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# IDENTIFYING ANTHROPOGENIC METALLIC POLLUTANTS USING FREQUENCY DEPENDENT MAGNETIC SUSCEPTIBILITY MEASUREMENTS IN ABUJA METROPOLIS

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***Abstract***
*Soil formed from lithological and weathering processes of parent rocks generally exhibit paramagnetic properties due to some minerals contained in the rocks and thus have significant value of magnetic susceptibility. This susceptibility arising from the influence of the parent rocks tend to mask anthropogenic grains pollutants released into the environment by human activities. Hence, it becomes difficult to identify the effect of the lithological and anthropogenic magnetic susceptibility in complex soil found in urban areas. The superparamagnetic effect of lithological soil, a single state domain and multi-domain state of anthropogenic grains can easily be investigated by frequency dependent measurements where readings between 0-2.0% indicates the absence of lithological influence, 2.0-8.0% indicates multi-domain grains or mixture of both single stage and multi-domian grains and 8.0-12% indicates the superparamagntic (SP) grain from lithological origin. In this work frequency dependent measurements were carried out along 5 selected road networks within the 5 districts of Abuja phase 1. Measurements were also carried out in 379 random points at the surface and depth of 40.0cm to investigate the distribution of anthropogenic grains in Abuja metropolis using the Bartington susceptibility meter. Frequency dependent measurements along the selected road networks indicate0-3.0% immediately after the roads pavement to a distance of about 3.0m from the road, indicating that the magnetic susceptibility arise mostly form anthropogenic influence rather than lithological processes. At the distance of 3.0-8.0m, frequency dependent values of about 3.0-8.0% were recorded, indicating mixture of both superparamagnetic and multi-domain grains. Beyond the distance of 8.0m, the frequency dependent values are mostly above 8.0.0%, indicating virtually all SP grains. The spatial distribution frequency dependent surface map shows the presence of anthropogenic grains in most part of the areas with frequency dependent values between 0-8.0% while at the depth of 40.0cm the lithological influence of the SP grains is evident with frequency dependent values above 8.0%. From the result, we conclude that the frequency dependent values obtained immediately after the road pavements and on the surface soil of Abuja arise mostly from anthropogenic dust falls of metallic pollutants released mostly from vehicular and industrial activities. While at a distance of about 8.0m and depth of 40cm most of the recorded frequency dependent values arise from the lithological processes of the parent rocks. We conclude that it is possible to identify the effect of lithological magnetic grains from anthropogenic grains using frequency dependent measurements.*

Keywords: Abuja, anthropogenic, magnetic susceptibility, superparamagnetic grains

## 1. INTRODUCTION

In environmental magnetism pollution studies, discriminating of anthropogenic from lithogenic components of the topsoil and subsurface is generally a difficult task especially where boundary



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demarcation between anthropogenic and lithological influenced susceptibility is to be made in urban and industrial areas (Sabdoge et al., 2010). Generally, soils inurban and industrial areas are contaminated by heavy metal grains mostly form industrial wastes, vehicular emission and other form of anthropogenic activities. The metallic grains are mostly in the multi-domain (MD) stage while lithogenic grains are in the superparamagntism stage (SP).The interplay between superparamagnetic (SP) and stable single domain (SSD) or even multi-domain (MD) magnetic grains can be normally interpreted using frequency-dependent susceptibility of rocks, soils and environmental materials (Hrouda, 2010). Most of the anthropogenic pollutants released into the environment fall within the MD grains while lithological magnetic grains are mostly superparamagnetic (SP) grains. Frequency-dependent susceptibility is used to determine the present of superparamagnetic and multi-domain grains in soil samples (Dearing et al., 1996; Aguilar et al., 2013). In this work, we seek to investigate the distribution of MD (anthropogenic influenced susceptibility) around roads and surface soil of Abuja as well as at a depth of 30.0cm. In section 2, we explain the structure of the study are (Abuja phase 1), section 3 shows data and methodology; in section 4 we show results and their interpretation while section 5 consist concluding remarks.

## 2. THE STUDY AREA

Abuja is located in north central Nigeria and has an estimated population of about 3.1 million. It is a well-planned city and the capital of Nigeria. The city (Phase 1) is divided into five major districts namely Wuse, Garki, Central Area, Maitama and Asokoro (Figure 1).

