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Elemental Concentration and Physicochemical Properties of Soils under Different Landuses in Gashua a Sahel Region of Nigeria

Research Article

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Abstract

Soil elements assessment under various land uses is vital in knowing the status of the soils in terms of fertility and toxicity. Therefore, a study was conducted to investigate some elements concentrations of soils under three different land uses in Gashua, Yobe State, Nigeria. Samples were randomly taken at 0-15 and 15-30 cm soil depth intervals from land uses. The land uses are Dry upland (DU), Lowland (LL) and Residential area (RA). The selected elements were determined in the laboratory using Atomic Absorption Spectrophotometer (AAS), while some physicochemical properties were determined using routine soil analysis methods. The results indicated significantly higher concentrations of Iron (6.96 mg kg^{-1}), Manganese (3.12 mg kg^{-1}) and clay content (12.88%), except for Nickel which was higher in DU (2.36 mg kg^{-1}) but at par with the content in LL (2.04 mg kg^{-1}) land use. There was no significant difference within the following soil elements within the study location: Cadmium (Cd), Chromium (Cr), Copper (Cu) and Lead (Pb) were below detection limit within the soils of the chosen land use types. Generally the soils textural class is sandy loam with higher mean bulk density (1.62g cm^{-3}) and a neutral soil pH (6.81). The physicochemical properties and elements investigated didn't show significant differences with soil depth. The basic elemental concentrations within the soils were mostly adequate for crop production, except Zn, with little variability within the landuse. They were generally below the utmost ecological risk permissible level set by WHO and FAO.
Keywords: Gashua, land use, soil texture, trace elements.

1. INTRODUCTION

Soil as a non-renewable resource and dynamic nature is prone to rapid degradation with land misuse (Eswaran et al., 2001). Land use is defined as the type of activities to which land is subjected to, including the inputs added, manipulation and management practices employed to produce, utilize and preserve (Ufot et al., 2016). Judicious land use is a principal factor underlying sustained agricultural production, maintenance and enhancement of the productive potential and life-support processes of natural resources

(Srivastava et al., 1993). Different land uses, because of the different activities taking place on them may impact the soils physico-chemical properties differently, which may also require different management strategies. The physical properties of soils determine their adaptability to cultivation and the level of chemical and biological activity in the soil. Soil physical properties affect to a large extent soil water content and air for proper growth of plants. Soil physical properties can also be affected greatly by changes in land use systems and management practices (Tilahun, 2007; Sanchez, 1976).

Properties such as soil texture, structure, bulk density, porosity, moisture content and retention capacity are among the common soil physical properties. Soil texture refers to the relative percentage of sand, silt and clay within a soil layer and Bulk density is an indicator of soil compaction and reflects the soil ability to function for structural support, water and solute movement, and soil aeration (Arshad et al., 1996). Soil texture is an important aspect because it affects other physical and chemical properties such as water holding capacity and base saturation. It is also the primary factor determining the vertical distribution pattern and storage of carbon, nitrogen and phosphorus in savanna soils (Tabor et al., 2017). Bulk density is another physical property of soil that has a great influence on the soil porosity and compaction. It may cause restrictions to root growth and poor movement of air and water through the soil (Weil and Brady, 2017).

Elements are released overtime due transformations and various reactions of some minerals in the soil inherited from the parent materials. These elements perform different functions, some are essential in plant and animal nutrition, while others, their roles are not link to nutrition and their presence above known safe limits may endanger the environment as well as both plant and animal health (Weil and Brady, 2017). Elements like Cobalt (Co) Copper (Cu), Iron (Fe), Manganese (Mn), Nickel (Ni) and Zinc (Zn) are considered essential in plant and animal nutrition while, Cadmium (Cd), Chromium (Cr) and Lead (Pb) are not considered essential in their nutrition (Weil and Brady, 2017).

Timely and periodic assessment of the impact of land uses on elemental availability, distribution and ecological risks is indispensible for sustainable management of the soils of any area. The study is exploratory due to lack of information on background concentrations of the elements in soils of the study area. The objective of the study is to evaluate the concentrations of Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn in soils within three land use types in Gashua, Yobe State, Nigeria.

