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# Soil Quality Assessment on Former Agricultural Sites of the University of Man (Côte d'Ivoire)

**Abstract:** The use of chemical fertilizers to increase agricultural production contributes significantly to soil pollution. This study determines the long-term impact of chemical fertilizers containing residual heavy metals on the soils of three former agricultural sites at the University of Man in Côte d'Ivoire. Soil sampling was carried out at different soil horizons. In the laboratory, the samples underwent the standard preparations for soil analysis, namely drying, quartering, grinding and sieving. The pH and redox potential were measured using the HANNA multi-parameter analyser. Organic carbon was determined using the Malkley and Black method. After extracting heavy metals (HM) from their matrix (dissolution), the analysis (arsenic and lead) was carried out using an OPTIMA 2100 Dual View spectrometer (ICP-OES 2100 DV). Data analysis reveals that the soil pH is acidic, ranging between 4.06 and 5.30. Overall, organic matter varies from 10% to 17%. Across all sites, regardless of soil horizon, the ecological risk assessment yields results below 40. Concerning trace metals, the concentrations of arsenic (0.06 to 0.39 mg/kg) and lead (0.05 to 0.3 mg/kg) are below WHO standards (100 mg/kg for Pb and 40 mg/kg for As) and Canadian standards (70 mg/kg for Pb and 12 mg/kg for As). The geo-accumulation index is below 0 at all sites regardless of soil horizon, and the ecological risk assessment yields results below 40. The soils at the various sites contain some concentrations of Pb and As despite years of non-use. However, they pose no ecological risk and are therefore of good quality.

**Keywords:** Contamination; heavy metals; agricultural sites; Côte d'Ivoire.

## 1. Introduction

The use of chemical fertilizers has become an essential means of supplying nutrients to plants, increasing agricultural production and improving crop quality (Giroux et al., 2005; Asadua et al., 2024).

This method has also become a suitable solution for improving infertile soils (FAO et IFA, 2000; Guo and Wang, 2021). Every year, large quantities of chemical fertilizers are applied to the soil to increase its productivity. Between 1970 and 2000, fertilizer's use increased by 450% in Asia, 200% in Latin America and 100% in Africa (Ramade, 2005). These fertilizers contain copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn). These micronutrients (trace elements) are beneficial to plants when used in appropriate quantities, thereby promoting plant growth (Aziz et al., 2015). However, when concentrations of these chemical elements exceed maximum acceptable limits, they become toxic to plants (Simon et al., 2016; Wen et al., 2017; Chen et al., 2018; Guo and Wang, 2021). Furthermore, phosphate-based chemical fertilizers are known to be a source of metallic and radioactive pollutants (Nziguheba and Smolders, 2008). Trace metallic elements such as arsenic (As), cadmium (Cd), zinc (Zn), iron (Fe), lead (Pb), rare earth elements such as lanthanum (La), cerium (Ce), ytterbium (Yb), samarium (Sm) and naturally occurring radioactive elements such as uranium (U), thorium (Th), potassium (K) and radium (Ra) found in chemical fertilizers, accumulate in soils following fertilization (Gupta et al., 2014). Several studies have shown that the irrational use of fertilizers leads to an increase in the concentrations of EMEs in soils (Huang et al., 2018). Furthermore, these elements have high mobility and an ability to migrate through the soil, thereby polluting the groundwater and soil and contaminating the food chain (Simon et al., 2016).

Man, a town in western side of Côte d'Ivoire, is considered as one of the most fertile areas in the country due to the rainy climate relating to the presence of mountains. With a steadily growing population (241,969 people counted in 2021 compared to 153,427 in 2014), farming practices have consequently shifted towards the use of fertilizers and pesticides to meet the population's high demand for food in an increasingly limited space. This ever-increasing demand has led to the excessive use of fertilizers and pesticides in an attempt to boost yields. The excessive use of fertilizers and plant protection products by almost all farmers is not without consequences for the soil, water, plants and the health of living beings. The University of Man site was formerly used for large fields, but some crops remain on plots. It is necessary to demonstrate the long-term impact of chemical fertilizers on the concentrations of residual heavy metals that remain in these fertilizers during their manufacture on these soils in order to protect life. It is within this context that this study determines the long-term impact of chemical fertilizers used on former agricultural plots by assessing soil quality. More specifically, to determine pH, redox potential, organic matter content, levels of lead (Pb) and arsenic (As) contamination, and the degree of soil toxicity across the various sites.

