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The use of magnetic susceptibility measurements to determine pollution of agricultural soils in road proximity

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This research work presents a study on the application of magnetic susceptibility measurements and geochemical analysis for mapping or assessing heavy metal pollution in the agricultural soil in road proximity. The research work was also done to check any runoff of heavy metals pollution to the Owabi dam which serves as the main water sources to catchment areas and the whole of Kumasi Metropolis. This research work was conducted along the asphalt road closed to Amamfrom Community in the southern part of Ghana. The study revealed that magnetic susceptibility measurements can be used as a proxy and fastest method of determining heavy metal pollution in agricultural soils. The results showed three most important trends: 1) the samples collected near the road have higher values of magnetic susceptibility and mean heavy metals content than those collected far from the road exhaust; 2) some of the sample areas undisturbed by erosion and weathering have significant magnetic susceptibility and heavy metals contents; 3) some of the sample areas washed away by erosion are believed to be deposited in Owabi Dam due to their low ground reliefs. Therefore, future research should concentrate on Owabi Dam which may be polluted by the runoff from these heavy metals.

Key words: Magnetic susceptibility, heavy metal, pollution, road proximity.

INTRODUCTION

Soil is a crucial component of environment that supports crops and plants growth and land management is the main key to soil quality. Soil nutrients, are been affected, disturbed or washed away by human activities like mining, industrial and factory wastes, manufacturing wastes and the use of synthetic product which accumulate heavy metals into the agricultural soil over a period of time. Heavy metals also occur naturally in agricultural soil by erosion activities, plate tectonics activities, earthquakes, old landfill sites, old orchards that used insecticides containing arsenic as active ingredient and field that had past application of waste water and municipal sludge. Excess heavy metals accumulation is very toxic to human and other animals due to food chain

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transfer and toxic level of these heavy metals in agricultural soil are best investigated using magnetic susceptibility meter and X-ray spectrometer.

Magnetic minerals present in soils may either be inherited from the parent rocks (lithogenic origin) formed during pedogensis (pedogenic origin) or may stem from anthropogenic activities (secondary ferromagnetic materials). Hematite and magnetite are common minerals that occur as primary and secondary minerals in soil and solid wastes and provide a major sink for pollutants such as heavy metals in soils. They have been known as major minerals contributing to the magnetic susceptibility of a soil. In addition to the presence of these minerals, the content of Fe, Mn, Cr, Co and Ni also affect magnetic susceptibility of the soil.

Magnetic susceptibility is a measure of the ability of any substance to be magnetized. In geology, magnetic susceptibility is one characteristic of a mineral type. The term "heavy metal" refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. The use of magnetic measurements as a representation of chemical methods is largely approved because pollutants and magnetic particles are related (Hanesch and Scholger, 2002). The magnetic susceptibility technique has been utilized in a variety of soil science researches such as soil genesis and morphology. Recently, the technique was adopted as a tool for mapping environmental pollutant distribution (Wang and Qin, 2005). Magnetic susceptibility measurement has been considered as a rapid and cheapest screening tool for the determination of spatial distribution of contamination level of heavy metals in soils. The use of magnetic measurement as a proxy for chemical method is possible because pollutant and magnetic minerals are genetically related (Hanesch and Scholger, 2002).

Heller et al. (1991) and Bityukova et al. (1999) reported close relationships of magnetic susceptibility with heavy metal contamination in soil which was proven by combined analyses of chemical and magnetic data. Magnetic susceptibility thus provides an indicator of heavy metal contamination of soils. Hoffmann et al. (1999) successfully measured road traffic pollution by evaluating the spatial distribution of magnetic susceptibility in the nearby soils. Only a fraction of the pollutants was airborne.

