond the depth of 20 cm, it has brought about an increase in the electrical conductivity. This simply means that the amount of ionic chemical species capable of conducting electricity has increased in the soil water, which contains a bit more hydrogen ions [38].

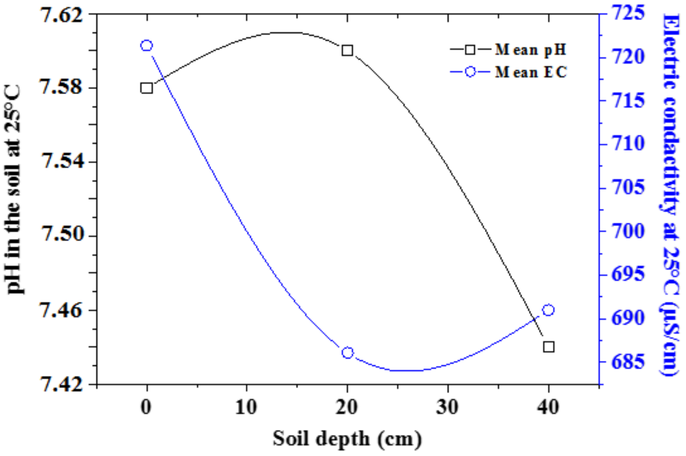

**Figure 3:** Changes in the average soil pH and electric conductivity versus the soil depth.

At a depth of 20 cm, the average concentrations of copper, cobalt and iron are consistent with the quality standards of soils intended for agricultural use. This is not the same when one goes at a depth of 40 cm, given that the average concentrations of cobalt and cadmium are higher than the threshold set by soils quality standards. This reveals a pollution of mineral origin in the soil under study. Figure **4** below shows the variation in the average heavy metal concentrations as a function of soil depth.

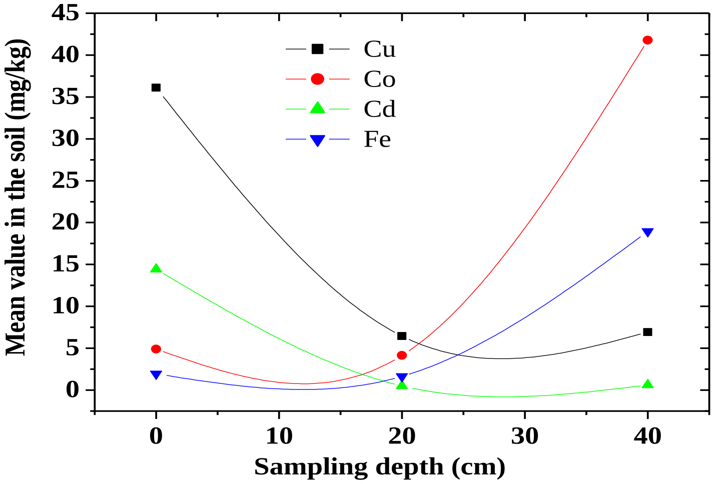

**Figure 4:** Variation of heavy metals average contents versus the sampling depth.

It is easy to realize (Figure **4**) that the average concentrations of copper and cadmium display a downward trend as the depth of the soil increases. This is not the same for the average cobalt and iron concentrations because their values increase with the soil sampling depth. However, the concentrations of copper and iron remain smaller than the limits set by the quality standards applicable to agricultural soil. They contrast with concentrations of cobalt and cadmium that reveal the pollution of mineral origin of the soil under study.

The analysis of the behavior of the metals concentrations as the depth of the soil changes provides proof that changes in the ionic mobility [38] enable establishing a cause-effect relationship between variations in electrical conductivity and the change in soil pH. Indeed, in the first 20 cm of the soil, the pH has become slightly more alkaline, i.e., its value has increased (few free ionic chemical species or hydrogen ions), bringing about a drop in electrical conductivity. Similarly, the concentrations of the analysed metals have reached their lowest values in the soil. In the last 20 cm of the soil, the pH has decreased, i.e., it has become a bit acidic or less alkaline (more free ionic chemical species or hydrogen ions), and this has brought about an increase in electrical conductivity. Similarly, the concentrations of certain metals of interest have reached the highest values.

### 3.2. Spatial Distribution of Parameters Measured in the Study Area Soil

This section of the article is reserved for discussing results given by the sample analysis. These results are depicted as spatial distributions of each parameter studied. For each sampling depth, an endeavor was made to find a link between variation in the concentration of a given heavy metal, its behavior, and the pH and electrical conductivity values in the soil [22].

#### *3.2.1. pH and Electric Spatial Conductivity Distribution*

As a function of the soil sampling depth, the spatial distribution of the pH and electric conductivity in the study area are depicted in Figures **5a** and **5b**.

