Assessment of Soil Pollution in Kumasi-Ghana, by Vehicular Emissions Using Magnetic Mapping Method

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***Abstract*— In this work, magnetic susceptibility mapping was carried out along the Accra-Kumasi road and the KNUST Business school road in the greater Kumasi metropolis. The magnetic susceptibility of the soil samples along the Accra-Kumasi road was very high compared to the low values measured along the KNUST Business School Roadside. The maximum average magnetic susceptibility recorded along the Accra-Kumasi road was (347.26 - 349.90) ×10^{-5} SI while that at the KNUST Business School Road was (99.16 - 115.25) ×10^{-5} SI. A plot of magnetic susceptibility against distance shows a decreasing magnetic susceptibility with increasing distance away from the edge of the road for the measured magnetic susceptibility values along the Accra–Kumasi road. The KNUST Business School Road shows no specific trend or pattern. The high magnetic susceptibility recorded along the Accra-Kumasi road could be attributed to high vehicular traffic and its associated emissions. The vehicular emissions contained magnetic particles (heavy metals) which apparently enhanced the magnetic susceptibility of the topsoil along the Accra-Kumasi road. These comparatively high magnetic susceptibility readings obtained with soil samples give an indication of pollution of the topsoil.**

Keywords—magnetic susceptibility; KNUST; Accra-Kumasi Road; soil pollution; vehicular emissions

I. INTRODUCTION

In general, soil pollution is the addition of harmful substances into the soil to cause adverse effects. These pollutants can be from either elsewhere or naturally occurring in the polluted environment.

This paper ascertains the degree of pollution of the top soil as a result of the emission from vehicles. Soil pollution is due to the accumulation of contaminants including cancer-causing substances. Heavy metals and hydrocarbons form the biggest chunk of these non-environmentally friendly materials.

Agricultural processes such as the use of weedicides and pesticides cause soil pollution. Unacceptable levels of radioactive nuclides such as nitrogen and phosphorus occur in farm centres with lots of farm animals. These chemicals have the potential of infiltrating the subsurface and polluting the groundwater and soil. When plants are watered with the contaminated or polluted water, heavy metals pollutants are thereby introduced into the soil and plants. Heavy metals of industrial origin such as steel and iron are major contributors to the pollution of the environment.

Another major source of soil pollution is from vehicular emissions. Emissions from vehicles will normally be nitrogen oxides, sulphur, various groups of hydrocarbons, lead and even mercury [1]. These are the main origins of pollutants of the top soils especially along our major roadsides. Lead is a toxic non-biodegradable element. The use of fuels with lead as additive contributes enormously to pollution in our communities [2].

Reference [3] in a study involving gradient density and magnetic separation methods found increased levels of lead-containing substances originating from vehicles in sampled soils. They found sulphates of lead, hematite, iron aluminium silicate and magnetite in the samples as well.

In another study, [4] using magnetic separation method that leaded fuels contained magnetite. These were released through the exhaust fumes of the cars. There were also iron and iron-bearing particles that were assumed to be from rusting of the body of the cars or abration within the inner part of the exhaust and break.

Soil pollution releases large amounts of magnetite in the surrounding environment. This paper uses the magnetic mapping tool for the spatial assessment of pollution of roadside soils due to emissions from vehicles [5-13] in relation to the concentration of ferromagnetic soils as proxy for spatial assessment of soil pollution from vehicular emissions. The method is very preferable because it is fast, affordable and helps in gathering many data required for statistical and graphical interpretation of spatial magnetic pollution trends.

The effect of pollution on inhabitants include severe headaches, fatigue, nausea, pregnancy losses and skin infections. While these could be short term consequences other effect like liver and kidney damages, reproductive issues, cancer, brain and spinal cord problems. Immune system weakness and lack of proper growth and development in children is a major effect on children especially.

Besides pollution of the soil affects plant and crops grown by farmers. Lettuce and other crops can harbour these pollutants and consumed by humans and animals. The pollutants can destroy a whole farm and thereby leading acute hunger problems in certain areas in the world.

The whole of our ecosystem stands in jeopardy if we do not take measure to stop the contamination. These contaminations threaten our very existence. This paper therefore looks at the level of vehicular emission on soils close to the roadside along the Accra-Kumasi roadside and the KNUST Business School roadside.

II. Background

Different types of soils have different mineral contents and different magnetic properties. These minerals sometimes occur in nature while others come from industry. The amount of magnetic mineral contained in given soil sample can be expressed in broad terms using the magnetic susceptibility [14]. The physical quantity called Magnetic susceptibility describes the quantity of iron in a material. It gives and an indication of the material type and the amount of iron it contains.

Reference [15] investigated the amounts of some heavy metals including lead in soils along the sides of roads in crop farms in Bangladesh. In their work, soil samples were taken at distances of 0 m, 50 m, 100 m etc. They realised the levels of the heavy metals in the crops reduced with increasing distance from the road. They concluded that the vehicular emission had influence on the concentration of the heavy metals. Only Cadmium concentrations were found to have no relation with distance.

Pollution in our major communities is due to vehicular traffic and the emission [16]. Emissions from vehicular sources contain different sizes and shapes of particle. Some as very small that they are measured in nanometers. These particles can originate from the engine or the exhaust or sometimes formed from chemical reactions that precede the emissions. Other particles, which are sizeable enough, result from the action between the road and vehicle tyres. These emitted particles have the potential of causing diseases that relate to the heart of people who inhale them [17-19].

