

Distribution of Heavy Metals in Soils in the Vicinity of the Proposed Mkuju Uranium Mine in Tanzania

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Abstract

Tanzania is at advance stages in the preparation to start uranium mining at Mkuju River Deposit. In order to implement best practice in environmental management in uranium mining as required by national and international regulations and standards, a set of site specific baseline data have to be established prior the mining operation. In order to establish heavy metal baseline data for this purpose, a total of 84 soil samples were collected from clustered area of about 1,300 km² at two depths: 0-15 cm and 15-30 cm. Analysis of the data using EDXRF showed a total metal concentration ranges of 3570-19400 for Al, 15200-58600 Fe, 400-1400 Mn, 15.2-54.9 Cr, 13.5-51.0 Zn, 2.2-45.3 Pb, 2.1-37.3 Cd, 0.2-23.0 Hg, 1.8-25.1Cu, 2.1-22.7 Ni and 0.8-9.1 mgkg⁻¹ for Co. Since the spatial distributions of heavy metals in the vicinity of the planned uranium mine are comparable to established global concentration ranges in soils, it is an indication that the distribution is natural. By virtue of their strong association with uranium and immobility in soil, spatial distributions of lead and copper concentrations would be more sensitive indicators for monitoring uranium related soil contaminants when the uranium mine become operational.

Keywords: baseline, best practice, heavy metals, Mkuju river

1. Introduction

The toxicity and tolerance limits of heavy metals are well documented and in many cases they have been used in formulation of national or international standards (Tricopoulos, 1997; EU, 2002; USEPA, 2002; Cheng et al., 2006; TBS, 2007; Momodu & Anyakora, 2010; Jintao et al., 2011; Lokeshappa et. al., 2012). By definition, tolerance limits are expressed in terms of exposures above background levels. For this reason verification of compliance with tolerance limits requires knowledge of natural background distribution for comparison. When established prior to the commencement of mining operations, the background distribution is called baseline data for the mining in that specific area (Ming et al., 1999). Unfortunately, baseline data are site specific and their accurate establishment prior to planned activity can be very demanding for various reasons. First, the area for which the baseline data has to be established can be very extensive and therefore sampling and data processing needed to reproduce a good representation of the spatial and temporal distributions of the area is challenging. Second, for data to be a good representative of a point, soil sampling is done by taking samples at least two layers. This approach makes it possible to establish data base for mobile and immobile heavy metals (Swenson et al., 1984). Third, for the sake of accuracy, duplicates or triplicates of analyses have to be made for each sample taken. If all these requirements are taken into consideration, establishment of baseline data can be costly and time consuming. In this work a method to reduce sampling points without sacrificing spatial and temporal distribution representation of concentration of heavy metals in soil at Mkuju river basin is presented.

2. Materials and Methods

2.1 Selection of the Study Area and Sampling Points

Mkuju river basin is hosting a viable uranium project namely Mkuju River Project (MRP). The MRP is located in the Southern part of Tanzania between latitudes 9° 45' to 10° 30' S and longitudes 30° 30' to 37° 00'E in Namtumbo district, in Ruvuma region (MSL, 2011). The study area consisting of the area within the MRP and the surrounding area likely to be affected by the project is shown in Figure 1. The MRP area covers about 3000 km² (MSL, 2011) and the area to be affected around the MRP was estimated by AERMOD dispersion model.

This model uses particles characteristics, meteorological factors and topographical characteristics of the terrain of the area as inputs and drift distance as output (Pasquill & Smith, 1983; Marticorena & Bergametti, 1995; Holmes & Morawska, 2006). In this study the boundary of the area to be affected by the mining process was demarcated by decreasing the drift distance from the maximum value of 5 km downwind by 0.5 km for consecutive 30 degrees to a minimum drift distance of 2 km upwind predicted by the model. As a result an area of about 1300 km² was formed round the project boundary. This area includes the already populated villages of Likuyu-Sekamaganga, Mtonya in Namtumbo district and the Selous wildlife world heritage.

