Implications of Soil Magnetic Susceptibility Measurements from the Waste Site Deposit of Independence Hall, Kwame Nkrumah University of Science and Technology (K. N. U. S. T), Kumasi.

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Abstract- The applicability of magnetic susceptibility measurements was tested to detect soil contamination from a waste site deposit in the topsoil in the vicinity of the Independence Hall, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. Magnetic susceptibility (volume specific) measurements of the near surface topsoil (~ 15 cm top layer) were taken along four radial profiles from the centre of the 100 m^2 deposit at 1 m intervals using the Bartington MS2 (MS2D Field Loop Sensor) magnetic susceptibility system. The results of the measurements showed that the near surface soil around the waste site deposit lies in the region of paramagnetic and (canted) anti- ferromagnetic materials. The average magnetic susceptibility values recorded along profiles taken in the direction of run-off was 350×10^{-5} SI, and this was about 7 times higher than that observed along the other profiles. Atmospheric particulates from vehicular emissions and other contaminants from the waste site infiltrate the soil through the agency of rainfall. This result will be useful for understanding the extent of pollution from waste deposition sites. The continuing use of the area as a waste site deposit should be discouraged since it poses a high pollution threat.

Index Terms- magnetic susceptibility, antiferromagnetic, contaminant, waste deposit

I. INTRODUCTION

The magnetic properties of soils are largely due to the presence of ironic compounds, in particular, oxides and sulfides of iron. The level of concentration of iron oxides in the soil depends on the age and nature of the soil, pedogenic and biological activities, and soil temperature. The distribution of pollution in soil depends on many factors, of which distance from the source, landscape morphology, vegetation and dominant wind direction are the most influential (Klučiarová et al., 2007).

Iron originates from the primary minerals contained in the parent materials, thus, it becomes concentrated in the weathered material because of its low solubility under oxidizing conditions at the natural pH. Iron is less easily integrated than aluminum within the clayey secondary phylosilicates and, therefore, iron is generally in the form of iron oxides and hydroxides, such as hematite, limonite, goethite, lepidocrite, magnetite, and maghemite (Stacey and Banerjee, 1974). Soil particles differ in their degree of magnetism because of differences in their iron components, which control the magnetic order within the soil (Parker, 1983). In stable soils, magnetic susceptibility gradually increases from the deep soil layers to the surface, but in degraded soils, this pattern is absent and magnetic susceptibility is lower.

Investigations into topsoil magnetism lead to useful applications in the fields of archaeology, hydrology and sedimentology, landslide characterization and environmental pollution (Dearing, 1999). Since the 1970s, magnetic susceptibility has been used in environmental studies (Thompson et al., 1980; Oldfield, 1977, Thompson and Oldfield, 1986), many of which mainly focused on identification of the sources of sediments. In most cases, the Bartington susceptibility meter for field measurements has been used though no standard procedure is known to carry out such investigations (Strzyszcz, 1999). The compatibility of different set-ups of instruments used for magnetic susceptibility measurements has been shown in Schibler et al.,(2002) to be very consistent both for low and high values. Magnetic susceptibility measurements on top soils have often been used during the last few years to detect anthropogenic pollution (especially from heavy metals) on soil and sediment samples (Schmidt et al., 2005). The use of soil magnetic signatures to assess soil degradation is based on differences in the specific behaviour of iron components, which have near full control over the magnetic order in the soil (Strzyszcz et al., 1996). Magnetic susceptibility measurements find useful applications in magnetic and magneto-mineralogical studies of forest soils (Kapicka et al., 1999), soil contamination studies (Strzyszcz et al., 1996, Canbay, 2009) among others.

This paper discusses the implications of near surface (~ 15 cm top layer) magnetic susceptibility measurements from the region surrounding the waste site deposit at the Independence Hall, K. N. U. S. T, Kumasi. This deposit is one of the many waste site deposits found on the campus of K. N. U. S. T. The results from these measurements would help educate the public on the impact of such waste sites on the environment.