Magnetic susceptibility is a good mapping tool for investigating soils along our roadsides [5-7, 9, 10]. Several scientific works showed the link between magnetic susceptibility and heavy metal concentration and its adverse effect on the soil [7, 13, 20, 21].

A. Magnetic susceptibilty

Most of the materials surrounding us are magnetic. As we may describe objects and materials by their size, colour or chemical composition, so we may also describe them by their magnetic properties. This may come as a surprise to anyone without a physics background because in everyday life we usually come across magnetism in rather limited ways, in terms of magnets and metals, or recording tape. We do not think about the magnetic behaviour of rocks or soil, or the dust in the air that we breathe - and most of us would certainly not consider the magnetic properties of river water or leaves on a tree. However, all matter is affected by a magnetic field. The effect may be extremely weak or even negative, but it exists and can be measured easily. During the 1970s and 80s, scientists realised that magnetic properties were useful for describing and classifying all types of environmental materials [22]. Magnetic susceptibility is a parameter that characterises the magnetization of a substance when it is subjected to a magnetic field. The magnetic susceptibility is the important parameter in magnetic exploration. Soils of higher magnetic susceptibilities will have a high content of magnetic minerals or magnetic elements.

For materials for which the induced magnetization, M_i is parallel and proportional to the applied field, H, we can write the simple relation;

$$M_i = \chi H \quad (1)$$

where χ is the susceptibility, a characteristic constant for a magnetic material and it is dimensionless [23].

The total magnetisation (M), is given as;

$$M = M_i + M_r \quad (2)$$

where M_r is the remnant magnetisation [23].

But

$$M_i = \chi H \quad (3)$$

Therefore, the total magnetization can be written as;

$$M = \chi H + M_r \quad (4)$$

III. STUDY AREA

A. *Background and Location*

The 2010 Census results show that the total population of the Kumasi metropolis was 1,722,806 people. Women made up 52.2 percent of Kumasi's population and men represented 47.8 percent. Fifty-six percent (56%) of the total population was under the age of 25.

The total land area of the metropolis is 254 m^2. Total arable land area is 15,920 ha but the land area under cultivation is 11,930 ha. Out of this, the percentage of available farmland is 74.9 %. The land ownership is stool, leasehold, family land, sharecropping, (abunu or abusa).

Massive infrastructural development is fast limiting agriculture, making sedentary agriculture a preferred agricultural option. The vegetation of the metropolis falls within the moist semi-deciduous section of the South-East Ecological zone (See Fig. 1).

The Climate of Kumasi metropolis falls within the sub-equatorial type of climate and is characterised by average temperatures ranging from 21.5 0C to 30.7 0C. Average annual rainfall is 625 mm with peaks of 214.3 mm and 16.2 mm in June and September respectively. The rainfall pattern is generally good and evenly distributed. The average humidity is about 84.16% at 09.00 GMT and 60% at 15.00 GMT. The major soil type of the Metropolis is the Forest Ochrosol with geology dominated by the middle Precambrian Rock. It is within the plateau of the South-West physical region which ranges between 250-300 m above sea level.