Recently, there is a growing interest in using magnetic techniques for monitoring environmental pollution. Many studies have reported excellent relationships between soil magnetic susceptibility and the contents of some heavy metals in street dust or industrial/urban soils. Non-destructive and rapid magnetic techniques seem promising in monitoring soil pollution. Some recent studies have successfully applied soil magnetic susceptibility mapping as a tool for preliminary pollution monitoring and mapping areas polluted by industrial emissions (El Baghdadi et al., 2012). Heavy metals constitutes a group of inorganic chemical hazards, and those most commonly found at contaminated sites are lead (Pb), chromium (Cr), cadmium (Cd), copper (Cu), arsenic (As), zinc (Zn), mercury (Hg) and nickel (Ni) according to GWRTAC (1997). Soils are absorbers of heavy metals released into the environment by the human activities and unlike organic contaminants which are oxidized to carbon (iv) oxide by microbial action, most metals do not undergo microbial or chemical degradation (Kirpichtchikova et al., 2006), and their total concentration in soils persists for a long time after introduction (Adriano, 2003). Heavy metal contamination of soil may pose risks and hazards to humans and the ecosystem through direct ingestion or contact with contaminated soils, the food chain (soil-plant, human or soil, plant-animals-human), drinking of contaminated water, reduction in food quality (safety and marketability) via photo toxicity and reduction in land usability for agricultural production causing food insecurity (McLaughlin et al., 2000). The adequate protection and restoration of soil ecosystems contaminated by heavy metals require their characterization and remediation.

This paper investigates the relationship between heavy metal contamination and magnetic susceptibility and further confirms the fact that magnetic susceptibility is a representation of heavy metal concentration which can be used for the rapid identification of contaminated areas. This will allow subsequent geochemical sampling and analysis to be focused on smaller areas, thereby decreasing costs and time considerably.

MATERIALS AND METHODS

Description of study area

This project was carried out along the asphalt road closed to Amanfrom Community in the southern part of Ghana where two parcels of land A and B on latitude 6° 45’35.95”N, longitude 1° 40’ 51.40” W and latitude 6° 40’ 45.57” N, longitude 1° 40’ 45.78’’ W respectively can be found. Geology of the study area (Figure 1) and the region is dominated by the middle Precambrian rocks and forms part of the Eburnean plutonic suite, where it mainly composes of the biotite, granite and minor granodiorite and K-feldspar porphyritic rocks. Kumasi granitoid complex dominates much of the basin area and contains large proof pedants of metasedimentary schists (Kesse, 1972). The soils have a fairly high moisture holding capacity. The common parent materials found in the Parcel B consists of hematite and magnetite that provides a major sink for pollutants such as heavy metals in soils. They have been known as major minerals contributing to the magnetic susceptibility of a soil. The nature of soil materials in Parcel A is made up of loose oxide materials rich in organic matter. The type of road along these parcels of land ply by commercial and private cars is asphalt. It takes every 1-2 min for a car to ply on the road.

