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Magnetic Susceptibility and Heavy Metal Contamination in Farmland Soils of Mangu area, Plateau State, Nigeria

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ABSTRACT

Magnetic susceptibility measurements of soil samples collected at depths 0, 15, 30, and 45cm from thirty-three different farmlands within the study area were made using MS2G Sensor connected to Bartington MS 2 susceptibility meter. The concentration of heavy metals in thirty-three soil samples and most used fertilizers in the study area was determined using a flame atomic absorption spectrophotometer. Spatial distribution of mass-specific susceptibility ($\chi_{mLF)}$ with depth show highest χ_{mLF} values at the surface (0 cm) and 15 cm deep in most of the districts apart from Kerang district, which had the highest value at 45 cm depth for two sample locations, implying probable magnetic enhancement within the A-horizon of the soil profile.χ_{mLF} results also revealed that 81% of the dried soil samples exhibited ferromagnetic behaviour, and 19% exhibited paramagnetic behavior. The concentration of Cadmium, Copper, Iron, Lead, and Zinc obtained for soil samples were compared with the international regulatory standards, and this revealed that the soil samples were neither contaminated with these heavy metals nor toxic. Cadmium, Cobalt, Chromium, Copper, Iron, Nickel, Lead, and Zinc in the two most used fertilizer brands revealed that Cadmium, Cobalt, Chromium, Copper, Iron, Lead, and Zinc was more in Fertilizer A than Fertilizer B. At the same time, Nickel was more in Fertilizer B than A. Continuous application of these fertilizers can contaminate the soils. The relationship between χ_{mLF} and Fe, Cd, Pb, Zn, and Cu, respectively, showed a strong positive correlation or relationship between χ_{mLF} and these heavy metals.

1.0 Introduction

Magnetic Susceptibility measurement is a physical property measurement of a substance that determines the substance's ability to be magnetized. Magnetic susceptibility is an essential parameter in an environmental magnetic study for the spatial distribution of heavy metals. Thus identifying the spatial distribution of magnetic susceptibility is vital since it can give indirect information on heavy metal content (Dankoub et al., 2012). The heavy metals present in the soil are either natural (through lithogenesis, pedogenesis) or anthropogenic, resulting from mining, agricultural and industrial activities (Wolink and Fricke, 1985; Thompson and Oldfield, 1986). Soil magnetic susceptibility is a technique with great potential for mapping and indirectly quantifying soil attributes (Camago et al., 2014; Matias et al., 2014). The techniques that employ soil's magnetic properties have been widely applied by environmental scientists and have been a tremendously successful determinant in pollution research (Magiera et al., 2006; Jordanova et al., 2006).

In recent years, this method is widely adopted for its use in agriculture (Canbay, 2010). The increased recognition of sustainable production has stimulated studies on evaluation techniques and methods of the agricultural potentials on a detailed scale that are fast, accurate, and economical. Therefore, evaluating the agricultural system's expected performance must be improved by applying a quantitative indicator such as the soil's magnetic susceptibility (Siqueira et al., 2010). The rapid and accurate characterization of soil attributes' spatial variability can facilitate effective local management practices. Moreover, this information is used to develop global indexes and land-use changes (Rockström et al., 2009). Marques Jr. et al. (2014) opined that it could increase the accuracy in the delineation of areas of different variability patterns of soil properties. Siqueira et al. (2010) used it to quantify physical, chemical, and mineralogical soil attributes with low iron content and tools that enable sustainable agriculture production.

In a nation such as Nigeria where farming activities are intensive, it is crucial to monitor contaminant levels in farmland soils because many farmers improve soil fertility and hence crop yield use inorganic or mineral fertilizers. Some of these inorganic fertilizers contain heavy metals; for example, according to FAO(2006), some Phosphorus fertilizers may contain heavy metals that originate from Phosphate rocks. Most metal micronutrients (Fe, Mo, Mn, Ni, Cu, and Zn) are also heavy metals. Thus, not all heavy metals are toxic, especially where present within permissible limits. The toxicity of a metal depends on its concentration to plant needs and tolerance. At excessive concentrations, even micronutrients can become toxic. Excessive accumulation of heavy metals in farmland soils may not only result in environmental contamination. However, it may also pose risks and hazards to humans through direct ingestion or contact with contaminated soils, the food chain (soil-plant-human or soil-plant-animal-human), reduction in food quality (safety and marketability), and reduction in land usability for agricultural production causing food insecurity (El Baghadadi et al., 2011; McLaughlin et al., 2000). Farming is an essential and major activity in Mangu LGA of Plateau State, where multiple cropping systems are practiced for insurance. Maize and Irish potatoes are produced in large quantities, and among crop plant species, maize is one of the most important cereal crop in the world, (Malkwowski et al., 2005; Hussain et al., 2013)

Mangu Local Government Area (LGA) of Plateau State, Nigeria is divided into eleven districts. Mangu is highly dynamic in terms of relief, characterize by hilly ranges, flatlands, dotted hills, and mountains. Mangu LGA forms part of the Jos plateau and has geology made up of the Precambrian gneisses, migmatites, and granites known in general as Basement Complex rocks; medium to coarse-grained granites known as the Younger Granites rocks thought to be of Jurassic age of about 160 million years old (Jacobson et al., 1958; Macleod et al. 1971). The study area was also affected by volcanic activities from the Tertiary to the Recent times especially in the following districts; Ampang-West, Dai, Kerang-Tulu, Kogul, Naroghos Mandyen, and Sambe, and this has created numerous volcanoes and vast Basaltic plateaus from the lava flow and a significant crater lake in the area. The Basalts have been affected by various degrees of weathering where they have been decomposed to lateritic soils (Gusikit, 2010). Tertiary to recent lateralized Older Basalts and unlateritized Older Basalts are generally associated with the study area, and the evidence can be traced to reasonably well-preserved cones found in most parts of the area. The ferruginous soils in the study area are mostly derived from Basalts and Basement rocks' weathering products, it has a low nutrient status but responds quite well to fertilizers, which makes the cultivation of food crops such as Irish Potatoes, Maize, Acha, Millet and Vegetables possible.

This study aimed to determine the magnetic susceptibility and magnetic behavior of Mangu farmland soil samples; determine the concentration of some heavy metals in these soil samples and two most used fertilizer brands in Mangu Local Government Area, Plateau State, Nigeria

2.0 Materials and methods

2.1 Soil Sampling

Soil samples were collected from thirty-three different farmlands using the free survey method and were labelled A_1, A_2, A_3 to K_1, K_2, and K_3 with three Pedons from each district at 0, 15, 30, and 45cm depth. The soils were collected during the wet season in August 2018, air-dried, gently crumbled and impurities such as fallen leaves, plant roots, rocks, and animal residues removed. Fig. 1 shows locations where samples were collected.