In principle, for data collected from a contaminated area to be a representative distribution of contaminants in the area, a square grid of 10 m x 10 m has been used in previous studies (NRC, 1992). When related to the study area of 1300 km², estimated in this study, this sampling approach would require enormous amount (2 x 10⁸) of sample points. Since this study aims at establishing baseline data whose distribution varies slowly with distance, the grid was increased to 100 m x 100 m to reduce the sampling points without sacrificing representation of heavy metal distributions. Further reduction was achieved by grouping the area in regions with similar soil taxonomy (FAO, 1988) in combination with aerial photographic and topographic maps obtained from the Ministry of Agriculture (private communication). With this approach the study area was divided into 42 clusters of sampling plots shown in Figure 1. The number of samples (n=84) was then calculated at a confidence level of 95% according to the equation 1 (Santos Santos et al., 2006).

$$n = \frac{Za^2 p(1-p)}{d^2} \tag{1}$$

Where Za^2 is 1.96, p is a proportional value at 0.05 and d is a precision factor 8.5%.

2.2 Sample Collection and Packing

Prior to sample collection, organic material and debris were removed. A 25 mm diameter stainless steel soil auger was marked at height of 15 cm and 30 cm to determine precisely the sequential depth intervals of the samples being collected. The auger was pushed straight down into the soil to the desired depth when the samples were removed. The samples were removed from auger using a stainless steel rod. Before moving to a different plot, the auger and stainless steel rod were thoroughly cleaned with light brush to remove any soil from the previously sampling plot.

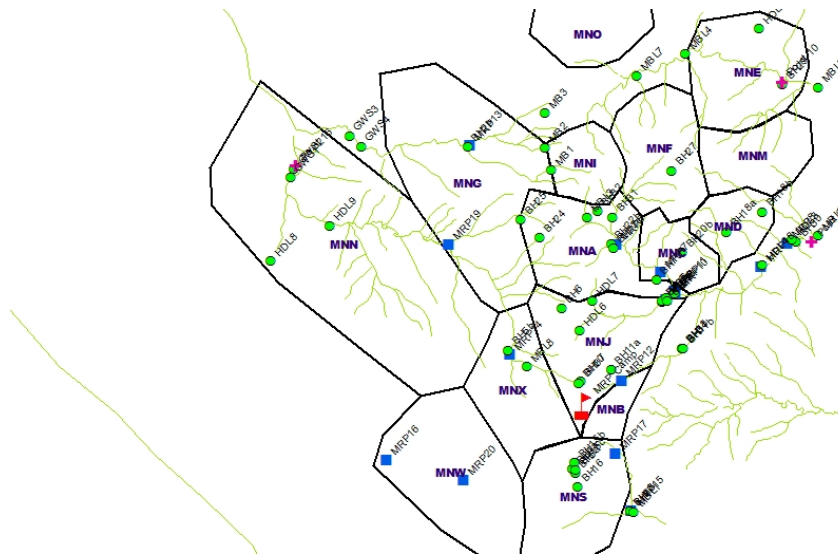


Figure 1. Map of the MRP showing the sampling locations

Three subsamples were taken randomly at each layer from different points of each plot. The subsamples with similar depths were homogenized to acquire a composite from which a representative sample for the depth in a plot was drawn. At each sampling plot, replicate samples were collected from depth range: 0 to 15 cm to represents metals retained in the topsoil and from depth range: 15 to 30 cm to represents metals in the subsoil. In addition, four points in the concession area were also selected and sparsely sampled to produce data for future

rehabilitation. All the sampling plots in Figure 1 were geo-referenced using a global positioning system (GPS). The collected samples were placed each in a separate clean zip top polyethylene bag, sealed and legibly labeled with sample date, plot number and soil depth before stored for subsequent transportation to the analytical laboratory.

2.3 Sample Preparation

The samples were oven dried at 100°C for 24 hours to reduce its moisture content until constant weight was achieved. Each sample was ground into fine powder using an agate mortar and pestle then passed through 2 mm stainless steel sieve. 6 g of each sieved sample was mixed with 1.35 g of binder material and then homogenized in a pulverizer. A mixture of sample and binder was homogenized, weighed and pressed at 12 tons into a pellet of 32 mm diameter using a die pellet maker.

