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Preliminary Investigation of Soil and Sediments Using Magnetic Susceptibility Method in Kogi State, Nigeria

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Abstract

Over the years, there has been significant increase in population and urbanization in Kogi State as a result of rural - urban migration. This has become a major threat to soil sustainability which is a natural non-renewable resource. The aim of this research is to carry out magnetic susceptibility mapping on the surface and subsurface soil of Kogi State using environmental magnetism techniques and geochemical analysis. The susceptibility test on rock samples and background soil samples within the study area shows an average of about $112.0 \times 10^{-5}\, SI$. The magnetic susceptibility measurement on soil from Kogi State shows magnetic susceptibility enhancement of about $(450.0 - 700.0) \times 10^{-5}\, SI$. These values were dominant along the major towns, road pavements and commercial areas at the surface to a depth of about $50.0\, cm$ in soil profiles. The 2D spatial distribution of magnetic susceptibility with depth reveals that theses magnetic grains are distributed in the subsurface as a result of anthropogenic loading. The frequency-dependence of magnetic susceptibility (χ_{fd}%) values are very low ($2 - 10.0$ %) in most of the areas on the surface soil. This values indicate that the magnetic properties are predominantly contributed by the coarse multi - domain (MD) and stable single domain (SSD) grains of anthropogenic origin. Atomic Absorbtion Spectrometer (AAS) analysis of these soil samples indicates the presence of Lead $(300.0 - 900.0)\, mg/l$ and Cadmium $(20.0 - 60.0)\, mg/l$ in large concentration at the surface soil in most part of the Kogi State. While Chromium show relatively low concentration on the surface soil. From the statistical correlation analysis, Lead and Cadmium show high positive correlation with magnetic susceptibility. These results suggests that the high enhancement of magnetic susceptibility on the surface and sub-surface soil in most part of Kogi State arise from anthropogenic activities rather than lithological and pedogenic processes and most likely cause by high concentration of Lead and Cadmium.

Keywords: Anthropogenic; 2D spatial distribution; Magnetic Susceptibility; Pedogenic.

I. INTRODUCTION

The recent rise in urbanization and increased in population growth has become a threat to soil sustainability which is a natural non-renewable resource [1]. The introduction of pollutants on the soil, most especially the topsoil causes it to lose its input of organic matter and nutrients; therefore it can eventually lead to desertification [2]. This has important implications for agriculture and thus food security.

Topsoil forms at a rate of approximately 10mm of soil per 100 to 400 years [3], while natural or geological erosion of the soil occurs at approximately the same rate. Soil degradation due to anthropogenic factors, known as 'man-accelerated' erosion, is at a rate higher than that of soil formation [4]. The soil also plays an important role in the evolution of the subsurface and the exchange of matter between the bedrock and the atmosphere and, as such, the understanding of its properties is a prerequisite in numerous fundamental problems and environmental applications [5]. Reconstructing the past history of deposition and erosion of a given soil, for example, is useful for the reconstruction of past climates [6-7]. To assess this history of a given soil or its ability to store, release or transmit pollutants, some knowledge of its physical and chemical properties is needed. Unfortunately, the introduction of pollutants especially metallic pollutants in the soil affect its physical properties greatly and therefore make it a complex and difficult to characterize and even model. It is therefore essential that we recognize topsoil as a resource in Nigeria and develop methods that are both easy to applied, as well as efficient and unambiguous to investigate the nature of spread of these pollutants. This might be of great help, in particular in a context of the planet's threatened soils [8]. The aim of this research is to carried out magnetic susceptibility mapping on the surface and subsurface soil of Kogi State using environmental magnetism techniques and geochemical analysis, as this will expose the pollution implications of heavy metals due urbanization over time.

A. Study Area

Kogi State is located in North Central Nigeria and bounded between latitude 7°30'N and 7°50'N and longitude 6°42'E and 6°70'E. It has a landmass of 29,833 Square Kilometres. The State is popularly called the confluence state because of the confluence of River Niger and Benue at its capital Lokoja which happen to be the first administrative capital of modern Nigeria [9].

Kogi state consists of twenty-one Local Government Areas (see Fig. 1) and is the only state which shares boundaries with ten other states and thus serves as a link route to other parts of the country.