2.2 Soil Magnetic Susceptibility

The soil magnetic susceptibility measurements were made on dry soils to avoid the diamagnetic effects of water. The soil samples of the same location and depth were filled in three transparent 1 cm^3 plastic pots and weighed. The volume magnetic susceptibilities at low frequency were measured using Bartington MS2 susceptibility meter connected to the MS2G sensor. The values displayed were then converted to SI by multiplying by 10^{-5}. Measurements for 132 soil samples were conducted under controlled conditions at the most sensitive "0.1" setting. The mass-specific susceptibility at low frequency (χ_{mLF} $\times 10^{-6}$ m^3kg^{-1}) for each measurement was calculated from the relation

$$xm_{LF}=k/p \qquad (1)$$

Where κ is the volume magnetic susceptibility at low frequency in SI and P is the bulk density in kgm^{-3}. The average value of χ_{mLF} for the three measurements was calculated. The magnetic behavior of each sample was determined.

2.3 Heavy Metal Analysis

Thirty-three (33) soil samples with peak mass-specific susceptibility along the depth profiles of sampled locations were selected and determined for concentration of Cd, Cu, Fe, Pd, and Zn using flame atomic absorption spectrophotometer. Samples of the two most commonly used fertilizers in the area were also collected to determine the concentration of Cd, Co, Cr, Cu, Fe, Ni, Pb, and Zn using a flame atomic absorption spectrophotometer. Farmland soils typically contain low background levels of heavy metals which have a maximum permissible level in soils specified by different bodies

3.0 Results and Discusion

3.1 Soil Magnetic Susceptibility

The result of average mass-specific susceptibility measurements at low frequency for soil samples collected at 0cm, 15cm, 30cm, and 45cm depth for farmland in each district is presented as profiles of χ_{mLF} values with depth as shown in Figs 2-12. Relatively high average χ_{mLF}values up to5.8650×10^{-6} m^3kg^{-1}, 6.1093×10^{-6} $m^3kg^{-1}$and 7.4230×10^{-6} m^3kg^{-1}respectively was observed for Ampang-West, Jipal, and Kerang (Figs. 2, 5 and 6). Chakfem, Kombun, Mangu, and Mangun (Figs. 3, 7, 9 and 10) recorded average χ_{mLF} values up to 0.8628×10^{-6} m^3kg^{-1}, 2.7983×10^{-6} m^3kg^{-1}, 0.8154×10^{-6} m^3kg^{-1} and 2.3023×10^{-6} m^3kg^{-1} respectively. Gindiri, Langai Panyam, and Pushit (Figs. 4, 8, 11and12) recorded average χ_{mLF} values up to 0.1778×10^{-6} m^3kg^{-1}, 0.2079×10^{-6} m^3kg^{-1}, 0.3892×10^{-6} m^3kg^{-1} and 0.5706×10^{-6} m^3kg^{-1}respectively.

In the study, Kerang (Fig. 6) recorded the highest average χ_{mLF}value of 7.423×10^{-6} m^3/kg, and Gindiri (Fig. 4) with the lowest value of 0.0503×10^{-6} m^3/kg. Several factors could contribute to the mass-specific susceptibility values obtained in this study. These could include factors acting during soil formation (parent material, climate, fauna, and

