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A Preliminary Assessment of Soil Pollution in Some Parts of Jalingo Metropolis, Nigeria Using Magnetic Susceptibility Method.

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Abstract

An investigation of magnetic properties using magnetic susceptibility and frequency dependent susceptibility was conducted on 36 soil samples from parts of Jalingo, Taraba State, N-E Nigeria. The purpose was to assess the level of soil pollution and identify pollution hotspots using magnetic proxy parameters. The results of the mass specific low frequency magnetic susceptibility measurements show significant enhancement with values ranging from 67.8 - 495.3 x 10^{-6} m^3kg^{-1} with a mean value of 191.61 x 10^{-6} m^3kg^{-1} for the Jalingo College of Education JCOE data; 520.1 – 1612.8 x 10^{-6} m^3kg^{-1} with a mean value of 901.34 x 10^{-6} m^3kg^{-1} for the Jalingo Main Market, JMM and 188.5- 1203.6 x10^{-6} m^3kg^{-1} with an average value of 574 92 x 10^{-6} m^3kg^{-1} for the Jalingo Motor Park JMP. The significant magnetic enhancement indicates high concentration of ferrimagnetic minerals in the soil and thus increases pollution. The magnetic susceptibility of the different land use studies decreased in the order commercial area (market) > motor park > official area. The results of the percentage frequency dependence susceptibility showed that most of the samples have a mixture of superparamagnetic SP and coarse multidomains grains or superparamagnetic grains < 0.05µm. In the JCOE samples, the value of percentage frequency dependent susceptibility ($\chi_{fd}\%$) ranges from 2.68 – 13.80% with an average value of 8.67%. Five samples (that is about 30%) are virtually all SP grains as they have $\chi_{fd}\%$ in the range of 12 – 14 %, while other samples have values in the range of 2 – 10 % indicating the presence of a mixture of SP and Multi Domain MD magnetic grains. In the Jalingo Main Market (JMM) samples, seven samples fall within the medium range of 2 – 10 % and may be said to have a mixture of SP and coarse MD grains; three samples have low $\chi_{fd}\%$ of < 2% implying that they have no SP grains while only one sample has high $\chi_{fd}\%$ of 10.04 % meaning that the dominant magnetic component of this soil is SP ferrimagnetic grains. For the JMP samples, about 70% of the samples have $\chi_{fd}\%$ value in the medium range, and this can be interpreted as soils with admixture of SP and coarser non-SP grains or < 0.005µm SP grains. Two samples (about 20%) of the JMP samples have $\chi_{fd}\%$ > 10%, indicating soils where virtually all the iron component is SP grains, while about 10% of the samples contains no SP grains. Generally, most of the samples in the studied area contain a mixture of SP and MD magnetic grains.

Key words: Soil Pollution, Magnetic Susceptibility, Frequency Dependent Susceptibility, Mineral Magnetic, Ferrimagnetic

1. Introduction

The adverse effect of human impact, especially atmospheric pollution in the environment has increased in recent years and has become a subject of global concern. So, pollution has become a subject widely investigated from various fields, such as geology, geophysics, chemistry, and agriculture. Atmospheric pollution has been identified as one of the most harmful factors for ecosystems (Petrovsky and Elwood, 1999). The various pollution sources, whether industrial, vehicular and domestic emissions, usually contain heavy metals and toxic elements. When these pollutants are released into the atmosphere, they are incorporated into the environment or in living organism such as vegetation, animals and human beings, posing serious risks to human health. Pope and Dockery (2006) showed that long-term exposure to

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airborne pollutants can lead to respiratory and cardiovascular diseases. Before now organic lead compounds (tetraethyl lead and tetramethyl lead) were extensively used as additives in gasoline, but at present unleaded gasoline is used in most countries of the world. Africa has contributed substantially to global lead pollution (Nduka and Orisakwe, 2010). In Nigeria, gasoline, with an average lead content of 0.66g/l, is still in use (Fakayode and Olu-Owolabi, 2003). The national consumption of petrol in the country is estimated at 20 million litres per day, with about 150 people/car/city, therefore, close to 15,000 kg of lead is emitted into the environment through combustion. The release of lead into the environment is further compounded by the poor road network, dilapidated nature of existing roads and the large volume of importation of fairly used vehicles, which leads to a high number of irreparable and decomposing automobile parts littered on the roadsides. These contaminants that are released into the atmosphere, soils and sediments are rich in magnetic particles, resulting in magnetic enhancement of the urban soils and sediments. A measure of the amount of magnetic enhancement is expressed by its magnetic susceptibility and in recent years, it has been successfully used to monitor anthropogenic pollution, especially heavy metal pollution in soils (Strzyszcz and Maigiera, 1998; Petrovsky *et al*., 2000; Gautam *et al*., 2004; Canbay, 2010, Sandeep, 2012; among others).