Soil sampling and characterization

The study was conducted with two topsoil parcels, A and B; with

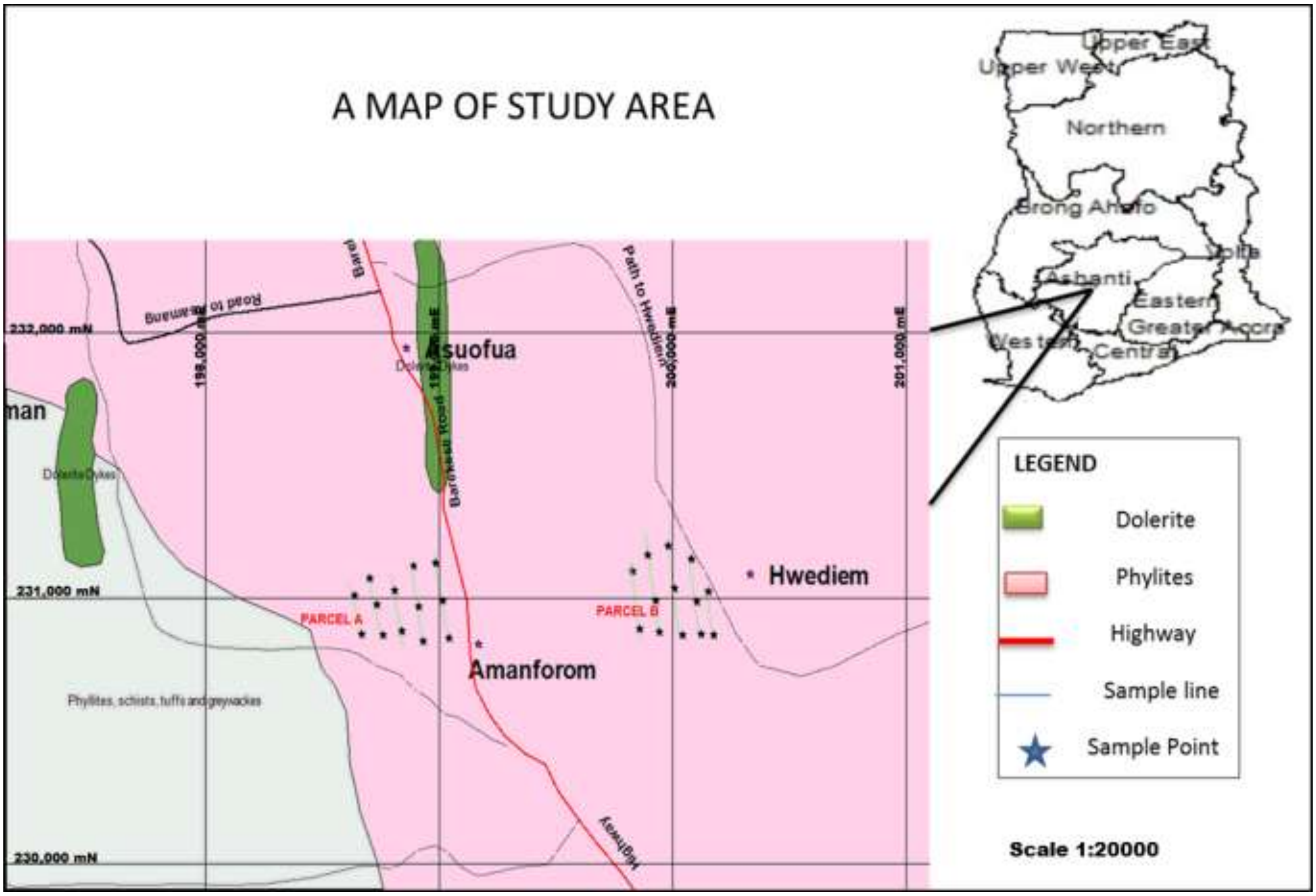


Figure 1. A map and geology of the study area.

distances of 6.5 and 231.8 m respectively from the road exhaust. Five (5) soil samples from each line in the parcels were picked at a depth of 6 cm. Distances between lines and sampling points on a row were 10 and 5 m, respectively. Laboratory measurements of the magnetic susceptibility and elements in samples were obtained using the MS2B dual frequency sensor and X-ray fluorescence spectrometer respectively. Soil samples from each line on land parcels, A and B were mixed, air dried and sieved to reduce the biasing effect of air, water and pebbles. The soil samples with less than 2 mm diameter were stored in a polyethylene bottle for further chemical, mineralogical analysis and magnetic measurement. The mineralogical composition of the soil samples was determined with an X-ray diffractometer. The magnetic susceptibility of the soil samples were also determined using magnetic susceptibility meter.

Magnetic susceptibility measurements

The samples were fed into sample containers and placed within the sensor of the MS2 magnetic susceptibility system. The sensor generates a magnetic field in the test coil which interacts with the minerals of the soil and displays the corresponding magnetic susceptibility value. Measurements were performed with an operating frequency of 0.465 KHz and sensitivity of 10^{-5} SI. A measurement represents a mean of three readings to avoid measurement error.

Measurement of heavy metals content in soil

The prepared soil samples were analyzed for their heavy metal concentrations using X-ray fluorescence (XRF) Spectrometer. 4 g of soil from each sample container was taken using an electronic balance, after which it was homogenized by mixing the 4 g soil sample with a wax. The mixed soil samples was then fed into a mould and placed in a hydraulic press, after which a weight of 80000 N was applied to change the mixed samples into round pellets. The pellets are placed in the X-ray fluorescence spectrometer and readings were taken from the computer connected to the spectrometer.

RESULTS AND DISCUSSION

Tables 1 and 2 show the results of magnetic susceptibility and concentration of heavy metals content in parcel A and parcel B, respectively. The heavy metals content

Table 1A. Magnetic susceptibility and concentration of heavy metals in parcel A.

Distance from road (m)	Magnetic susceptibility $(\times 10^{-5} SI)$	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)	Sr (mg/kg)	Zr (mg/kg)	Pb (mg/kg)	Ti (mg/kg)	Cr (mg/kg)
6.5	112.1	17.4±1.6	10.1±0.7	64.3±1.5	4.6±0.6	44.7±0.5	379±12	1.0±0.1	3703±34	302±14
14.1	87.6	20.0±1.6	9±0.7	40.9±1.3	8.0±0.7	21.1±0.4	648±15	1.6±0.1	4466±38	484±16
24.1	106.4	16.4±1.4	4.8±0.4	23.3±0.9	6.7±0.6	14.1±0.3	604±14	0.0±0.0	3852±34	455±15
35.9	159.2	13.8±1.3	7.0±0.5	30.9±1.0	4.7±0.5	35.1±0.4	629±14	0.0±0.1	3270±31	980±19
46.5	164.4	17.9±1.4	5.4±0.5	32.5±1.0	6.3±0.6	17.8±0.3	713±14	0.4±0.1	3728±33	572±16

Table 1B. Magnetic susceptibility and concentration of heavy metals in parcel B.