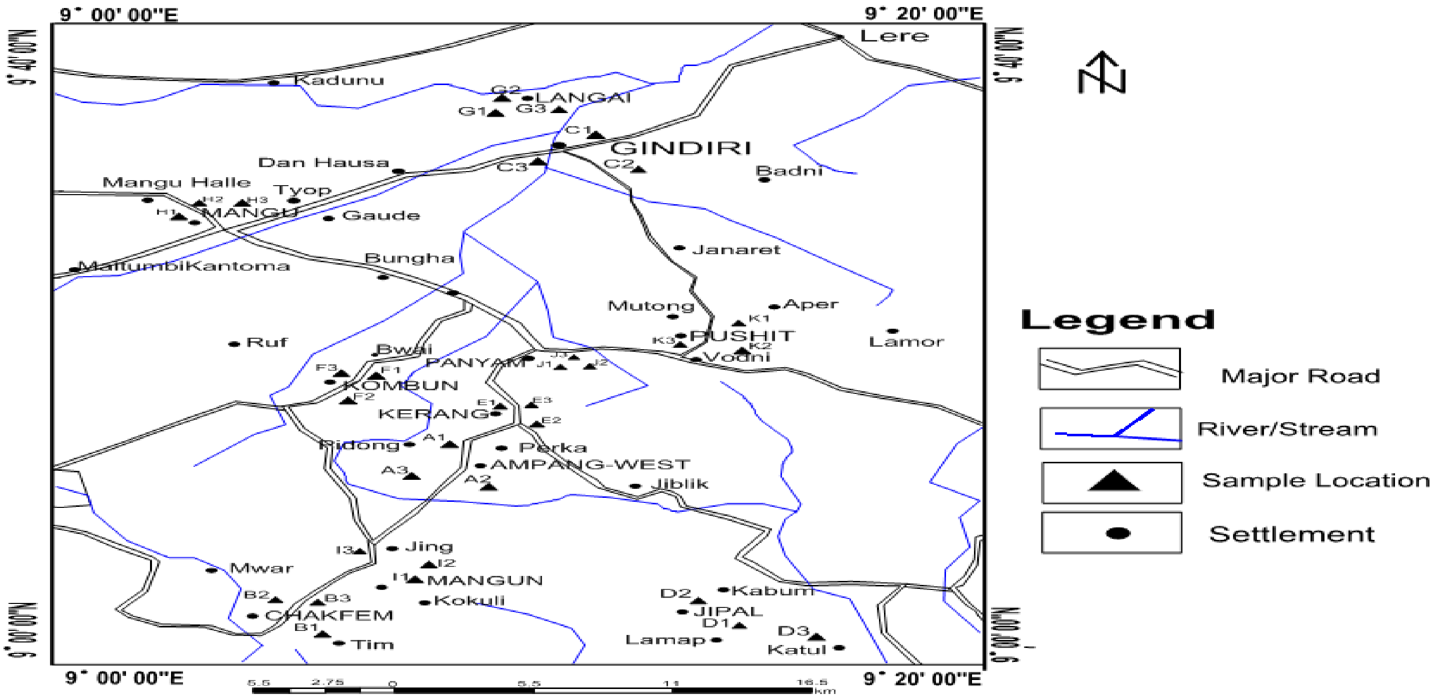

Fig. 1: Sample Location map

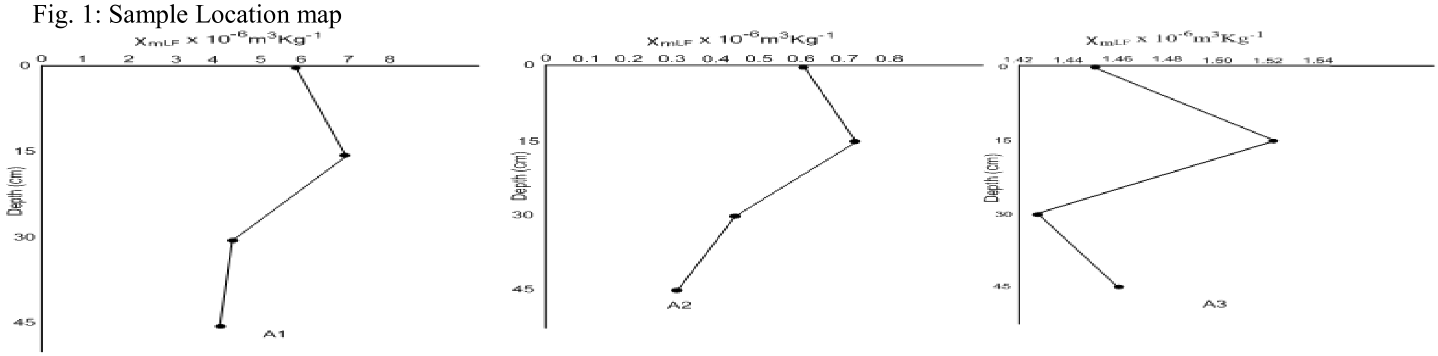

Fig. 2: Profile of χ_{mLF} with the depth of Ampang-West District Farmlands in Mangu LGA

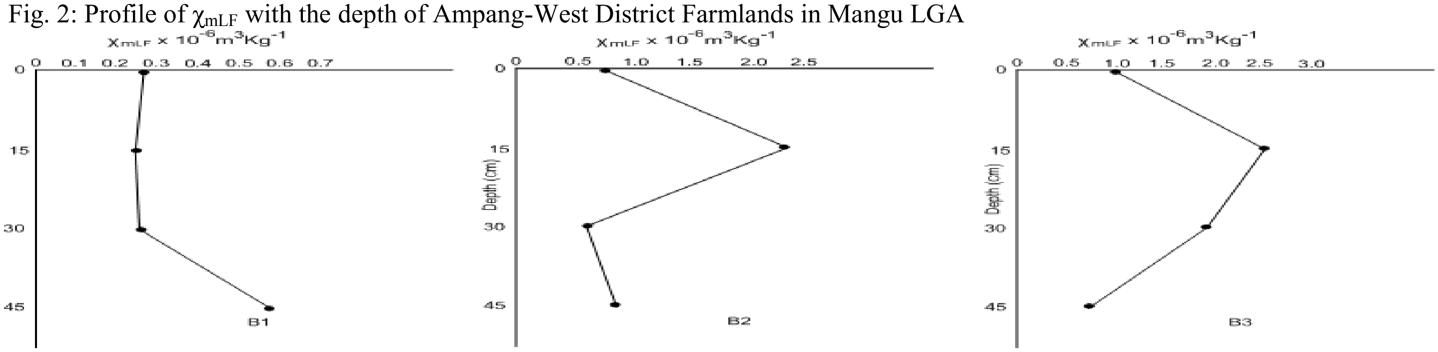

Fig. 3: Profile of χ_{mLF} with depth of Chakfem District Farmlands in Mangu LGA

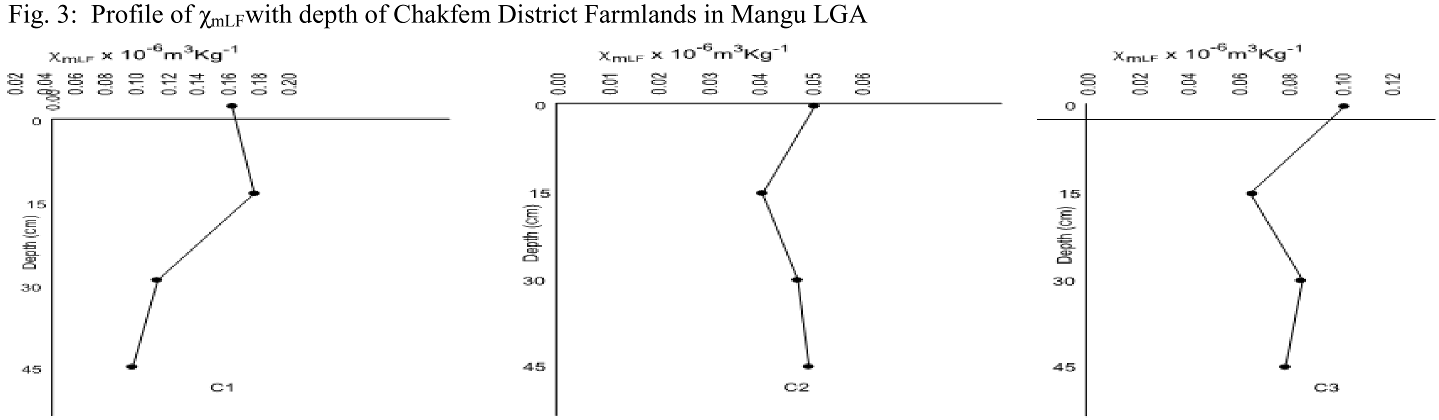

Fig. 4: Profile of χ_{mLF} with the depth of Gindiri District Farmlands in Mangu LGA