1.1 Background of Magnetic Susceptibility, X_m

From the atomic point of view a material may have a net magnetic moment resulting from the rotation of its electrons in the various shells around the nucleus or the electron spin about their axes. The magnetic behaviour of a material is as a result of magnetic moments produced from these effects. Magnetic susceptibility $\mathbf{X_m}$, (Dearing, 1999) is the ratio of magnetization

M [Am-1] to_the magnetic field strength H [Am-1]. Positive values of $\mathbf{X_m}$ imply that the induced magnetic field is in the same direction as H. The direction of the induced field is opposite to H when $\mathbf{X_m}$ is negative. In magnetic prospecting $\mathbf{X_m}$ is the fundamental property whose spatial distribution is determined. Based on the material magnetic susceptibility, materials are classified as paramagnetic (with unpaired electrons in incomplete electron shells slightly positive $\mathbf{X_m}$), diamagnetic (where all electron shells are filled with no net magnetic moment, slightly negative $\mathbf{X_m}$, common to all material), ferromagnetic (containing unpaired electrons in incomplete electron shells, magnetic moment of each atom is coupled in parallel arrangement with surrounding domain, electron orbits overlap, strongly positive $\mathbf{X_m}$), and anti- ferromagnetic (moments of neighbouring sub-lattices align opposite to each other and cancel out, no net magnetization, moderately positive $\mathbf{X_m}$) and ferrimagnetic (sub-lattices exhibit ferromagnetism but coupled antiferromagnetically between each other, strongly positive $\mathbf{X_m}$) (Dearing, 1999).

II. MATERIALS AND METHODS

2.1 Project site

Data was taken from the waste site deposit of the Independence Hall of the Kwame Nkrumah University of Science and Technology, Kumasi (Figures 2.1 and 2.2). Unity Hall is to the east of the waste site deposit. To the west and south of the deposit are the Independence Hall and the Round-About respectively. The road from the Round-About is about 26 m away from the study area and it is located east of the deposit. The site dips gently towards the south-west. Soil in the area is of the loamy clay type in the north and south but sandy in the east and south. Due to the passage of students and workers along the east and south of the site, during their daily activities, the surface is quite hard and smooth. Some trees are found in the north- east direction and grasses of some few centimeters high above the topsoil are found in the north. The south-east is quite disturbed by protruding roots of trees within the area. The west and south-west are free of vegetation but contain many small channels of run-off water. The waste site deposit which covers an area extent of 100 m^2 has been in existence for the past 20 decades, hence there was the need to investigate its impact on the environment.

2.2 Data acquisition

Insitu surface volume magnetic susceptibility measurements were performed using the MS-2D Bartington loop sensor with a diameter of 185 mm at the various stations. The system is developed for detecting very low quantities of magnetic Fe-oxides in compact (rocks) or loose substrates (mineral soil, humus layer). The susceptibility meter has a sensitivity of 0.1 to 1×10^{-5} SI units and can be used in a single readout mode. Soil samples were taken from various points around the waste site deposit. Four profiles lines a, b, c and d (30 m north, 30 m east, 24 m south and 24 m west) were constructed radially from the four sides of the waste deposit (Figure 2.3) and magnetic susceptibility measurements taken at 1 m intervals along these profiles. In order to reduce errors, observations at each station were taken four times and the average found.

Figure 2.1: The waste site deposit: A. Four-walled concrete waste collector. B: Waste water sprout