2. MATERIALS & METHODS

Description of the Study Area

The study was conducted at Gashua in Bade Local Government Area of Yobe State, Northeast Nigeria. It is situated 190 km North West of Damaturu, the State Capital. It is located between longitudes 9° 00’ and 10° 30’ N and latitudes 9° 30’ and 10° 30’E and at an altitude of 293 meters above sea level. The area is situated in the Sahel savanna agro-climatic zone with a unimodal rainfall pattern of an average annual rainfall of 300 - 430 mm and maximum rain is received between August and September. The annual mean minimum and mean maximum temperatures at the study area are 12 and 44°C respectively.

Land Use Types

Three land use types’ namely dry upland arable farms (arable crops such as millet, cowpea, sesame, sorghum etc. are grown), lowland farms along the floodplains of river Yobe (vegetables, rice and wheat are the common crops cultivated in these areas) and residential area (inhabited by human settlements) were studied in Gashua in Bade Local Government Area of Yobe State, Nigeria.

Soil Sample Collection

Stratified random-composite sampling design was adopted for the survey. Three representative soil samples were collected randomly using a soil auger from each of the four replicate of each land use type at two soil depths of 0 – 15cm and 15 – 30cm. The samples per replicate per depth were composite for laboratory analysis. Sampling cylinders were also used in taking undisturbed samples from each replicate closer to auger sampling points for bulk density determination (Estefan et al., 2013). The augured soil samples were then air-dried at room temperature for 5 days, sieved before analysis.

Soil Analysis

The soil properties analyzed include soil particle size distribution (PSD), bulk density (BD), pH, Cobalt (Co), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Manganese (Mn), Nickel (Ni), Lead (Pb) and Zinc (Zn). Soil particle size distribution was determined by the hydrometric method (Estefan et al., 2013). Soil bulk density was determined by the undisturbed soil core sampling method. The soil samples were dried in an oven at 104ºC to constant weights and calculated as:

$$BD\ (g\ cm^{-3}) = \frac{W}{V} \tag{1}$$

Where: W = weight of oven dry soil (g) and V = volume of soil sample (cm^{-3}). The pH of the soils was measured in a 1:2 (soil: water) suspension potentiometrically using digital pH meter (Estefan et al., 2013).

Soil samples were digested using Nitric-sulphuric-perchloric acid digestion method as modified from Idera et al (2015). Five gram of soil samples were measured into 125ml Beaker and a mixture of 2ml, 4ml and 25ml, of concentrated H_2SO_4, $HClO_4$ and HNO_3 were added respectively for digestion on a hot plate in a fumes hood. The digested sample was allowed to cool at room temperature and 50ml of deionized water was added and then filtered through a 0.45µ Millipore membrane filter paper. The filtered samples were then made up to 100ml with deionized water. The concentration of the selected elements (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) were then determined from the extract with Atomic Absorption Spectrophotometer (PerkinElmer 900T Boston, USA) using appropriate lamp.

Statistical Analysis

The analyzed data from the laboratory tests were subjected to descriptive statistics and analysis of variance technique using R version 3.6.1 statistical package. Differences among the means were separated using HSD criterion at 5% significance level (R, 2019)

3. RESULTS & DISCUSSION

The summary statistics of the soil properties determined were presented in Table 1. The results indicated normally distribution for the variables tested except for clay (1.47) and Mn (1.82) which were positively skewed. The means of the soil properties were not far from their median values; this indicated existence of very few outliers or none. The Coefficient of variation of the soil properties were low for soil pH (6.76%), BD (7.85%), sand (8.63%), Fe (9.03%), Zn (11.37%); moderate for Silt (28.80%) and higher in clay (38.56%), Co (48.66%), Mn (66.70%) and Ni (77.15%) according to the ratings in Tabi and Ogunkunle (2007). This revealed considerable variability as such site-specific management may be required.