## **2. Materials and methods**

### **2.1. Materials**

The equipment used consisted of an auger for sampling, plastic bags for packaging the samples, a GARMIN 64 Sx GPS for recording the coordinates of the sampling points, and sturdy plastic bags for transporting and mixing the samples. The analyses were carried out using: a HANNA multi-parameter meter for determining pH and redox potential; an OPTIMA 2100 Dual View (ICP-OES 2100 DV) spectrometer for determining Pb and As concentrations; and an asbestos test kit for determining organic matter.

### **2.2. Methods**

### 2.2.1. Soil sampling

The samples were taken from various agricultural soils at the University of Man site in Côte d'Ivoire, selected according to the type of crop. Visible traces of cultivation on the site facilitated their identification. Thus, three former agricultural sites were identified for the study, along with a control site. These agricultural sites are no longer in use. Table I shows the crop sites. Soil sampling was carried out at three (3) points at each site. Composite sampling was carried out. All the soil cores collected were placed in corresponding plastic bags to form a sample. Thirty soil cores were collected to obtain six (6) samples per site. The samples were taken from two (2) depth levels: 0–20 cm and 20–40 cm.

Table 1: Crop sites.

| Site         | Culture                                           | Area   | Coordinates                                |
|--------------|---------------------------------------------------|--------|--------------------------------------------|
| Site 1       | Rubber plantation ( <i>Hevea brasiliensis</i> )   | 3 ha   | Latitude 7°20'28"N<br>Longitude 7°37'21"W  |
| Site 2       | Coffee plantation ( <i>Coffea arabica</i> )       | 1.5 ha | Latitude 7°20'57"N<br>Longitude 7°36'38"W  |
| Site 3       | Palm tree plantation ( <i>Elaeis guineensis</i> ) | 3.5 ha | Latitude 7°21'00"N<br>Longitude 7°36'51"W  |
| Control site |                                                   | -      | Latitude 7°20'59" N<br>Longitude 7°37'39"W |

### 2.2.2. Sample preparation

In the laboratory, the soil samples underwent the standard preparation procedures for soil analysis, namely drying, quartering, grinding and sieving. Drying was carried out in the open air (at room temperature) and away from direct sunlight for one week. After drying, coarse material (stones, leaves, roots, snail shells, etc.) was removed. Quartering involved reducing the sample to the volume required for the work. Grinding, however, was carried out using a mortar. Finally, the samples intended for physico-chemical analysis were sieved using a 63 µm diameter sieve in accordance with standard NF ISO 11464.

### 2.2.3. Physico-chemical analyses

#### 2.2.3.1. pH, redox potential and organic carbon

The pH and redox potential were measured using the HANNA multi-parameter analyser. To do this, 10 g of soil was suspended in 100 mL of distilled water. The mixture was stirred for 1 hour on a magnetic stirrer, then left to stand for 2 hours. The pH and redox potential were determined by immersing the probe in the supernatant.

Organic carbon was determined using the Malkley and Black method. The organic matter is

oxidised by a mixture of potassium dichromate and sulphuric acid, added cold. The excess dichromate is titrated with Mohr's salt. Various reagents were used to prepare the soil samples for the organic matter analysis:

- Potassium dichromate ( $\text{Cr}_2\text{O}_7\text{K}_2$ ).

It is dried in a desiccator containing calcium chloride ( $\text{CaCl}_2$ ) or sulphuric acid ( $\text{H}_2\text{SO}_4$ ). Next, 50 g of potassium dichromate ( $\text{Cr}_2\text{O}_7\text{K}_2$ ) is dissolved in 1,000 mL of distilled water.