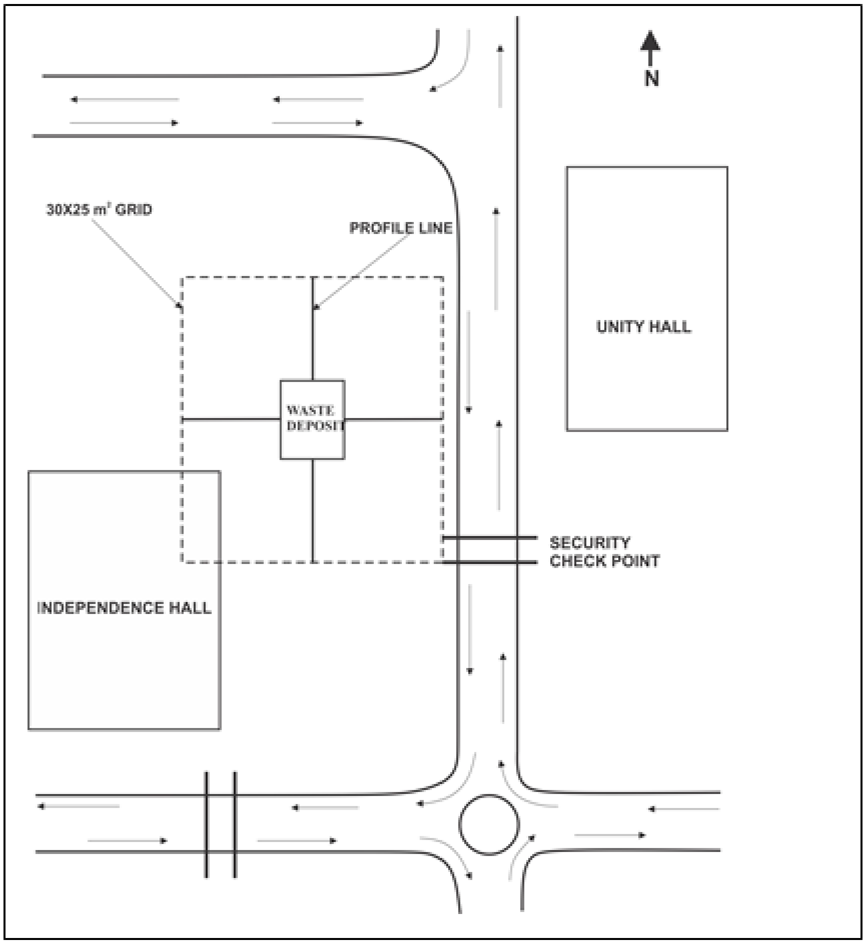

Figure 2.2 Schematic diagram of the waste site deposit and its location.

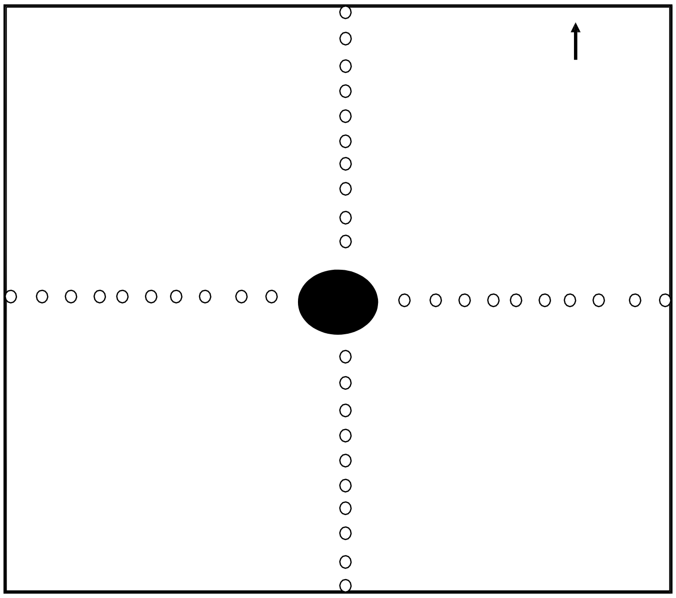

Figure 2.3 Profile layout: Large black circle is waste site deposit; Hollow circles indicate 1 m interval stations; a, b, c and d indicate profile lines.