Magnetic susceptibility is defined as the ratio of the total magnetization induced in a sample to the intensity of the magnetic field that produces the magnetization (Mullins, 1977). Magnetic susceptibility measures the concentration of magnetic crystals, grain size and the shape and type of the magnetic minerals present in a sample. Magnetic minerals present in soils may either be obtained from the parent rocks (lithogenic origin) during pedogenesis, or because of anthropogenic activities. The magnetic mineral content of the soil can broadly be expressed by its magnetic susceptibility. Magnetic susceptibility can be used to identify the type of mineral and the amount of iron bearing minerals contained in a material (Dearing, 1999). When the contribution of lithogenesis and pedogenesis to the overall magnetic properties of soils are minimal, magnetic susceptibility measurements become very important for monitoring environmental (anthropogenic) pollution. Soils are sinks to anthropogenic pollutants released into the atmosphere. Accumulation of anthropogenic ferrimagnetic particles, originating from oxidation process during combustion of fossil fuels, results in significant enhancement of topsoil magnetic susceptibility. The most important magnetic mineral is magnetite and in the atmosphere it can originate from combustion (and other industrial) processes (Petrovsky *et al*., 2000). One source of atmospheric pollution is road traffic. Hopke *et al.* (1980) found that Lead, Cadmium, Chromium, Cobalt and Arsenide, the primary constituents of automobile exhaust are in association with high-density magnetic particles (presumably magnetite). The iron particles results from car body rusting or ablation from the interior of car exhaust systems and breaks.

In Nigeria, most pollution studies (for example Fakayode and Olu-Owolabi, 2003; Adie and Osibanjo, 2009; Nduka and Orisakwe, 2010; among others) have been conducted using the traditional chemical analysis. Studies of magnetic proxies for pollution in Nigeria are scarce. This is a preliminary attempt to studying soil pollution using magnetic susceptibility in some parts of Taraba State, North-East Nigeria. The study aims at mapping and providing information on the level of soil pollution using magnetic proxy parameters. This study does not consider the relationship between heavy metal and magnetic susceptibility; it only utilizes the fast, nondestructive, and cost effective magnetic analyses as a preliminary tool to assess pollution hotspots. Further studies will hopefully consider the traditional, cost and time consuming geochemical technique on specific samples that are found to be highly polluted using the magnetic technique.

2. Materials and Methods

2.1. Geographical and Geological setting of the Study Area

Jalingo, the study area, is the administrative headquarters of Taraba State which is located between latitude $6^{\circ}30'$ and $8^{\circ}30'$ North of the equator and between $9^{\circ}00'$ and $12^{\circ}00'$ East of the Greenwich meridian (Figure 1). The state has a tropical wet and dry climate, dry season lasts for a minimum of five months (November to March) while the wet season spans from April to October. It has an annual rainfall of about 8000 mm. Jalingo is a city with no major industry. The major pollution source is the emission from traffic and power generating sets and other human activities such as indiscriminate dumping of waste, bush burning, household heating systems, etc.

The study area is underlain by the undifferentiated Basement Complex rocks, which consist mainly of the migmatites, gneisses and the Older Granites. Tertiary to Recent basalts also occurs in the area. The undifferentiated Basement Complex, particularly the migmatites, generally varies from coarsely mixed gneisses to diffused textured rocks of variable grain size and are frequently porphyroblastic (Macleod *et al*., 1971). This rock unit constitutes principally the undifferentiated igneous and metamorphic rocks of Precambrian age (Grant, 1971.)

The Pan African Older Granites are equally widespread in the area. They occur either as mafic or intermediate intrusives (Turner, 1964). Different kinds of textures, ranging from fine to medium to coarse grains, can be noticed on the Older Granites (McCurry, 1976). Other localized occurrences of minor rock types include some doleritic and pegmatitic rocks mostly occurring as dykes and vein. These occurrences are common to both the undifferentiated Basement Complex and the Older Granite rocks (Carter *et al*., 1963; McCurry, 1976). The Tertiary basalts, on the other hand, are found in the Mambila Plateau mostly comprised of trachytic lavas and extensive basalts, which occur around Nguroje (du Preez, 1965).