Table-1. Descriptive Statistics of the Mean values of the Physico-chemical Properties and Elemental Concentrations in the Soils of the Study Areas

Variables	Min	Max	Mean	Median	IQR	SD	SEM	CV (%)	Skewness
Sand (%)	61.00	88.00	76.00	76.00	8.50	6.56	1.34	8.63	-0.24
Silt (%)	7.00	21.00	14.00	14.00	6.50	4.03	0.82	28.80	0.08
Clay (%)	4.00	23.00	10.00	9.50	4.00	3.86	0.79	38.56	1.47
BD (g cm^{-3})	1.38	1.85	1.62	1.66	0.12	0.13	0.03	7.85	-0.57
pH	6.13	7.86	6.81	7.73	0.63	0.46	0.09	6.76	0.66
Co (mg kg^{-1})	0.01	0.38	0.20	0.22	0.14	0.10	0.02	48.66	-0.16
Mn (mg kg^{-1})	0.48	5.46	1.89	1.72	0.98	1.26	0.26	66.70	1.82
Ni (mg kg^{-1})	0.06	4.59	1.74	2.10	2.18	1.34	0.27	77.15	0.39
Fe (mg kg^{-1})	5.79	7.89	6.69	6.57	0.81	0.60	0.12	9.03	0.42
Zn (mg kg^{-1})	0.68	1.22	0.95	0.97	0.10	0.11	0.02	11.37	-0.18
Cd	ND	ND	ND	ND					
Cr	ND	ND	ND	ND					
Cu	ND	ND	ND	ND					
Pb	ND	ND	ND	ND					

Min = minimum, Max = maximum, IQR = interquartile range, SD = standard deviation, SEM = standard error of the mean, CV = coefficient of variation.

The soil particle size distribution (PSD) showed that the sand and silt fractions did not significantly differ among land use types (Figure 1 and 2 respectively). The overall mean of the clay fraction was found to be significantly higher in the Lowland (12.88%) compared to Dry upland (8.61%) and Residential area (8.50%) (Figure 3). High clay content in Lowland may presumably be due to the physiographic location of Lowland and the nature of the erosional sediments deposited and intensive soil management practices that promote further weathering processes could be a possible reason for higher clay content (Negasa et al., 2017). The dominant soil textural class (Sandy loam) throughout the study area indicates the homogeneity of soil forming processes and the similarity of parent materials. Soil bulk density was also not significantly affected by land use effects (Figure 4). The highest (1.67 g cm^{-3}) mean value of soil bulk density was recorded under cultivated lowland area (LL) and the lowest (1.57 g cm^{-3}) mean BD was found in Dry Upland (DU). Similar mean bulk density value (1.63 g cm^{-3}) was also reported for soils of Bade LGA in Yobe State, Nigeria by Alhassan et al. (2018). The average bulk densities recorded in the study area are marginally high for crop growth, because it was reported that for optimum movement of air and water through the soil, it is generally desirable for the soil to have a BD of < 1.5gcm^{-3} and that in general bulk densities greater than 1.6gcm^{-3} tend to restrict root growth (Hunt and Gilkes, 1992; McKenzie et al., 2004). The high bulk density recorded could be attributed to the high sand content of the soils as was reported that sand content have a greater effect on bulk density than other soil properties (Chaudhari et al., 2013). This was further substantiated by Lal (2006) who reported that normal range of bulk densities for clay is 0.90 to 1.40 gcm-3 and a normal range for sand is 1.40 to 1.90 gcm-3 with potential root restriction occurring at ≥ 1.40 gcm-3 for clay and ≥ 1.60 gcm-3 for sand.

Soil pH showed little variability across the land uses with a mean value of 6.81 and ranged from 6.57 to 6.95 (Figure 5), the soils are then categorized as neutral (6.51 to 7.5) by Weil and Brady (2017). Soil pH is an important secondary determinant of nutrients availability and transport as it affects their water solubility in the soil. The pH values of 6.5 to 7.5 is considered ideal for crop production (Estefan et al., 2013) therefore, the soil pH values of the study area is considered good for crop production and will not require any amendment.