III. RESULTS AND DISCUSSIONS

3.1 Results of Magnetic Susceptibility Measurements

Magnetic susceptibility is a characteristic parameter of a mineral. Its measurement gives information on Fe-bearing minerals especially magnetite (Fe_3O_4) which is about the main ferromagnetic mineral. It is often combined with other analysis techniques to determine elemental soil composition. The magnetic susceptibility measurements carried out purposely to get an insight into the general distribution of the magnetic susceptibility over the study area led to the following results (Figures 3.1 and 3.2).

Figures 3.1 and 3.2 indicate that at a distance of about 25 m from the waste site deposit, the west profile recorded the highest average susceptibility with concentration of Fe bearing minerals within the range of 100 to 350 $\times 10^{-5}$ SI (about 1.0 to 3.5×10^{-6} m^3/kg) followed by the north and east profiles which recorded magnetic susceptibility values within the range 20 to 210 $\times 10^{-5}$ SI (about 0.5 to 2.1×10^{-6} m^3/kg) and 50 to 200×10^{-5} SI (about 0.5 to 2.0 $\times 10^{-6}$ m^3/kg) respectively. The lowest susceptibility of 50 to 150 $\times 10^{-5}$ SI (about 0.5 to 150 ×10-6 m^3/kg) was recorded on the south profile.

The susceptibilities of the north profile (Figure 3.1 A) tend to decrease with increasing distance from the site for the first 15 m. The highest susceptibility measured on this profile (210×10^{-5} SI) was taken very close (1 m) from the site at a station which contained no vegetation cover. Vegetation where present helped preserve moisture content in the soil and the absorption of some of the Fe ion bearing minerals in solution by the roots may be a contributing factor to the decreasing susceptibilities along this profile.