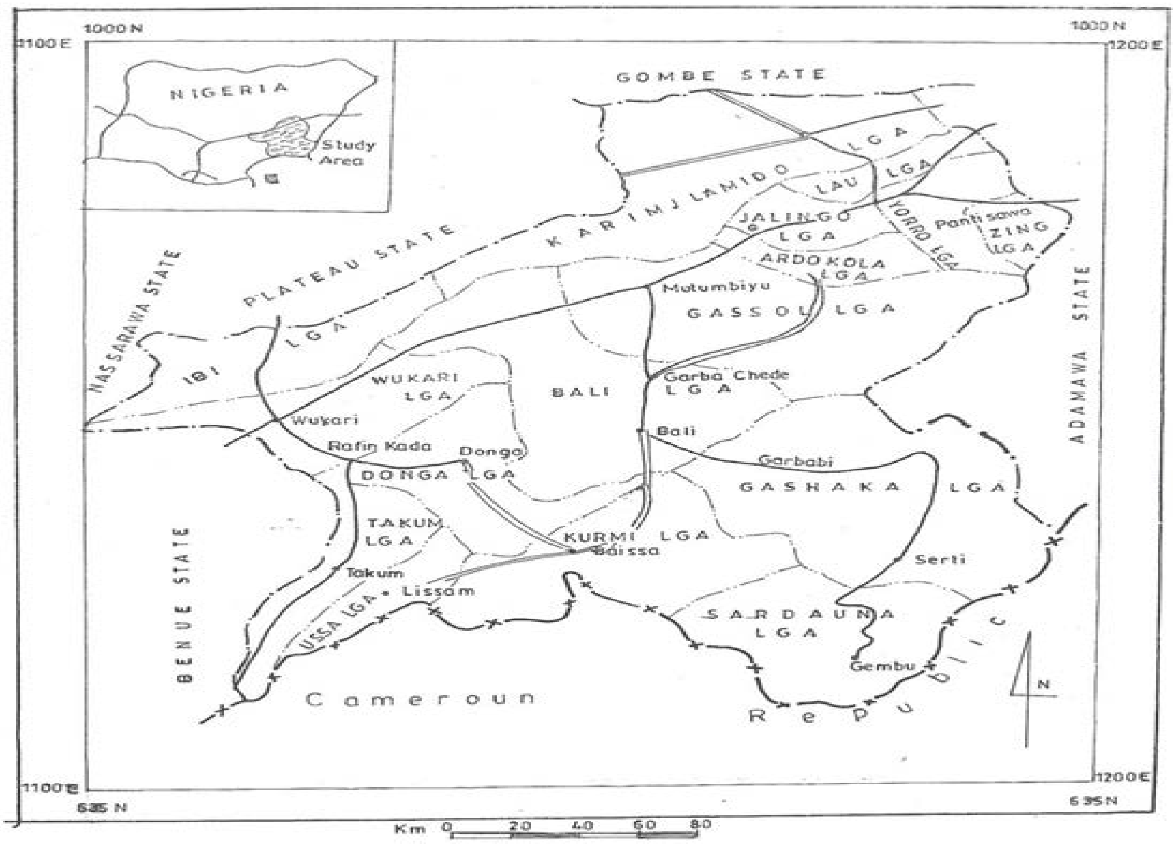

Figure 1. Map of study area (insert: map of Nigeria, showing study area).

2.2. Sampling and Analysis

Topsoil samples (0- 2 cm) were collected from three different locations using a plastic material to avoid contamination. The samples locations were determined using a 12 Channel Garmin Global Positioning System (GPS 12). A total of 36 samples were randomly collected, 15 samples from an official area, 10 samples from a motor park and 11 samples from a commercial area. The Jalingo College of Education (JCOE), which has been in existence for more than 25 years, was chosen to represent a school environment. The Jalingo Motor Park (JMP) has been in operation for more than 15 years with a land area of about 250 square meters with more than 500 vehicles moving in and out daily. The Jalingo Main Market (JMM), which is the major commercial centre of the city, has an area of about 500 square meters and was built more than two decades ago. Many commercial activities take place in this market and vehicular movement around the market area has been on the rise over the years.

The samples were air dried at a temperature of 30°C in the laboratory for several days to avoid any chemical reactions. They were then ground using agate mortar and sieved using a 1 mm sieve mesh (Kim *et al*., 1999) and stored in plastic containers for further laboratory measurements. The mass specific magnetic susceptibility measurements were then carried out on the sieved samples packaged in a 10 ml plastic container at laboratory temperature. Measurements of magnetic susceptibility were made at both low (0.47 kHz) and high (4.7 kHz) frequencies using MS2 dual frequency susceptibility meter. All measurements were conducted at the 1.0 sensitivity setting. Each sample was measured three times with an air reading before and after each series for drift correction. The mass specific frequency dependence susceptibility χ_{fd} was obtained from the relation:

$$\chi_{fd} = \chi_{lf} - \chi_{hf} \quad (1)$$

Where χ_{lf} and χ_{hf} are the low frequency and high frequency susceptibility, respectively.

This parameter is sensitive only to a very narrow grain size range crossing the superparamagnetic/single domain threshold (~ 20 – 25 nm for maghemite) (Worm and Jackson, 1999). For natural samples, which generally exhibit a continuous and nearly constant grain size distribution, χ_{fd} can be used as a proxy for relative changes in concentration in pedogenic fined – grained magnetic particles (Liu *et al*., 2005). The relative χ_{fd} also called Percentage frequency dependent susceptibility (χ_{fd}%) was then calculated following Dearing (1999) as:

$$\chi fd\ (\%) = \left(\frac{\chi lf - \chi hf}{\chi lf}\right) \times 100 \quad (2)$$

The magnetic map of the study area was obtained using a computer software program, surfer 7.0.

3. Results and Discussion

The results of the mass specific low field magnetic susceptibility, frequency dependence, and percentage frequency dependence of the samples are displayed in tables 1 - 3. The value of low frequency mass specific magnetic susceptibility ranges from 67.8 - 495.3 x 10^{-6} m^3kg^{-1} with a mean value of 191.61 x 10^{-6} m^3kg^{-1} for the JCOE data. The JMM has low frequency magnetic susceptibility values ranging from 520.1 – 1612.8 x 10^{-6} m^3kg^{-1} with a mean value of 901.34 x 10^{-6} m^3kg^{-1}, while the JMP has a low frequency magnetic susceptibility ranging from 188.5- 1203.6 x$10^{-6}m^3kg^{-1}$ with an average value of 574. 92 x 10^{-6} m^3kg^{-1}. The results obtained are comparable to urban soils in Shanghai, China, which has a magnetic susceptibility value ranging from 127.3 – 1959 x 10^{-8} m^3kg^{-1} (Hu *et al*., 2006). The magnetic susceptibility of the different land use studies decreased in the order commercial area (market) > motor park > official area. The differences in the values of magnetic susceptibility in the different areas are caused by the difference in the type and strength of human activity in these areas. The high magnetic susceptibility values of the JMM may be attributed to the high commercial activity in the market, tiny pieces of rusted metal parts that might be thrown to the ground and anthropogenic sources due to the high volume of traffic within the market area.

Table 1: Jalingo College of Education (JCOE) data.