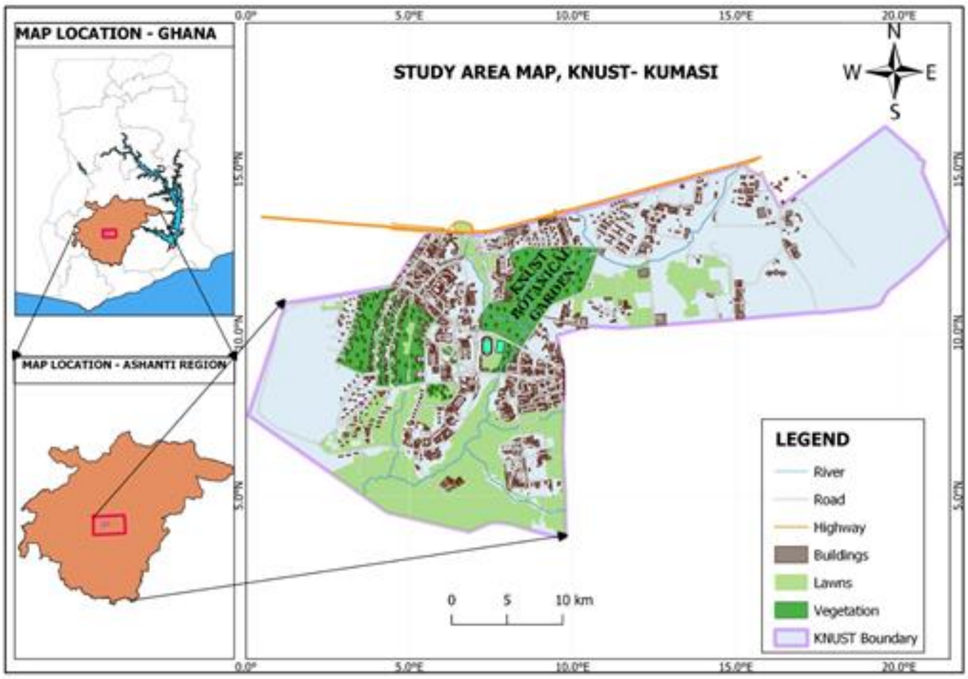

Fig. 1: *Location map of study area, KNUST, Kumasi-Ghana*

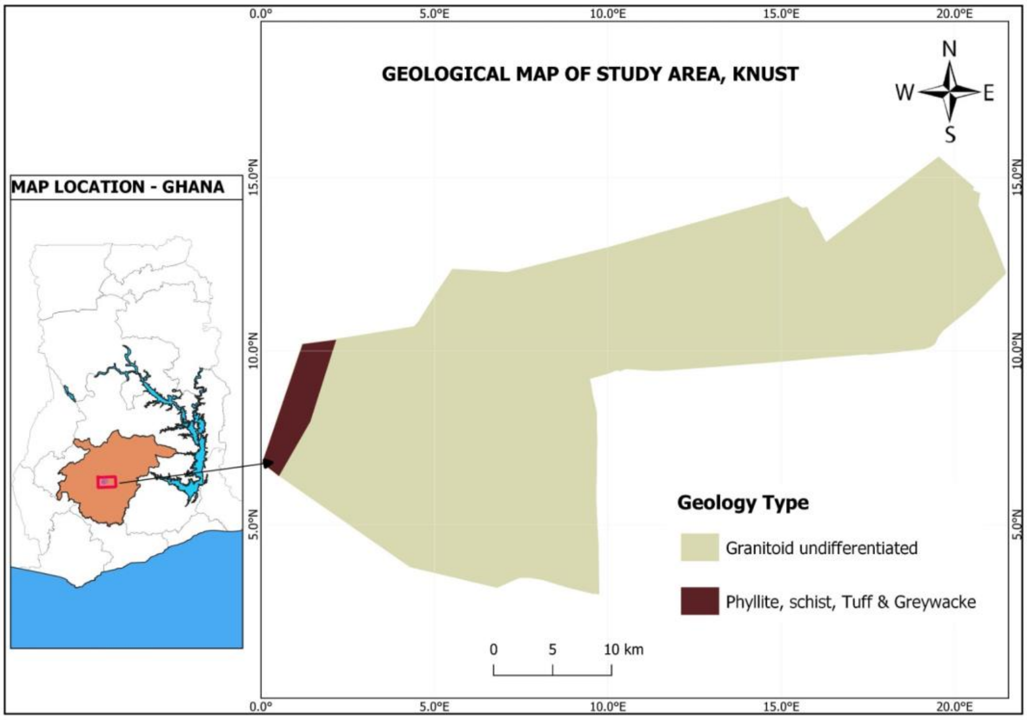

Fig. 2: *A geological map of KNUST*

The topography is generally undulating. The major rivers and streams in the metropolis include Subin, Wewe, Susan, Aboabo, Oda, Owabi, Suntre, Akrubu, Acheamponmene and Asuoyeboa.

The area is underlain by Dahomeyan formation, composed of granitoid undifferentiated rocks as shown on Fig. 2 and can be located on 6.6849083 °N and 1.5705194 °W. The Dahomeyan formation, consisting of mainly metamorphic rock such as gneiss and schist, occupies the south-southeastern corner of Ghana and occurs as four alternate belts of acid and basic gneisses, trending south-southwest to northeast direction [24].

B. Data Collection Procedure

The magnetic susceptibility values of soil samples were taken at two different locations (sites). The first was taken along a half kilometre stretch of the Accra-Kumasi roadside as shown in the Fig. 3 and the second set of readings were taken at the KNUST Business School road. The second measurement taken along the KNUST Business School roadside (Fig. 4) was to serve as a basis for comparison and for that matter to be able to come to a firm conclusion.

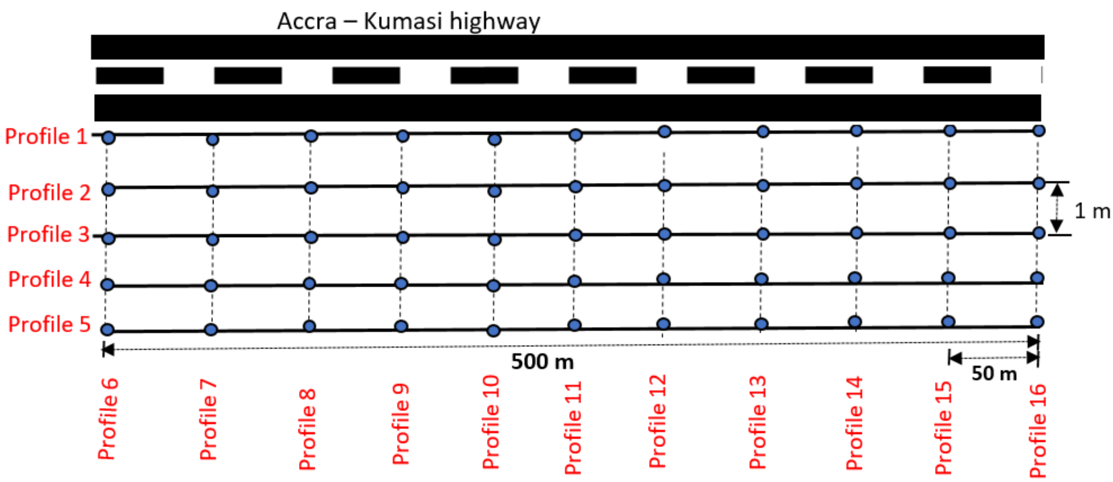

Fig. 3: *A schematic diagram of profile layout for Accra Kumasi roadside (Not drawn to scale).*