2.4 Sample Measurements

The analysis of total metal concentrations in the pellets was performed using polarized Energy Dispersive X-ray Fluorescence (EDXRF) located at the Tanzania Atomic Energy Commission. In order to increase the sensitivity of excitation of elements (sodium to uranium), the EDXRF consisted of three targets namely: High Oriented Pure Graphite (HOPG) target for light elements from sodium to vanadium, Molybdenum secondary target for middle elements from chromium to zirconium and Praseodymium to uranium, and a Barkla Aluminium Oxide (Al_2O_3) target for high energy elements from yttrium to cerium (Spectro, 2005). Each pellet was loaded into a cleaned sample holder and then was inserted in the X-ray excitation chamber. With the help of automatic sample changer system, irradiation of samples was performed by assigning a time-based programme controlled by an x-lab Pro™ software package provided with the system. In this technique, when a sample pellet is irradiated with primary X-rays (I_0), the X-rays absorbed by the sample to produce characteristic X-ray peaks (I_i) of the i^{th} element in the sample according to the Fundamental Parameter (FP) approach defined by Equation 1 (Van Grieken & Markowicz, 1993).

$$I_i = I_0 G_0 (\rho d) \eta_i \left(\frac{1 - e^{-\mu d}}{\mu d} \right) \quad (2)$$

Where G_0 (ρd) is spectrometer's geometric constant, η_i is the detection efficiency of the i^{th} element and the term the bracket is a correction factor for the matrix effect.

A spectrum of characteristic X-ray peaks was detected by a Si (Li) detector, displayed and stored on the Multichannel Analyser (MCA). The intensity of i^{th} element in each characteristic X-ray peak formed on the MCA was then estimated using x-lab Pro™ software package according to the FP approach to quantify total concentration of the i^{th} element in the sample. Heavy metals concentrations in the samples were measured in two parallel pellets. During irradiation, prior each sample change disposable vinyl gloves were worn to prevent contamination of the samples. The soil pH values was measured in a mixture of about 4 g of the soils in 10 mL of distilled water suspension using Hanna pH meter (model H19023C) (Radojevic & Bashkin, 2006). and electrical conductivity was measured in a mixture of 1g soil to 5 mL of distilled water suspension using a HI 9828 multi range conductivity with intelligent probe in the laboratory.

2.5 Quality Control

In order to evaluate the accuracy provided by the EDXRF technique, the Montana soil 2711A Standard Reference Material (SRM) obtained from National Institute of Standards and Technology, USA was also prepared and analysed under similar experimental conditions as the unknown samples. The concentrations determined in the SRM for each element were compared with certified values of the same element in a sample in order to establish the level of agreement between the measured and certified values. As shown in Table 1 for the elements investigated, the deviations between the measured and certified concentrations were within $\pm 8\%$.

In addition, the binder material was prepared through the entire analytical procedure and was analyzed to determine if there was significant contamination or interference in the analysis process that could have led to the reporting of elevated metals concentrations. The analytical results of binder material indicated that there was not significant contamination or interference for each analyte. The limit of detection (LOD) for each element: Aluminum (Al), Iron (Fe), Lead (Pb), Magnesium (Mg), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Manganese (Mn), Mercury (Hg), Nickel (Ni) and Zinc (Zn) was determined as shown in Table 1.

Table 1. Comparison of measured and certified metal concentration levels of metals based on SRM, Montana-2711A and LOD by EDXRF

| Element | Certified value | Measured EDXRF results | % Deviation | LOD (mgkg ⁻¹) |
|--------------------------|-----------------|---------------------------|----------------|------------------------------|
| Al (%) | 6.72±0.06 | 6.38±0.08 | 5.06 | 20.00 |
| Fe (%) | 2.82±0.04 | 2.72±0.02 | 3.55 | 5.00 |
| Pb (%) | 0.14±0.001 | 0.15±0.09 | -7.14 | 0.85 |
| Mg (%) | 1.07±0.06 | 1.16±0.06 | -8.41 | 5.00 |
| As (mgkg ⁻¹) | 107.00±5.00 | 109.04±6.01 | -1.91 | 1.31 |
| Cd (mgkg ⁻¹) | 54.10±0.50 | 56.44±1.00 | -4.33 | 6.60 |
| Cr (mgkg ⁻¹) | 52.30±2.90 | 50.41±1.00 | 3.61 | 15.70 |
| Co (mgkg ⁻¹) | 9.89±0.18 | 9.53±0.25 | 3.64 | 21.70 |
| Cu (mgkg ⁻¹) | 140.00±2.00 | 139.77±0.19 | 0.16 | 1.79 |
| Mn(mgkg ⁻¹) | 675.00±18.00 | 669.77±10.20 | 0.77 | 14.10 |
| Hg(mgkg ⁻¹) | 7.42±0.18 | 6.85±0.25 | 7.68 | 0.94 |
| Ni (mgkg ⁻¹) | 21.70±0.70 | 20.23±0.50 | 6.77 | 2.70 |
| Zn (mgkg ⁻¹) | 414.00±11.00 | 391.82±3.96 | 5.36 | 1.35 |

3. Results

Sample identity (ID), GPS coordinates of sampling locations shown in Fig 1, soil pH and electrical conductivity (EC) obtained are presented in Table 2. The minimum, maximum, average and median of metal concentrations in soil at depths 0 - 15 and 15 - 30 cm obtained as described in 2.4 using equations 2 and the calculated correlation coefficients of metal concentrations are presented in Table 4.