Sample	Mass (g)	Latitude (N)	Longitude (E)	χ_{lf} x10^{-6} m^3kg^{-1}	X_{hf} x 10^{-6} m^3kg^{-1}	χ_{fd} x 10^{-6} m^3kg^{-1}	χ_{fd} (%)
JCOE 1	16.29	8°54.080’	11°19.052’	226.7	197.0	29.7	13.10
JCOE 2	17.91	8°54.067’	11°19.078’	359.5	309.9	48.6	13.80
JCOE 3	18.31	8°54.104’	11°19.078’	175.7	171.0	4.7	2.68
JCOE 4	17.94	8°54.119’	11°19.044’	132.8	123.4	9.4	7.08
JCOE 5	18.58	8°54.129’	11°19.021’	200.8	182.4	18.4	9.16
JCOE 6	17.03	8°54.135’	11°19.009’	136.9	125.2	11.7	8.55
JCOE 7	19.72	8°54.111’	11°18.992’	156.7	149.7	7.0	4.47
JCOE 8	18.96	8°54.122’	11°18.962’	131.1	122.7	8.4	6.41
JCOE 9	17.70	8°54.078’	11°19.005’	495.3	437.2	58.1	11.73
JCOE 10	19.62	8°54.162’	11°19.087’	309.6	286.1	23.5	7.59
JCOE 11	18.95	8°54.186’	11°19.102’	81.0	74.0	8.6	9.31
JCOE 12	19.07	8°54.193’	11°19.072’	67.8	62.0	5.8	8.55
JCOE 13	18.26	8°54.191’	11°19.038’	110.8	96.8	14.0	12.64
JCOE 14	19.20	8°54.165’	11°19.049’	141.7	136.4	5.3	3.74
JCOE 15	17.11	8°54.220’	11°18.961’	147.1	130.5	16.6	11.28

Table 2: Jalingo Main Market (JMM) data.

Sample	Mass (g)	Latitude (N)	Longitude (E)	χ_{lf} x10^{-6} m^3kg^{-1}	X_{hf} x 10^{-6} m^3kg^{-1}	χ_{fd} x 10^{-6} m^3kg^{-1}	χ_{fd} (%)
JMM 1	16.63	8°53.714’	11°21.605’	658.3	622.3	36.0	5.47
JMM 2	18.06	8°53.711’	11°21.526’	520.1	510.0	10.1	1.94
JMM 3	18.05	8°53.678’	11°21.547’	1182.7	1115.9	66.8	5.65
JMM 4	16.87	8°53.703’	11°21.555’	1321.4	1229.2	92.2	6.98
JMM 5	15.79	8°53.692’	11°21.607’	623.5	599.8	23.7	3.80
JMM 6	17.44	8°53.689’	11°21.603’	571.5	568.7	2.8	0.49
JMM 7	17.13	8°53.690’	11°21.600’	556.1	549.7	6.4	1.15
JMM 8	17.17	8°53.651’	11°21.578’	1612.8	1503.4	109.4	6.78
JMM 9	16.28	8°53.619’	11°21.601’	656.6	611.9	44.7	6.81
JMM 10	17.41	8°53.591’	11°21.610’	1120.9	1008.4	112.5	10.04
JMM 11	18.10	8°53.548’	11°21.631’	1090.8	1020.3	70.5	6.46

Table 3: Jalingo Motor Park (JMP) data.

Sample	Mass (g)	Latitude (N)	Longitude (E)	χ_{lf} x10^{-6} m^3kg^{-1}	X_{hf} x 10^{-6} m^3kg^{-1}	χ_{fd} x 10^{-6} m^3kg^{-1}	χ_{fd} (%)
JMP1	17.86	8°56.267’	11°20.328’	401.7	349.3	52.4	13.04
JMP 2	18.15	8°56.301’	11°20.323’	842.4	811.8	30.6	3.63
JMP 3	18.57	8°56.306’	11°20.305’	444.3	418.7	25.6	5.76
JMP 4	16.90	8°56.300’	11°20.283’	286.0	261.5	24.5	8.57
JMP 5	18.38	8°56.290’	11°20.303’	442.6	440.1	2.5	0.56
JMP 6	17.46	8°56.277’	11°20.286’	188.5	167.7	21.8	11.03
JMP 7	18.34	8°56.265’	11°20.281’	466.7	453.3	13.4	2.87
JMP 8	17.86	8°56.274’	11°20.301’	903.9	855.3	48.6	5.38
JMP 9	18.94	8°56.257’	11°20.317’	1203.6	1149.9	53.7	4.46
JMP 10	17.71	8°56.242’	11°20.300’	569.5	550.5	19.0	3.34

Gautam *et al.* (2004) classified soils into three broad categories based on their magnetic susceptibility (MS) values as follows: 'normal' (MS < 10 x 10^{-6} m^3kg^{-1}), 'moderately magnetic' (MS 10 – 100 x 10^{-6} m^3kg^{-1}), and 'highly magnetic' (MS >100 x 10^{-6} m^3kg^{-1}). From the above classification, the soils from JMM and JMP can be said to be highly magnetic, while those of JCOE ranges from moderate to highly magnetic. The high values indicate high concentration of ferrimagnetic minerals in the soil. Previous studies showed that differences in variations in magnetic susceptibility are caused by differences in geology (lithogenic/geogenic), soil forming processes (pedogenesis), and the anthropogenic input of magnetic material (Thompson and Oldfield, 1986; and Dearing *et al*., 1996). The higher magnetic enhancement in JMM and JMP is caused by the higher volume of traffic in and around these areas and other human activities. Vehicular emissions comprise different fractions of particles formed in the engine in the exhaust pipes and released into the environment. These emissions are of magnetic character, which is determined by the enhancement in the MS. The moderate values of MS obtained from JCOE samples are expected since the area is an official area with less traffic. The high values obtained in some samples are attributed to emissions from vehicles and power-generating sets, as power is epileptic in this city. Most businesses are operated using private alternating current generators.