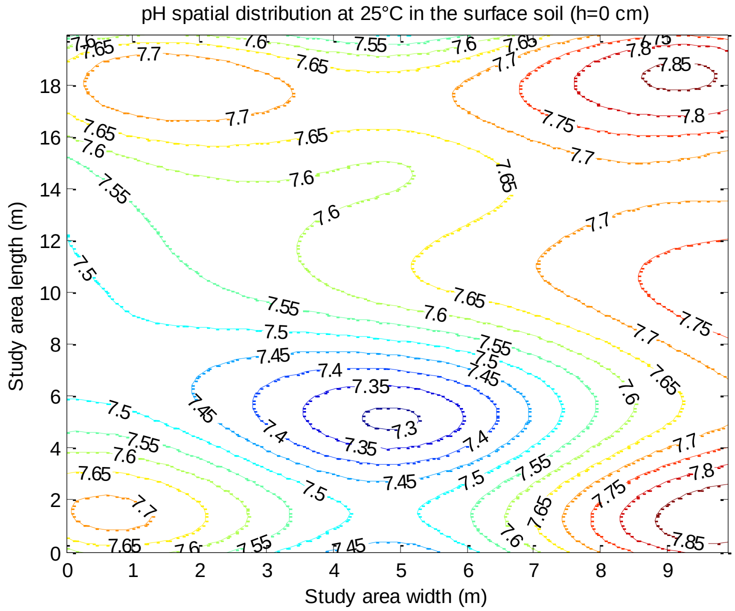

**Figure 5a:** Spatial distribution of pH in the surface soil.

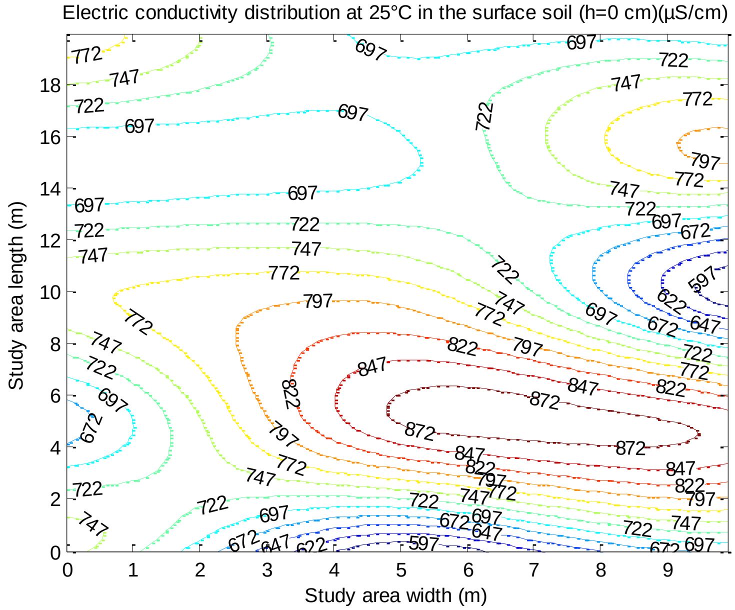

**Figure 5b:** Spatial distribution of electric conductivity in the surface soil.

From Figure **5a**, one can notice that the pH of the surface soil varies between 7.3 and 7.85 over much of the study area. When one moves from the center of the lower half of the study area towards the peripheral, whatever the direction chosen, the soil pH varies from 7.3 to values ranging from 7.45 to 7.85. The soil pH of the study area has changed from neutrality to alkalinity. Figure **5b** enables noticing that the electrical conductivity displays the most significant values (from 847 to 872 μS/cm) when one moves from the center of the lower part of the study area towards its lower left part. Higher electrical conductivity values are also observed towards different corners of the study area, that is, 772 μS/cm in the left and right top corners and 747 μS/cm in the left and right lower corners. The smallest value of the electrical conductivity (597 μS/cm) is observed in the middle of the lower part and the middle of the extreme right part of the study area. One can notice that in the surface soil, the electric conductivity displays the largest values in areas where the soil pH value changes from neutrality to alkalinity. Therefore, it can be assumed that the mobility of ions capable of transporting electricity in the soil is excellent in those parts. This situation enables an increased presence of hydroxyl ions among chemical species capable of easing electricity circulation within the soil water, and their ionic mobility is naturally greater as it is the case for hydrogen ions. In addition, the smallest value of the electrical conductivity is observed in areas where the soil pH is neutral and less alkaline. The behaviour of parameters of our interest is easily understandable because, under such conditions, most metals are present in the soil in speciation, which renders them less free in solution [33]. For areas with pH close to neutrality (see the center of the lower part of the study area), the lowered electrical conductivity observed in the soil can be attributed to the ionic chemical species resulting from the dissociation of salts. For places with low alkalinity (see the middle of the lower part), the electrical conductivity observed in the soil may be due to the presence of the chemical species and a lesser extent, due to hydroxyl ions. However, the surface soil presents an average electrical conductivity of 721.37 μS/cm or 72.137 dS/cm, a value that classifies it as strongly saline (≥ 16 dS/cm) and, therefore, unfit for any agricultural use (See Table **2**).

**Table 2: Saltiness class of soils as a function of the electrical conductivity**

| EC (dS/cm) | Saltiness class |
|---|---|
| 0<2 | Non-saline |
| 2<4 | Very slightly saline |
| 4<8 | Slightly saline |
| 8<16 | Moderately saline |
| 16≥ | Strongly saline |

The spatial distribution of the pH and the electric conductivity in the soil at a depth of 20 cm is depicted in Figures **6a** and **6b**.

Figure **6a** reveals that the soil pH is alkaline mainly. Its largest values ranging from 7.75 to 7.90, have been observed near the four corners of the study area. However, when one moves in the study area, that is, from the center to the left of its upper part, the soil pH gradually decreases from alkalinity (pH=7.7) to neutrality (pH=7.05).

As for the electrical conductivity of the soil sampled at a depth of 20 cm, its variations are such that the smallest values are observed in the center (560 μS/cm) and in the middle of the top part (488 μS/cm) as well as towards the lower-left corner (596 μS/cm) of the study area. These smallest electrical conductivities match pH values neighboring 7.6, that is, in the soil of which the alkalinity is not very strong. For the rest of the study area, the largest values of the electrical conductivity (794 μS/cm) are observed, with a decreasing trend, when one moves upward and downward as well as towards the top left and right corners of the study area (from 794 to 704 μS/cm). In the lower half of the study area, the soil's electrical conductivity decreases from 776 to 686 μS/cm when one moves from the right to the left. One may assume that variations in the electric conductivity observed when one moves in the study area, whatever the chosen direction, result from changes in the amount of hydroxyl ions which determines the pH value measured in the soil. Once again, the study area's soil cannot be used for agricultural purposes, given that measurements of the electrical conductivity have provided values qualifying the soil under consideration as strongly saline (see Table **2**).

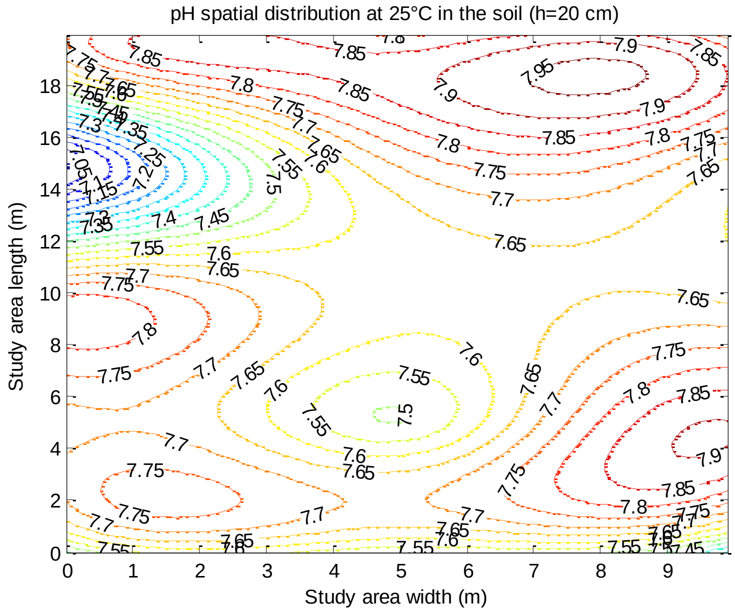

**Figure 6a:** Spatial distribution of the soil pH at the depth of 20 cm.

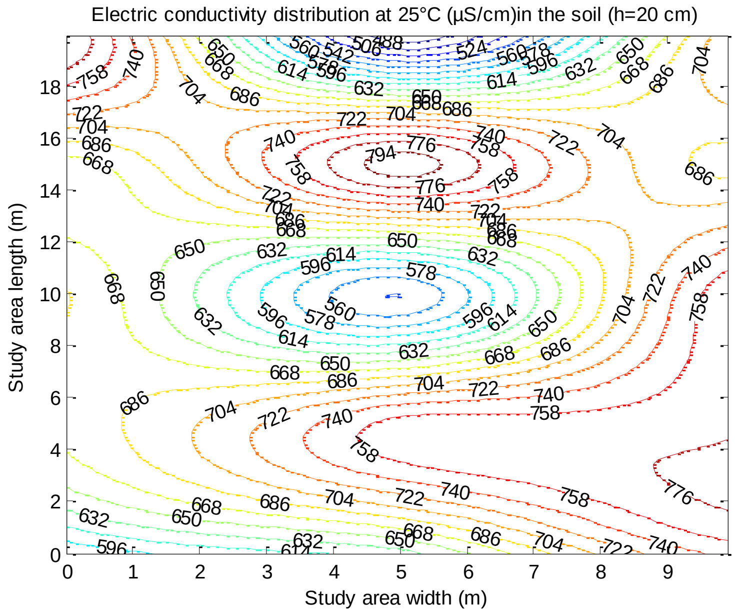

**Figure 6b:** Spatial distribution of the soil electric conductivity at the depth of 20 cm.

As for soil samples collected from the depth of 40 cm, the spatial distribution of the pH and electric conductivity is depicted in Figures **7a** and **7b** below.