Table 2. Plots or ID, pH and EC of soil and GPS (X and Y coordinates) for 42 sampling locations

| Sample ID | X Coordinate | Y Coordinate | pH (unit) | EC (mScm ⁻¹) |
|-----------|--------------|--------------|-----------|--------------------------|
| BH5A | 37L0233126 | 8885087 | 5.7 | 8.2 |
| BH5B | 37L0233140 | 8885367 | 5.7 | 8.7 |
| MRP14 | 37L0233182 | 8885255 | 6.3 | 7.2 |
| GWS1 | 37L0228061 | 8889395 | 7.6 | 6.4 |
| GWS2 | 37L0228139 | 8889582 | 7.8 | 6.4 |
| MRP23 | 37L0228199 | 8889639 | 7.5 | 7.0 |
| MBL2 | 37L0240380 | 8888047 | 6.2 | 6.6 |
| HDL2 | 37L0239796 | 8887938 | 7.4 | 6.9 |
| BH30 | 37L0239874 | 8887885 | 7.0 | 7.3 |
| MRP8 | 37L0239677 | 8887855 | 5.7 | 7.8 |
| MBL7 | 37L0236143 | 8891776 | 6.0 | 6.0 |
| MBL4 | 37L0237288 | 8892284 | 6.1 | 9.0 |
| MBL3 | 37L0235004 | 8888447 | 5.6 | 9.7 |
| MBL1 | 37L0234153 | 8889570 | 5.7 | 7.8 |
| MB2 | 37L0234000 | 8801002 | 6.0 | 7.3 |
| BH2B | 37L0232200 | 8890109 | 6.4 | 9.6 |
| MRP13 | 37L0232250 | 8890145 | 7.2 | 9.7 |
| HDL9 | 37L0228956 | 8888266 | 7.8 | 6.6 |

| | | | | |
|---------|------------|---------|---------|---------|
| HDL8 | 37L0227608 | 8887464 | 7.1 | 4.2 |
| MBL8 | 37L0233602 | 8884984 | 6.2 | 9.1 |
| 4A | 37L0230319 | 8882798 | 6.2 | 8.6 |
| MRP13 | 37L0230489 | 8882699 | 7.2 | 9.3 |
| BH3 | 37L0235989 | 8881609 | 7.8 | 9.3 |
| MBL7 | 37L0239012 | 8892878 | 6.7 | 5.1 |
| MRP 15 | 37L0236080 | 8881586 | 7.0 | 9.0 |
| SW1U | 37L0232976 | 8880136 | 5.5 | 4.6 |
| SW1D | 37L0232976 | 8880136 | 5.5 | 4.5 |
| SW2U | 37L0229538 | 8877601 | 6.4 | 4.9 |
| SW3U | 37L0227941 | 8874697 | 6.5 | 8.2 |
| SW3D | 37L0227913 | 8875007 | 6.8 | 7.4 |
| SW4U | 37L0223240 | 8867535 | 7.3 | 8.8 |
| SW4D | 37L0213216 | 8867527 | 7.3 | 8.4 |
| SW5U | 37L0209629 | 8861303 | 6.3 | 3.8 |
| SW5D | 37L0209618 | 8861304 | 6.4 | 3.7 |
| SW6U | 37L0206213 | 8860975 | 6.5 | 2.8 |
| SW6D | 37L0209213 | 8860986 | 6.5 | 2.6 |
| SW7U | 37L0207694 | 8860501 | 6.7 | 3.4 |
| SW7D | 37L0207700 | 8860559 | 6.5 | 3.8 |
| HDL15 | 37L0239012 | 8892875 | 5.8 | 8.1 |
| MBL5 | 37L0240397 | 8891490 | 7.1 | 7.0 |
| MRP24 | 37L0240409 | 8891490 | 6.4 | 9.7 |
| SW2D | 37L0229512 | 8877624 | 7.1 | 6.7 |
| Median | | | 6.5 | 7.3 |
| Average | | | 6.6±0.7 | 6.9±2.1 |