The magnetic susceptibility map of the study area is displayed in figure 2. The map shows a magnetic enhancement at the top NE and the NW regions.

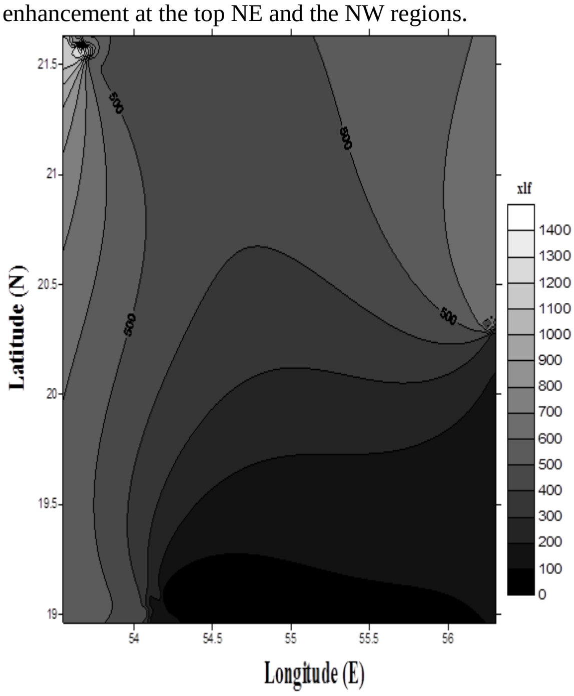

Figure 2: Contour map showing distribution of MS in the studied area.

Figure 3 shows the 3-D map of the distributions pattern of mass normalized MS (χ_{lf} x10^{-6} m^3kg^{-1}) for the surface soils studied. From the diagram, two high susceptibility peaks can be observed around the NW and NE regions. These regions correspond to the market area where a lot of human activities, including emissions from power generating sets, take place and the motor park where large emissions from car exhausts are experienced. Another MS contrast is observed around the SS region. This may correspond to the JCOE region where the lowest MS values are observed.

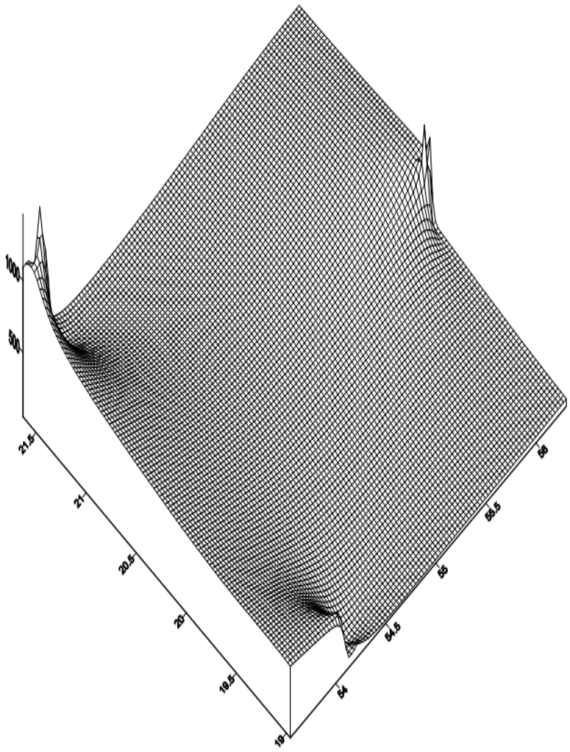

Figure 3: 3-D map of mass normalized MS (χ_{lf} x10^{-6} m^3kg^{-1}) showing distributions pattern for the surface soils studied.

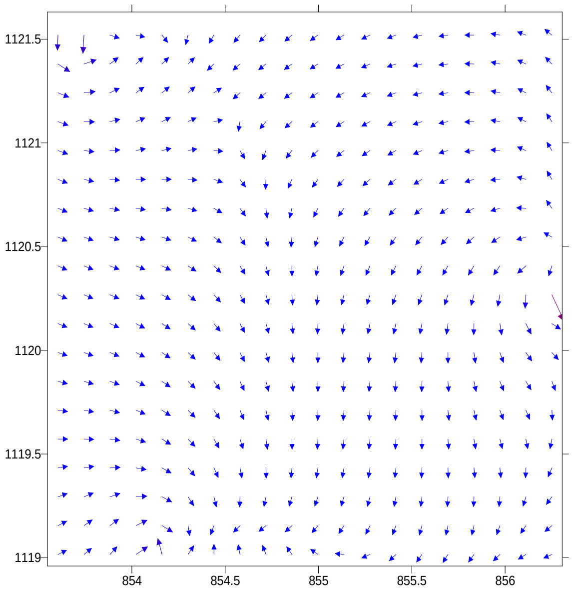

Figure 4: Vector map of the studied area.

A vector map can depict the local gradients of a topographic surface. In the vector map shown in figure 4, each arrow shows a slope direction and a magnitude associated with the location at which the arrow is drawn. The arrow points in the direction of steepest ascent and the size of the arrows are scaled to the magnitude of the local slopes. The slopes are gentle suggesting the surface run -

off as a major control of transportation and re-deposition of the anthropogenically loaded topsoil during rainy season.