The reading of Figure **7a** reveals that at a depth of 40 cm, the larger alkalinities (an increase from 7.51 up to 7.81) have been measured in areas near the top left corner and near the lower right corner of the study area. At spots around the center of the study area, the pH value is small and ranges from 7.41 to 7.51. The pH decreases until a value near neutrality (7.31 to 7.16) when one moves toward the lower left and the top right corners of the study area. This reveals that a significant part of the study area is made of alkaline soil (pH=7.16-7.81). As for the soil electrical conductivity, one can note that it displays higher values when one moves towards the lower right corner (674-834 µS/cm), along the direction going from the center of the study area towards the upper left corner (734-814 µS/cm) as well as when one moves towards the lower-left corner (714 to 734 µS/cm). Besides, when moving from the central part of the study area to the far right, one notices a gradual decrease in the soil's electrical conductivity (from 754 to 514 µS/cm). It is important to signal that the largest electrical conductivity values were located in portions of the study area wherein the soil displays high alkalinity. These electrical conductivity values could be due to high mobility related to the presence of hydroxyl ions in the soil water. As for the electrical conductivity's high value observed when one moves towards the lower-left corner, it could result from the presence of sodium ions, of which, unfortunately, the concentration has not been measured during the soil samples analysis. The gradual decrease in electrical conductivity observed when one moves from the center of the study area toward the far right could be related to variations in the soil pH, which has changed from alkalinity to neutrality. The above shows that there is a cause-effect relationship between variations in the pH and the value of the electrical conductivity of the soil at a depth of 40 cm. Again, the high electrical conductivity values at this depth make the soil unsuitable for any agricultural activity (see Table **1**).

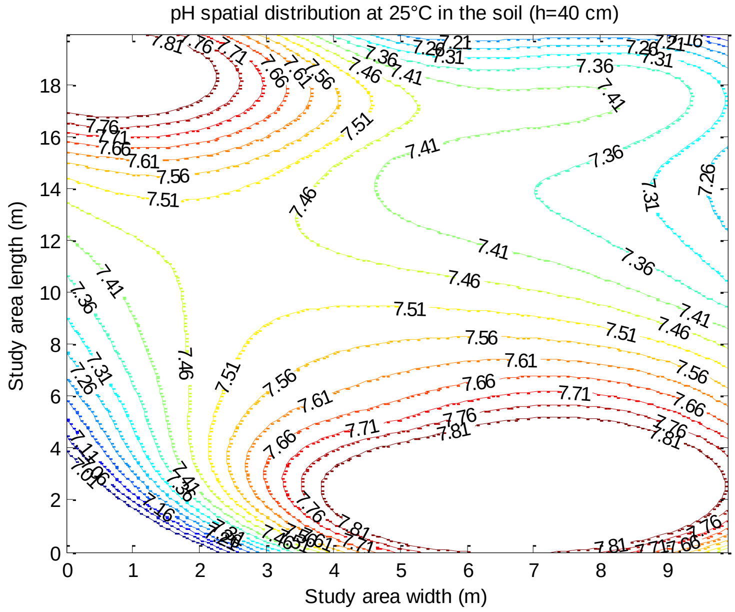

**Figure 7a:** Spatial distribution of the soil pH at the depth of 40 cm.

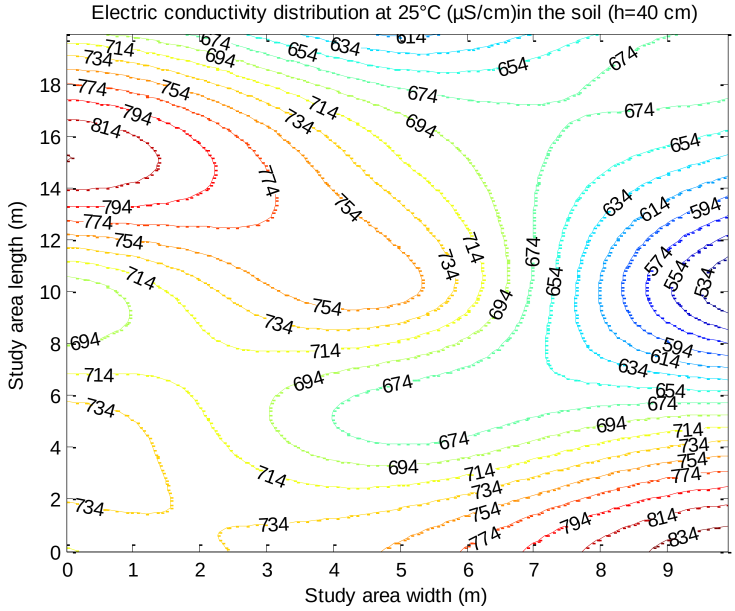

**Figure 7b:** Spatial distribution of the soil electric conductivity at the depth of 40 cm.

### *3.2.2. Copper Spatial Distribution*

The spatial distribution of copper concentration in the study area, as a function of the soil depth, is shown in Figure **8**.

Figure **8a** shows that the concentration distribution for copper in the surface soil of the study area goes from less than 20 to more than 90 mg/kg. However, these values remain below the limits set by the majority of quality standards for agricultural soils (See Table **1**). In the center of the upper half of the study area, concentrations of copper ranging from 40 to 70 mg/kg are observed in the soil. When one considers the guide values set for the copper concentration by the majority of the standards (Table **1**), the surface soil cannot be considered as polluted by copper despite the fact that high concentrations are observed in it, particularly in the upper and lower right corners of the study area. In contrast, according to [28], the soil of a significant part of the study area can be considered polluted by copper, given that the larger value of its concentration surpasses 40 mg/kg.

Considering larger values of the pH (7.85) and the electrical conductivity (797 µs/cm) measured in the soil sampled near the upper and lower right corners of the study area (Figures **5a** and **5b**), copper was observed to appreciable concentrations in the soil forming those corners may be found (Figure **8a**) also as hydroxides. This chemical speciation would prevent copper from being dispersed in soil water. Consequently, copper will be less bioavailable for plant uptake [22, 33]. However, this cannot be looked at as a guarantee for a lowered toxicity risk related to the presence of copper in the soil because most metals can undergo dissolution inside the plants' rhizosphere wherein the pH is ordinarily acidic even if the closer surrounding is alkaline [34].

At a depth of 20 cm (Figure **8b**), the spatial distribution for the concentration of copper is a bit different, particularly when one considers the soil forming the lower and upper right corners and the center of the upper half of the study area. Indeed, the concentration of copper ranges from 2 to 18 mg/kg, a range different from the one observed in the surface soil. The evoked difference also applies to the concentration range around the center of the upper half of the study area (Figure **8a**). In addition, the concentration of copper in the soil does not surpass limits set by different quality standards (Table **1**) despite the presence of the highest values (12 to 18 mg/kg) in the study area (l=5m and L=15m). These large values of the concentration of copper could have a link with those previously observed (see Figure **8a**) at the same spot in the surface soil. As time went on, it could be that the mineral pollution of the surface soil (> 40 mg/kg of copper) would have resulted in a migration of copper ions, of which large concentrations are observed in the soil sampled at a depth of 20 cm. The spatial distribution of the pH in soil sampled at a depth of 20 cm (Figure **6a**) enables stating that the copper is found in an alkaline environment wherein it may be present as hydroxides. The same environment is characterized by a larger value of electrical conductivity (Figure **6b**).

At a depth of 40 cm (Figure **8c**), the copper concentration in the soil is distributed so that any coherent relationship may not be established either with its distributions at a depth of 20 cm or to that of the surface soil. Indeed, the concentrations of copper range from 3 to more than 10 mg/kg, and higher values (from 9 up to more than 10 mg/kg) appear at spots that are different from those found at a depth of 20 cm and in the surface soil. However, those concentrations comply with the quality standards for agricultural soils (see Table **1**) despite the marked presence of copper towards the upper right corner, when one moves from the center until the far left and the far right near the lower right corner of the study area. This significant presence of copper in the soil at a depth of 40 cm may be related to large pH values (Figure **7b**), revealing greater alkalinities. The same copper presence matches high electric conductivity values (Figure **7c**). What precedes suggests considering that copper may be present in soil as hydroxides [33].