Distance from road (m)	Magnetic susceptibility $(\times 10^{-5} SI)$	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)	Sr (mg/kg)	Zr (mg/kg)	Pb (mg/kg)	Ti (mg/kg)	Cr (mg/kg)
231.8	145.2	26.6±1.7	8.9±0.7	21.8±0.9	5.7±0.6	18.1±0.4	624±14	0.0±0.0	3357±31	518±16
237.7	153.6	24.0±1.6	7.3±0.6	23.0±0.9	10.4±0.6	23.4±0.4	713±15	1.6±0.1	3632±31	411±14
243.1	122.3	22.7±1.5	7.2±0.6	23.1±0.9	11.0±0.6	24.6±0.4	662±14	0.8±0.1	3469±30	421±14
249.5	160.8	28.3±1.6	10.9±0.8	27.2±1.0	9.4±0.6	26.0±0.4	652±14	1.2±0.1	3893±33	444±15
256.3	154.8	23.5±1.5	12.5±0.8	30.1±1.0	10.5±0.6	29.3±0.4	826±15	1.6±0.1	3664±32	345±13

Table 2A. The mean, maximum, minimum and standard deviation of heavy metals in parcel A.

mg/kg of soil	Magnetic susceptibility $(\times 10^{-5} SI)$	Ni	Cu	Zn	As	Sr	Zr	Pb	Ti	Cr	Total
Mean	125.94	17.10	7.26	38.38	6.06	26.56	594.60	0.60	3803.80	558.60	5052.96
Max	164.40	20.00	10.10	64.30	8.00	44.70	713.00	1.60	4466.00	980.00	
Min	87.60	13.80	4.80	23.30	4.60	14.10	379.00	0.00	3270.00	302.00	
Standard deviation	34.02	2.26	2.27	15.78	1.43	12.88	127.11	0.69	430.60	254.90	847.94

present in agricultural soil of the study areas include: Ni, Cu, Zn, As, Sr, Zr, Pb, Ti and Cr.

Statistical analysis of soil magnetic susceptibility

Magnetic susceptibility of parcel A ranges from 87.6 to 164 × 10^{-5} SI while parcel B ranges from 122.30 to 160.80 × 10^{-5} SI. Agricultural topsoil at parcel B (far away from road) shows consistent enhancement or even distribution of magnetic susceptibility when compared with parcel A closed to the road. Parcel A recorded highest value of magnetic susceptibility in the last line of the sample points (as compared to parcel B) but not consistent to the first four sample lines. This is due to the fact that by visual inspection, parcel A had undergone numerous physical, chemical and biological processing, which include intense weathering with associated erosion. On the other hand, topography of parcel B showed uniform

Table 2B. The mean, maximum, minimum and standard deviation of heavy metals content in parcel B.

mg/kg of soil	Magnetic susceptibility ($\times 10^{-5}$SI)	Ni	Cu	Zn	As	Sr	Zr	Pb	Ti	Cr	Total
Mean	147.34	25.02	9.36	25.04	9.40	24.28	695.40	1.04	3603.00	427.80	4820.34
Max	160.80	28.30	12.50	30.10	11.00	29.30	826.00	1.60	3893.00	518.00	
Min	122.30	22.70	7.20	21.80	5.70	18.10	624.00	0.00	3357.00	345.00	
Standard Deviation	15.06	2.34	2.31	3.49	2.15	4.10	79.79	0.67	204.41	62.42	376.74