Generally, the magnetic susceptibility measured at high frequencies (4.7 kHz) has lower values than the low frequency (0.47 kHz) magnetic susceptibility measurements (Dearing *et al*., 1996; Dearing, 1999). This is further confirmed about soils in Jalingo Metropolis, as shown in figures 5 to 7. Measurements made at these two frequencies at a constant applied field are generally used to detect the presence of ultrafine ferrimagnetic (also called super paramagnetic fraction of less than 0.03 µm) minerals occurring as crystals and to some extent the single domain (approximately greater than 0.03 to less than 0.06 µm fractions) (Sangode *et al.*, 2010). Higher frequency measurements do not allow super paramagnetic grains to react with the applied magnetic field, as it changes more quickly than the required relaxation time for super paramagnetic grains. As a result, in higher frequency, lower values of MS are encountered and the difference is used to estimate the super paramagnetic ferromagnetic particles (Sangode, *et al*., 2010). When super paramagnetic minerals are present in a soil sample, the MS values at high frequency are slightly lower than the values of MS at low frequency. If there are no super paramagnetic (SP) minerals, the two measurements are identical (Dearing, 1999).

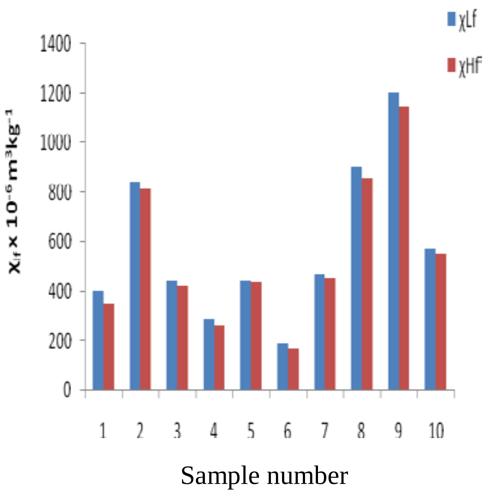

Figure 5: Magnetic susceptibility values (x 10^{-6} m^3kg^{-1}) for JMP samples both at high and low frequency.

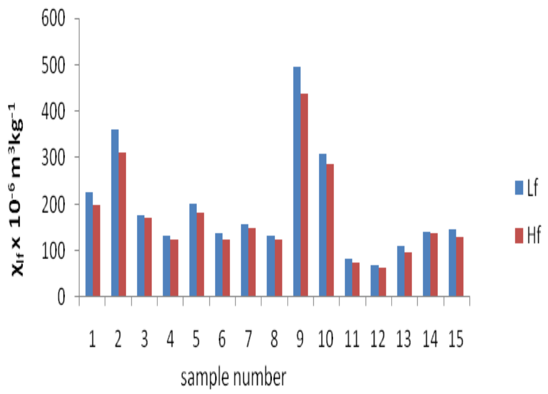

Figure 6: Magnetic susceptibility values (x 10^{-6} m^3kg^{-1}) for JCOE samples both at high and low frequency.

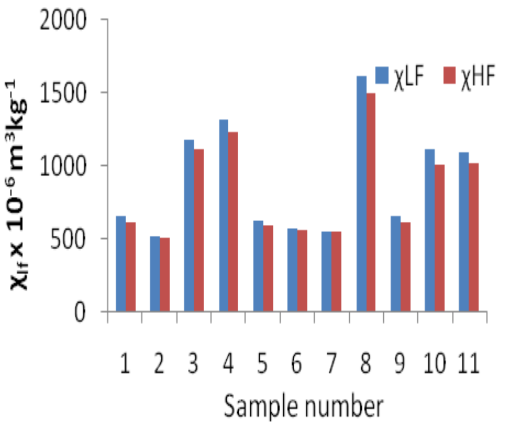

Figure 7: Magnetic susceptibility values (x 10-6 m3kg-1) for JMM samples both at high and low frequency.

There is a great difference between measured values of χLF and χHF , which indicates the presence of admixture of SP minerals in the studied soil. This difference is expressed by the frequency dependent MS (χfd) shown in tables 1-3. The values of varied between 4.7 – 58.1 x $10^{-6}m^3kg^{-1}$ with an average of 17.99 x $10^{-6}m^3kg^{-1}$ for the JCOE, 2.8 – 112.5 x $10^{-6}m^3kg^{-1}$ with a mean value of 52.28 x $10^{-6}m^3kg^{-1}$ for JMM and 2.5- 53.7 x $10^{-6}m^3kg^{-1}$ with a mean of 29.21 x $10^{-6}m^3kg^{-1}$ for the JMP. According to Dearing (1999), the mass specific frequency dependent susceptibility ranges from ~30 x $10^{-6}m^3kg^{-1}$ in stable single domain (SSD) grains to 75 – 160 x $10^{-6}m^3kg^{-1}$ in the SP range. From this information, the majority of the samples studied falls within the SSD range, while only about 20% from the JMM are in the SP range.

Figure 8 relates the χLF and χHF values in the topsoil samples of JMP. The graph shows a linear relationship between χlf and χHF with very significant correlation coefficient.