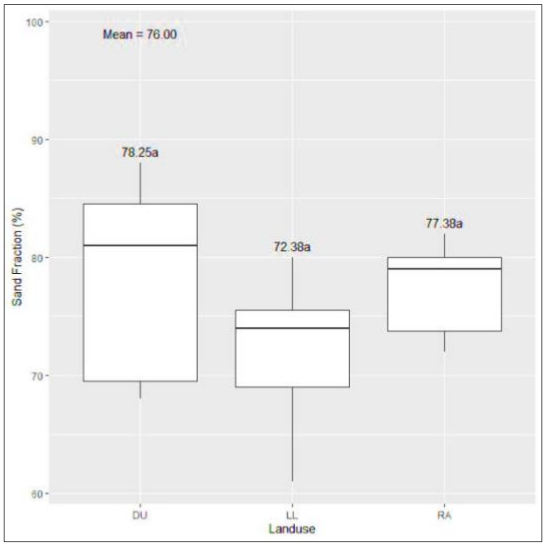

Figure-1. Sand Fraction Distribution of the Soils Under Landuse types (Dry Upland Farm (DU), Lowland Farm (LL) and Residential Area (RA)

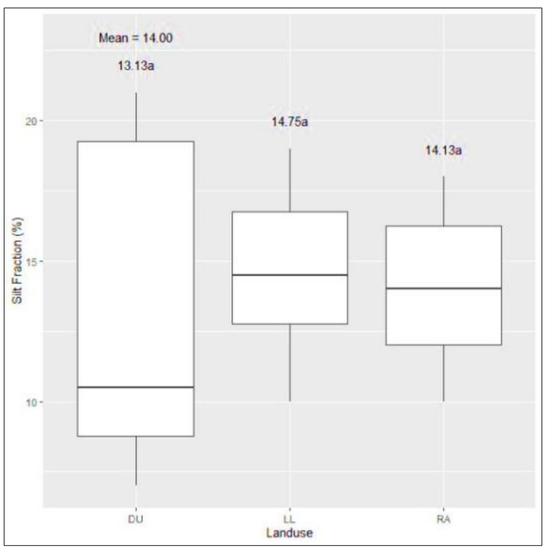

Figure-2. Silt Fraction Distribution of the Soils under Landuse types (Dry Upland Farm (DU), Lowland Farm (LL) and Residential Area (RA)

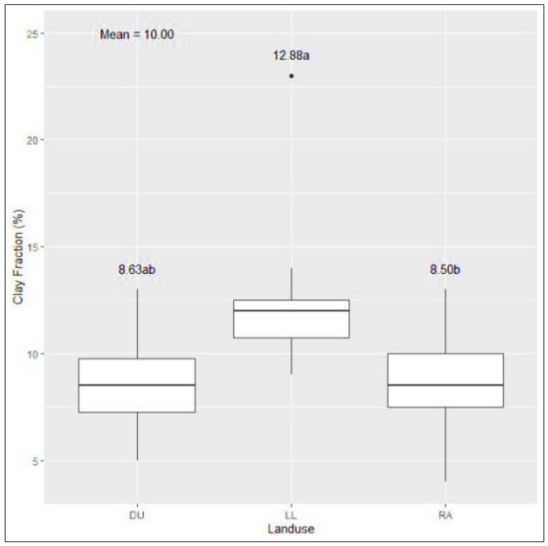

Figure-3. Clay Fraction Distribution of the Soils under Landuse types (Dry Upland Farm (DU), Lowland Farm (LL) and Residential Area (RA)

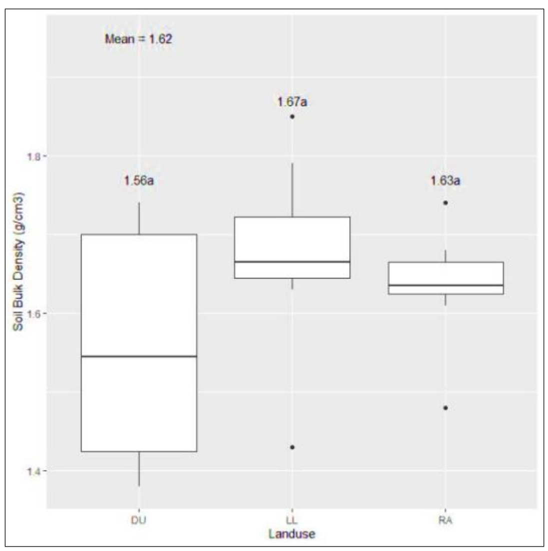

Figure-4. Bulk Density (g cm^{-3}) of the Soils under Landuse types (Dry Upland Farm (DU), Lowland Farm (LL) and Residential Area (RA)