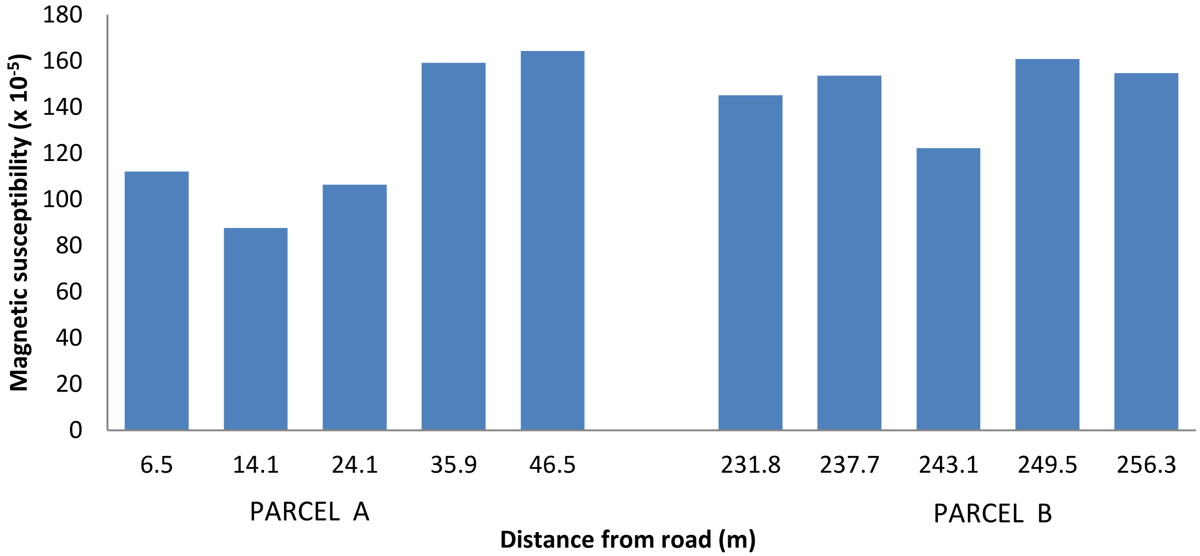
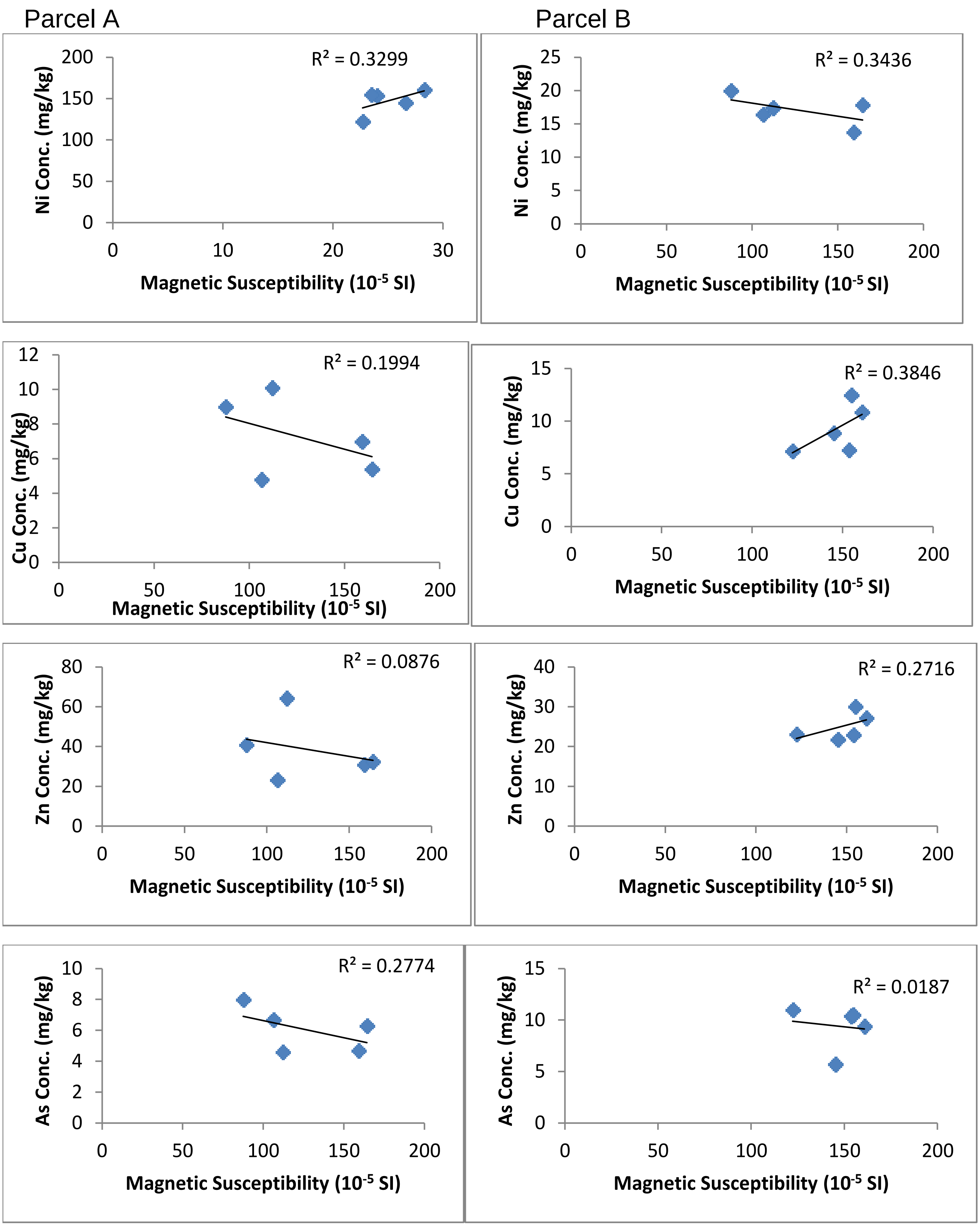