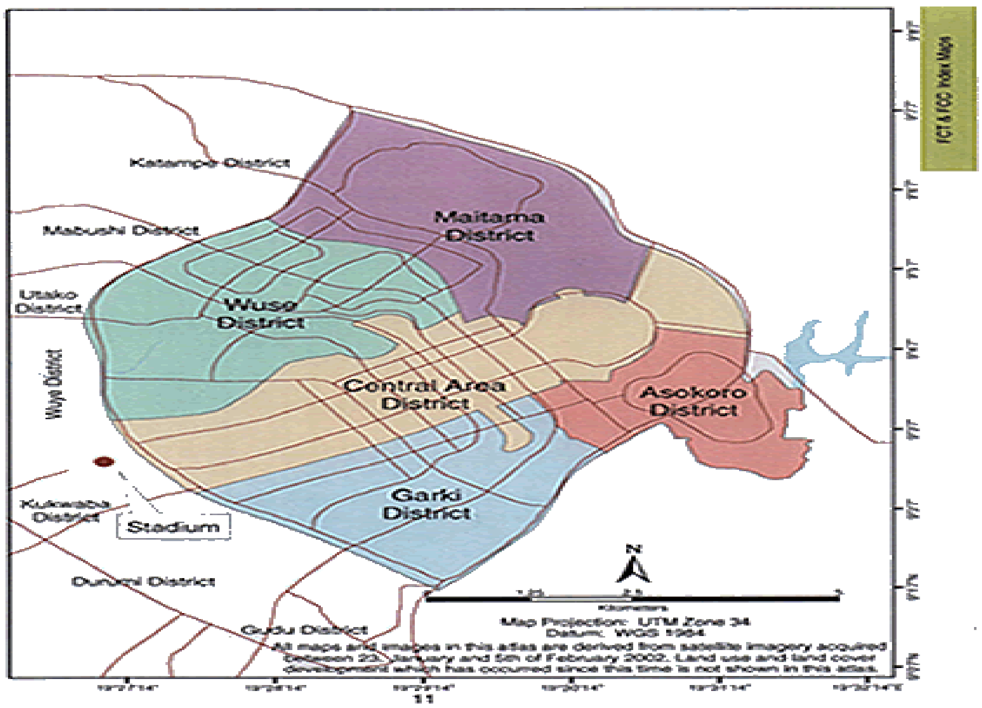


***Figure 1. Map of the study area (Abuja, Nigeria) showing the five districts (Ujoh et al., 2010)***

Abuja is underlain by high grade metamorphic and igneous rocks of the Precambrian age trending NN-E-SS-W direction. These rocks consist of gneiss, migmatites, older granites, granodiorites and the schist belt (Kogbe, 1978). The rocks consists of diamagnetic, paramagnetic and ferromagnetic




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minerals, and these minerals contribute to the magnetic susceptibility of the rocks which in turn affects the magnetic susceptibility of the surrounding soil which are weathered products of the rocks. The residual soils of Abuja can be divided into two major groups; the residual soil which are lateritic and a product of intense weathering of the parent rocks and the transported soil formed by the physical transportation of the soil particles. The residual soils are formed in most parts of the area except along river valleys and at the foot and summit of slopes (Malomo et al., 1983)

Generally, the study area has less industrial activities, aside from major construction works going on around the city. However, the large influx of vehicles into the city remains a major source of environmental pollution. As most of the vehicles release magnetic particles directly into the atmospheric, these finally settle down mostly around roadside corridors and commercial places.

## 3. FREQUENCY MAGNETIC SUSCEPTIBILITY

Magnetic susceptibility in the environmental studies is due to the contribution of the ferro, ferri, antiferro, para and the diamagnetic constituents found within the soil samples (Sangode *et al*., 2010). Frequency dependent susceptibility is obtained from magnetic susceptibility measurements performed at two different frequencies: low ($\chi_{lf}$) and high ($\chi_{hf}$). Measurements made at these two frequencies are generally used to detect the presence of ultrafine (<0.03 μm) super paramagnetic (SP) minerals in samples. Samples where SP minerals are present will show slightly lower values when measured at high frequency; samples without super paramagnetic minerals will show identical magnetic susceptibility, $\chi$, values at both frequencies (Dearing, 1999). Under low external field, this parameter indicates the presence of grains layering at the single domain/superparamagnetic boundary; at higher frequencies of measurement, a proportion of these grains will become "block in" and will nolonger contribute to the susceptibility as superparamagnetic but as single domain grains (Maher 1986). Frequency dependent susceptibility is mostly expressed as a percentage of the mass-specific frequency dependent susceptibility;