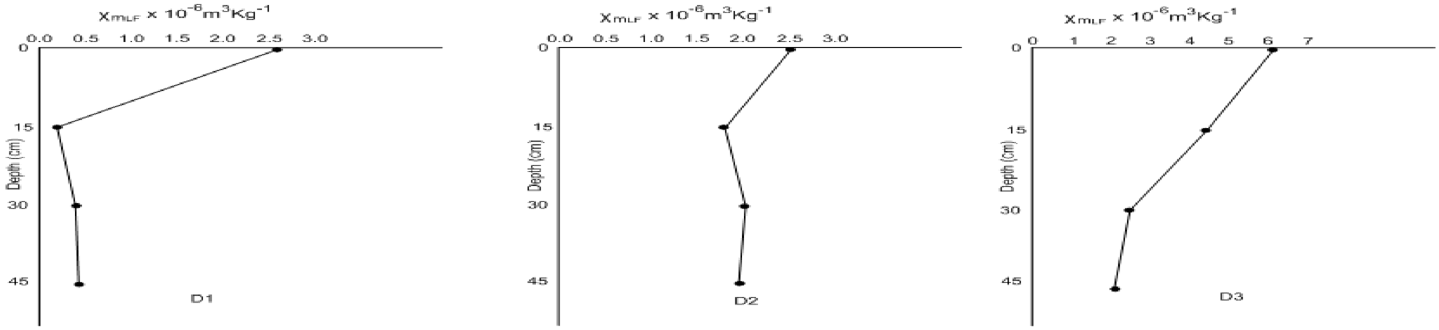

Fig. 5: Profile of χ_{mLF} with depth of Jipal District Farmlands in Mangu LGA

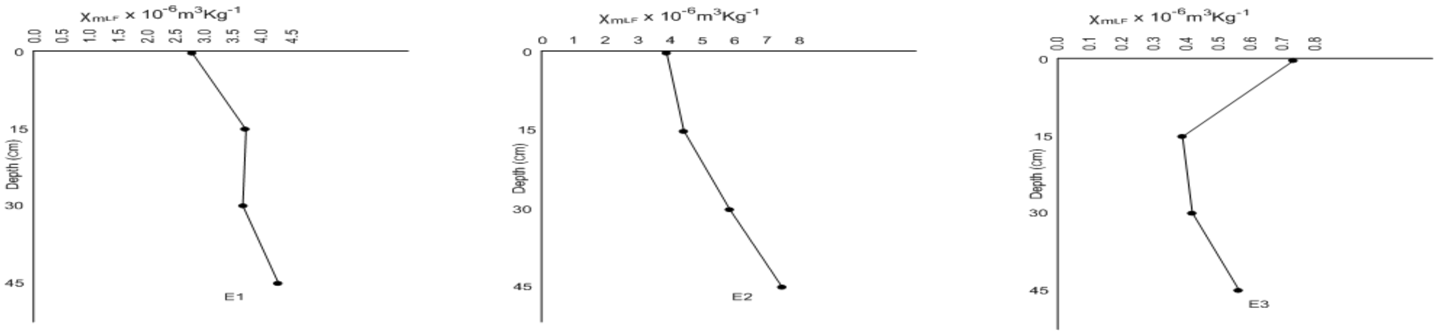

Fig. 6: Profile of χ_{mLF} with depth of Kerang District Farmlands in Mangu LGA

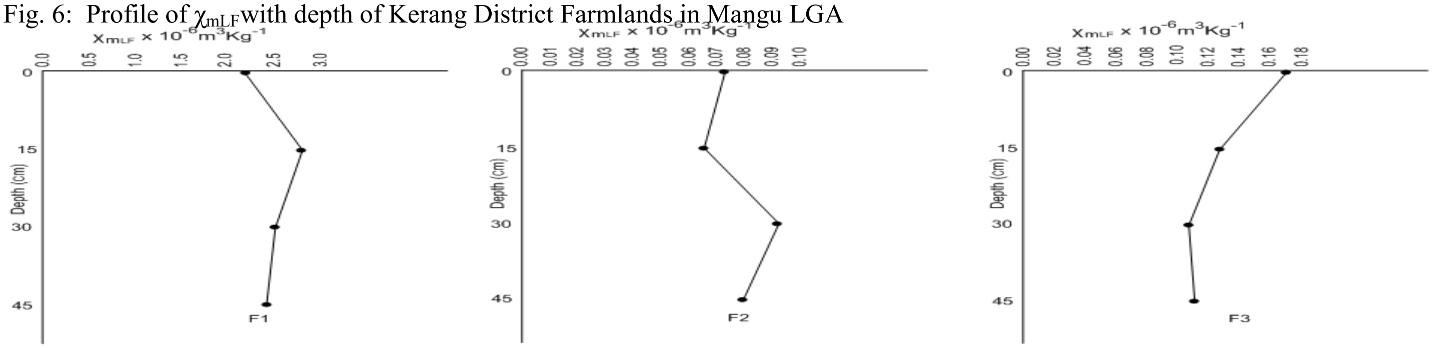

Fig. 7: Profile of χ_{mLF} with the depth of Kombun District Farmlands in Mangu LGA

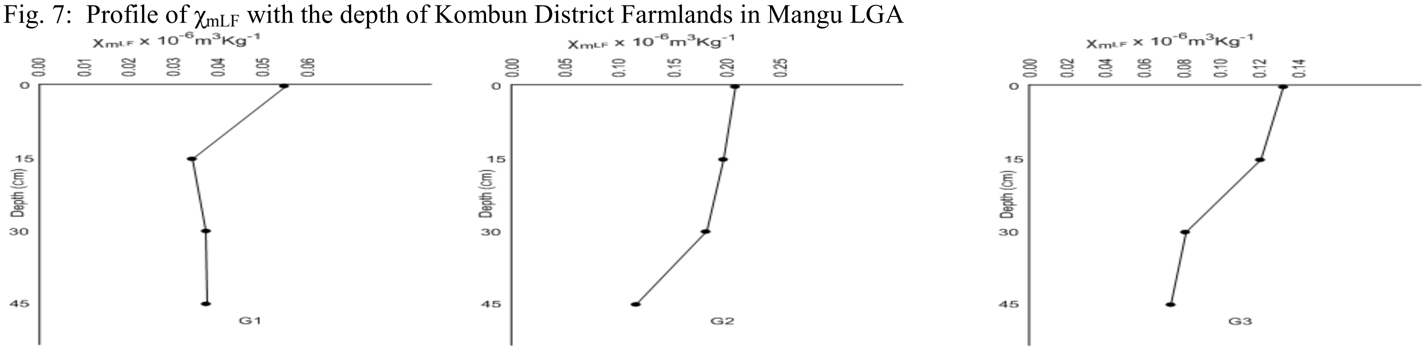

Fig. 8: Profile of χ_{mLF} with the depth of Langai District Farmlands in Mangu LGA

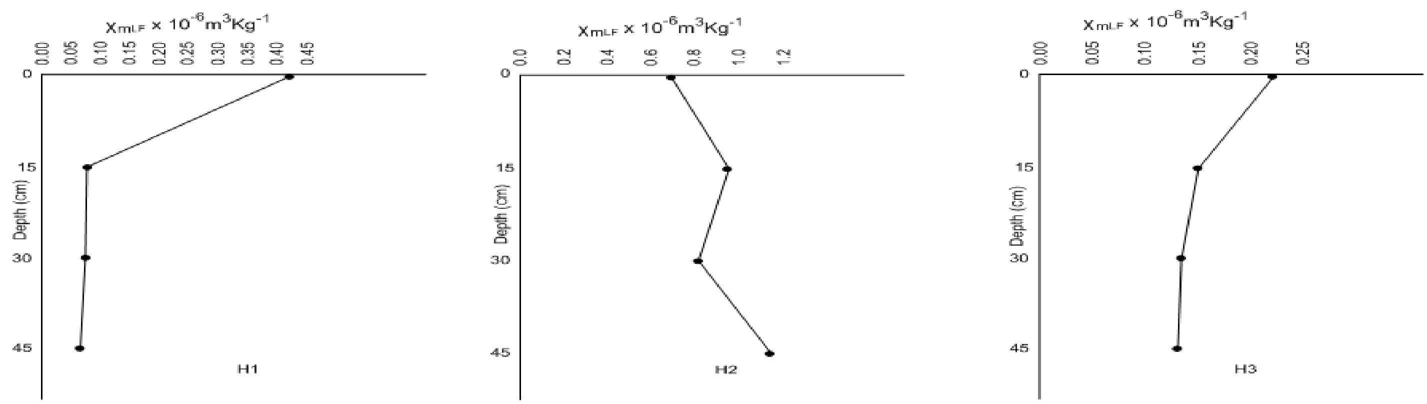

Fig. 9: Profile of χ_{mLF} with the depth of Mangu District Farmlands in Mangu LGA