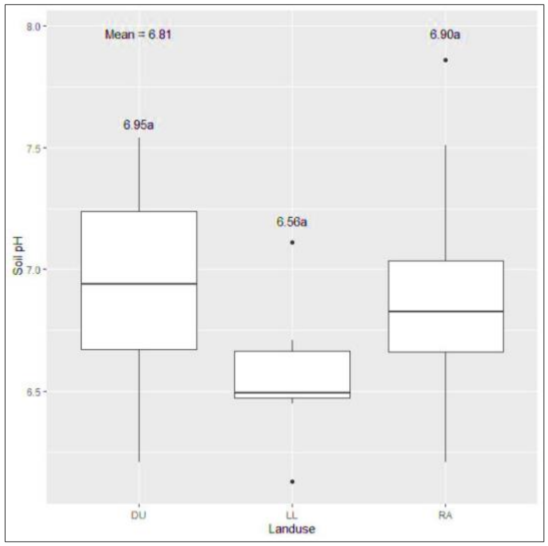

Figure-5. pH of the Soils under Landuse types (Dry Upland Farm (DU), Lowland Farm (LL) and Residential Area (RA))

The mean elemental concentrations (mgkg^{-1}) in the soils of the land use types were presented in Figures 6 to 10. Result showed that Cobalt (Co) was not significantly different between the land uses (Figure 6). Cobalt is considered an essential nutrient in trace amounts for ruminant animals, largely due its requirement for rumen bacteria, atmospheric N_2-fixation by microorganisms and for plants (Ma and Hooda, 2010). A concentration of Co (4.6–9.1 mgkg^{-1}) was reported for some soils in Nigeria (Agbenin et al., 2009). The mean concentration of Co recorded at the study sites were below the WHO/FAO (2001) ecological risk permissible limit of 100 mgkg^{-1} for soils.

The mean concentration of iron (Fe) ranged from 6.23 to 6.96 mgkg^{-1} with a mean value of 6.69 mgkg^{-1} (Table 1). The result indicated significant difference between the land uses with high concentration in LL which was at par with RA and lower in DU (Figure 7). The mean concentration of Fe recorded was above the critical limit (>5 mgkg^{-1}) for crop production (Esu, 1991) and below the FEPA (1991) guidelines for heavy metals in soils ecological risk threshold value of 400.00 mgkg^{-1}. In agreement to our findings Mulima et al. (2015) reported higher values of Fe for the soils of similar agro-ecological zone and Munkholm et al. (1993) reported that Fe and Mn deficiencies in tropical Africa are rare. The high mean Fe content in the soil indicates that Fe deficiency is not likely for crops grown on these soils. However, the presence of Fe in high concentrations in soils could lead to the formation of phlintite upon complex chemical reactions Plinthosols are more common type of soils in the wetter parts of the Sahel and are always rich in iron (Decker's et al, 1995).

Significantly higher Mn concentration (3.12 mg kg^{-1}) was recorded in LL and lower at DU (1.12 mg kg^{-1}) at par with RA (1.41 mg kg^{-1}) (Figure 8). The mean value (1.88 mg kg^{-1}) indicated moderate availability for crop production (Esu, 1991; Shukla and Gupta, 1975). It was further supported by Horneck et al. (2011) that soil test values for Mn of between 1 and 5 ppm are usually sufficient for crop production. In contrast Mulima et al. (2015) reported a very high mean value of Mn (10.23 mgkg^{-1}) for the soils of similar environment in Nigeria.