- Mohr's salt.

196.05 g of Mohr's salt ( $\text{S04Fe}$ ,  $\text{S04}(\text{NH}_4)_2 \cdot 6\text{H}_2\text{O}$ ) are dissolved in 1,000 mL of sulphuric acid.

- Diphenylamine.

0.5 g is dissolved in 100 mL of concentrated sulphuric acid ( $\text{SO}_4\text{H}_2$ ). Then pour into 20 mL of water (with care) and store in a brown bottle.

- Sodium fluoride powder.

After preparing the various reagents, 10 g of soil is placed in a conical flask. 10 mL of dichromate and 20 mL of concentrated sulphuric acid were added, and the mixture was stirred for 1 minute. The mixture was then left to stand for 30 minutes on a sheet of asbestos paper. Next, 200 mL of water, 10 mL of phosphoric acid ( $d = 1.71$ ) and 3 drops of diphenylamine were added. The excess dichromate is titrated with Mohr's salt solution directly in the digestion flask. The colour changes from bluish-grey to light green (the soil's own colour interferes). Shortly before the colour change, the hue turns purplish, then the colour change is abrupt. The concentration of organic matter was determined according to equation (1).

$$\text{MO \%} = C \times 1.724 \quad (1)$$

Where:

$$C = (10 - VX) \times 0.39 / P$$

P = weight of the soil sample;

V = volume of Mohr's salt used (mL);

X = correction factor for Mohr's salt.

#### 2.2.3.2. Trace metals

The analysis of trace metals was carried out in two stages: the extraction of trace metals from their matrix (dissolution) and instrumental analysis. Extraction involved dissolution using hydrofluoric acid (HF) and perchloric acid ( $\text{HClO}_4$ ) in accordance with standard NF X 31-147. To do this, 100 g of soil dried (at  $105^\circ\text{C}$ ) and sieved ( $315 \mu\text{m}$  mesh) was calcined at  $450^\circ\text{C}$  for 3 hours. Next, the ash obtained during calcination was rinsed with a few drops of distilled water; 5 mL of HF (40%) plus 1.5 mL of  $\text{HClO}_4$  (70%) were added and brought to the boil in a sand bath until a cake was obtained. Next, 1 mL of  $\text{HNO}_3$  and 5 mL of distilled water were added to the cake. The mixture was heated for a few minutes, filtered, and made up to the required volume with distilled water. The analysis of heavy metals (arsenic and lead) was carried out using an OPTIMA 2100 Dual View (ICP-OES 2100 DV) spectrometer. The ICP-OES 2100 DV has a detection limit of  $5 \mu\text{g/L}$ . For reliable use of this technique, a calibration line is required for each series of analyses. This line is obtained by plotting a calibration curve via the analysis of a sample range (5, 10 and  $20 \mu\text{g/L}$ ) derived from a PERKIN ELMER stock solution comprising 30 elements. Arsenic analysis was carried out in accordance with the method specified in ISO 11885 (2007). The expression of ETM concentrations is given by formula (3):

$$T (\text{mg/kg}) = C \times V / S \quad (3)$$

Where:

T: concentration of the element in mg/kg;

C: determined concentration of the element in mg/L;

S: weight of the soil sample in g;

V: extraction volume in mL.

#### 2.2.4. Determination of soil toxicity levels

The degree of soil contamination by As and Pb in agricultural soils at the University of Man was assessed using the geo-accumulation index (Igeo) described by Müller (1969) according to equation 4.

$$I_{geo} = \log_2 \left( \frac{C_{ETM}}{1.5 \times C_{référence}} \right) \quad (4)$$

Where:

$\log_2$ : Logarithm to the base 2;

C (ETM): Concentration of the ETM in question in the soil sample;

C reference: Reference concentration of the ETM in question in the Earth's crust (As = 2 mg/kg; Pb = 17 mg/kg), according to Wedepohl (1995) Based on the Igeo values obtained, contamination levels are defined and recorded in Table II.