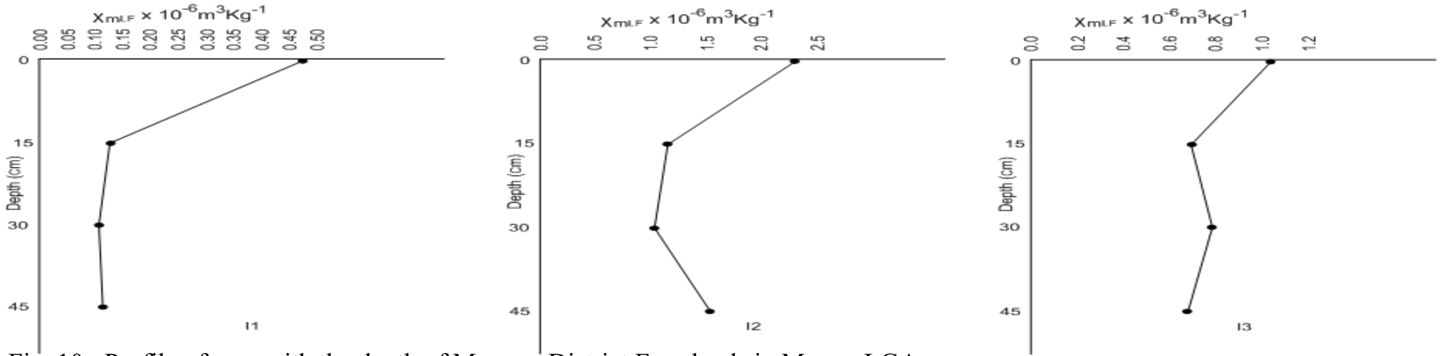

Fig. 10: Profile of χ_{mLF} with the depth of Mangun District Farmlands in Mangu LGA

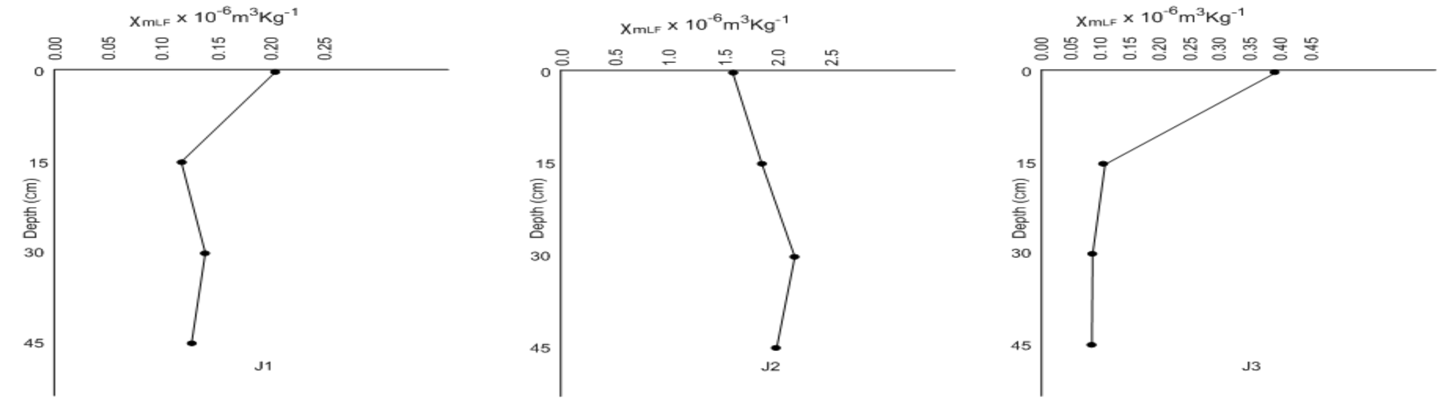

Fig. 11: Profile of χ_{mLF} with the depth of Panyam District Farmlands in Mangu LGA

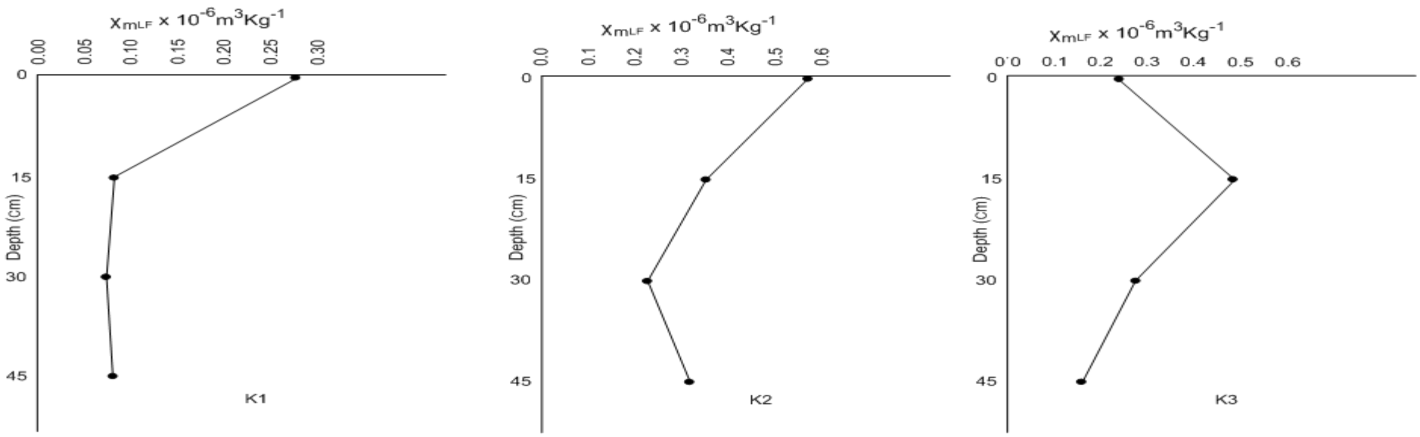

Fig. 12: Profile of χ_{mLF} with the depth of Pushit District Farmlands in Mangu LGA

flora, water) and soil type; human activities on farmlands (such as pesticides, herbicides, soil manure, and inorganic fertilizers.