Although copper has not been observed in the soil to greater concentrations, it cannot be excluded that its absorption by the plants such as lettuce, spinach, and carrot that could be grown on this soil could not, in the long run, endanger the consumers' health [15].

### *3.2.3. Cobalt Spatial Distribution*

The spatial distribution of cobalt in the soil sampled at different depths of the study area is given in Figure **9**.

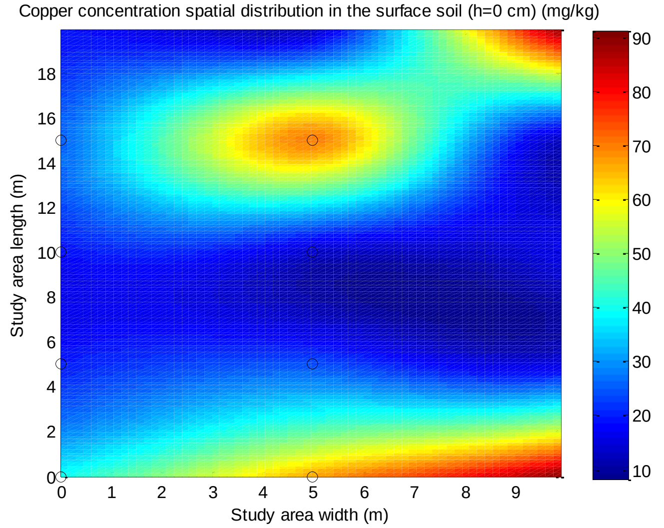
Copper concentration spatial distribution in the surface soil (h=0 cm) (mg/kg)

**Figure 8a:** Copper spatial distribution in the surface soil.

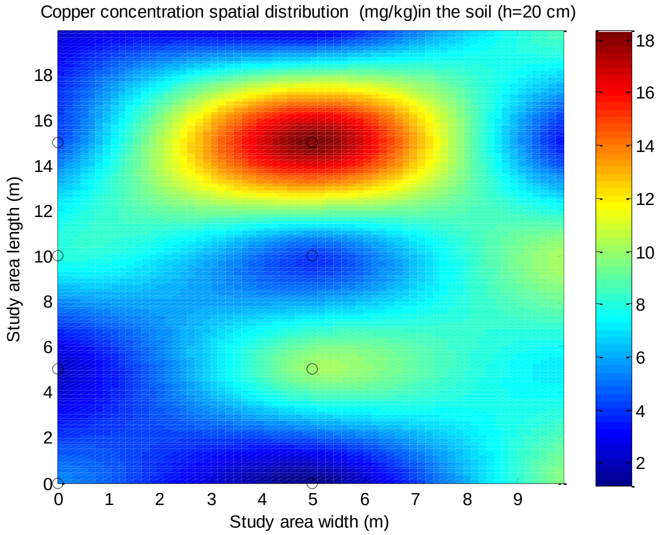
Copper concentration spatial distribution (mg/kg)in the soil (h=20 cm)

**Figure 8b:** Copper spatial distribution in the soil at the depth of 20 cm.

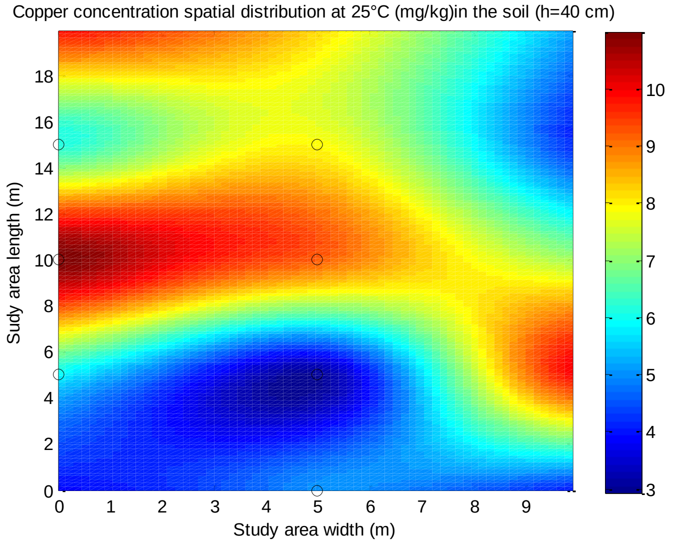
Copper concentration spatial distribution at 25°C (mg/kg)in the soil (h=40 cm)