Table 2: Classification of soil contamination levels based on determined Igeo values (Müller, 1969).

| Classes  | Igeo values       | Soil contamination level                    |
|----------|-------------------|---------------------------------------------|
| Classe 0 | $I_{geo} \leq 0$  | No contamination                            |
| Classe 1 | $0 < I_{geo} < 1$ | No contamination to moderately contaminated |
| Classe 2 | $1 < I_{geo} < 2$ | Moderate contamination                      |
| Classe 3 | $2 < I_{geo} < 3$ | Moderate to heavy contamination             |
| Classe 4 | $3 < I_{geo} < 4$ | Heavy contamination                         |
| Classe 5 | $4 < I_{geo} < 5$ | Heavy to extreme contamination              |
| Classe 6 | $I_{geo} > 5$     | Extreme contamination                       |

The ecological risk posed by heavy metals (As and Pb) in soil was determined using the Ecological Risk Index (Eri). This index is used to assess the ecological risk associated with the presence of a single metal in the soil. It is calculated using Equation 5 described by Hakanson (1980).

$$E_r^i = T_r^i \times \frac{C_{ETM}}{C_{référence}} \quad (5)$$

Where:

$T_r^i$ : Biological toxicity factor of the individual element (As = 10; Pb = 5) according to Hakanson (1980) [15].

$C_{ETM}$ : Concentration of the ETM in question in the soil;

$C_{référence}$ : Reference concentration of the ETM in question in the Earth's crust (As = 2 mg/kg; Pb = 17 mg/kg) according to Wedepohl (1980). Table 3 presents the different classes of ecological risk level for soils based on the value of  $E_r^i$  obtained:

Table 3: Soil ecological risk classes according to Hakanson (1980).

| $E_r^i$ value        | Soil ecological risk level |
|----------------------|----------------------------|
| $E_r^i < 40$         | Low                        |
| $40 \leq E_r^i < 80$ | Moderate                   |

|                        |             |
|------------------------|-------------|
| $80 \leq E_r^i < 160$  | Significant |
| $160 \leq E_r^i < 320$ | High        |
| $E_r^i \geq 320$       | Very high   |

### 2.2.5. Statistical analysis

Statistical analysis was performed using analysis of variance (ANOVA), and a t-test ( $p < 0.05$ ) was used to compare the concentrations of arsenic and lead in the different groups of normally distributed soil samples.

## 3. Results and Discussion

### 3.1. Hydrogen ion concentration

Figure 1 shows the variations in pH at the different sites surveyed. The average pH values obtained range from  $4.06 \pm 0.33$  to  $4.11 \pm 0.07$  for the coffee plantation,  $4.56 \pm 0.36$  to  $4.10 \pm 0.04$  for the palm plantation,  $4.36 \pm 0.27$  and  $4.31 \pm 0.59$  for the rubber tree site, and  $5.30 \pm 0.25$  and  $5.20 \pm 0.31$  for the control site. The highest pH values were recorded at the control site. The pH values range between 4.06 and 5.30, indicating a slightly acidic pH. These values could be explained by the application of phosphate fertilisers at the sites. Indeed, phosphate fertilisers increase soil acidity according to Chen et al. (2006). However, these values are broadly similar to the results obtained by Korzeniowska et al. (2025) in Jelcz-Laskowice near Wroclaw, Poland. In contrast, Kao et al. (2007) obtained alkaline pH values ranging from 8.36 to 8.59 during their studies of agricultural soils in the city of Settat (Morocco).