The pH values presented in Table 2 vary from 5.5 to 7.8 with a minimum pH observed in two samples obtained in locations with IDs SW1D and SW1U and a maximum value in sample obtained at ID BH3. Generally, pH values were divided into three groups: weak acidic pH 5.5 to 6.8, neutral pH 6.9 to 7.1 and weak alkaline pH 7.2 to 7.8. As can be seen in the results, about 64 % of the soil samples (BH5A, BH5B, MRP14, MBL2, MRP8, MBL1, MBL3, MBL4, MBL7, MBL8, 4A, BH2B, MB2, SW1U, SW2U, SW1D, SW3U, SW3D, SW5U, SW5D, SW6U, SW6D, SW7U, SW7D, HDL15 and MRP24) was weak acidic. About 12 % of samples (BH30, HDL8, MRP15, MBL5 and SW2D) represented neutral pH and about 24 % of soil samples (GWS1, GWS2, MRP23, HDL2, MRP13, HDL9, MRP13, BH3, SW4U and SW4D) accounted for weak alkaline. An overall mean pH of pH 6.6±0.7 and median of 6.5 shows that soil at MRP is weak acidic. The median value of 6.5 is about 79 % of the maximum recommended pH for normal soils in Tanzania (TBS, 2007). EC values in Table 2 varied gradually from a minimum of 2.6 mScm⁻¹ obtained at one location (ID: SW6D) while the maximum of 9.7 mScm⁻¹ was obtained in samples measured at three locations (IDs: MBL3, MRP24 & MRP13). The mean and median EC were 6.9±2.1 and 7.3 mScm⁻¹, respectively, are much lower than the 400 mScm⁻¹ reported for normal soil by Horneck et al., (2007) known to be associated with soil salinity detrimental to plant growth.

With the exception of Al, Mn and Fe all the heavy metals whose measured concentrations are listed in Table 3 have association with uranium ore deposits. Therefore, knowledge of their concentrations and spatial distribution prior uranium mining can be useful baseline data to assess future pollution associated with uranium extraction. As seen in Table 3, with the exception of Cd, the difference of total concentrations of elements in soils obtained at different depths and locations are marginal. This means the observed concentrations have had little interference with contamination from outside and therefore serve as good baseline data. This feature reduces the need to increase sampling points to establish the baseline data for the proposed uranium mining project at

Mkuju.

Arsenic concentrations at both depths and sampling locations were below detection limit of $1.31 \pm 0.98 \text{ mgkg}^{-1}$; therefore future detection above this value would have strong association with uranium mining activities. Analysis of the data using EDXRF showed a total metal concentration of 3570-19400 for Al, 15200-58600 Fe, 400-1400 Mn, 15.2-54.9 Cr, 13.5-51.0 Zn, 2.2-45.3 Pb, 2.1-37.3 Cd, 0.2-23.0 Hg, 1.8-25.1Cu, 2.1-22.7 Ni and 0.8-9.1 mgkg^{-1} for Co. While the mean and maximum metal concentrations presented in Table 3 are below permissible levels recommended by the United State Environmental Protection Agency (USEPA), European Union (EU) and Tanzania Bureau of Standards (TBS) also shows the measured concentration values should serve as baseline data to be used as indicators when the uranium mining industry should take precaution to minimize pollution.

Table 3. Mean, Standard Deviation (STD), Median, Minimum and Maximum concentrations of Elements obtained from 84 Soil Samples at two depths compared to Permissible Levels from USEPA, EU and TBS