Although the concentration of Iron and Manganese recorded are adequate for crop production, the values are far below those reported in other parts of Nigeria. 10.8 mg kg^{-1} and 34 mg kg^{-1} respectively for Fe and Mn were reported for soils of Northern Guinea Savanna region of Nigeria by Mustapha et al. (2011), 19.6 mg kg^{-1} for Fe in Sudan Savanna by Oyinlola and Chude (2010), 22.5 mg kg^{-1} and 21.5 mg kg^{-1}for soils of Bauchi, northern guinea Savanna (Oluwadare et al., 2013) and 14.48 mg kg^{-1} and 17.59 mg kg^{-1}for soils of Billiri, northern guinea Savanna of Nigeria (Ibrahim et al., 2011). This could be attributed to the neutral pH in where the availability of Fe and Mn tend to be low. It was reported that with increase in soil pH decreases the solubility of most trace elements, which often leads to their low concentrations in soil solution (Kabata-Pendias, 2011).

Nickel is an essential micro nutrient for plants and is equally important to animals. As with other trace metals, elevated Ni concentrations in soils have potential negative impact on plants, microorganisms and animals (Ma and Hooda, 2010). The mean concentrations of nickel recorded in the soil samples ranged from 0.80 to 2.36 $mgkg^{-1}$ with a mean value of 1.73 $mgkg^{-1}$ (Figure 9). This value is lower than 12.6–25.7 mg kg^{-1} reported for some soils in northern Nigeria (Agbenin et al., 2009) and Ogundele et al. (2015) reported 1.83 – 14.87 $mgkg^{-1}$ as the mean concentration of Ni in soil for North Central Nigeria. The mean concentrations of Ni recorded from the studied land uses were below the WHO/FAO (2001) permissible limit of 50 $mgkg^{-1}$ for soils. Large variability of Ni could be attributed to spatial variability in the sampling points within the lowland area as reported that micronutrient content in the soil often shows considerable spatial variation (Hengl et al., 2017), while the low mean value may be due to high pH level of the soils. The Ni concentration in soils of the studied area may not pose environmental problem and is above lowest required level (< 0.5 $mgkg^{-1}$) for plant nutrition (Guodong et al, 2020).

The mean concentration of zinc (Zn) ranged from 0.90 to 0.98 $mgkg^{-1}$ with a mean value of 0.95 $mgkg^{-1}$ (Figure 10). This is in agreement with Mulima et al. (2015) who reported low mean Zn status (0.85 $mgkg^{-1}$) for the soils of Geidam in Yobe State, Nigeria and lower than the mean value of 3.00 $mgkg^{-1}$ recorded for Kano urban agricultural lands in Nigeria (Dawaki et al., 2013) and 31.17 $mgkg^{-1}$ for some soils in South Western Nigeria (Adagunodo et al., 2018). Zinc deficiency was also reported that it predominates the list of micronutrients that are deficient in sub Saharan African arable soils (Kihara et al., 2020), therefore crops like rice and maize that are susceptible to Zn deficiency may require Zn fertilization in the study area. The mean concentration of Zn recorded in the study area was below the WHO/FAO (2001) ecological risk permissible limit of 300 $mgkg^{-1}$ for soils.

Cadmium (Cd), Chromium (Cr), Copper (Cu) and Lead (Pb) were not detected in the soils of the study area as such they pose no threat to the environment (Table 1).

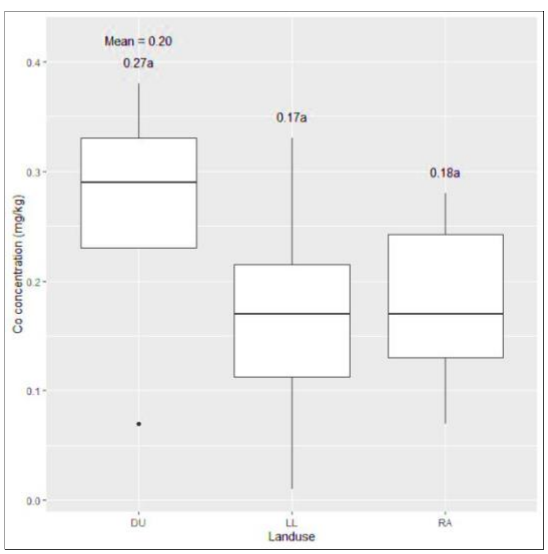

Figure-6. Cobalt (Co) concentration (mg kg^{-1}) of the Soils under Landuse types (Dry Upland Farm (DU), Lowland Farm (LL) and Residential Area (RA))