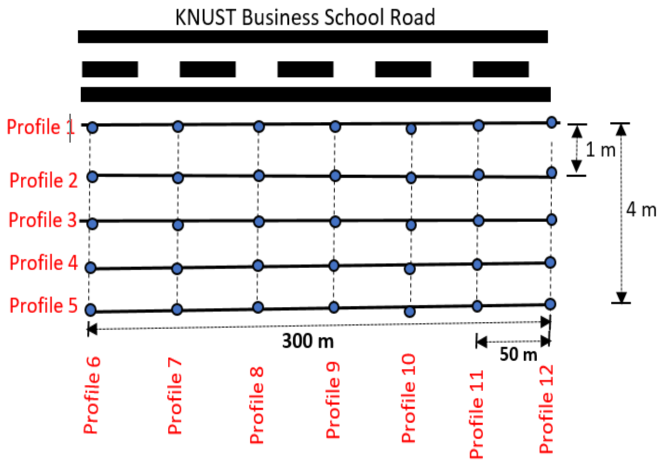

Fig. 4: *A schematic diagram of profile layout for the KNUST Business school roadside (Not drawn to scale).*

C. *Magnetic Susceptibility Measurement of Soil Samples*

The MS2 magnetic susceptibility meter was first held in air and magnetic susceptibility readings taken and the average recorded as free air reading. The next was to measure the magnetic susceptibility of the pots (empty containers into which the soil was sampled). The values for the magnetic susceptibility of the pots were measured by lowering the pots in the MS2 meter and their values taken accordingly.

At both roads, magnetic susceptibility of the soils collected or sampled were measured along five different profiles running parallel to the road starting from the edge of the road and at 1.0 m distance apart.

The process was repeated for eleven (11) profiles, which run perpendicular to the roadside. The data therefore formed a grid (Fig. 3 and Fig. 4). The magnetic susceptibility of the soil samples were determined by placing the covered 10 cm^3 pots in the MS2 meter. The raw magnetic susceptibility values were corrected by subtracting the free air magnetic susceptibility value and the magnetic susceptibility value for the 10 cm^3 pots (5).

$$\chi\,(corrected) = \chi\,(sample) - (\chi\,(free\ air) + \chi\,(10\,cm^3\ pots)) \quad (5)$$

The corrected magnetic susceptibility values were also tabulated. The whole procedure was repeated at the second site and the values tabulated.

IV. Results and Discussion

A. *Analysis of Data from the Accra-Kumasi Roadside*

The plots shown in figures 5, 6 and 7 are the plots of magnetic susceptibility values running parallel to the Accra- Kumasi road, Contour map of the gridded data covering the entire survey area at the Accra-Kumasi roadside and a plot magnetic susceptibility against distance perpendicular to the roadside respectively.

A critical look at the magnetic susceptibility values for the Accra-Kumasi road indicates a very interesting trend. From Fig. 4, it is clearly seen that the magnetic susceptibility values decrease sharply as one moves away from the road. The high magnetic susceptibility at the north-eastern side is most likely due to high vehicular emissions. Thus, the presence of a roundabout at this location slows down vehicular movement drastically as they negotiate the roundabout.

The highest recorded magnetic susceptibility values occur along profile one (1) with a range between (347.26 - 349.90) $\times 10^{-5}$ SI. Additionally, the next highest value was observed on profile two (2) with a range of (299.61 - 347.26) $\times 10^{-5}$ SI. Low magnetic susceptibility values were observed from the first profile down to the fifth profile all as one moves away from the road. This certainly indicates that magnetic susceptibility decreases with increasing distance away from the roadside. Similar results were obtained by [15] in their work on highways in Gazipur, Bangladesh. The magnetic susceptibility values along this stretch of the Accra-Kumasi road are generally high due to the bad condition of vehicles plying the road. In addition, most heavy-duty vehicles that emit heavy metals at a higher rate use this road more often. Additionally, many commercial vehicles (trotro) whereas the majority are over age ply this road as well.

From Fig. 4 where there is a plot of magnetic susceptibility values for profiles running parallel to the road, there is not much variation of magnetic susceptibility values except the spike in on profile one (1). This is possibly because within that inter-profile spacing the degree of vehicular emission influences the tops soils almost the same way.