**Figure 8c:** Copper spatial distribution in the soil at the depth of 40 cm.

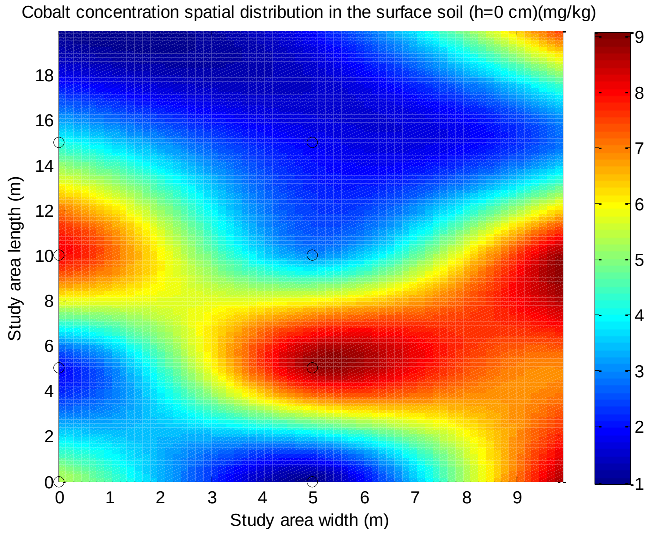

**Figure 9a:** Cobalt spatial distribution in the surface soil.

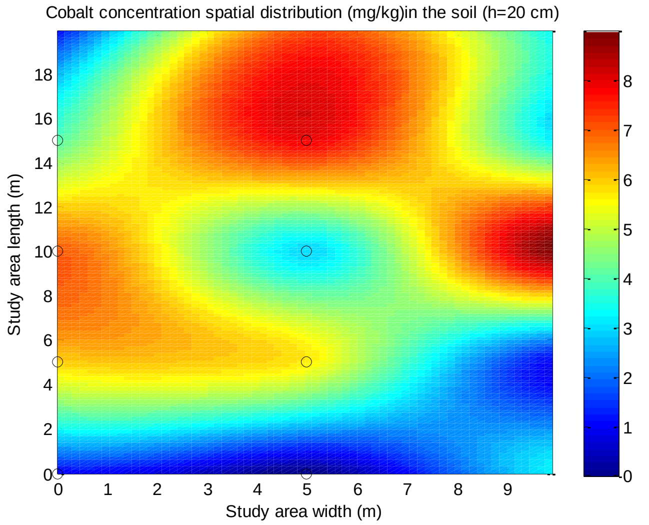

**Figure 9b:** Cobalt spatial distribution in the soil at the depth of 20 cm.

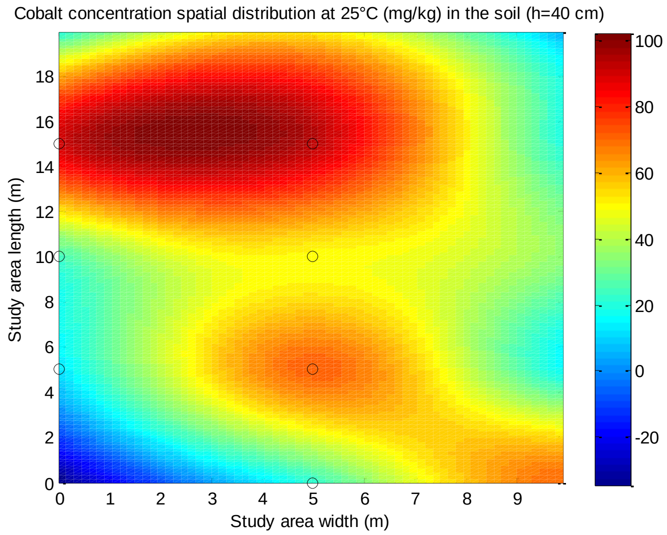

**Figure 9c:** Cobalt spatial distribution in the soil at the depth of 40 cm.

At first glance, the reading of the distribution of cobalt in the surface soil (Figure **9a**) reveals that its concentrations are below the limit (15.2 mg/kg) set by the quality standards for agricultural soils [35]. This distribution of cobalt can be linked to the pH of the soil (Figure **5a**). Indeed, its highest concentrations are observed at spots where the pH is alkaline (7.5 up to 7.85) and match high electrical conductivity values (Figure **5b**). In a pH range with a maximal limit smaller than 8.2 (Figure **5a**), cobalt cannot be mainly as precipitates in the soil but also as free ions. Consequently, the chemical speciation in which it may be found will favour an increase in its mobility or bioavailability [36] for its uptake by the plants. Indeed, [33] stated that at circum-neutral pH values, most metals are in a form that makes them unavailable for direct plants uptake in the aqueous form.

At a depth of 20 cm, the spatial distribution of cobalt in the soil is so that its concentration ranges from less than 1 up to more than 8 mg/kg (Figure **9b**). Its concentration is far smaller than the limit set by quality standards. Consequently, the soil can be considered suitable for agricultural use.

Their highest values are observed in the center of the upper half of the study area, which means, up to its top part, in the middle of the far-right, and from the center of the lower half of the study area until the middle of the far left part. In the aforementioned areas, the soil pH is alkaline (Figure **6a**) but not sufficient higher so that cobalt may be present mainly in the form of a precipitate. As a result, its bioavailability may be higher, as proven by high electrical conductivity values (Figure **6b**). What precedes enables assuming that cobalt can build up in edible plants and endanger the consumers' health.

It is clear that cobalt concentrations (from 20 to more than 100 mg/kg) observed in deep soil, i.e., 40 cm from the surface, far exceed the quality standards limit used (15.2 mg/kg)[35]. This is true specifically when one moves from the lower right corner towards the center of the lower half part of the study area. The same applies when one moves toward the far left part leaving the center of the upper half of the study area. Consequently, the soil can be considered unsuitable for any agricultural use. Indeed, the marked presence of cobalt can favor its build-up in edible plants endangering the consumers' health [39, 40]. Additionally, according to [41] cited by [22], the natural concentration of cobalt in a given soil may increase up to 40 mg/kg [42].

It is worth recalling that it is the Central Africa Copperbelt region (DR Congo and Zambia) wherein the City of Likasi is found. In this region, the soil is highly contaminated by cobalt [43]. [27] indicated that heavy metals like cobalt, when present in the soil to excess concentrations, hinder its biological functioning. As a result, a decrease in crop yields occurs with the increased presence of cobalt in plants' tissues [36, 37, 42, 44, 45]. According to [43], average concentrations of cobalt in plant tissues are usually low and range from 0.03 to 0.55 mg per kg of dry matter. The highest concentration of cobalt found in the soil slightly surpasses 100 mg/kg, that is, a limit value set for a mining area [36]. The greatest cobalt concentration in soil may reach 500 mg/kg [45].

### *3.2.4. Cadmium Spatial Distribution*

The spatial distribution of cadmium in the study area was also determined at different soil depths (Figure **10**).

The spatial distribution of cadmium (Figure **10a**) in the study area reveals that the higher concentrations observed in the surface soil (From 4 to more than 7 mg/kg) surpass the highest limit (3 mg/kg) set by quality standards used (Table **1**). What precedes reveals that the soil under study is polluted by cadmium, of which the spatial distribution resembles that established for copper (see Figure **9a**). This means that their highest concentrations appear in the same areas. These are characterised by great alkalinities (Figure **5a**) and high electrical conductivities (Figure **5b**). The finding done in the case of the surface soil does not apply to the distribution of cadmium (from 0.5 up to 3 mg/kg) at a depth of 20 cm (Figure **10b**). The situation is quite different for the spatial distribution of cadmium in the deep soil (Figure **10c**). Indeed, the highest cadmium concentrations are observed only in the upper left corner of the study area. Moreover, at both the depth of 20 and 40 cm, the concentration of cadmium in the soil is sometimes greater or smaller than the limit set by any of the standards used [28], and this, depending on areas considered in the study area. In the surface soil, the cadmium concentration increases (from 4 to more than 7 mg/kg) as one directs towards the lower and upper right corners of the study area. In the center of the upper half of the study area, cadmium seems to have scattered in alkaline soil (Figure **5a**), with its concentrations varying from less than 3 up to about 6 mg/kg. It is important to bear in mind that the presence of heavy metals in agricultural soil, particularly cadmium, to concentrations above the permissible limit, poses a threat to public health [9, 21, 28, 36, 46]. Besides, cadmium is classified as a carcinogen to humans and is easily transferable from soil to the food chain [46].