$$\chi fd\% = \frac{\chi lf - \chi hf}{\chi lf} X\ 100 \qquad 1$$

Higher frequency measurements do not allow SP grains to react with the applied external field, as it changes more quickly than the required relaxation time for SP grains. As a result, in the higher frequency, lower values of susceptibility are encountered and the difference is equated to estimate the ferromagnetic particles (Thompson and Oldfield 1986).

Table 1 shows values of $\chi_{fd}$% indicating the presence of SP particles in the sample.

***Table 1. Interpretation of $\chi_{fd}$% values (Dearing, 1999; Michal, 2012)***

| | | |
|---|---|---|
| **Low $\chi_{fd}$%** | < 2.0 | Virtually no SP grains |
| **Medium $\chi_{fd}$%** | 2.0-10.0 | Mixture of SP and coarser grains, or SP grains <0.05μm |
| **High $\chi_{fd}$%** | 10.0-14.0 | Virtually all SP grains |
| **Very High $\chi_{fd}$%** | >14.0 | Erroneous measurement, anisotropy, weak sample or contamination |

Generally, below a critical particle size, thermal energy becomes large enough to spontaneously switch the magnetic moments of small, single-domain grains in a relatively short time (Nee1, 1949). For example, if a population of such grains is magnetized and then the field removed, a measurement of remanence after a time (t)=*t* will reveal that the value has decreased to l/e of its



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initial value. This is known as superparamagnetic relaxation and t is known as the relaxation time. The importance of time in magnetic measurements of small grains is exploited in the measurement of the frequency dependence of magnetic susceptibility. The difference between magnetic susceptibility measurements obtained at the two different frequencies is a function of the concentration of grains that have relaxation frequencies (i.e. l/t) that lie between the two measuring frequencies. The relationship between the critical blocking volume ($v_b$) of a SP grain and the relaxation frequency (z is 2 times the measurement frequency f,) is governed by the equation

$$log\left(\frac{2f_m}{f_0}\right) = -\left(\frac{K_{vb}}{kT}\right) \qquad \textbf{2}$$

where K is the effective anisotropy constant, *k* is Boltzmann's constant, T is temperature and $f_0$ is a constant = 10Hz (Dickson *et al.,* 1993). The exponential relationship between relaxation time and grain volume means that the threshold between grains that behave superparamagnetically and those that behave stably is very narrow.

## 4. DATA AND METHODOLOGY

Single magnetic susceptibility (χ) measurements were made using a Bartington MS2 magnetic susceptibility meter connected to a Bartington MS2B dual frequency susceptibility sensor. Measurements were taken at low frequency (0.47 kHz; ($\chi_{LF}$)) and high frequency (4.65 kHz; ($\chi_{HF}$)). Both low and high frequency susceptibilities were measured ($\chi_{LF}$ and $\chi_{HF}$) to allow frequency dependent susceptibility to be calculated ($\chi_{FD}$%).
Also random magnetic susceptibility measurements were taken at 324 points at the surface and vertical soil profiles of 40.0cm (Figure 2).