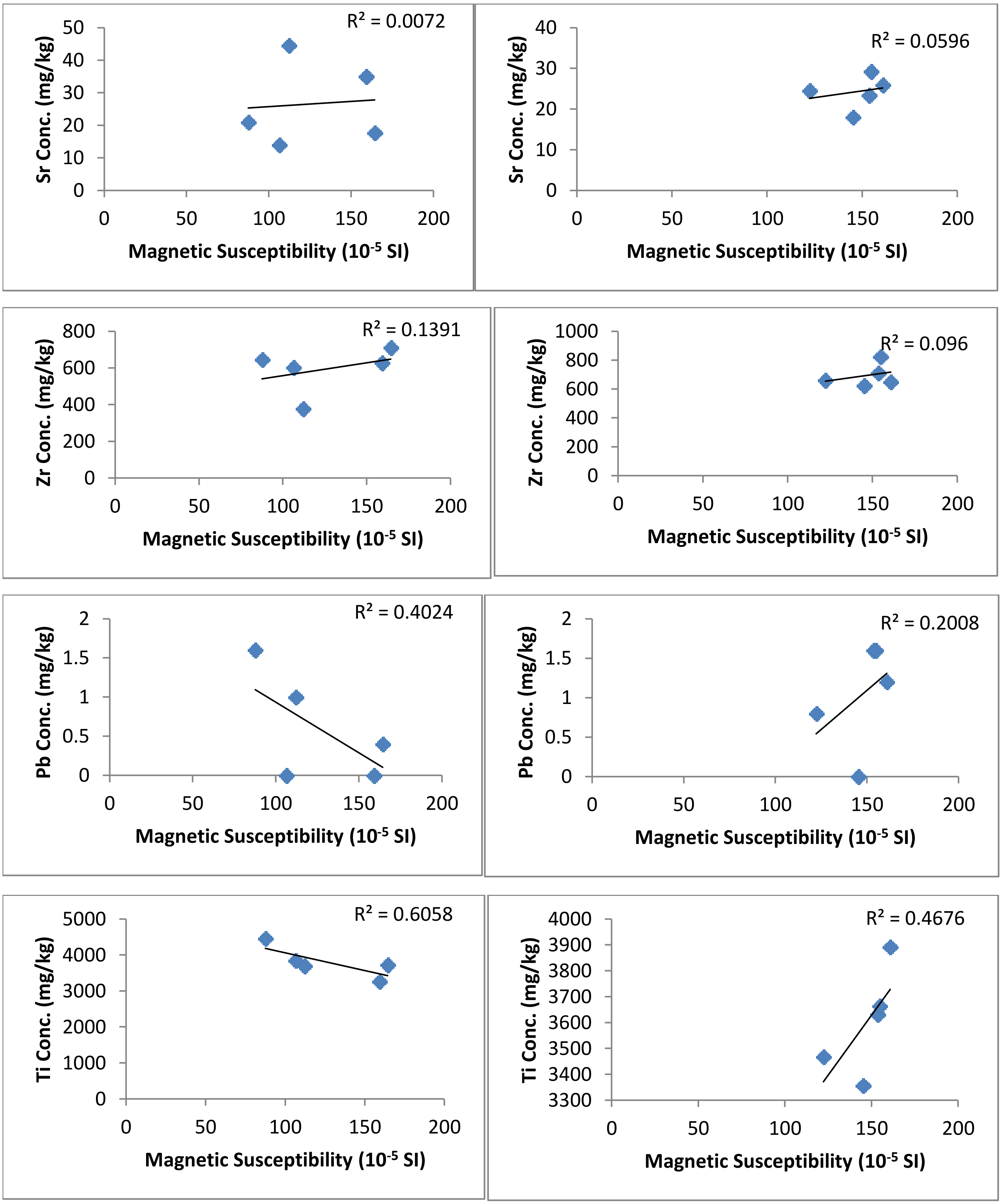
Figure 2. Magnetic susceptibility and distance from the road.