| | Depth | Al* | Cr | Mn* | Fe* | Co | Ni | Cu | Zn | Cd | Hg | Pb |
|------|--------------------|-------|------|------|------|-----|------|------|-------------|------|------|------|
| MEAN | (cm) | 79.2 | 28.3 | 0.8 | 25.9 | 3.1 | 8.6 | 8.7 | 28.5 | 12.2 | 1.9 | 24.8 |
| STD | 0-15 | 17.2 | 6.8 | 0.2 | 7.5 | 1.8 | 3.9 | 3.1 | 7.6 | 6.1 | 3.8 | 8.2 |
| MED | | 80.3 | 27.9 | 0.9 | 24.7 | 2.6 | 8.3 | 8.6 | 28.5 | 12.7 | 0.9 | 24.7 |
| MIN | | 35.7 | 15.2 | 0.4 | 15.2 | 0.8 | 2.1 | 3.2 | 13.5 | 2.1 | 0.2 | 2.2 |
| MAX | | 110.2 | 53.1 | 1.1 | 54.5 | 8.7 | 15.0 | 15.4 | 47.0 | 37.3 | 23.0 | 39.1 |
| MEAN | 15-30 | 89.1 | 33.8 | 0.9 | 30.1 | 4.9 | 10.3 | 11.3 | 32.9 | 15.2 | 1.9 | 25.6 |
| STD | | 15.1 | 6.9 | 0.2 | 9.2 | 2.2 | 4.6 | 4.5 | 8.0 | 5.5 | 3.4 | 7.4 |
| MED | | 87.3 | 32.5 | 0.9 | 29.0 | 4.5 | 10.8 | 10.8 | 32.1 | 14.8 | 1.1 | 24.8 |
| MIN | | 47.9 | 19.0 | 0.4 | 16.4 | 1.1 | 2.1 | 1.8 | 19.0 | 3.4 | 0.2 | 2.6 |
| MAX | | 119.4 | 54.9 | 1.4 | 58.6 | 9.1 | 22.7 | 25.1 | 51.0 | 36.8 | 20.6 | 45.2 |
| MEAN | 0-30 | 84.2 | 31.1 | 0.9 | 28.0 | 4.0 | 9.4 | 10.0 | 30.7 | 13.8 | 1.9 | 25.2 |
| STD | | 17.0 | 7.4 | 0.2 | 8.7 | 2.3 | 4.4 | 4.1 | 8.2 | 6.0 | 3.6 | 7.8 |
| MED | | 84.6 | 30.4 | 0.9 | 27.1 | 3.5 | 9.8 | 9.9 | 31.5 | 13.8 | 1.0 | 24.7 |
| MIN | | 35.7 | 15.2 | 0.4 | 15.2 | 0.8 | 2.1 | 1.8 | 13.5 | 2.1 | 0.2 | 2.2 |
| MAX | | 119.4 | 54.9 | 1.4 | 58.6 | 9.1 | 22.7 | 25.1 | 51.0 | 37.3 | 23.0 | 45.2 |
| MEAN | World ¹ | 71 | 100 | 0.6 | 38 | | 40 | 30 | 50 | 0.06 | 0.03 | 10 |
| MIN | | 10 | 1 | 0.02 | 7 | | 500 | 2 | 10 | 0.01 | 0.01 | 2 |
| MAX | | 300 | 1000 | 3.0 | 550 | | | 100 | 300 | 0.7 | 0.3 | 200 |
| MAX | TBS ² | | | 1.5 | | | 100 | 200 | 150 | 1 | | 200 |
| MAX | EPA ³ | | 11 | | | | 72 | 270 | 1100 | 0.43 | | 200 |
| MAX | EU ⁴ | 150 | 75 | 140 | 300 | | 3 | | 1 | 300 | | |

Note: *=multiplied by 10^3 ; 1¹(Vinogradov, 1959; Lindsay, 1979; Murthy, 2008); 2=(TBS, 2007); 3=(USEPA, 2002); 4=(EU, 2002).

3.1 Correlation Analysis

In principle, the concentrations of elements that occurred naturally have a certain association because of their common origin. Therefore knowledge of this association could be used as additional baseline data because subsequent pollution would distort the association. Since correlation is strong index this association, it was calculated for the concentration of all elements present in the samples (in achieves-too large to be presented) and the values obtained are presented in Table 4.