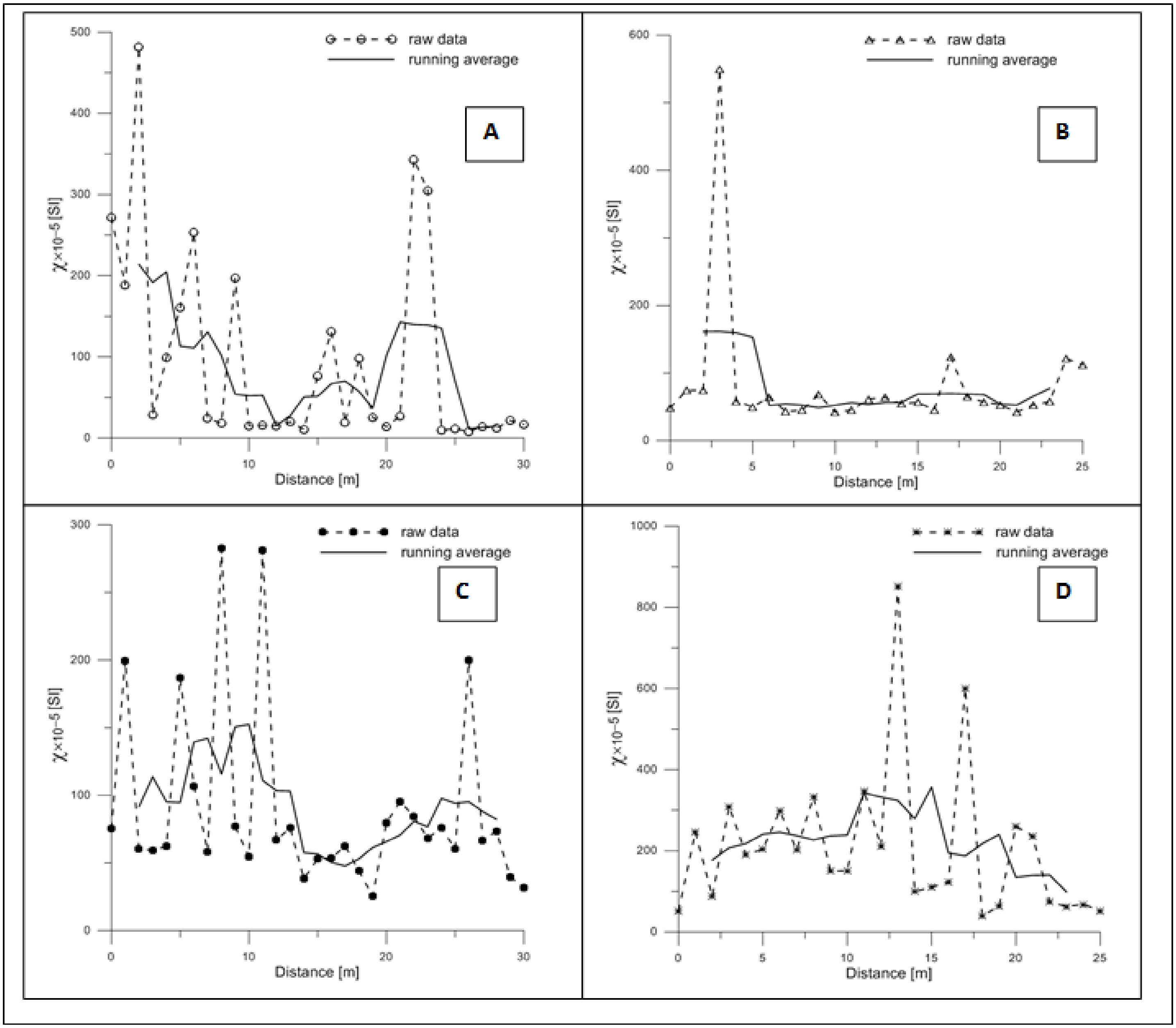

Figure 3.1 A – north profile, B – east profile, C – south profile, D – west profile

The lowest average susceptibility of the south profile (Figure 3.1 C) is an indication of the presence of paramagnetic material (such as epidote, pyrite, illite, biotite, chalcopyrite and dolomite) with low Fe ion concentration. This region may also be considered to be dominated by paramagnetic materials such as dolomite over the anti-ferromagnetic materials (hematite) because measured average susceptibility is slightly positive. The strong wavy nature of magnetic susceptibility-distance plots of this region and that of the north side may be caused by uneven distribution of broken rocks or materials by roots of trees and weeds. A distance between 17 to 30 m has no weeds and protruding roots but contain only loose sand. This is shown by the gentle 'rise' of the magnetic susceptibility-distance plot.

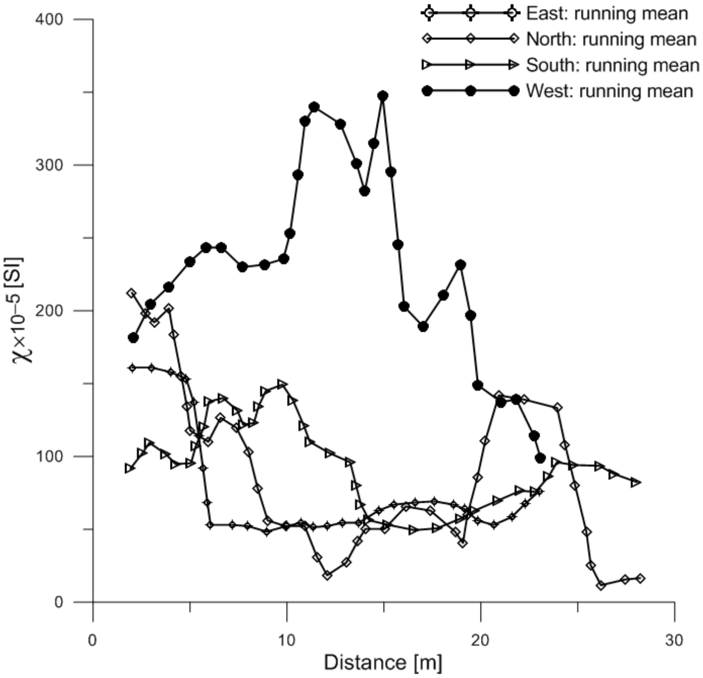

Figure 3.2 Trend of magnetic susceptibility running means.