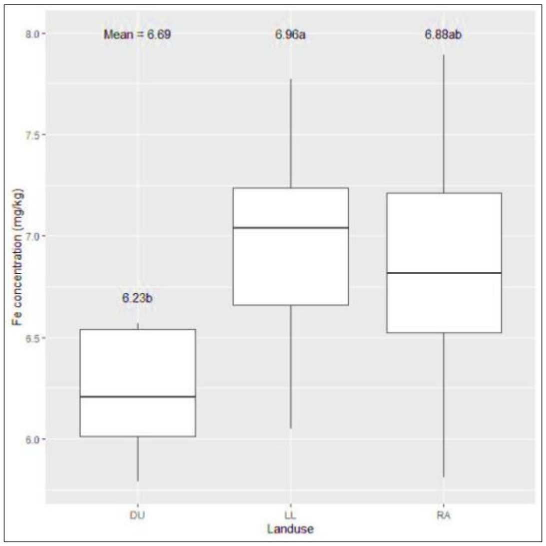

Figure-7. Iron (Fe) concentration (mg kg^{-1}) of the Soils under Landuse types (Dry Upland Farm (DU), Lowland Farm (LL) and Residential Area (RA))

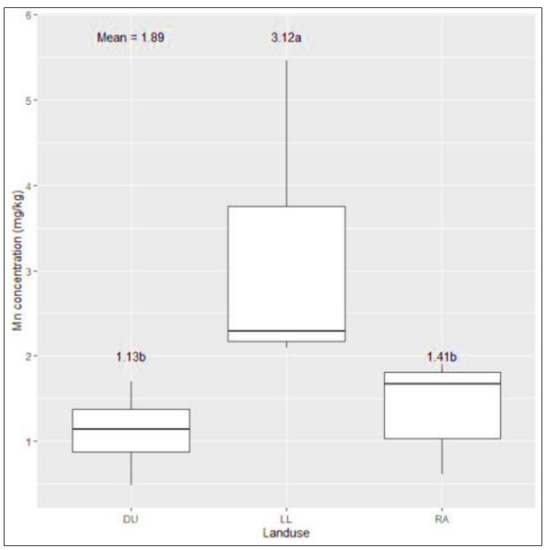

Figure-8. Manganese (Mn) concentration (mg kg^{-1}) of the Soils under Landuse types (Dry Upland Farm (DU), Lowland Farm (LL) and Residential Area (RA))

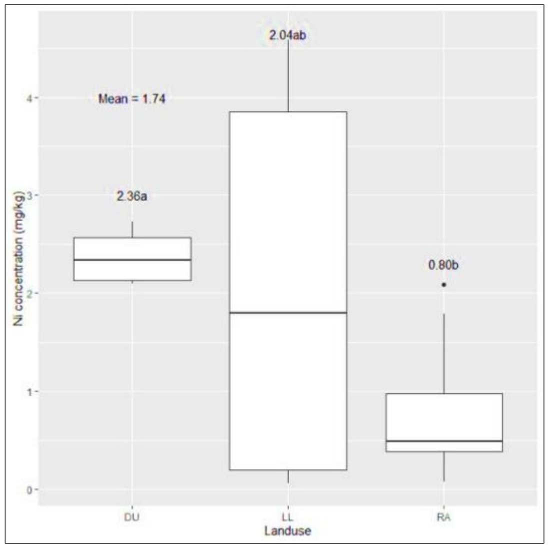

Figure-9. Nickel (Ni) concentration (mg kg^{-1}) of the Soils under Landuse types (Dry Upland Farm (DU), Lowland Farm (LL) and Residential Area (RA))