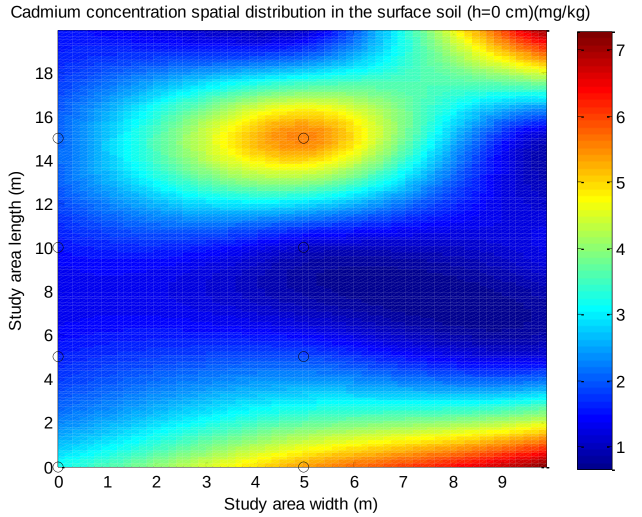

**Figure 10a:** Cadmium spatial distribution in the surface soil.

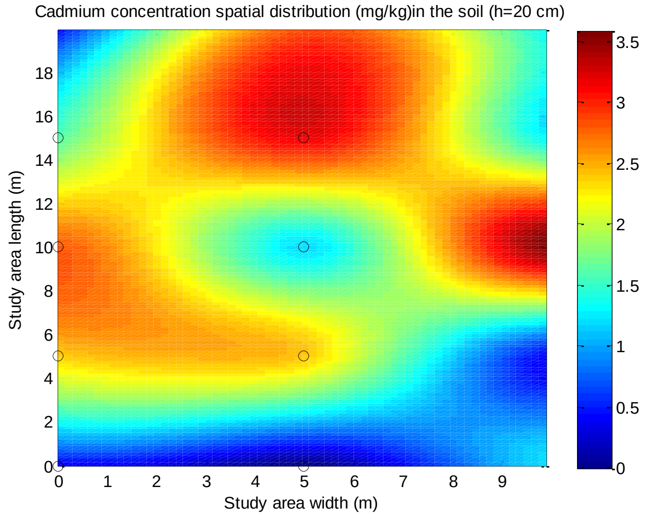

**Figure 10b:** Cadmium spatial distribution in the soil at the depth of 20 cm.

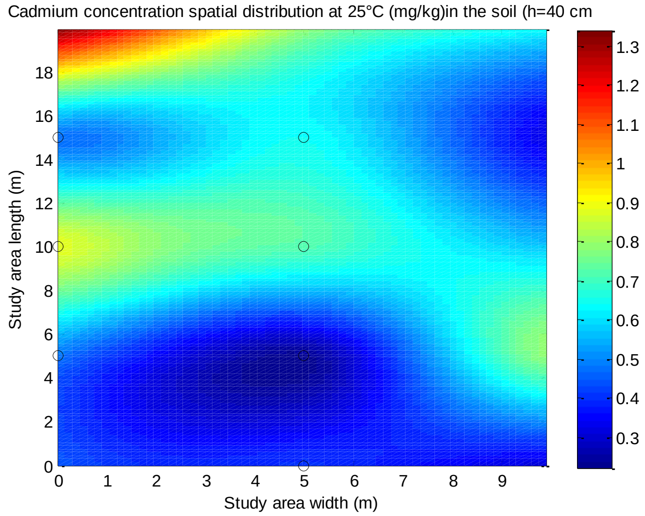

**Figure 10c:** Cadmium spatial distribution in the soil at the depth of 40 cm.

As with the copper concentration (Figure **8a**), the increase of that of cadmium when one approaches the upper and lower right corners matches a variation in soil pH from slight alkalinity to neutrality (Figure **5a**) [33]. A similar variation is observed in the electric conductivity value (Figure **5b**). It resembles the one already displayed by the studied heavy metals, of which the average concentration has changed as a function of the soil depth (Figure **4**). Referring to the available quality standards, it can be stated that the soil under study is contaminated with cadmium. Therefore, it is unsuitable for any agricultural purpose, given the possibility of the build-up of cadmium in plants that could be grown there.

In most of the soil in the study area, i.e., at a depth of 20 cm, the cadmium concentration is above the lowest limit (0.48 mg/kg) set by the quality standards used (Figure **10b**). It is only around the center of the upper half of the study area and towards the middle of the far-right part that the cadmium concentration surpasses the higher limit (3 mg/kg) set by the standards used. It is around and within an area of triangular shape located on the far left of the study area that the cadmium concentration in the soil varies between 2 and 3 mg/kg.

It is not easy to establish a coherent relationship between the distribution of cadmium in soil and the pH or the electrical conductivity (Figures **6a** and **6b**). Moreover, it is evident that the distribution of cadmium in the soil at a depth of 20 cm is such that its concentration varies between 0.5 and more than 3.5 mg/kg. This is sufficient for considering the soil unfit for any agricultural activity. When one closer analyses the distribution of cadmium in the soil sampled at 40 cm from the surface (Figure **10c**), one will quickly realize that its concentration is greater towards the upper left corner of the study area (0.5 and more than 1.3 mg/kg). It surpasses the limits set by three of the quality standards used (see Table **1**).

The highest cadmium concentrations are observed in areas characterised by the highest alkalinity and electrical conductivity measured in the soil (Figures **7a** and **7b**). Again, common sense would want the most stringent soil quality standard to be used and therefore, the soil is considered unsuitable for any agricultural use. Worth recalling is that cadmium has harmful effects on crops quality, namely via its impact on the uptake of micronutrients such as potassium [47]. Those micronutrients enable plants resisting against illnesses. Besides, when present in high concentrations, cadmium induces significant changes in the soil's biological properties inhibiting its enzymatic activity and inducing a drop in fertility and in crops yield [48, 49].

### *3.2.5. Iron Spatial Distribution*

Iron's spatial distribution in the study area was also determined at different soil depths, as shown in Figure **11**.

At first glance, the concentration of iron in the soil is far below the limit set by soil quality standards (Table **1**). The distributions of its concentration in both the surface and deep soils (Figures **11a** and **11b**) are completely different, not allowing to establish any coherent relationship between them. However, the soil cannot be considered unsuitable for agricultural use in this case.

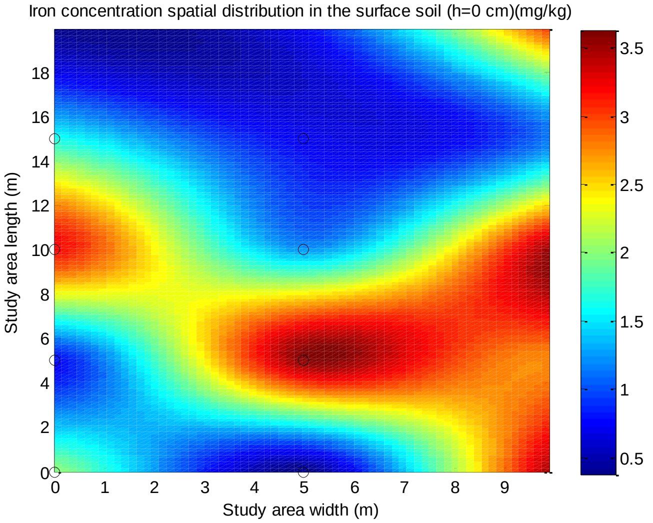

**Figure 11a:** Iron spatial distribution in the surface soil.

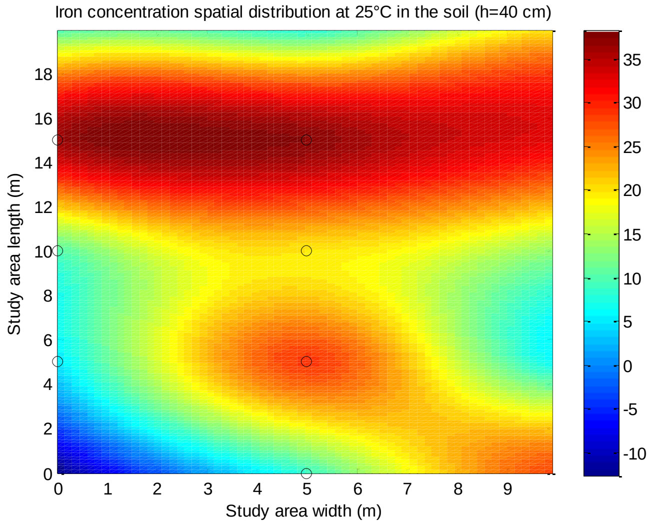

**Figure 11b:** Iron spatial distribution in the soil at the depth of 40 cm.

# 4. Conclusion

The results obtained demonstrate that the soil bordering the Kimpulande drain in the commune of Shituru in Likasi contains cadmium and cobalt at concentrations exceeding the limits set by soil quality standards. The electrical conductivity of the soil has displayed values that match a strong saltiness (High electrical conductivity values), rendering it unsuitable for agricultural use. Heavy metals make the soil unsuitable for any agricultural use because of their capacity to accumulate in the tissues of plants and given serious health risks they may represent to consumers. Urgent measures or decisions need therefore be taken by the public authority to discourage the urban agriculture of edible plants in order to protect the health of people living in the city of Likasi, given that it is practiced on soils polluted by heavy metals.