Table 4. Correlation Coefficient of Concentration values of different Elements in 84 Soil Samples from Mkuju river Basin. Significantly at levels of α 0:05

| | Al | Cr | Mn | Fe | Co | Ni | Cu | Zn | Cd | Hg | Pb |
|----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----|
| Al | 1 | | | | | | | | | | |
| Cr | 0.33 | 1 | | | | | | | | | |
| Mn | 0.28 | 0.21 | 1 | | | | | | | | |
| Fe | 0.31 | 0.21 | 0.22 | 1 | | | | | | | |
| Co | 0.08 | 0.28 | 0.10 | 0.29 | 1 | | | | | | |
| Ni | 0.40 | 0.41 | 0.13 | 0.62 | 0.31 | 1 | | | | | |
| Cu | 0.13 | 0.38 | 0.23 | 0.28 | 0.43 | 0.24 | 1 | | | | |
| Zn | 0.32 | 0.36 | 0.16 | 0.45 | 0.19 | 0.54 | 0.22 | 1 | | | |
| Cd | 0.11 | 0.06 | 0.18 | 0.15 | 0.34 | 0.09* | 0.23 | 0.06 | 1 | | |
| Hg | 0.26 | 0.12 | 0.08* | 0.34 | 0.27 | 0.13 | 0.01 | 0.41 | 0.05* | 1 | |
| Pb | 0.21* | 0.12* | 0.33 | 0.11* | 0.07* | 0.16* | 0.16* | 0.15* | 0.18* | 0.05* | 1 |

Note: *=negative correlation

From this table, it is clear that the correlation of elemental concentrations could be grouped in three categories: high ($r =$ above 0.4, $p < 0.05$), medium ($r =$ positive but less than 0.4, $p < 0.05$) and low ($r =$ negative values). The elements in the first category include: Cr-Ni, Cr-Cu, Cr-Zn, Zn-Ni, Zn-Hg, Fe-Ni, Cu-Co and Fe-Zn. The elements in the second category include: Al-Cr, Al-Mn, Al-Fe, Al-Co, Al-Cu, Al-Zn, Al-Cd, Al-Hg, Cr-Mn, Cr-Fe, Cr-Co, Cr-Cd, Cr-Hg, Mn-Fe, Mn-Co, Mn-Ni, Mn-Cu, Mn-Zn, Mn-Cd, Mn-Pb, Fe-Co, Fe-Cu, Fe-Cd, Fe-Hg, Co-Ni, Co-Zn, Co-Zn, Co-Cd, Co-Hg, Ni-Co, Ni-Hg, Cu-Zn and Cu Cd. Thus, future deviations of these correlations could be interpreted as being caused by pollution related to the mining of the Mkuju River Project.

4. Discussion

For a concentration value to serve as baseline data it has to have various features. It must represent the natural distribution elemental concentration of the area likely to be affected by the mining project and location of sampling points must be reproducible. In principle, establishment of baseline data for such a vast area, about 1300 km² in this case, can be a very challenging undertaking because it requires an enormous amount of sampling points, sample transport, preparation and elemental concentration measurements. As described earlier, the first requirement was achieved by finding methods to reduce sampling points using clustering areas with similar soil profile and dose rate. The second one was achieved by assigning GPS to each sampling point.

Since most of the heavy metals are not radioactive, use of dose rate for clustering of similar elemental concentration has its limitations in achieving the first requirement. Assuming that during soil formation elements were uniformly distributed in the soil profile, subsequent variation of elemental concentration or retention in soil at different layers would strongly depend on soil texture. Therefore use of soil texture would be a better approach to achieve this requirement. In this study both dose rate and soil texture were used to reduce the number of samples, as indicated in Table 2, to demarcate the vast area into 42 sample plots identifiable using ID number with GPS reference for future reproducibility of sampling locations. From the minimum, maximum and mean concentration values obtained it is evident that the variations of concentration levels for adjacent plots were not radically different. This means the measured spatial distribution of elemental concentrations (in achieves) is a good representation of the current elemental distribution in the region. Therefore could serve as baseline data needed to assess future pollution that will be related to the uranium mining.

5. Conclusion

The aim of this study was to establish baseline reference data for 13 heavy metals in soils adjacent of the proposed Mkuju river uranium project for subsequent monitoring for compliance with best practices in uranium mining. Gradual variation of elemental concentration values in adjacent plots is a strong indication that the elemental concentration obtained before averaging is a good representative of the background elemental distribution of the area surrounding the planned uranium mining project and therefore can be used as baseline data. However, some of the observed features make concentrations of some elements better baseline data than others. Since the association of lead and copper to uranium mining is high and their mobility values in soil are

low, the concentration levels of these elements form important baseline data for assessing future pollution by the uranium mining process. Moreover, implicit in high correlation between metals is indication of similar origins, degradation of correlation between zinc and mercury and nickel would be a strong indicator for pollution due to the future uranium mining process. The correlation between copper and cobalt serve similar purpose.

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