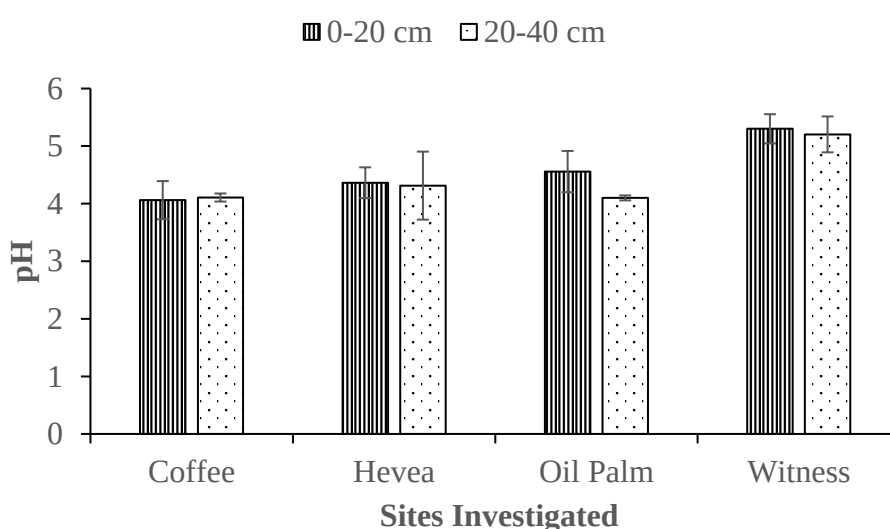


Figure 1: Variation in pH at the sites investigated as a function of depth.

The results of the variation in redox potential are shown in Figure 2. The Eh values range from 304.9 mV to 316.4 mV, with averages between  $310.6 \pm 5.53$  and  $307.9 \pm 2.74$  for the coffee plantation, from 228.2 mV to 320.7 mV, with average values of  $282.3 \pm 46.82$  and  $309.6$

$\pm 16.23$  for the rubber tree. For the palm grove, the values range from 258.1 mV to 305.1 mV, with an average value of  $276.3 \pm 17.24$  mV to  $295.6 \pm 12.38$  mV. As for the control site, the average values range from  $260 \pm 18.31$  mV to  $258.1 \pm 15.99$  mV. However, it is noted that the redox potential is slightly lower at the control site. The redox potential measured in the soils at the university ranges from 228.5 to 316.4. These soils fall within the range of moderately reducing environments (100 to 400 mV) according to Husson (2013). At the rubber tree and palm grove sites, a slight increase in the redox potential (Eh) is observed, which could be explained by the action of the plants in the soil. Indeed, according to Obeidy et al. (2016), root penetration could decompact and aerate the soil, thereby increasing the redox potential.

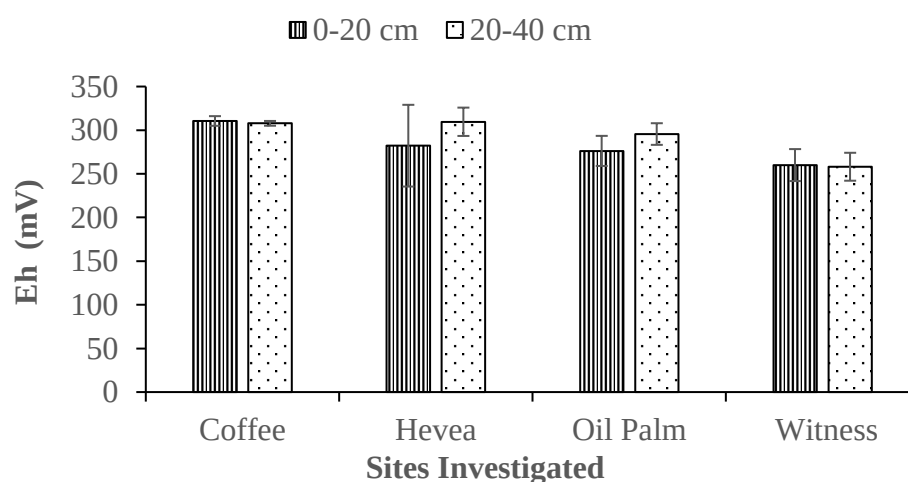


Figure 2: Variation in the redox potential of the sites investigated with respect to depth