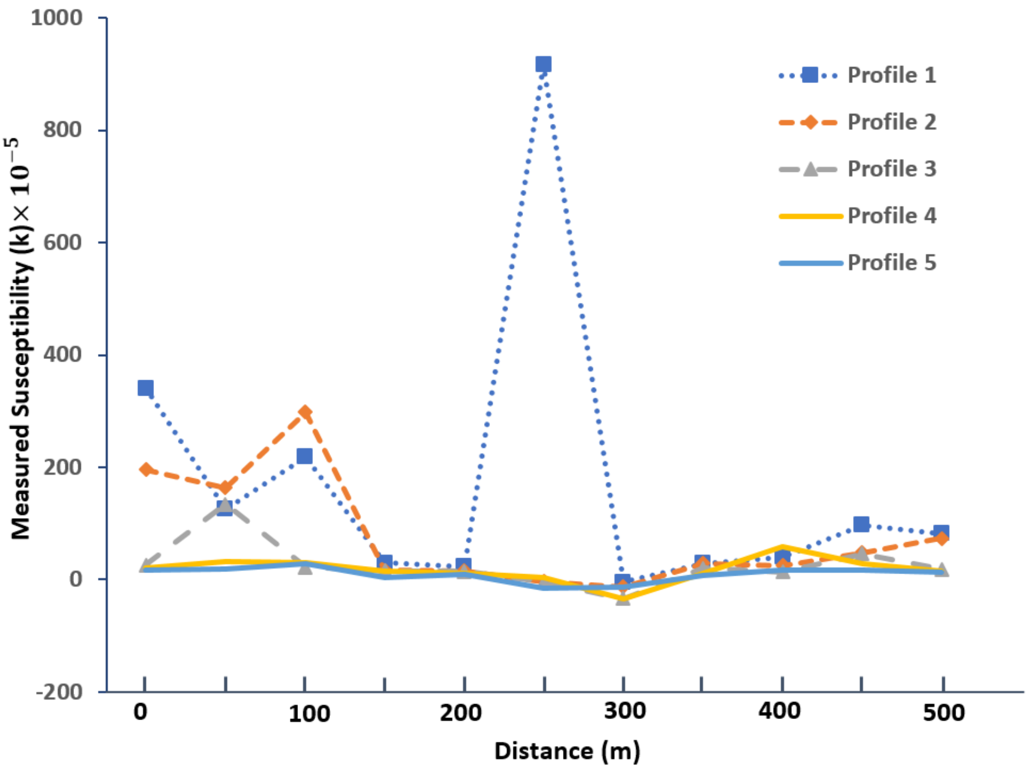

Fig. 5: *Plot of Magnetic Susceptibility(SI) for profile running parallel to the Accra –Kumasi road.*

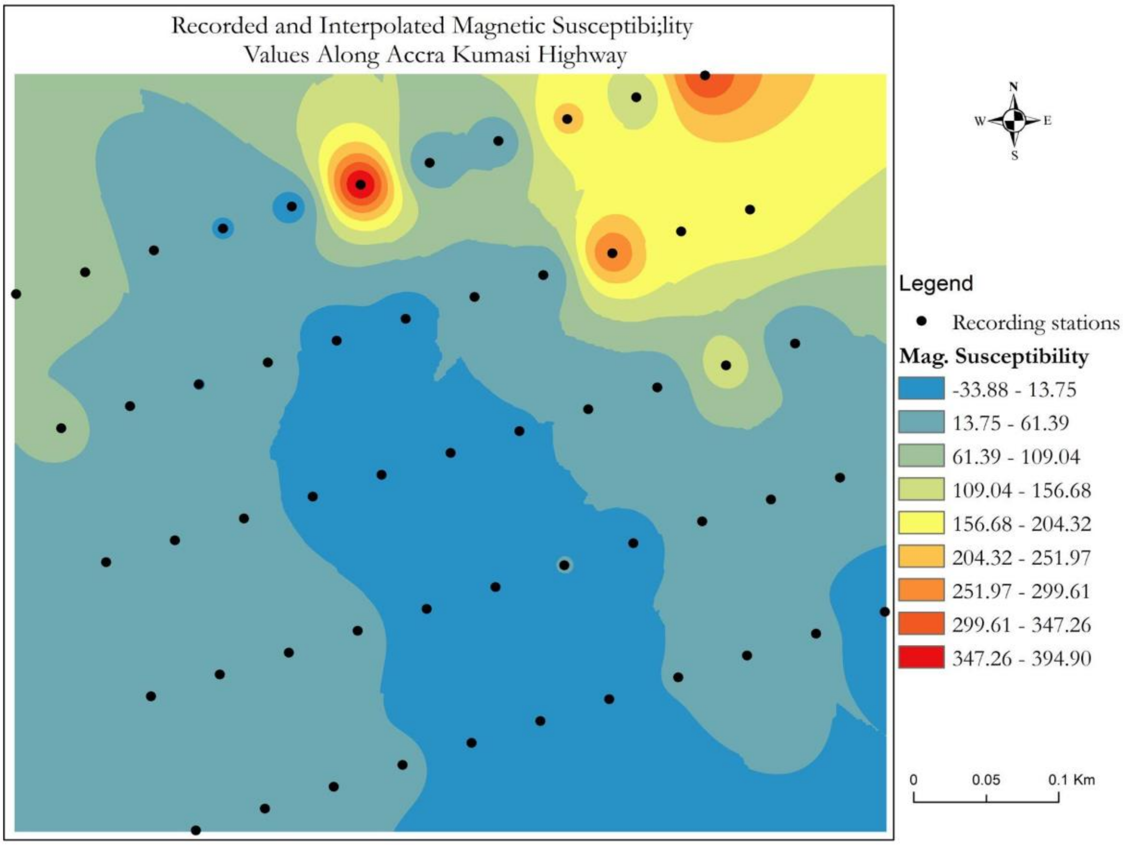

Fig. 6: *Contour map of the Accra-Kumasi roadside magnetic susceptibility values*