# References

[1] Natural Resource Governance Institute. Copper Giants: Lessons from State-Owned Mining Companies in the DRC and Zambia, pp.1-52. Accessible via https://resourcegovernance.org/sites/default/files/nrgi_NMC_English.pdf.

[2] Zaragoza MA. In search of clean water: human rights and the mining industry in Katanga, DRC. A report developed in collaboration with Sabin Mande, from the Natural Resources in DRC Network (RRN-RDC in French) and with inputs from Helene Ramos dos Santos, Natalia Uribe and Tobias, A project conducted with the support of the City of Antwerp and the Belgian Development Cooperation, Antwerp, 2013, pp. 1-33. Accessible via https://reliefweb.int/sites/reliefweb.int/files/resources/In%20search%20of%20clean%20water%20-%20Katanga%20DRC.pdf.

[3] Partow H. Water Issues in the Democratic Republic of the Congo Challenges and Opportunities, Technical Report from the United Nations Environment Programme, Nairobi, KENYA, 2011, pp. 1-90. Accessible via https://postconflict.unep.ch/publications/UNEP_DRC_water.pdf.

[4] Yamba Amisi Mwana, VranKen I, Nkulu J, Lubata Toto Rwananza F, Kyanika D, Scott Tshiban Nawej S, Mastaki Upite F, Bulambo mwema J-P, Bogaert J. L’activité minière au Katanga et la perception de ses impacts à Lubumbashi, Kolwezi, Likasi et Kipushi: in Bogaert J, Colinet G, Mahy G (eds). Anthropisation des paysages katangais, Les presses universitaires de liège — Agronomie – Gembloux, 2019, pp. 267-279.

[5] Pesa I. Between waste and profit: Environmental values on the Central African Copperbelt, The Extractive Industries and Society (in Press), pp. 1-8. Accessible via https://doi.org/10.1016/j.exis.2020.08.004.

[6] Scheele F, Umpula NE, Ben-Bellah D, Bwenda C, De Haan E, Kiezebrink V. Cobalt blues: Environmental pollution and human rights violations in Katanga’s copper and cobalt mines, A publication made possible with financial assistance from the Dutch Ministry of Foreign Affairs and by Friends of the Earth Netherlands (Milieudefensie) and produced with funding of the European Union, The Centre for Research on Multinational Corporations (SOMO), Amsterdam, The Netherlands, 2016, pp. 1-54. Accessible via https://www.somo.nl/wp-content/uploads/2016/04/Cobalt-blues.pdf.

[7] Mazalto M. Gouvernance du secteur minier et enjeux de développement en République Démocratique du Congo, Thesis submitted as a partial requirement of the doctorate in Sociology, University of Québec in Montréal, 2010, 530p. Accessible via https://archipel.uqam.ca/2851/1/D1901.pdf.

[8] Jun Yang, Silu Mal, Jingcheng Zhou, Yongwei Song, Fei Li. Heavy metal contamination in soils and vegetables and health risk assessment of inhabitants in Daye, China. Journal of International Medical Research, 2018; 46(8), 3374-3387.

[9] Nur Fatin Najihah Ismail, Siti Marwanis Anua, Nurul Izzah Abdul Samad, Nurul Ainun Hamzah, Nurzafirah Mazlan. Heavy Metals in Soil and Vegetables at Agricultural Areas in Kota Bharu and Bachok Districts of Kelantan, Malaysia. Malaysian Journal of Medicine and Health Sciences 2020; 16(SUPP11): 159-165.

[10] Pourret O, Lange B, Bonhoure J, Colinet G, Decree S, Mahy G, Seleck M, Shutcha M, Faucon M-P. Assessment of soil metal distribution and environmental impact of mining in Katanga (Democratic Republic of Congo). Applied Geochemistry 2016; 64: 43-55.

[11] Countois Y, Maurice R, Arpin M, Demers B. Étude sur la restauration des mines de cuivre et de cobalt en République Démocratique du Congo, Rapport d'étude initiale N M-6708 (603082) des recherches en République Démocratique du Congo et rédigé par SNC-Lavalin International, Division Environnement, Montréal (Canada), 2003, pp.1-213. Accessible via https://documents1.worldbank.org/curated/en/851161468243902395/pdf/E7390v120Env0Audit0Gecamines.pdf.

[12] Peša I. Mining, Waste and Environmental Thought on the Central African Copperbelt, 1950–2000. : Environment and History 2021; 27 (4): 1-26. DOI: https://doi.org/10.3197/096734019X15755402985703.

[13] Kabange BN, Mwema EM, Deplancke M-PO. Mining Waste from the Cobalt Circuits of the Hydrometallurgical Plants of Shituru (DR Congo), a Potential Mineral Source for the Cement Industry in DR Congo, International Journal of Science and Research 2021, 10(3), 1554-1561. DOI: 10.21275/SR21228174430.

[14] Mustafizur Rahman Md, Farhad Howladar M, Mohammed Omar Faruque. Assessment of soil quality for agricultural purposes around the Barapukuria coal mining industrial area, Bangladesh: insights from chemical and multivariate statistical analysis, Environmental Systems Research 2017; (6):24, 1-13. Accessible via https://doi.org/10.1186/s40068-017-0101-x.

[15] Puschenreiter M, Horak O, Friesl W, Hartl W. Low-cost agricultural measures to reduce heavy metal transfer into the food chain – a review, Plant Soil Environment 2005; 51(1): 1–11.

[16] Ettler V, Vaněk A, Mihaljevič M, Bezdička P. Contrasting lead speciation in forest and tilled soils heavily polluted by lead metallurgy, Chemosphere, 2005; 58 (10): 1449-1459

[17] Bogaert J, Colinet G, Mahy G. Anthropisation des paysages katangais, Les Presses Universitaires de Liège — Agronomie - Gembloux, 2018, pp. 1-311.

[18] Lumbala AM, Mulobe P. Rapport de l'atelier stratégique de réduction de la pollution de l'environnement due aux activités minières dans la ville de Likasi, Project for advocating against environmental pollution from mining activities in the City of Likasi carried out by UMOJA NGO for the fight against AIDS and poverty through the management and promotion of governance, peace, gender and social justice, Workshop held in Likasi, October 7, 2013. Accessible via: https://www.rse-et-ped.info/wp-content/uploads/2014/01/RAPPORT-ATELIER-STRATEGIQUE-REDUCTION-DE-LA-POLLUTION-MINIERE-A-LIKASI.pdf.

[19] Peša I. Mining, Waste and Environmental Thought on the Central African Copperbelt, 1950–2000. : Environment and History 2021; 27 (4): 1-26. DOI: https://doi.org/10.3197/096734019X15755402985703.

[20] Sharma HP. Study of the impact of municipal solid waste dumping on soil quality in Guwahati city. Pollution Restoration 2008; 27(2):327–330.

[21] Akande FO, Ajayi SA. Assessment of Heavy Metals Level in Soil and Vegetables Grown in Peri-Urban Farms around Osun State and the Associated Human Health Risk. International Journal of Environment, Agriculture and Biotechnology 2017; 2(6):3250-3261. Accessible via http://dx.doi.org/10.22161/ijeab/2.6.61.

[22] Ilunga MF, Shengo LM. Polluted Waters Use in the Urban Agriculture and Its Impact on the Quality of the Grown Vegetables. The Global Environmental Engineers 2020; 7: 73-82.