### 3.3. Organic matter

The variation in soil organic matter concentration at the different sites as a function of soil depth is shown in Figure 3. The recorded organic matter concentrations range from 10 to 15%, 12 to 17%, 11 to 16% and 10 to 11% respectively in the soils of the coffee plantation, rubber plantation, palm plantation and control site. The lowest concentrations are found in the soils of the control site. The recorded organic matter concentrations range from 10% to 17% in the soils. The lowest concentrations are found in the soils of the control sites. However, in general, the soils of the various sites are moderately rich in organic matter according to the French non-genetic classification, with values ranging from 10% to 30%. This richness could be linked to the use of fertilisers at the sites and could reduce the availability and mobility of certain elements (Guo et al., 2012). These results are higher than those obtained in agricultural soils in the north-east of Algeria by Majour et al. (2024), which were 4.20%.

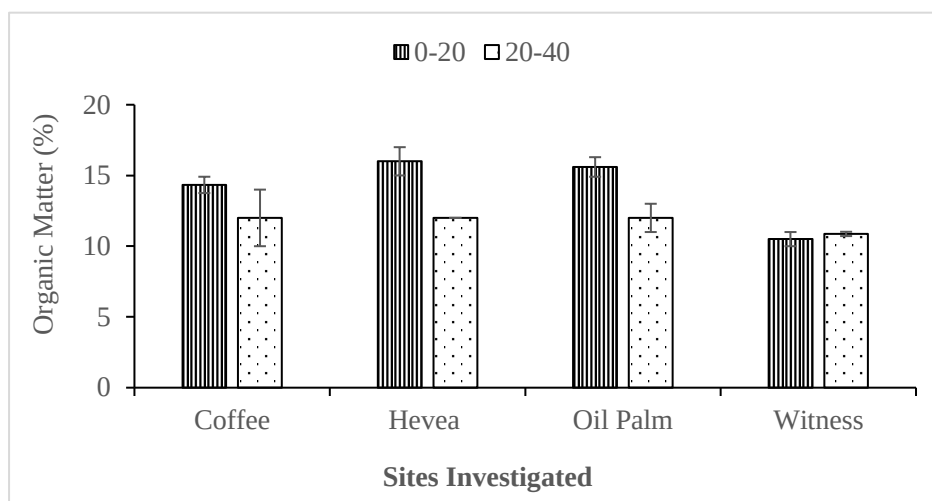


Figure 3: Variation in organic matter content at the investigated sites with depth.

### 3.4. Heavy metal concentrations

Figure 4 shows the results for lead concentrations at the various sampling sites. Lead concentrations are higher in the upper soil layers (0–20 cm). Overall, average Pb concentrations decrease very slightly with depth and are lower in the soils of the control site compared to the other sites. Statistical analysis reveals that the concentrations obtained are not significantly different, either within the same site or between different sites, with the exception of the control site (t-test). Average values range from 0.3 to 0.27 mg/kg for the coffee plantation, from 0.29 to 0.265 mg/kg for the rubber plantation, from 0.29 to 0.27 mg/kg for the palm plantation, and from 0.05 to 0.04 mg/kg for the control site. These values represent the average lead concentrations for the depths of 0–20 cm and 20–40 cm, respectively.