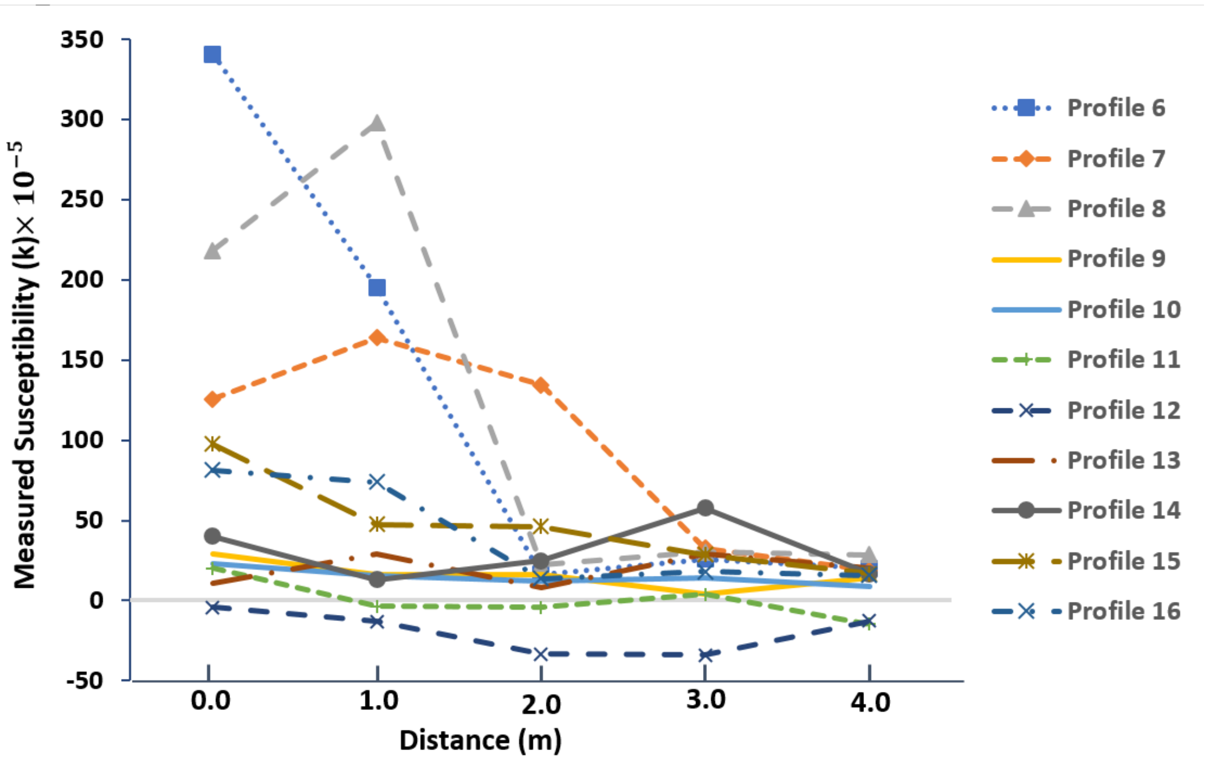

Fig. 7: *A plot of magnetic susceptibility (SI) perpendicular to the Accra –Kumasi road.*

From Fig. 6, it is observed that, all the magnetic values for the various profiles decrease sharply as one moves away from the roadside. At about 4.0 m, they magnetic susceptibility values for all the profiles fall below 50.0 ×10^{-5} SI

B. Analysis of Data from the KNUST Business School Road

The plots shown in figures 8, 9 and 10 are the plots of magnetic susceptibility values running parallel to the KNUST Business road, a plot magnetic susceptibility against distance perpendicular to the KNUST Business roadside and Contour map of the gridded data covering the entire survey area at the KNUST Business roadside respectively.

The maximum magnetic susceptibility value measured from the KNUST Business School road was within the range of (99.16 - 115.25) ×10^{-5} SI and a minimum range of (-29.52 – 13.44) ×10^{-5} SI as shown on fig 10. This was observed to be lower compared to that of the Accra - Kumasi highway. The plot of magnetic susceptibility against distance away or perpendicular from the roadside does not also show any general trend (Fig. 9) as was observed in the Accra - Kumasi road. This could be possibly due to the less vehicular activity observed along that stretch of the road. To confirm this, it was observed during data collection that, at least no commercial vehicle uses that road with few private cars also usually in good condition hence giving out less emission.

There are isolated high magnetic susceptibility values around the southern and eastern part of the colour map (Fig. 10). This same effect is observed on Fig. 8 profiles 9 and 12. This could possibly be due to soil samples from the area containing material with high magnetite content. The reason why it did not extend to large areas. In addition, there are isolated areas of extremely low values of magnetic susceptibility around the western end of the map. This could also be due to material around the area being low in magnetite content. Even though this appears a bit expansive, the degree of low magnetic susceptibility values improves gradually from the two very low points.

With little or no emission, it means that less or no heavy metal and other magnetic pollutants will be released into the soil leading to less pollution of the soil along the roadside. It can be said that these magnetic susceptibilities that were measured from the roadside could be due to the aggregation of the magnetic susceptibilities of the individual particles that make up the soil samples from the roadside.