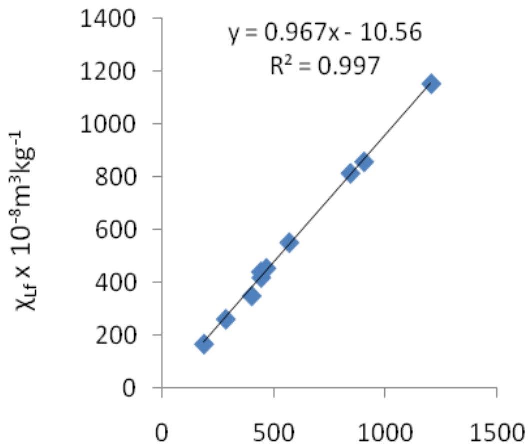

Figure 8: Relation between low frequency and high frequency susceptibility for Jalingo motor park.

Figures 9 -11 compare the χ_{fd} and χ_{LF} values in the topsoil samples. An increase in MS appears to be related to an increase in the χ_{fd}. According to Foster *et al.* (1994), such linear correlation indicates that with increasing magnitude the susceptibility is more controlled by the contribution from the fine magnetic fraction. The JMM and JCOE were more correlated with correlation coefficients of 0.84 and 0.85, respectively.

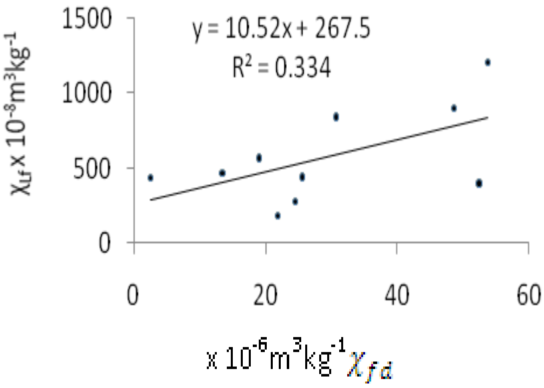

Figure 9: Linear regression between χ_{fd} and χ_{LF} for JMP.

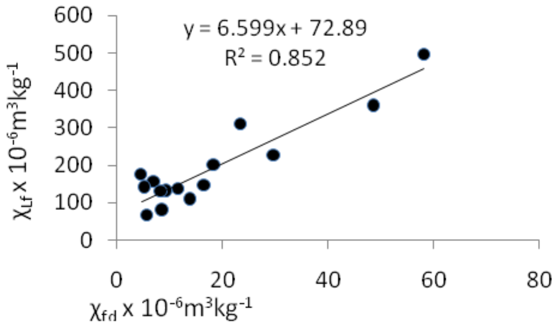

Figure 10: Linear regression between χ_{fd} and χ_{Lf} for JCOE samples.

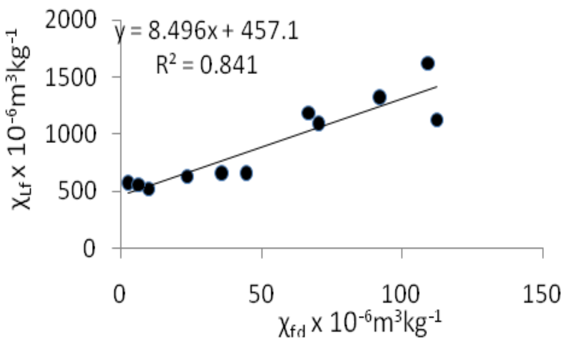

Figure 11: Linear regression between χ_{fd} and χ_{LF} JMM samples.

Percentage frequency dependent susceptibility $\chi_{fd}\%$ is used to approximate the total concentration of SP grains, while coarse multi domain (MD) magnetic grains are frequency independent as they show similar susceptibility values at low and high frequencies. Dearing (1999) proposed a model for the interpretation of percentage frequency dependence as follows:

$\chi_{fd}\%$	Interpretation
< 2%	Virtually no SP grains
2 – 10%	Admixture of SP and coaser non-SP (MD) grains or SP grains < 0.005μm
10 – 14%	Virtually all (> 75%) SP grains
>14%	Rare values, erroneous measurement, anisotropy, weak samples or contamination

Based on the semi quantitative model above by Dearing (1999), the results of this work demonstrated that about 67% of the samples have a mixture of SP and coarse grains or SP grains < 0.05μm. In the JCOE samples, the value of $\chi_{fd}\%$ ranges from 2.68 – 13.80% with an average value of 8.67%. Five samples (that is about 30%) are virtually all SP grains as they have $\chi_{fd}\%$ in the range of 12 – 14 %, while other samples have values in the range of 2 – 10 % indicating the presence of a mixture of SP and MD magnetic grains. In the JMM samples, seven samples fall within the medium range of 2 – 10 % and may be said to have a mixture of SP and coarse MD grains, three samples have low $\chi_{fd}\%$ of < 2% implying that they have no SP grains, while only one sample has high $\chi_{fd}\%$ of 10.04 % meaning that the dominant magnetic component of this soil sample are SP ferrimagnetic grains. For the JMP samples, about 70% of the samples have $\chi_{fd}\%$ value in the medium range and this can be interpreted as soils with admixture of SP and coarser non-SP grains or < 0.005μm SP grains. About 20% of the JMP samples are soils where virtually all the iron component are SP grains, while about 10% of the samples contains no SP grains. Generally, most of the samples in the studied area contain a mixture of SP and MD magnetic grains.

Figures 12 – 14 are the respective scattergram of χ_{lf} - $\chi_{fd}\%$ for JMP, JCOE and JMM showing typical sample positions for the various domains and sources.