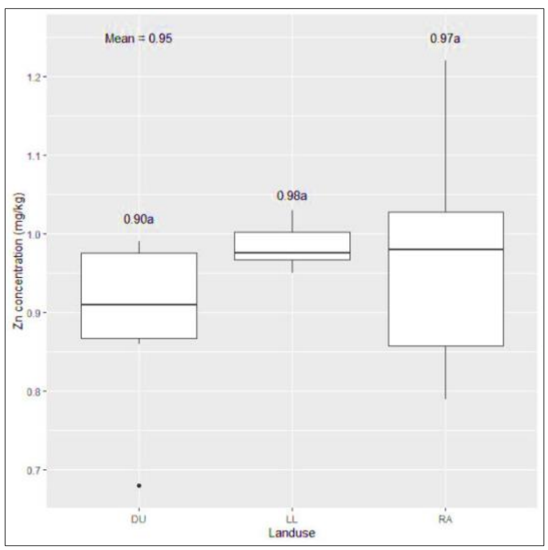

Figure-10. Zinc (Zn) concentration (mg kg^{-1}) of the Soils under Landuse types (Dry Upland Farm (DU), Lowland Farm (LL) and Residential Area (RA))

The soil depth (0-15 and 15-30cm) was found not to have significant influence on all the measured soil variables (Table 2), but clay fraction showed high coefficient variability (37.50%) and in the concentrations elements such as Co (48.94), Mg (40.76%), Mn (67.95%) and Ni (78.87%).

Table-2. Effect of Soil Depth on the Soil Properties

Soil Properties	0 - 15cm	15 -30cm	Mean	SE	CV (%)
Sand (%)	74.5	77.5	76	2.66	8.58
Silt (%)	14.33	13.67	14	1.68	29.35
Clay (%)	11.17	8.83	10	1.53	37.5
Textural class	SL	SL			
Bulk Density (g cm^{-3})	1.58	1.66	1.62	0.05	7.6
pH	6.76	6.85	6.81	0.19	6.87
Calcium ($mgkg^{-1}$)	2.91	3.23	3.07	0.23	18.32
Cadmium ($mgkg^{-1}$)	ND	ND	ND		
Cobalt ($mgkg^{-1}$)	0.19	0.22	0.20	0.04	48.94
Chromium ($mgkg^{-1}$)	ND	ND	ND		
Copper ($mgkg^{-1}$)	ND	ND	ND		
Potassium ($mgkg^{-1}$)	0.52	0.51	0.51	0.01	6.61
Iron ($mgkg^{-1}$)	6.92	6.46	6.69	0.23	8.53
Magnesium ($mgkg^{-1}$)	2.85	3.48	3.17	0.53	40.76
Nickel ($mgkg^{-1}$)	1.71	1.76	1.73	0.56	78.87
Lead ($mgkg^{-1}$)	ND	ND	ND		
Zinc ($mgkg^{-1}$)	0.98	0.92	0.95	0.04	11.03

LL = lowland, RA = residential area, DU = dry upland, SE = standard error, CV = coefficient of variation, ND = not detected

4. CONCLUSION

The results showed that five of the elements analyzed (Co, Fe, Mn, Ni and Zn) were present in soil samples at the three landuses sites, while Cu, Cr, Cd, and Pb were not detected. Significant differences were found between the land uses in the concentrations of Fe, Mn and Ni, higher values were recorded under LL except for Ni while lower concentrations were mostly recorded in DU. Generally, the concentrations of the elements in soils under varying landuses studied are within the required concentrations for crop production except for Zn. The elemental concentrations in the soils do not exceed the maximum permissible concentration limit according to USEPA (2002) and WHO/FAO (2001) guidelines.

There is a need for regular assessment and monitoring of these elements in the study area in order to sustain agricultural production and protect the environment as well as human and animal health from the hazards that elevated levels of the elements may pose. The variability of the concentrations under difference landuses may require site specific management. Addition of organic matter (OM) can be useful in improving soil physical condition, reduce compaction, supply plant nutrients and maintain elemental balance in the soil.

5. ACKNOWLEDGEMENT

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6. CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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