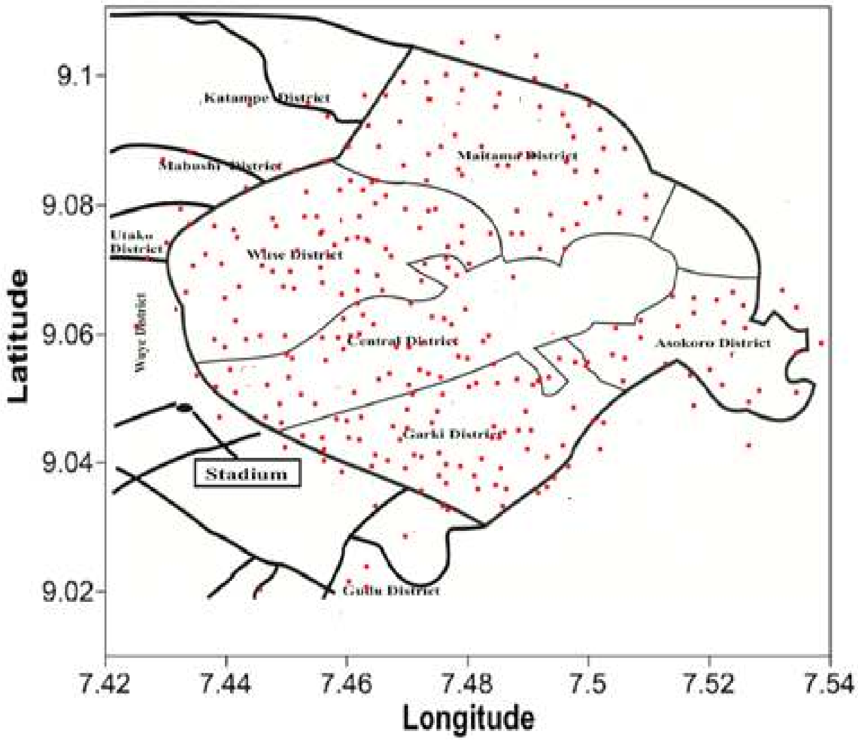


***Figure 2. Map of Abuja with the red dots indicating the location of the surface and vertical magnetic susceptibility soil profiles measurements.***


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Measurements were conducted in the vertical soil profiles using a specially designed device SM 400 (Petrovsky et al., 2004). The main part of the SM 400 is a plastic tube with the magnetic sensor inside that is being moved upward and downward during the measurement. Before the measurement, the 40.0cm deep drilling was made using HUMAX SH 300 sampler, thereafter, the tube of SM 400 was inserted into the40.0cm prepared hole where the measurements of soil magnetic susceptibility was performed.

## 5. INTERPRETATION OF RESULTS

### 5.1. Interpretation of results along road network

The fine grains distribution along selected road in Central district area is shown in Figure 3. From the Figure, the frequency magnetic susceptibility distribution indicates that near the road pavement has no SP grains. About 4.0 to 12.0 m from the road pavement there are indication of mixture of fine grains and coarser grains or SP grains less than <0.05μm. Concentration of SP grains occurs at the middle of the road profile at a distance of 8.0m to 12.0m.

In Garki district, (Figure 4) the distribution of SP grains is not clearly evidence as most of the covered section of the road indicate frequency dependent values between 0-5.0%. This indicates the presence of magnetic fraction of anthropogenic origin release due to vehicular activities.

Near the road pavement in Wuse district (Figure 5), SP grains are virtually absent; however, at the center of the road section, a circular anomaly indicating virtually all SP grains is visible with frequency dependent values above 8.0%. This anomalous feature may represent an outcrop with superparamagnetic grains of pedological origin

In Maitama district (Figure 6), there are virtually no SP grains near the road pavement. A linear trend is observed from 4.0 m from the road pavement. These linear trends indicate high concentration of SP grains along the road profile. This may be due to the present trench along the profile lines.

Mixture of SP and coarser grains of SP grain are evident in the profiles in Asokoro district area from the road pavement. Traces of high concentration of SP grains are also observed at a distance of 5.0 m from the road pavement (Figure 7).


***Figure 3: Distribution of frequency dependence magnetic susceptibility along selected road profile in Central district***


***Figure 4: Distribution of frequency dependence magnetic susceptibility along selected road profile in Garki district***



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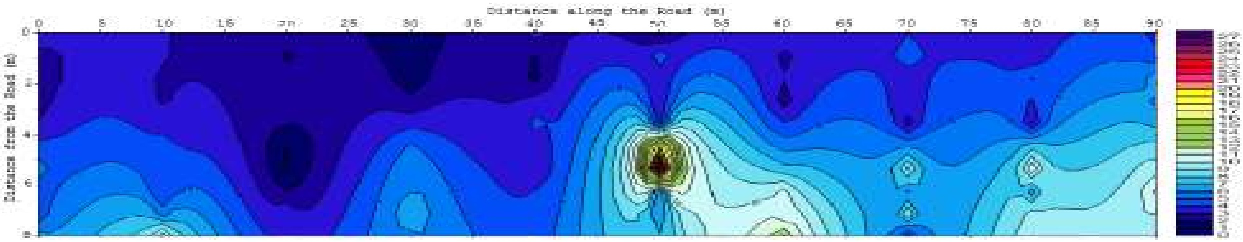