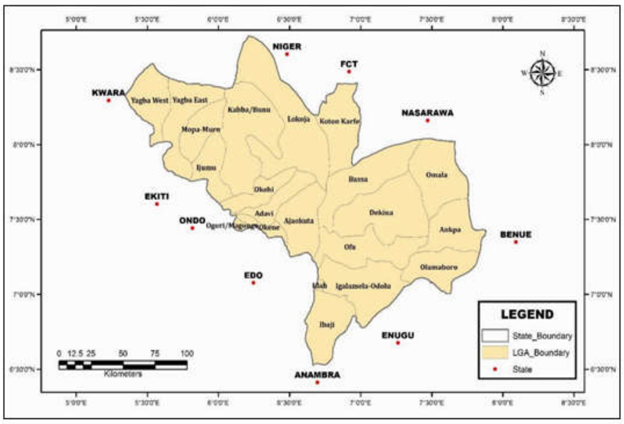

Fig. 1 Map of Kogi State showing the local Government Area and the boundaries [9].

B. Geology of Kogi State

The geological setting of Kogi State (Fig. 2.) is unique in view of the occurrence of the two major components of Nigerian geology (Basement Complex and Sedimentary Basin). Approximately, half of the State is covered by crystalline Basement Complex while the other half is covered by Cretaceous to Recent sediments. The Basement Complex are predominantly underlain the western flank of the State. They are made up of Migmatite Gneiss Complex, and the Pan-African Older Granites [10]. The eastern flank of the State lies within the Anambra Basin and form part of Cretaceous to Recent sediments of Nigeria [11]. It is mainly made up of different Formations of Nkporo, Mamu, Ajali and Nsukka [9]. These Formations are inter-bedded with sandstones, siltstones, carboniferous-shale, coal, sandstones of fluvial marine nature with distinct across beddings and laterite.

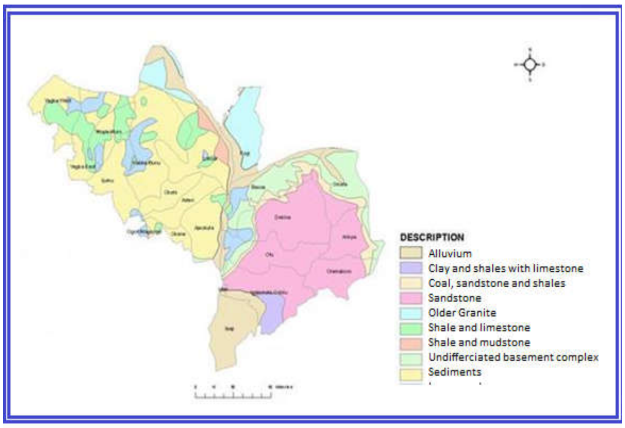

Fig. 2 Geological Map of Kogi State by Local Government Areas [9].

II. MATERIALS AND METHODS

A. Collection and Preparation of Samples

The sampling strategies used in this study include a combination of design features that have shown to work successfully in other studies [12, 13,14,15,16,17,18,19 and 20]. Samples were collected random from 120 locations (bearing in mind reasonable spacing) using a stainless spoon at the surface after clearing the loose soil and also at a depth of 50.0 cm using a 3.0 cm diameter stainless pipe to drill the hole at each sampling point across the state (Fig. 3). The samples are dried and package in a polythene bags and taken to Advance Chemical Laboratory, Ahmadu Bello University, Zaria for analysis.

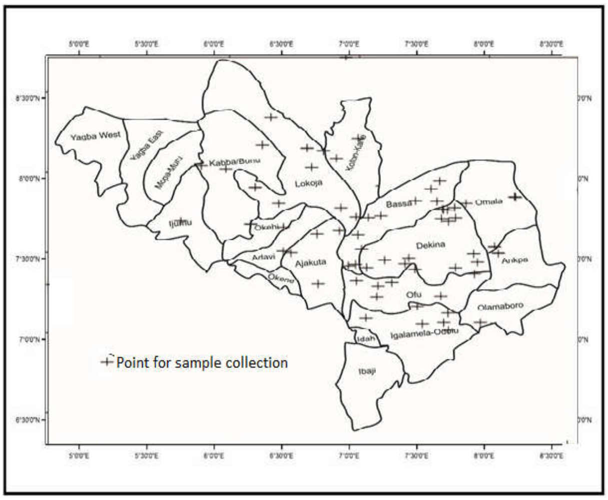

Fig. 3 Sample location of were measurements were carried out in Kogi State (Points reduced for clarity)

B. Magnetic Susceptibility

Magnetic susceptibility is one of the parameters used in environmental magnetism investigation and involves the application of rocks and minerals magnetic techniques to situations in which the transport, deposition or transformation of magnetic grains are influenced by the environmental processes in the atmosphere, hydrosphere and lithosphere [21]. Magnetic susceptibility (MS) is a powerful tool, which is being applied increasingly on environmental studies especially in paleoclimate, sedimentology, paleoceanography, archaeology and more recently in particulates pollution especially in anthropogenic pollution studies [22, 23]. Magnetic susceptibility is independent of the earth's magnetic field at any point, and is largely a function of the volume of magnetic minerals [24]. The measurements are designed to measure the response of natural materials to a range of artificially applied magnetic field. These non-naturally remanent characteristic (also called non-directional magnetic measurements) is the foundation of this branch of geophysical [25].