landscape with highly goethite materials covering the near subsurface of the earth, hence, even distribution of magnetic minerals. Because parcel A recorded highest value of magnetic susceptibility and partly undergone chemical and biological processes, it can be concluded that magnetic susceptibility of agricultural soil closed to the road is higher than one far away from the road (confirming what early researchers had proposed).

In order to show the strength of magnetic susceptibility with respect to distance on the road side, histogram distribution of magnetic susceptibility and distance is shown in Figure 2.

In parcel A, magnetic susceptibility shows inconsistent values with highest peak at 46.5 m from the road with standard deviation of 34.2 × 10^{-5} SI. Similarly, in parcel B, magnetic susceptibility distribution is slightly homogeneous with standard deviation of 15.06 × 10^{-5} SI. Reasonably, high magnetic susceptibility values suggested that top


Parcel A
Parcel B
R² = 0.3299
Ni Conc. (mg/kg)
Magnetic Susceptibility (10⁻⁵ SI)
R² = 0.3436
Ni Conc. (mg/kg)
Magnetic Susceptibility (10⁻⁵ SI)
R² = 0.1994
Cu Conc. (mg/kg)
Magnetic Susceptibility (10⁻⁵ SI)
R² = 0.3846
Cu Conc. (mg/kg)
Magnetic Susceptibility (10⁻⁵ SI)
R² = 0.0876
Zn Conc. (mg/kg)
Magnetic Susceptibility (10⁻⁵ SI)
R² = 0.2716
Zn Conc. (mg/kg)
Magnetic Susceptibility (10⁻⁵ SI)
R² = 0.2774
As Conc. (mg/kg)
Magnetic Susceptibility (10⁻⁵ SI)
R² = 0.0187
As Conc. (mg/kg)
Magnetic Susceptibility (10⁻⁵ SI)


R² = 0.0072
Sr Conc. (mg/kg)
Magnetic Susceptibility (10-5 SI)
R² = 0.0596
Sr Conc. (mg/kg)
Magnetic Susceptibility (10-5 SI)
R² = 0.1391
Zr Conc. (mg/kg)
Magnetic Susceptibility (10-5 SI)
R² = 0.096
Zr Conc. (mg/kg)
Magnetic Susceptibility (10-5 SI)
R² = 0.4024
Pb Conc. (mg/kg)
Magnetic Susceptibility (10-5 SI)
R² = 0.2008
Pb Conc. (mg/kg)
Magnetic Susceptibility (10-5 SI)
R² = 0.6058
Ti Conc. (mg/kg)
Magnetic Susceptibility (10-5 SI)
R² = 0.4676
Ti Conc. (mg/kg)
Magnetic Susceptibility (10-5 SI)