***Figure 5. Distribution of frequency dependence magnetic susceptibility along selected road profile in Wuse district***


***Figure 6. Distribution of frequency dependence magnetic susceptibility along selected road profile in Maitama district***


***Figure 7. Distribution of frequency dependence magnetic susceptibility along selected road profile in Asokoro district***

## 5.2. Spatial Frequency Dependent Magnetic Susceptibility Distribution in Abuja with Depth

The frequency dependent magnetic susceptibility at the surface soil of Abuja is show in Figure 8. From the Figure, it is observed the frequency dependence varies between 0-14 percent. This large variation indicates the heterogenic composition of the top soil in Abuja.

From the field measurements it is observed that the frequency-dependence of magnetic susceptibility ($\chi_{fd}$%) values are very low (from 0-5.0%) in most of the areas. Low frequency-dependence susceptibility values indicate that the magnetic properties are predominantly contributed by the coarse multi-domian (MD) and stable single domain (SSD) grains rather than super paramagnetic grains (Adyin and Akyol, 2015). Hence, this indicates the anthropogenic nature of the magnetic particles, which are derived from the phenomena associated with the movement of vehicles, industrial and precipitation of the particles floating in the air (Sylwia, 2014). From the surface map, low frequency-susceptibility is mostly observed in Wuse, Garki and Part of Central districts, these districts have high commercial activities and vehicle movement. In Asokoro district, the frequency-dependence susceptibility is mostly above 6%, this is due to the contribution of the super paramagnetic grains. Another likely cause of high frequency-dependence is the fact that the




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area is rocky and on higher altitude than any portion of Abuja. Other portions that show high frequency-dependence susceptibility are mostly around the boundaries of Abuja Phase 1, these areas are mostly reserved or undeveloped sections and thus commercial activities is less. Therefore the contributing factor is generally super paramagnetic of the pedogenic origin.

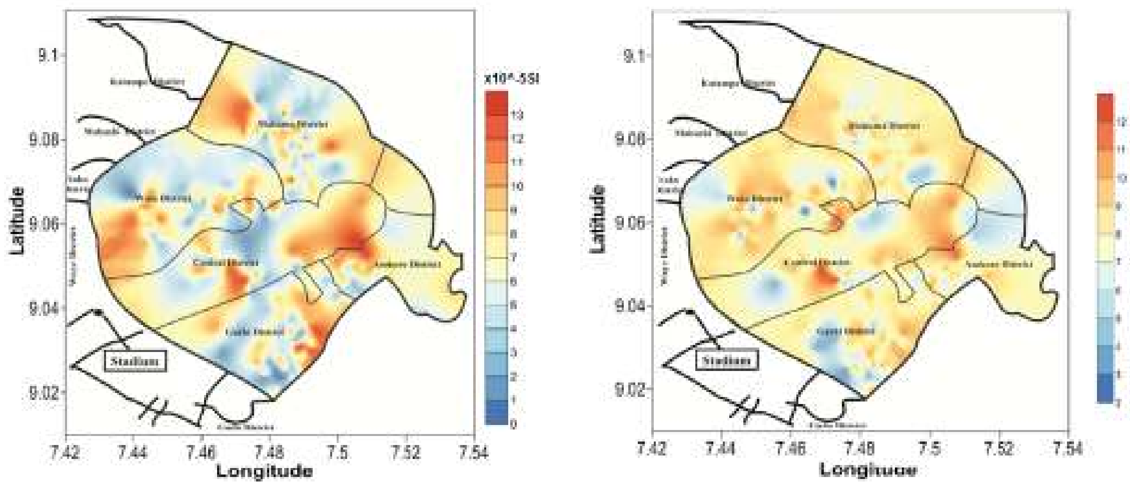


*Figure 8. Distribution of frequency-dependence magnetic susceptibility values for the surface soil of Abuja*

At a depth of 40.0cm (Figure 9), the subsurface map clearly show frequency-dependence susceptibility greater than 6% in almost all the area with exception of few portions. This indicates that, super paramagnetic grains are the main contributors to the magnetic susceptibility at that depth. These super paramagnetic grains are mostly from pedogenic origin rather than anthropogenic source. From this, we can infer that magnetic grains do not penetrate through the soil except in some cases where over time they keep depositing and thus may form a record guide to understanding the activities of the place from ancient periods. However, this may only happen if there is no transportation means like running water or wind to move them any from the surface as soon as they are released.