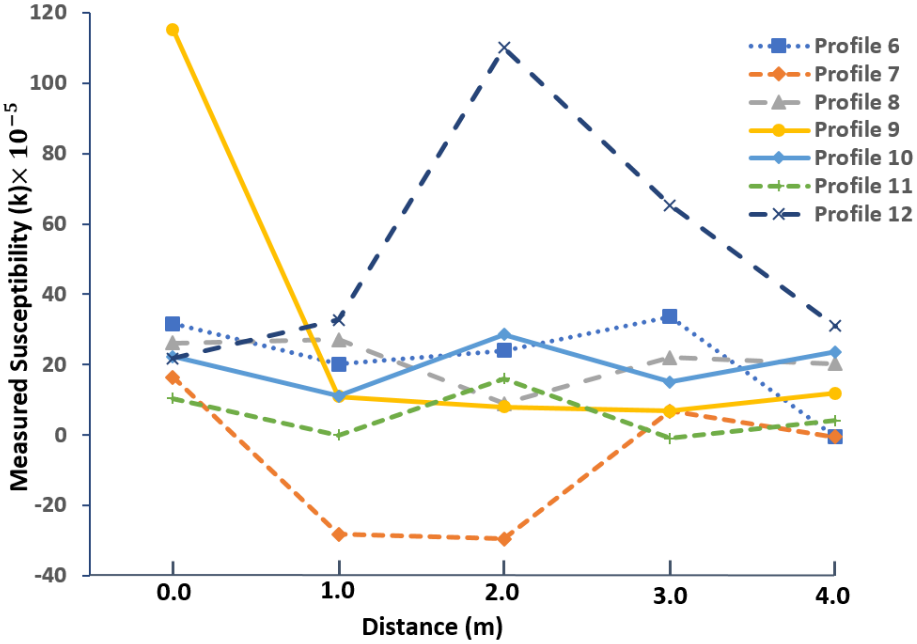

Fig.8: *A graph of magnetic susceptibility values parallel to the KNUST Business School road*

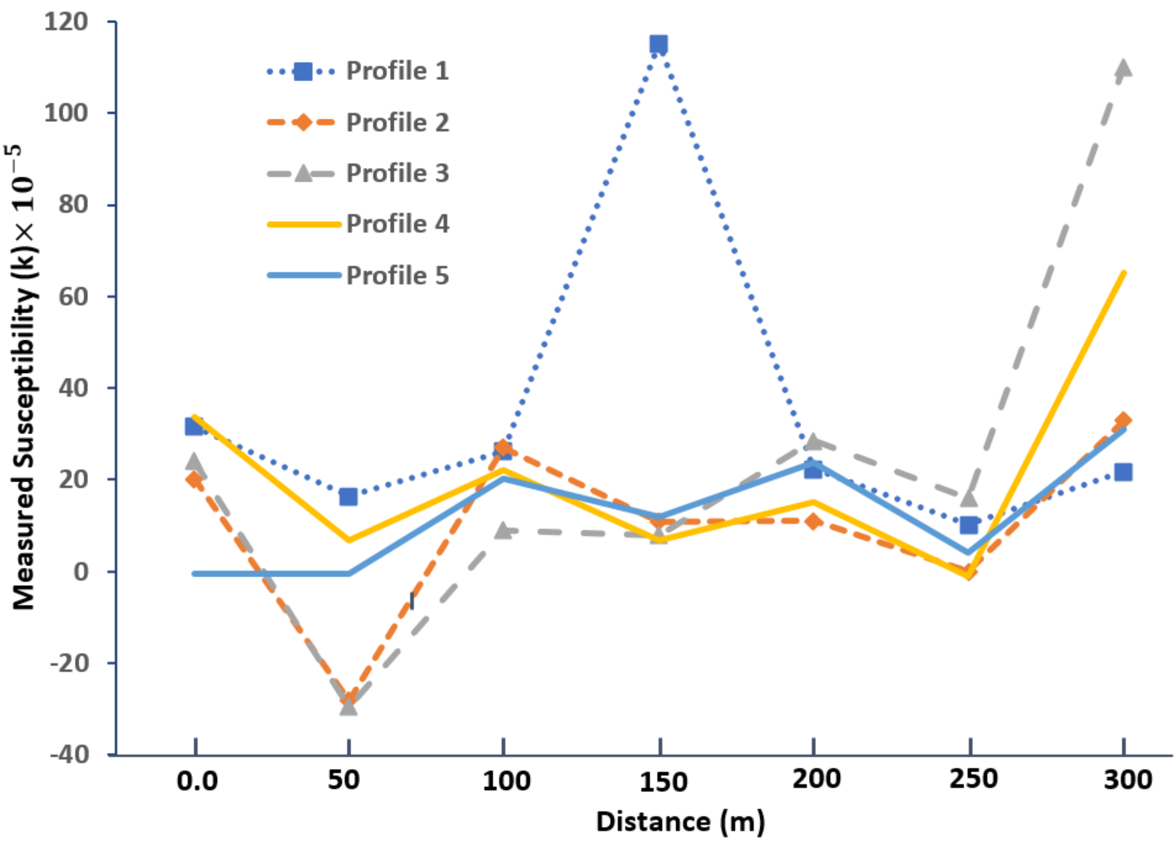

Fig. 9: *A graph of magnetic susceptibility (SI) values perpendicular to the KNUST Business School road*