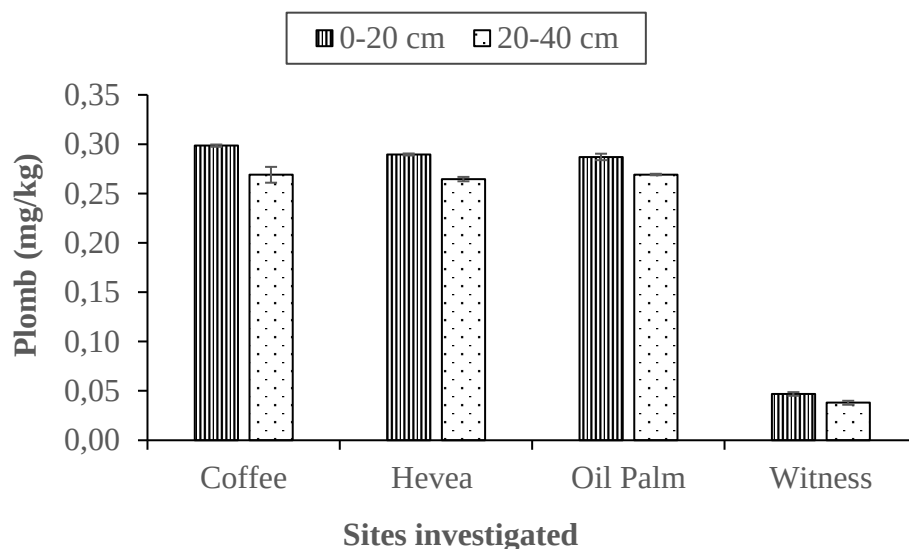


Figure 4: Variation in lead concentrations at the sites investigated at U-Man according to depth.

Figure 5 shows the variations in arsenic concentrations in the soil at the different sites. Concentrations remain broadly similar and decrease with depth. The lowest concentrations are found at the control site. The ANOVA shows no significant difference in concentrations with

depth within the same site. Furthermore, no difference is observed between the different sites, except in the case of the control site. The mean concentration values range from 0.37 mg/kg to 0.39 mg/kg for the coffee plantation, from 0.37 mg/kg to 0.38 mg/kg for the palm plantation, from 0.36 mg/kg to 0.38 mg/kg for the rubber plantation and from 0.06 mg/kg to 0.1 mg/kg for the control site.

Lead and arsenic levels vary from 0.05 to 0.39 mg/kg and from 0.04 to 0.3 mg/kg respectively. Higher concentrations are observed at the agricultural sites (coffee plantation, palm grove and rubber plantation) compared with the control site. However, the concentrations of As and Pb in all soil layers within the area are below the limit values set by the Canadian standard (70 mg/kg for Pb and 12 mg/kg for As) and the WHO (100 mg/kg for Pb and 40 mg/kg for As). These relatively low values can be explained by the fact that these sites are no longer in operation and therefore no longer receive inputs of lead and arsenic from fertilisers. However, the concentrations of these heavy metals in the soil layers decrease with depth across all the plantations. This decrease in concentration within the soil profile is thought to be due to the role played by the physical characteristics of the soil, particularly organic matter and pH. Indeed, organic matter in the soil also plays an important role in the mobility of MTE, as it tends to combine with their ions to form organic complexes, which can reduce the availability and mobility of these elements (Guo et al., 2012). As for pH, when it is high, it reduces the solubility of many MTE; conversely, a decrease in pH causes them to migrate from the solid phase into water and plants (Katana et al., 2013). According to Li et al. (2014), this contamination profile is characteristic of anthropogenic pollution. Alengebawy et al. (2021) demonstrated that heavy metal concentrations in the soil are caused by anthropogenic pollution, the majority of which is attributed to the application of chemical fertilisers.

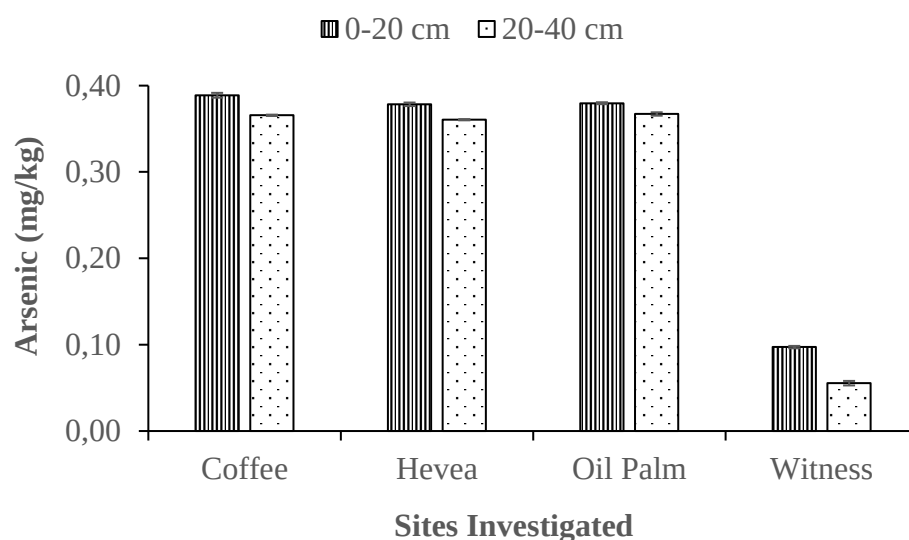


Figure 5: Variation in arsenic levels at the sites investigated at U-man according to depth.