## 6. MULTIVARIATE STATISTICAL ANALYSIS

A plot of $\chi_{fd}$% versus $\chi_{lf}$ may help to discriminate between grain-size and domain state, and may give a first order classification of magnetic properties and even sources (Table 2).

***Table 2. Origins of magnetite/maghemite and greigite with domain size (Dearing, 1999 and modified by the author)***

| | MD | PSD | SSD | SP |
|---|---|---|---|---|
| **Primary** | | | | |
| **Magnetite/titanomagnetite** | X | X | (X) | (X) |
| **Secondary** | | | | |
| **Fuel Combustion** | X | X | (X) | (X) |
| **Pedogenesis** | | (X) | X | X |
| **Bacterial Magnetosomes** | | (X) | X | (X) |
| **Burning** | | | (X) | X |

**MD**-multidomain, **PSD**-pseudo-single domain, **SSD**-stable single domain,
**SP**- superparamagnetic, (x) - some evidence, but not normally expected


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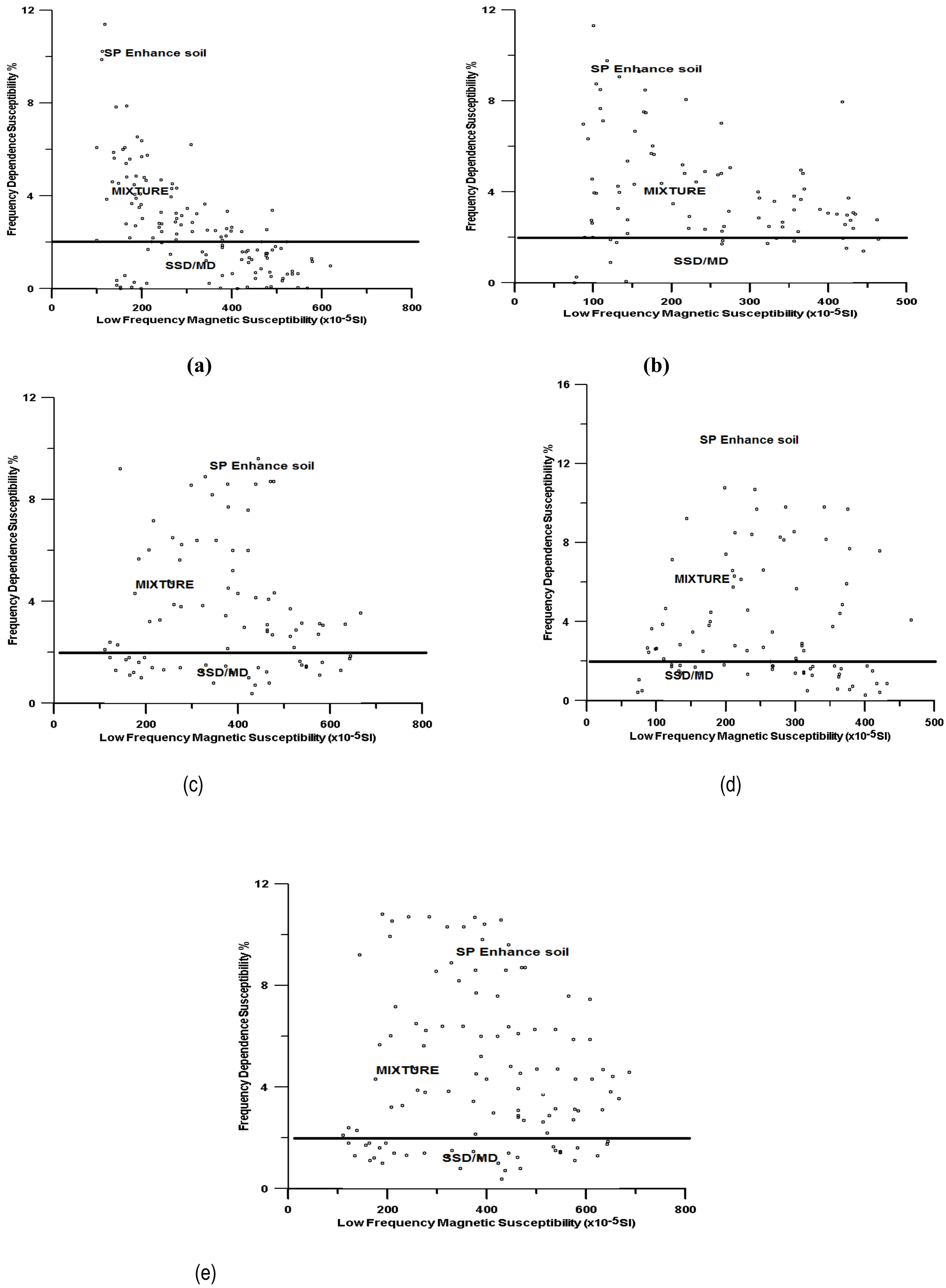