C. Magnetic Susceptibility

Magnetic Measurements of magnetic susceptibility were performed using the Bartington MS2 magnetic susceptibility meter connected to a Bartington MS2B dual frequency susceptibility sensor. Measurements were taken at low frequency (0.47 kHz; (χ_{lf})) and high frequency (4.65 kHz; (χ_{HF})). Both low and high frequency susceptibilities were measured (χ_{lf} and χ_{hf}) to allow frequency dependent susceptibility to be calculated (χ_{fd} %) using (1).

$$\chi_{fd(\%)} = \frac{\chi_{lf} - \chi_{hf}}{\chi_{lf}} \times 100 \quad (1)$$

The concentration of metals in the sample was performed using Perkin-Elmer Atomic Absorption Spectrometer on 78 samples collected [26].

III. RESULTS AND DISCUSSION

A. Background Test

Magnetic susceptibility mapping and geochemical analysis were successfully carried out on soil samples within Kogi State, North central, Nigeria. From the geological mapping carried out, the study area falls within the basement complex of North Central and part of the sedimentary basin of the middle Benue trough. The rocks within the area are predominantly igneous rocks with magnetic susceptibility ranging between $65.0 - 250.0 \times 10^{-5}\, SI$, with an average value of $112.5 \times 10^{-5}\, SI$. The mean susceptibility value of $112.0 \times 10^{-5}\, SI$ is an indication that the magnetic susceptibility is controlled by paramagnetic minerals. The background magnetic susceptibility values are in agreement with the rock magnetic susceptibility values obtained from the geological mapping. This result serves as the control for our interpretation. This is in conformity with previous works carried out within the area [26, 27 and 28]. In other to evaluate the magnetic susceptibility values obtained in this work, we consider the average magnetic susceptibility of the parent rocks and the soil as the natural background susceptibility of the area and the susceptibility classification in Table I which assigned soil neutral to severe impact on the environment.

Table I Classification of magnetic susceptibility effect on the Environment [29].

Classification	Magnetic Susceptibility ($10^{-5}\, SI$)
Neutral	0-50.0
Moderate	50.0-500.0
Severe	500.0-2000.0
Very severe	>2000

B. Magnetic Susceptibility Data

From the 2D spatial contour maps at surface and at a depth of 50.0cm, high magnetic susceptibility of about $400.0 - 600.0 \times 10^{-5}\, SI$ is clearly observed at the surface map (Fig. 4a). The high magnetic susceptibility enhancement occurred mostly at the boundaries of the various road networks, commercial areas and major towns within Kogi State. In the

Eastern part of the state, low magnetic susceptibility are observed, in Idah, Ibaji, Igalamela and Olamoboro areas, the low magnetic susceptibility values observed are attributed to the terrain of the area which is sloppy and hence most of the magnetic grains deposition are easily transported to a nearby River Niger in the area and also it falls within the sedimentary basin. At the depth of 50.0 cm (Fig. 4b), it is clearly observed that magnetic susceptibility decreases with depth, although some places still indicate high values, but conclusively, the decreases in magnetic susceptibility with depth is due to the fact that magnetic pollutants have less penetrating factor and also most of them are easily transported and deposited either in the river, lakes etc. According to [29], the surface soil of Kogi state is considered to have moderate to severe effect on the environment.