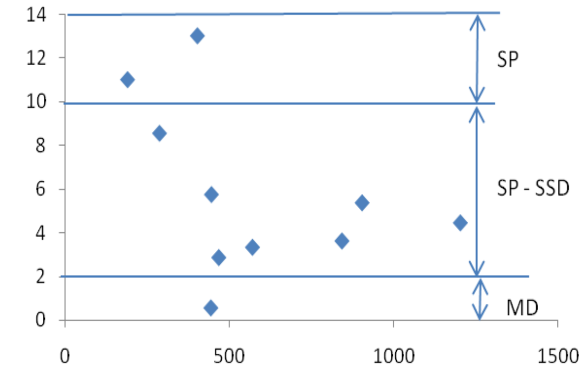

Figure 12: A schematic - scattering diagram showing typical positions of samples from JMP.

The JMP samples showed negative correlation between χ_{lf} and $\chi_{fd}\%$ while the JCOE and JMM samples showed positive correlation. The negative correlation observed in the JMP samples indicates that the main susceptibility variations are due to magnetic enhancement because of industrial and anthropogenic pollution. The negative correlation between χ_{lf} and $\chi_{fd}\%$ further shows that pedogenic SP grains contribute little to the magnetic enhancement of urban soils, the magnetic enhancement is mainly contributed by coarse magnetic grains from industrial and anthropogenic pollution. Similar results were also obtained by Lu *et al*. (2007) for urban topsoils from Luoyang and Lu and Bai (2008) for urban soils from Hangzhou. The positive correlation of the JMM and JCOE samples indicates that the MS enhancement is due to SP ferromagnetic grains. The MS of soils derived from sedimentary rocks usually increase with an increase in frequency dependent susceptibility (Lu 2003). Many authors (Zhu *et al*., 2001; Wang *et al*., 2003; among others) also reported a positive correlation between χ_{lf} $and\ \chi_{fd}\%$ for Chinese loess and paleosols.

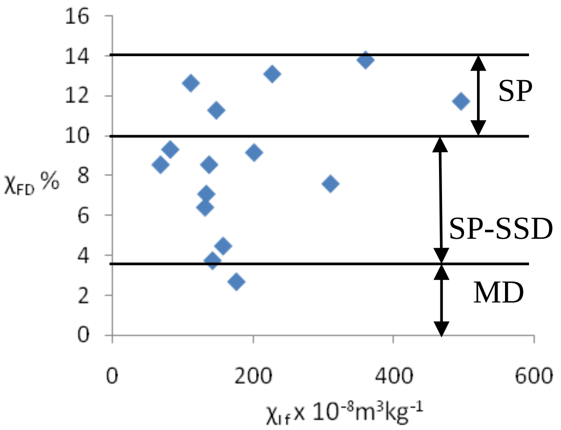

Figure 13. A schematic χ_{lf} - $\chi_{fd}\%$ scattering diagram showing typical positions of samples from JCOE.

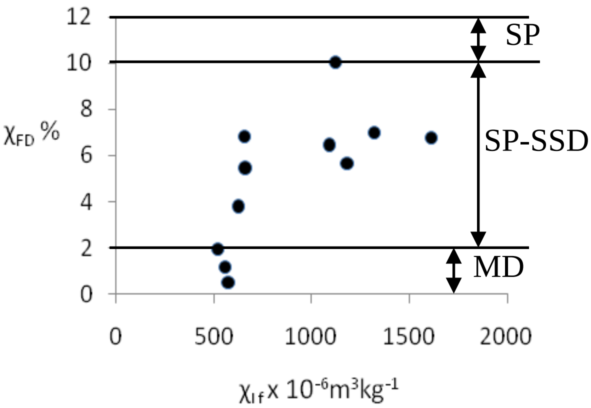

Figure 14: A schematic χ_{lf} - $\chi_{fd}\%$ scattering diagram showing typical positions of samples from JMM.

4. Conclusion

This paper presents preliminary results of magnetic susceptibility studies of soils in Jalingo, Taraba State, Nigeria and is probably the first study of this kind in this area.

The results of the mass specific low frequency magnetic susceptibility ranges from 67.8 - 495.3 x 10^{-6} m^3kg^{-1} with a mean value of 191.61 x 10^{-6} m^3kg^{-1} for the JCOE data; 520.1 – 1612.8 x 10^{-6} m^3kg^{-1} with a mean value of 901.34 x 10^{-6} m^3kg^{-1} for the JMM and 188.5-1203.6 x$10^{-6}m^3kg^{-1}$ with an average value of 574.92 x 10^{-6} m^3kg^{-1} for the JMP. The results showed significant magnetic enhancement, which indicates high concentration of ferrimagnetic minerals in the soil. The magnetic susceptibility of the different land use studies decreased in the order commercial area (market) > motor park > official area. The significant magnetic enhancement also indicates that the study area is polluted; pollution distribution can be known by analysis of magnetic susceptibility. Since the MS method is cheap, fast and capable of measuring a very wide area within a short time, it can be used as a preliminary tool to detect highly polluted areas before the application of the time consuming and expensive geochemical method on select representative sampling.

A linear positive correlation between MS and χ_{fd} was obtained. This indicates that the MS is controlled by the contribution from the fine magnetic fraction in the soil.

The results of the percentage frequency dependence showed that most of the samples have a mixture of SP and coarser non-SP grains. The average value of χ_{fd} (%) are 8.67%, 5.05% and 5.86% for the JCOE, JMM and JMP, respectively. Specifically, 24 samples had a mixture of SP and MD grains, eight (8) samples were in the SP grain size range while four (4) samples were within the MD range

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