### 3.5. Soil toxicity levels

#### 3.5.1. Geoaccumulation indices for heavy metals in the soils investigated

Table 4 presents the geo-accumulation index values for heavy metals at the agricultural sites of the University of Man. The investigated sites show negative geo-accumulation indices overall ( $I_{geo} \leq 0$ ). However, a higher geo-accumulation value is observed for As at the various sites compared to Pb.

Table 4: Heavy metal geo-accumulation index values at the sites investigated.

| Sites                | Plomb (Pb) | Arsenic (As) |
|----------------------|------------|--------------|
| Control site         | -9.23      | -5.3         |
| Coffee plantation    | -6.49      | -2.99        |
| Rubber plantation    | -6.52      | -3.02        |
| Palm tree plantation | -6.52      | -3.01        |

### 3.5.2. Ecological risk posed by lead and arsenic at the sites investigated

The levels of ecological risk posed by arsenic and lead in the soil at agricultural sites are shown in Table 5. It can be seen that at the sites studied, arsenic and lead have values ranging from 0.38 to 1.89 and from 0.01 to 0.08 respectively. However, the risk values are higher for arsenic than for lead. The geo-accumulation index values are negative for all sites ( $I_{geo} \leq 0$ ). The ecological risk values range from 0.01 to 0.08 for Pb and from 0.38 to 1.89 ( $E_r^I < 40$ ). The results therefore suggest that the soils at the various sites in the area are not contaminated with heavy metals. The soils are of good quality with a low ecological risk. These results differ from those obtained by Bounar et al. (2020), who, based on these pollution index values, suggests that all sites in the Wilaya of Jijel are contaminated with ETMs to varying degrees and would pose risks to public health if the produce were consumed.

Table 5: Ecological risk of the metals studied.

| Sites                | Pb   | As   |
|----------------------|------|------|
| Control site         | 0.01 | 0.38 |
| Coffee plantation    | 0.08 | 1.89 |
| Rubber plantation    | 0.08 | 1.85 |
| Palm tree plantation | 0.08 | 1.87 |

## 4. Conclusions

The study evaluated selected physicochemical properties and trace-metal concentrations in former agricultural soils at the University of Man. The soils were acidic, had moderate to high organic matter contents, and showed moderately reducing conditions. Lead and arsenic were detected in the former agricultural sites and in the control site, with generally higher concentrations in the cultivated sites than in the control. However, the measured concentrations of both metals remained low in all samples. Geo-accumulation index values were negative for all sites, and the ecological risk values for lead and arsenic were below the threshold for low ecological risk. These results suggest that the investigated soils are not contaminated by lead and arsenic according to the indices and reference values used in this study. Nevertheless, the conclusion should be limited to the measured elements and selected soil indicators. Regular monitoring remains necessary, particularly if future agricultural activities involve fertilizers, pesticides, herbicides, or fungicides that may contain trace metallic elements.

### Limitations

This study was limited to three former agricultural sites and one control site within the University of Man area. Only two trace metals, lead and arsenic, were analyzed, although other metals may also be relevant for evaluating agricultural soil quality. The assessment did not include soil texture, nutrient status, cation exchange capacity, microbial indicators, or crop uptake. The sampling design and statistical outputs were also limited, and seasonal variation was not considered. Therefore, the findings should be interpreted as a preliminary assessment of selected soil-quality indicators rather than a complete evaluation of overall soil health.

## Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

## Conflict of interest

The authors declare no conflicts of interest.

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