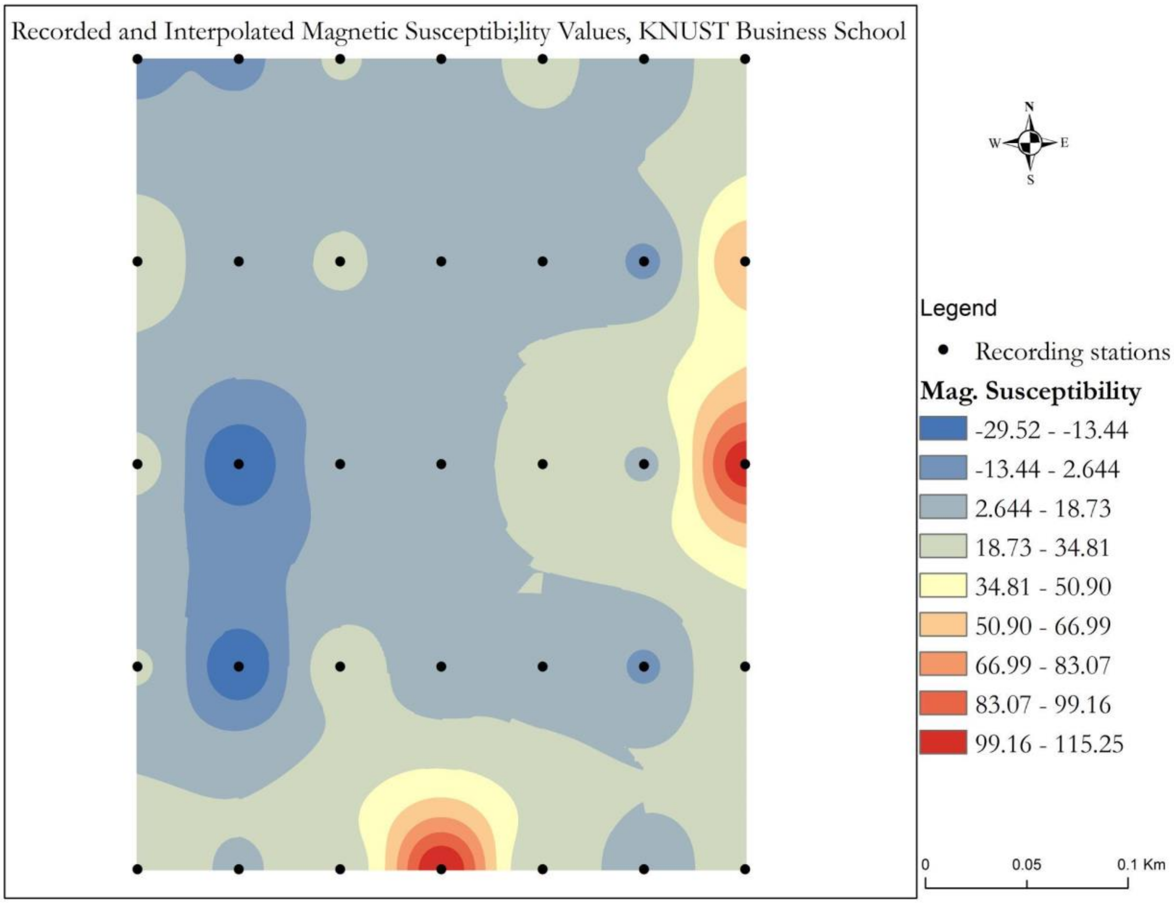

Fig. 10*: Contour map of the KNUST Business School roadside Magnetic susceptibility values*

V. Conclusion

Magnetic susceptibility measurement is fast becoming a tool for the mapping of various pollutants globally. The paper employed this method in determining the roadside soil pollution along two roads in the Greater Kumasi metropolis in Ghana. Thus, the Accra-Kumasi roadside and the KNUST Business School roadside, both on KNUST campus. A statistical analysis of the data from the Accra – Kumasi roadside shows that the magnetic susceptibility values were very high for soil samples along this road which has high vehicular traffic.

Magnetic susceptibility values measured along the Accra-Kumasi road were generally high with maximum range of (347.26 - 349.90) $\times 10^{-5}$ SI whiles that of the KNUST Business School Road were generally very low with maximum range of (99.16 - 115.25) $\times 10^{-5}$ SI.

Given that the Accra-Kumasi road has very high vehicular traffic whiles the KNUST Business School Road has very low vehicular traffic, it could be concluded that the magnitude of the magnetic susceptibility values measured for samples from the Accra-Kumasi road were greatly influenced by the vehicular emissions [25, 26]. As has been confirmed by results from this work, burning of hydrocarbon fuel which is the source of energy on which these vehicles run, do emit heavy metals (Mercury, Cadmium, Lead, Chromium, Zinc, Lead), into the atmosphere and the top soil along roads [27]. Even those emitted into the atmosphere find their way back into the soil and the vegetation along the roadside. This usually happens when these particles coagulate and therefore become heavy and fall back into the topsoil and onto the vegetation along the roadside and any place they are blown into.

It can also be concluded that the magnetic susceptibility for the samples from the KNUST Business School Road could possibly be due to the composition of the materials or particles that make up the topsoil. This is against the backdrop that the soil types are similar (Forest Ochrosol), [5, 6], at the two locations. For similar soil types we expect their magnetic susceptibility to be the same, hence for such a vast difference in magnetic susceptibility values from the two sites, lends much credence to the fact that the values were influenced by the particles emitted by the vehicles. The high value measured along the Accra-Kumasi road was due to the high vehicular traffic.

It is also known that high vehicular traffic with its associated high vehicular emissions has an increasing effect on magnetic susceptibility values of soil samples along such roadsides. Since this increase in magnetic susceptibility is a result of heavy metals emitted into the soil and knowing that metals are pollutants and therefore pollute the topsoil, it is a strong indication of soil pollution. This is in particular reference to magnetic susceptibility values recorded along roads with high vehicular traffic.

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