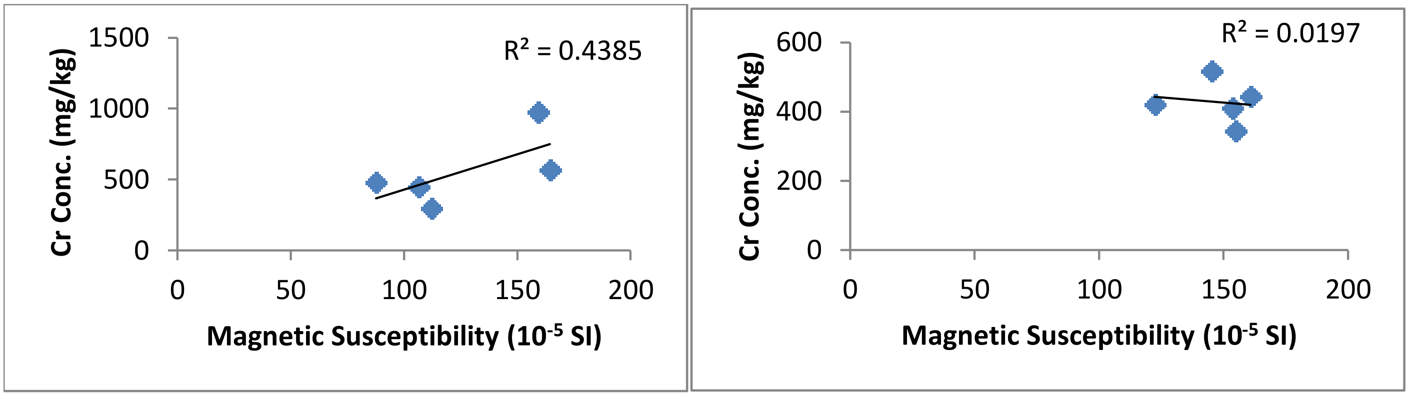


Figure 3. Scatter diagrams of the concentration of heavy metals and magnetic susceptibility values for parcels of agricultural soils.

soil is enriched with ferri/ferro-magnetic materials as a result of vehicular emission, anthropogenic activities and repeated application of fertilizer in the soil.

Statistical analysis of heavy metals in soil

In parcel A, the mean concentration of Ni, Cu, As, Sr, Zr, Pb, Ti and Cr content in top soil were 17.10, 7.26, 38.38, 6.06, 25.56, 594.60, 0.60, 3803.80 and 558.60 mg/kg, respectively. In parcel B, the mean concentration of Ni, Cu, As, Sr, Zr, Pb, Ti and Cr in top soil were 25.02, 9.36, 25.04, 9.40, 24.28, 695.40, 1.04, 3603.00 and 427.80 mg/kg, respectively. As a common element, the concentration of Fe is missing throughout the two agricultural soils. Parcel A contains 51.18% of the total heavy metals content measured as compared to 48.82% of heavy metals content in soils measured in parcel B away from the road. The results indicate that top soils near the road have higher concentration of heavy metals than top soils away from the road due to vehicular emission and anthropogenic activities.

Correlation between magnetic susceptibility and heavy metal content in soil

A graph of each heavy metal contents present in each parcel of agricultural soils is plotted against magnetic susceptibilities measured in the same parcels of soils. Correlation coefficient, R^2 for each heavy metal of agricultural soils are calculated and analyzed. According to correlation analysis of each parcel of soil, all heavy metals analyzed show positive correlations with magnetic susceptibility values (Figure 3). Heavy metalcontent, Ti in both parcels of soils show relativity strong positive correlation coefficients (0.60) with magnetic susceptibility as compared to the rest of other heavy metals. Heavy metals such as Ni, Cu, Pb and Cr showed significant values (< 0.50) of correlation coefficient with magnetic susceptibilities in both parcels. The rest of the metals such as As, Sr, Zn and Zr gave inconsistent values (≤0.02) of correlation coefficient with magnetic susceptibilities in both parcels.

Conclusion

Accumulation of lead (Pb) content closed to the road (parcel A) may be from vehicular (traffic) emission. Enrichment of Ni, Cu, Zn, As and Ti in Parcel A may be due to anthropogenic activities rather than influence of vehicular exhausts. It seems that slightly higher magnetic susceptibility values in Parcel A in comparison with Parcel B, are result of physical, chemical and biological processing rather than influence of transport. Correlating magnetic susceptibility measurement with heavy metals content can give a better insight into environmental management. Preventing heavy metal pollution is critical because cleaning contaminated soils is extremely expensive and difficult. This study shows that magnetic susceptibility can be used as a proxy for mapping high concentration of heavy metals in agriculture top soils. It was also discovered that washing away of the top soils in Parcel A are likely to settle in Owabi Dam, which serves as water sources to catchment communities and Kumasi Metropolis. Hence further research is recommended on the Owabi Dam to check heavy metals pollution.

RECOMMENDATION (FUTURE PROSPECTS)

Further research work is recommended to be carried out in the nearby streams or dams to check if the top soils believed of washing away by erosion or weathering processes are clearly deposited in the nearby streams or dams which serve as water sources for inhabitants of

Kumasi Metropolis and surrounding villages.

Conflict of Interests

The author has not declared any conflict of interests.

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