*Figure 9. A $\chi_{lf}$ -$\chi_{fd}$ % scattergram showing typical positions ofsamples dominated by various domains and sources at a road in (a)Centre , (b) Garki , (c) Wuse (d) Maitama and (e) Asokoro districts of Abuja*




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Figures 9 shows the patterns of values plotted on a bivariate $\chi_{lf}$-$\chi_{fd}$% scattergram of different measurements from selected roadside in Central Area, Garki, Wuse, Maitama and Asokoro in Abuja. Measurements dominated by relatively coarse-grained non-SP ferrimagnets from igneous rocks or combustion products show relatively high $\chi_{lf}$ but virtually zero $\chi_{fd}$. Values of $\chi_{fd}$% < 5% are typical where non-SP grains dominate the assemblage or where extremely fine grains (<0.005 μm) dominate the SP fraction. For locations with $\chi_{fd}$ % 10-14%, SP grains usually from soil dominate the assemblage and $\chi_{fd}$ can be used semi-quantitatively to estimate their total concentration. There is at present insufficient experimental data to construct with confidence a quantitative model for interpreting $\chi_{fd}$ and $\chi_{fd}$% in terms of absolute proportions of different grain-sizes. At present, it is prudent to interpret frequency dependence data semi-quantitatively as shown in Table 2.
Values of $\chi_{fd}$ % will be depressed by the presence of frequency-independent grains or grains with weak frequency-dependence and will be exaggerated by the presence of a significant diamagnetic component. Values of $\chi_{fd}$ % greater than 12 to 14 % are rare.
In this research, and in nature, it is unlikely that grains exist either independently of each other or in narrow size ranges of discrete grains. They will probably adhere to form clusters. It is probable, for instance, that low frequency-dependent values in relatively large crystals are caused by small numbers of SP crystals attached to their surfaces.

## 7. CONCLUSION

Frequency-dependent magnetic susceptibility distributions of fine grain are irregular along most of the road pavements. (The distribution of frequency-dependence susceptibility of less than 5.0 percent dominated the plot from the road pavements to a distance of about 5.0-8.0m in some cases. This indicates the presence of coarse multi-domain and single state domain grain in the roadside dust rather than super paramagnetic grain. In the road in Asokoro district frequency-dependence susceptibility greater than 5.0 percent is predominantly found there, an indication of super paramagnetic grains. Single State domain and multi-domain grains are mostly release from anthropogenic sources while super paramagnetic grains are found from pedogenic source, hence from this observation, it should be of interest to know that most of the roadside dust and surface soil of Abuja metropolis are cover with magnetic dust release through anthropogenic sources like vehicular and industrial activities. At the sub-surface (depth of 40.0cm), it is observed that the frequency-dependence susceptibility varies mostly between 7.0-11.0 percent, these percentage clearly indicate the presence of super paramagnetic grains as a dominant contributor.
The scattergram plot of magnetic susceptibility with frequency-dependence susceptibility clearly shows the distribution of the magnetic grains according to their sizes. From the plot it is obvious that the percent of super paramagnetic grains is less when compared to multi-domain and single state domain grains.
Generally super paramagnetic grains are mostly from pedogenic rather than anthropogenic sources. From this, we can conclude that multi-domian and single state domain grain mostly accumulate at the surface and hardly do they find their way to depth of 40.0cm. From this result it is possible to investigate and discriminate anthropogenic pollutants from lithological originated susceptibility in complex soils.

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