[23] Naveedullah, Muhammad Zaffar Hashmi, Chunna Yu, Hui Shen, Dechao Duan, Chaofeng Shen, Liping Lou, Yingxu Chen. Risk Assessment of Heavy Metals Pollution in Agricultural Soils of Siling Reservoir Watershed in Zhejiang Province, China. BioMed Research International 2013, 1-10. Accessible via http://dx.doi.org/10.1155/2013/590306.

[24] Peša I. Crops and Copper: Agriculture and Urbanism on the Central African Copperbelt, 1950–2000. Journal of Southern African Studies 2020; 46 (3): 527-545. https://doi.org/10.1080/03057070.2020.1750872.

[25] Kosiorek M, Wyszkowski M. Remediation of Cobalt-Contaminated Soil Using Manure, Clay, Charcoal, Zeolite, Calcium Oxide, Main Crop (Hordeum vulgare L.), and After-Crop (Synapis alba L.). Minerals 2020; 10 (429): 2-17. Doi: 10.3390/min10050429.

[26] Sandip Singh Bhattia, Vaneet Kumara, Navdeep Singha, Vasudha Sambyalb, Jaswinder Singhc, Jatinder Kaur Katnoriaa, Avinash Kaur Nagpala. Physico-chemical Properties and Heavy Metal Contents of Soils and Kharif Crops of Punjab, India. Procedia Environmental Sciences 2016; 35: 801 – 808.

[27] Zaborowska M, Kucharski J, Wyszkowska J. Biological activity of soil contaminated with cobalt, tin, and molybdenum. Environmental Monitoring and Assessment, 2016; 188 (398): 1-10. DOI 10.1007/s10661-016-5399-8

[28] Abbas MN, Al-Tameemi IM, Hasan MB, Al-Madhhachi A-ST Chemical removal of cobalt and lithium in contaminated soils using promoted white eggshells with different catalysts. South African Journal of Chemical Engineering, 2021; 35:23-32. https://doi.org/10.1016/j.sajce.2020.11.002.

[29] Crowson P. The copper industry 1945–1975. Resources Policy, 2007, 32(1-2):1-18. DOI: 10.1016/j.resourpol.2007.03.004.

[30] Shengo LM, Mutiti CWN, Nonda1 KA Mukadi AT. Health issues related to the intake of cabbages grown at soils irrigated with contaminated waters. Journal of Chemical, Biological and Physical Sciences, Section B: Biological Sciences, 2014, 4(4): 3223-3231.

[31] Duraisamy Vasu, Pramod Tiwary, Padikkal Chandran, Surendra Kumar Singh. Soil Quality for Sustainable Agriculture: in R. S. Meena (ed.), Nutrient Dynamics for Sustainable Crop Production, Springer Nature Singapore Pte Ltd. 2020, pp. 41-66. https://doi.org/10.1007/978-981-13-8660-2_2.

[32] International Soil Reference and Information Centre (ISRIC). Procedures for soil analysis, Technical paper: In Van Reeuwijk LP (ed.), Sixth edition, Food and Agriculture Organization of the United Nations, Wageningen, 2002.

[33] Roberts D, Nachtegaal M, Sparks Dl. Speciation of Metals in Soils. In MA Tabatabai and DL Sparks (Co-eds.), L Al-Amoodi and WA Dick (Eds.). Chemical Processes in Soils, Number 8, The Soil Science Society of America Book Series, Madison, Wisconsin, USA, pp.619-654.

[34] Kalis EJJ. Chemical speciation and bioavailability of heavy metals in soil and surface water. Ph.D. thesis Wageningen University, Wageningen, the Netherlands 2006, 139p.

[35] Sustainable Rice Development Project in Sierra Leone (SRDP), Japan International Cooperation Agency (JICA). Soil Analysis Manual, Ministry of Agriculture, Forestry and Food Security (MAFFS), Sierra Leone Agricultural Research Institute (SLARI) and Rokupr Agricultural Research Centre (RARC), 2014, pp. 1-38. Accessible via https://openjicareport.jica.go.jp/pdf/1000025769_01.pdf.

[36] Kosiorek M, Wyszkowski M. Effect of cobalt on the environment and living organisms - A review. Applied Ecology and Environmental Research, 2019; 17(5):11419-11449. DOI: http://dx.doi.org/10.15666/aeer/1705_1141911449.

[37] Mahey S, Kumar R, Sharma M, Kumar V, Bhardwaj R. A critical review on toxicity of cobalt and its bioremediation strategies. SN Applied Sciences 2020; 2:1279 | https://doi.org/10.1007/s42452-020-3020-9.

[38] Song Hi Lee, SH, and Rasaiah, JC. Proton transfer and the mobilities of the H+ and OH− ions from studies of a dissociating model for water. The Journal of Chemical Physics 2011, 135, 124505, 1-10.

[39] Bakshi S, Banik C. The impact of heavy metal contamination on soil health: in Reicosky, D. (ed.), Managing soil health for sustainable agriculture Volume 2: Monitoring and management, Burleigh Dodds Science Publishing, Cambridge, UK, 2018, pp.1-33.

[40] Kaya Muyumba D, Ilunga wa Ilunga E, Faucon M-P, Mahy G, Liénard A, Séleck M, Ngongo Luhembwe M, Colinet G. Factors of Variation of Soil Chemical Properties in Metalliferous Ecosystems of Tenke-Fungurume, Katanga, Democratic Republic of the Congo. Tropicultura 2019; 37 (1) 250: 1-23. DOI: 10.25518/2295-8010.250.

[41] Palit S, Sharma A. Effects of Cobalt on Plants. The Botanical Review 1994; 60(2): 150-161.

[42] Kosiorek M, Wyszkowski M. Remediation of Cobalt-Contaminated Soil Using Manure, Clay, Charcoal, Zeolite, Calcium Oxide, Main Crop (Hordeum vulgare L.), and After-Crop (Synapis alba L.). Minerals, 2020; 10(429): 1617. Doi: 10.3390/min10050429.

[43] Blume H-P, Brümmer GW, Fleige H, Horn R, Kandeler E, Kögel-Knabner I, Kretzschmar R, Stahr K, Wilke B-M. Scheer/Schachtschabel. Soil Science; Springer: Berlin/Heidelberg, Germany, 2016; pp. 1–618.

[44] Kosiorek M, Wyszkowski M. Remediation of cobalt-polluted soil after application of selected substances and using oat (Avena sativa L.). Environmental Science and Pollution Research, 2019; 26:16762–16780. https://doi.org/10.1007/s11356-019-05052-x.

[45] Kosiorek M, Wyszkowski M. Selected properties of cobalt-contaminated soil following the application of neutralising substances. Environmental Protection and Natural Resources, 2016; 27:1(67): 22-25. DOI 10.1515 /OSZN-2016-0006.

[46] Wang P, Chen H, Kopittke PM, Zhao F-J. Cadmium contamination in agricultural soils of China and the impact on food safety. Environmental Pollution, 2019; 249:1038-1048.

[47] Ciećko Z, Kalembasa S, Wyszkowski M, Rolka E. Effect of Soil Contamination by Cadmium on Potassium Uptake by Plants. Polish Journal of Environmental Studies, 2004; 13(3): 333-337.

[48] Wyszkowska J, Wyszkowski M. Effect of Cadmium and Magnesium on Enzymatic Activity in Soil. Polish Journal of Environmental Studies, 2003; 12 (4): 473-479.

[49] Wyszkowski M, Wyszkowska J. The effect of soil contamination with cadmium on the growth and chemical composition of spring barley (Hordeum vulgare L.) and its relationship with the enzymatic activity of soil. Fresenius Environmental Bulletin, 2009; 18 (7): 1046-1053.