In this study, soil samples were collected from the surface (0 cm), 15 cm, 30 cm, and 45 cm depths at each farmland. These depths fall within the topsoil or A-horizon and part of the soil profile's subsoil or B-horizon (FAO, 2006). The topsoil or A-horizon is richest in organic matter, nutrients, and various soil organisms. Plants mainly use the topsoil as rooting volume to obtain water and nutrients, but they can also use the subsoil (partly corresponding to B horizon) or even lower layers up to 1 m or even deeper (FAO,2006). Spatial distribution of χ_{mLF} with depth show highest χ_{mLF}values at the surface (0 cm) and 15 cm deep in most of the districts apart from Kerang district which had the highest value at 45 cm for two sample locations. Thus, most soil samples collected within the A-horizon recorded the highest χ_{mLF} values implying probable magnetic enhancement within the A-horizon, probably due to anthropogenic sources. Also, most profiles revealed a drop ofχ_{mLF}at a depth greater than 15cm implying a drop in χ_{mLF} values within the B-horizon.

An infinite number of environmental conditions give rise to an extensive range of mineralogies and magnetic susceptibility values. According to Dearing (1999), as a rule-of-thumb, mass-specific susceptibility values taken at low frequency, $\chi_{mLF}$of any sample with a value less than 0.1 x $10^{-6}m^3kg^{-1}$ is controlled by the concentration of paramagnetic minerals and for values more significant than this by ferrimagnetic minerals. Besides, negative values are controlled by the dominance of diamagnetic minerals. There are exceptions to this rule, especially in some weak samples where the susceptibility may be controlled by minute concentrations of ferrimagnetic minerals (Dearing, 1999). The dried soil samples' magnetic behavior revealed that 81% of the soil samples showed ferrimagnetic behavior, while 19% of the soil samples showed paramagnetic behavior.

3.2 Heavy metal Analysis

A trace amount of some heavy metals is required at optimum value by living organisms to maintain good health. However, an excess amount of these metals can be detrimental to the organisms (Khan et al., 2009). Heavy metals occur in the soil in soluble form and combined state. However, only soluble, exchangeable metal species in soils are mobile and hence more available to plants. Metal uptake by food crops depends on soil physicochemical properties and plant species (Flores-Magdaleno et al., 2011). Metals such as Cd, Cu, Fe, Pd, Zn, Co, Cr, and Ni can be a chemical hazard in pre-harvest production, introduced into the soil from previous farming practices. In this study, only concentrations of Cadmium,(Cd) Copper (Cu), Iron (Fe), Lead(Pb), and Zinc(Zn) in Mangu Farmland soils were determined and the result presented in Table 1. The data were compared with the international regulatory standard (Toth 2011, UNEP), presented in Table 2. According to Adagunodo et al., 2018, the standards in Table 2 are classified under the threshold and permissible limits. The threshold limit is used to checkmate the minimum toxicity in all soil environments. The permissible limit applies to agricultural soils; if the values of the metals exceed the permissible limit, such soil is regarded as contaminated soils for agricultural activities (Toth 2011, UNEP)

The concentration of Cadmium, Copper, Iron, Lead, and Zinc obtained for soil samples from Mangu farmlands were compared with the international regulatory standards. It was observed that the concentration of these elements was less than the permissible and threshold values of the

Table 1. Heavy Metal Concentrations in Mangu Farmland soils

Sampled Location	Depth (cm)	The concentration of Heavy Metal (mg kg^{-1})				
		Cd	Cu	Fe	Pb	Zn
A1	0	0.0018	0.0032	1.9723	0.1206	0.0451
A2	15	0.0015	0.0005	0.4928	0.1393	0.0433
A3	15	0.0009	0.0006	1.0722	0.0420	0.0457
B1	45	0.0002	0.0006	0.4078	0.0453	0.0429
B2	15	0.0013	0.0022	0.8236	0.1520	0.0464
B3	15	0.0020	0.0064	0.9012	0.0873	0.0461
C1	15	0.0019	0.0010	0.0042	0.1452	0.0464
C2	0	0.0024	0.0018	0.0008	0.0003	0.0440
C3	0	0.0022	0.0014	0.0044	0.0550	0.0279
D1	0	0.0017	0.0068	0.5275	0.0688	0.0471
D2	0	0.0016	0.0051	0.3812	0.0025	0.0454
D3	0	0.0021	0.0003	1.8358	0.1247	0.0461
E1	45	0.0020	0.3635	1.8358	0.0603	0.0429
E2	45	0.0089	0.6602	1.9827	0.3628	0.0805
E3	0	0.0018	0.4779	0.0470	0.0240	0.0473
F1	15	ND	0.0087	0.4164	0.0894	0.0159
F2	30	0.0014	0.0017	0.0471	0.0622	0.0472
F3	0	0.0027	0.0013	0.0233	0.0175	0.0404
G1	0	0.0008	0.0043	0.0097	0.0431	0.0345
G2	0	0.0003	0.0125	0.0487	0.1051	0.0357
G3	0	0.0007	0.0060	0.0511	0.1012	0.0365
H1	0	0.0009	0.0974	0.0425	0.0375	0.0422
H2	45	0.0019	0.0089	0.4814	0.0343	0.0468
H3	0	0.0010	0.0595	0.1693	0.1654	0.0296
I1	0	0.0010	0.0020	0.3171	0.1112	0.0342
I2	0	0.0008	0.0097	0.3510	0.0461	0.0353
I3	0	0.0010	0.0093	0.3465	0.0267	0.0330
J1	0	0.0018	0.0074	0.0823	0.1771	0.0457
J2	30	0.0023	0.0052	1.9232	0.1913	0.0456
J3	0	0.0010	0.0056	0.1799	0.0681	0.0461
K1	0	0.0013	0.0109	0.1604	0.0124	0.0372
K2	0	0.0018	0.0138	0.2242	0.0954	0.0341
K3	0	0.0018	0.0058	0.1134	0.0665	0.0448

Table 2. Threshold and permissible limits for heavy metals in soils (Toth et al., 2013, UNEP)

Heavy metal	Threshold limit (mg kg^{-1})	Permissible limit (mg kg^{-1})
Cd	1	10
Cu	100	150
Fe	-	50
Pb	60	200
Zn	200	250
Co	20	100
Cr	100	200
Ni	50	100

regulatory standards. This implies that the concentration of these heavy metals in Mangu Farmland soils does not exceed the permissible limit, the soils are not contaminated with these heavy metals, and the soil is not toxic.
The concentration of Cadmium, Cobalt, Chromium, Copper, Iron, Nickel, Lead, and Zinc in the two most used fertilizer brands in Mangu farmlands are presented in Table 3. From the Table, Cadmium, Cobalt, Chromium, Copper, Iron, Lead, and Zinc are more in Fertilizer A than Fertilizer B while Nickel is more in Fertilizer B than A. The types of fertilizer commonly produced and used in Nigeria include urea, Nitrogen-Phosphorous-Potassium (NPK), and Superphosphate (SSP) [Liverpool-Tasie et al. (2010)]. Phosphate Rock is the primary raw material used to produce phosphate fertilizers, and these rocks contain useful elements. Incidentally, they also contain potentially hazardous elements that may persist through the manufacturing process including undesired heavy metals, e.g. Cd, Cr, Hg, Pb, and radioactive elements, e.g. U considered to be toxic to human and animal health (FAO, 2004b). With continuous use of fertilizers A and B, particularly fertilizer B to the soil for increased crop yield, the soil's possibility of contamination with Cobalt, Chromium, Copper, Iron, Nickel, Lead, and Zinc over time is high.