The east profile (Figure 3.1 B) which in general has no vegetation cover but has loose sandy particles, showed a sharp decrease in suscpetibil1ty from 160×10^{-5} to 50×10^{-5} SI, that is 5 m away from waste deposit. However, from the 5 m position (Figure 3.1 B) until the end of the 30 m long profile, the variation in susceptibilities is within a small range between 50×10-5 and 90×10^{-5} SI. In this region, the paramagnetic and anti-ferromagnetic materials likely to be found are those with very small difference in susceptibilities when compared. Therefore the source of these magnetic materials as well as concentration of Fe ions appears to be homogeneously distributed. Even though the road is closer to this profile, it does not give high susceptibility anomalies. The soil in this area is loose and lacks the ability to bind the metallic particulates from vehicular emission together. Thus, these are most likely carried away by the wind.

The south and east profiles (Figure 3.1 C and B) indicated an overall decrease in the magnetic susceptibility with increasing distance. These two areas have no grass cover and soil particles are quite loose compared to the north and west. The west profile (Figure 3.1 D) recorded the highest average magnetic susceptibility. The magnetic susceptibility plot of the profile (Figure 3.1 D) shows an unevenly increasing susceptibility with distance 15 m (350×10^{-5} SI) from the waste deposit. The lowest susceptibility recorded here was 100×10^{-5} SI. The measured susceptibilities compared to the susceptibilities of materials measured by Dearing (1999) suggest that the region is more of antiferromagnetic materials than paramagnetic materials. The reverse is noted for the last 15 m distance along this profile.

The west profile (Figure 3.1 D) lies in the same direction of the slope of the site. The region has no grass and weeds but rather clayey-sand soil that can hold solvent containing both soluble and insoluble magnetic and non-magnetic materials as a result of run-off water from the waste. Thus, the accumulation of solvents of contaminants of Fe ions is highly possible during infiltration within this region. A decreasing susceptibility is a clear indication of decreasing trend in iron forming compounds. High amount of Fe ions in soil is an indication for soil contamination. Though the area consists of paramagnetic and anti-ferromagnetic minerals, the strength of the Fe ions were decreasing with increasing distance.

3.2 Discussions

In the natural environment, magnetizability provides information on the type of minerals found in soils, rocks, dusts and sediments, particularly Fe-bearing minerals. Soil magnetic susceptibility measurements provide information similar to that produced by other mineralogical techniques like X-ray diffraction on heavy mineral analysis (Dearing, 1999). Magnetic properties of different types of soil display different aspects of soil mineralogy. The minerals that are present in soil are either natural (through lithogenesis, pedogenesis) or of anthropogenic origin (waste deposits, vehicular emissions). The magnetic mineral content of the soil can be expressed in very broad terms by its magnetic susceptibility (Thompson and Oldfield, 1986).

Comparing measured magnetic susceptibility values to that of some materials considered by Dearing (1999), it can be inferred that, the lateral variation of susceptibility within this region is indicative of antiferromagnetic and paramagnetic materials. This is because the magnetic susceptibilities measured are positive (antiferromagnetic) and slightly positive (paramagnetic) as compared to strongly positive values which characterize both ferromagnetic and ferrimagnetic materials.

In general, it can be deduced that magnetic susceptibility and Fe-bearing mineral concentrations are both high (resulting from mostly the antiferromagnetic materials), in the south-east region and the source is most likely to be anthropogenic. Conversely, when magnetic susceptibilities are high but Fe concentrations are low, the source is most likely a natural one, indicating the presence of geogenical anomalies. The transportation of Fe-bearing minerals away from the source in several ways and the atmospheric, geological, anthropogenic effects might have resulted in the high susceptibilities of the south-western region of the deposit. The nature of the investigated site, indicates that it slopes towards the south-west. This facilitates the transport, accumulation or deposition of Fe-bearing minerals and this preferred transport direction is aided by the presence of cracks and fractures in the soil and agency of rainfall. Consequently, there is a higher concentration of Fe bearing minerals resulting in higher magnetic susceptibility measurements in the south-western part of the deposit as compared to the north-eastern part.