3.3 Correlation between Magnetic Susceptibility and Heavy Metal

Magnetic susceptibility values of soil samples have been acknowledged by several authors to be related to the concentration of heavy metals in soil samples [Dearing et al. (1996), and Brempong et al. (2016)]. To determine how these variables relate for the study area, a scatter plot of mass-specific susceptibility at low frequency (χ_{mLF}) versus concentration of Cd, Cu Fe, Pb, and Zn respectively in Mangu farmland soil samples was made and the results are shown in Figs 13, 14, 15,16 and 17. The scatter plots show an overall positive correlation between mass-specific susceptibility at low frequency (χ_{mLF}) versus concentration of Cd, Cu Fe, Pb, and Zn. The correlation coefficient was in the following decreasing order; 0.8794 (χ_{mLF} and Fe), 0.5573 (χ_{mLF} and Cd),(0.4940 χ_{mLF} and Pb), 0.4783 (χ_{mLF} and Zn) and 0.4683 (χ_{mLF} and Cu). χ_{mLF} show is strong to very strong positive correlation or relationship with Fe, Cd, Pb, Zn, and Cu. This result shows that magnetic susceptibility has a positive relationship or correlation with Fe, Cd, Pb, Zn, and Cu for Mangu farmlands and can be used in the absence of expensive and rigorous heavy metal analysis which implies that magnetic susceptibility measurements can be used for reconnaissance survey of heavy metals for farmland soils.

Table 3.The concentration of Heavy Metals in Fertilizers

Heavy Metal	Fertilizer A	Fertilizer B
Cd	0.0130	0.0094
Co	0.3328	0.3243
Cr	0.0767	0.0077
Cu	0.0052	0.0032
Fe	0.1330	0.1270
Ni	0.0232	0.0420
Pb	0.5269	0.5015
Zn	0.4816	0.4673

4.0 Conclusion

This study to determine magnetic susceptibility and heavy metal contamination in farmland soils of Mangu LGA, Plateau State, Nigeria, revealed most soil samples collected within the A-horizon recording the highest χ_{mLF} values implying magnetic enhancement within the A-horizon probably due to anthropogenic sources such as fertilizer applica-

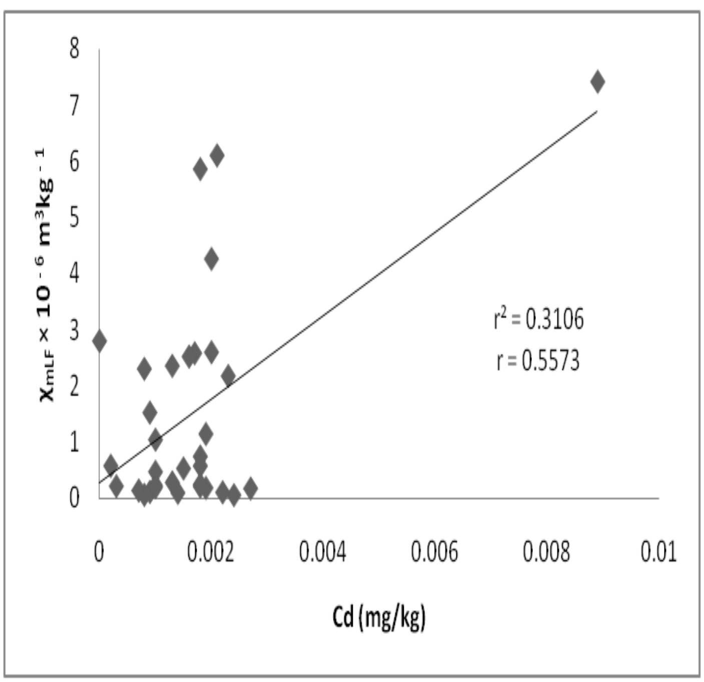

Fig. 13: Scatter plot of Cadmium Concentration and Mass Specific Susceptibility at low Frequency for Mangu Farmland soil samples

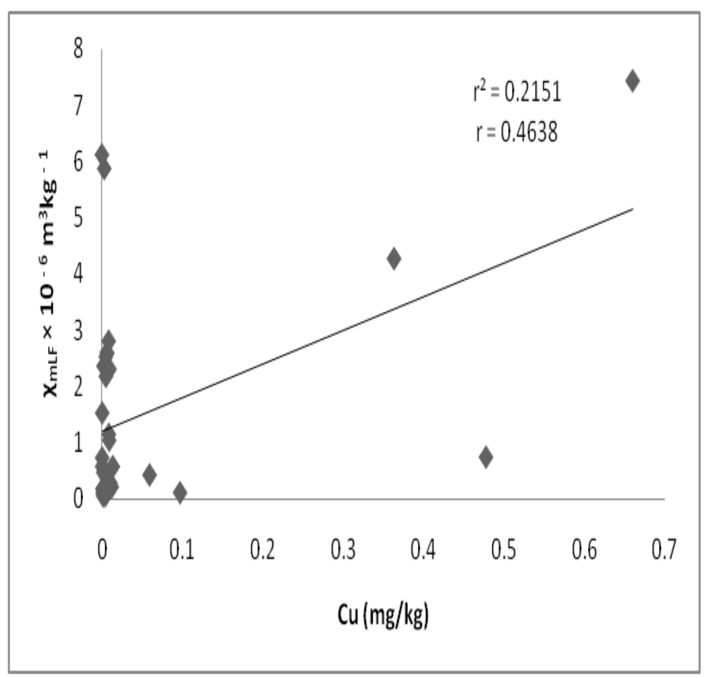

Fig. 14: Scatter plot of Copper Concentration and Mass Specific Susceptibility at low Frequency for Mangu Farmland soil samples