Protrusions of plant roots within the anomalous zones affect the magnetic susceptibility distributions. The magnetic susceptibility of the soil was found to be relatively lower in the vegetated than the non-vegetated part of the deposit. It is likely that the plants play a major role in reducing the magnetic susceptibility of the area. The enrichment of soil with other metals such as Pb and Zn may be caused by the emissions from the vehicles as well as the long distance transportation from remote sources of emissions. The transport of these emissions by wind and run-off which has its course channeled in the South-West direction is a major cause of the distribution of the magnetic susceptibility in the area. The anthropogenic emission sources in the study area are that of atmospheric particulates from vehicular emissions, domestic and industrial waste disposal.

The results of this study also reveal the extent to which vegetation and soil moisture affect the magnetic susceptibility of the soil in the study area. The grass cover and the trees have helped preserve the moisture content and organic matter of the soil in the north and these tend to decrease the susceptibility of the soil since they are diamagnetic in nature. The soil of the south-western part of the site with no vegetation cover has more Fe ion bearing minerals. The relatively low magnetic susceptibility values in the north and south may be due to the uneven distribution of the roots of trees beneath the top soil absorbing some of the Fe ion bearing minerals and other minerals in solution.

The continuous usage of the area as a waste site deposit should be discouraged since it poses a great pollution threat. The results indicate that the susceptibility of the area will continue to increase with time due to the transport and infiltration of contaminants from the waste deposit through the agency of precipitation. The sighting of a borehole in the area will not be appropriate because there is the tendency of seepage into the water table with time. If the diversion of the road close to the study area would be a problem, then it is recommended that the waste site be relocated. Vegetation has contributed to the reduction of the magnetic susceptibility in the study area. Thus, the Independence Hall administration should encourage the growing of grass and trees especially in the regions with high susceptibility anomalies. This will help lower the concentration of these contaminants in the surface soil and enhance a cleaner environment.

IV. CONCLUSIONS

Magnetic methods offer a wide range of tools to study the various environmental components both in their natural and polluted states (Evans and Heller, 2003). From these tools, magnetic susceptibility was applied in an area known for dumping waste on the campus of K. N. U. S. T. When it rains, the slope of the area determines the flow rate of run-off. Thus, contaminants from waste site deposit tend to flow towards the south-west leading to an increase in the magnetic susceptibility values.

The area around the waste site deposit lies in the region of paramagnetic and (canted) antiferromagnetic materials due to the weakly positive magnetic susceptibility measured. A further chemical and grain size analysis would reveal the presence of some possible paramagnetic and antiferromagnetic minerals and iron-forming compounds such as Biotite (0.05-0.95 $\times 10^{-6}$ m^3/kg), Pyroxene (0.04-0.94 $\times 10^{-6}$ m^3/kg), Chamosite (0.9×10^{-6} m^3/kg), Nontronite (0.863 $\times 10^{-6}$ m^3/kg), Amphibole (0.16-0.69 $\times 10^{-6}$ m^3/kg), Epidote (0.25-0.31 $\times 10^{-6}$ m^3/kg).

The west profile (Figure 3.1 D) recorded the highest averaged magnetic susceptibility, followed by the north profile (Figure 3.1 A), then the east profile (Figure 3.1 B) with the south profile (Figure 3.1 C) recoding the lowest averaged magnetic susceptibility. The anthropogenic emission sources in the study area are the atmospheric particulates from vehicular emissions, domestic and industrial waste disposal. The presence of the deposit gives rise to soils with high magnetic constituents. Such soils catalyze weathering and aid eventual infiltration of water-bearing contaminants into the subsurface. Further magnetic susceptibility survey and geochemical analyses are recommended to be carried out in the region to investigate the susceptibility of soils and channels created by run-off water. In future it will be interesting to determinate the elemental compositions using either the X-ray Fluorescence Analysis or the Atomic Absorption Spectrometer.

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