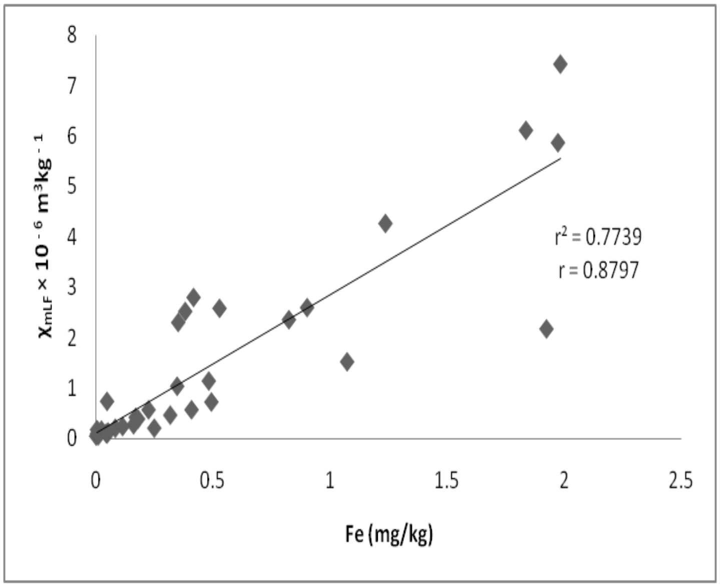

Fig. 15: Scatter plot of Iron Concentration and Mass Specific Susceptibility at low Frequency for Mangu Farmland soil samples

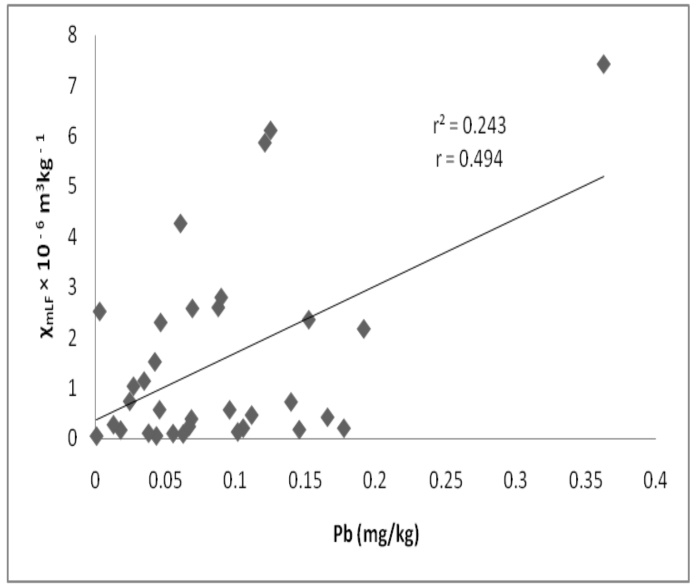

Fig. 16: Scatter plot of Lead Concentration and Mass Specific Susceptibility at low Frequency for Mangu Farmland soil samples

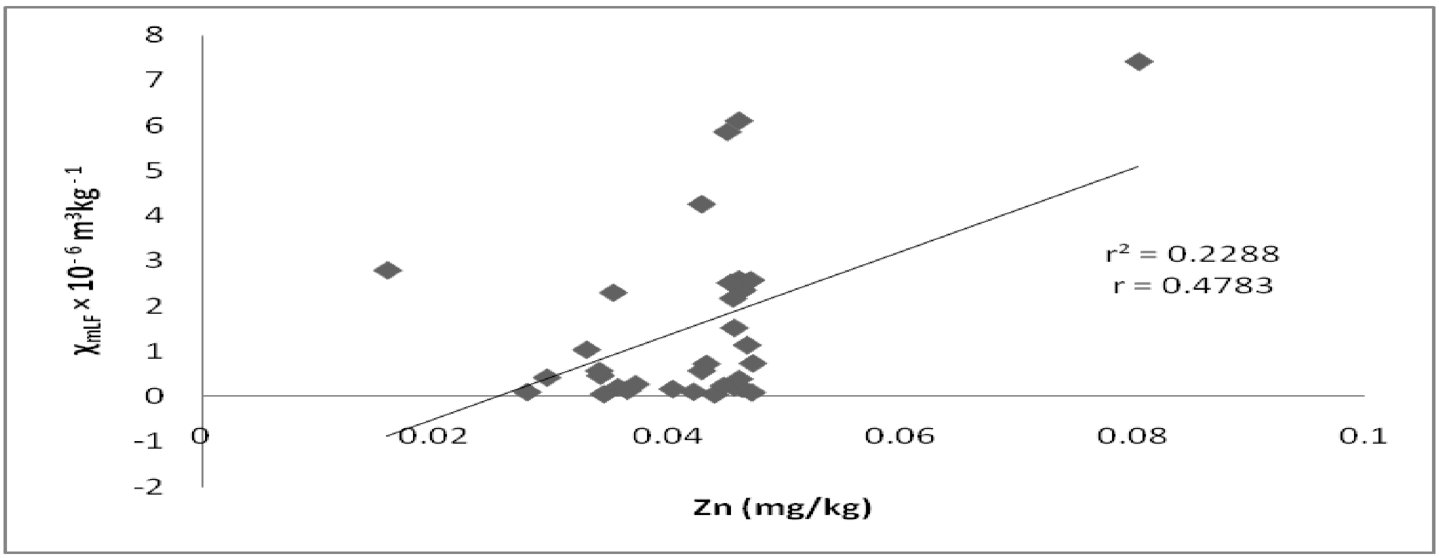

Fig. 17: Scatter plot of Zinc Concentration and Mass Specific Susceptibility at low Frequency for Mangu Farmland soil samples

tion. Also, most profiles revealed a drop of χ_{mLF} at a depth greater than 15 cm implying a drop in χ_{mLF} values within the B-horizon. χ_{mLF} results also revealed that 81% of the dried soil samples exhibited ferrimagnetic behavior, and 19% exhibited paramagnetic behavior. Heavy metal (Cadmium, Copper, Iron, Lead, and Zinc) concentration in the soils and its comparison with international regulatory standards revealed that the soil samples were neither contaminated with these heavy metals nor toxic. The concentration of Cadmium, Cobalt, Chromium, Copper, Iron, Nickel, Lead, and Zinc in the two most used fertilizer brands in Mangu farmlands revealed that the concentration of Cadmium, Cobalt, Chromium, Copper, Iron, Lead, and Zinc was more in Fertilizer A than Fertilizer B. At the same time, Nickel was more in Fertilizer B than A. Hence, the continuous application of these fertilizers can contaminate the soils with time. The relationship between χ_{mLF} and Fe, Cd, Pb, Zn, and Cu respectively showed a strong to very strong positive correlation or relationship between these heavy metals which implies that magnetic susceptibility measurements can be used for reconnaissance surveys for farmland soils.

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