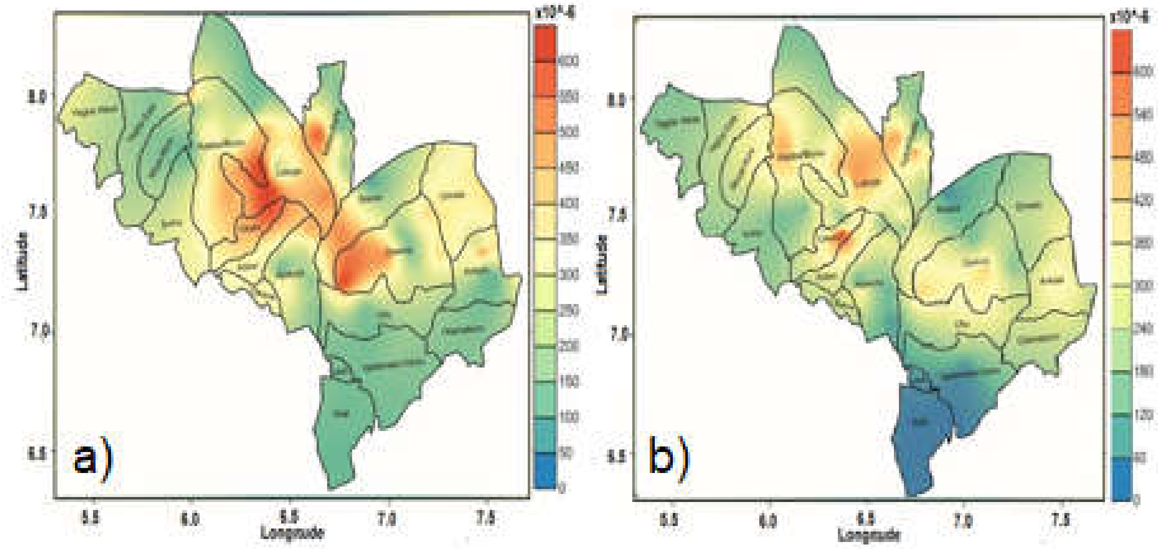

Fig. 4 Magnetic susceptibility of Kogi State (a) at Surface, (b) at 50 cm depth

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, χ, values at both frequencies [30]. Table II shows values of χ_{fd} % indicating the presence of SP particles in the sample.

Table II Interpretation of χ_{fd} % values [30, 31]

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

Fig. 5 depicts areas within Kogi State have frequency dependent susceptibility above 3.0. With 70 % of the area falling within the basement complex, this clearly indicates the presence of super paramagnetic minerals or mixture of SP and coarser grains. These grains are known to be of anthropogenic origin rather than lithogenic and pedogenic origin [31].

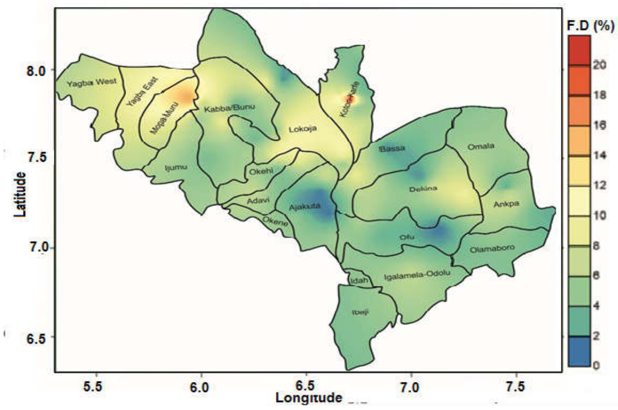

Fig. 5 Frequency dependent magnetic susceptibility at the surface

C. *Results from Geochemical Analysis*

Microscopy reveals Cr, Cd, Zn and Pb as anthropogenic magnetic grains predominantly found on Kogi State soil. From Fig. 6a, shows the spatial concentration of Lead (Pb) on the surface soil of Kogi State. Places with high commercial activities like Lokoja the state capital, and the central part of the state shows high concentration of lead on the surface soil $(600 - 900)\ mg/l$. While the eastern and western part of the state shows low concentration of lead on the surface. From the susceptibility results, it is clear that the high concentration of lead on the surface correspond to high magnetic susceptibility values obtained.

From Fig. 6b, it is evident that Cadmium is distributed evenly in almost all the areas at the surface with concentration ranging from $(2.0 - 60.0) mg/l$. Place like Lokoja, Dekina, Olamaboro, and Okehi have high concentration of cadmium at the surface $(30.0 - 60.0)\ mg/l$. The high concentration at the surface is mostly attributed to anthropogenic pollution, as cadmium is major releases around road pavements due to wearing of tyres. Comparing the surface spatial distribution of Cadmium and spatial magnetic susceptibility distribution map, there is a correlation between them. This indicates that Cadmium is among the contributors to the magnetic susceptibility at the surface.

Fig. 6c shows the 2D spatial concentration of Chromium on the surface soil map of Kogi State. The concentration of chromium is relatively low ranging from $(2.0 - 32.0)\ mg/l$. This indicates that most of the anthropogenic activities within Kogi State do not releases chromium to the environment and hence it does not contribute significantly to the magnetic susceptibility of the area.

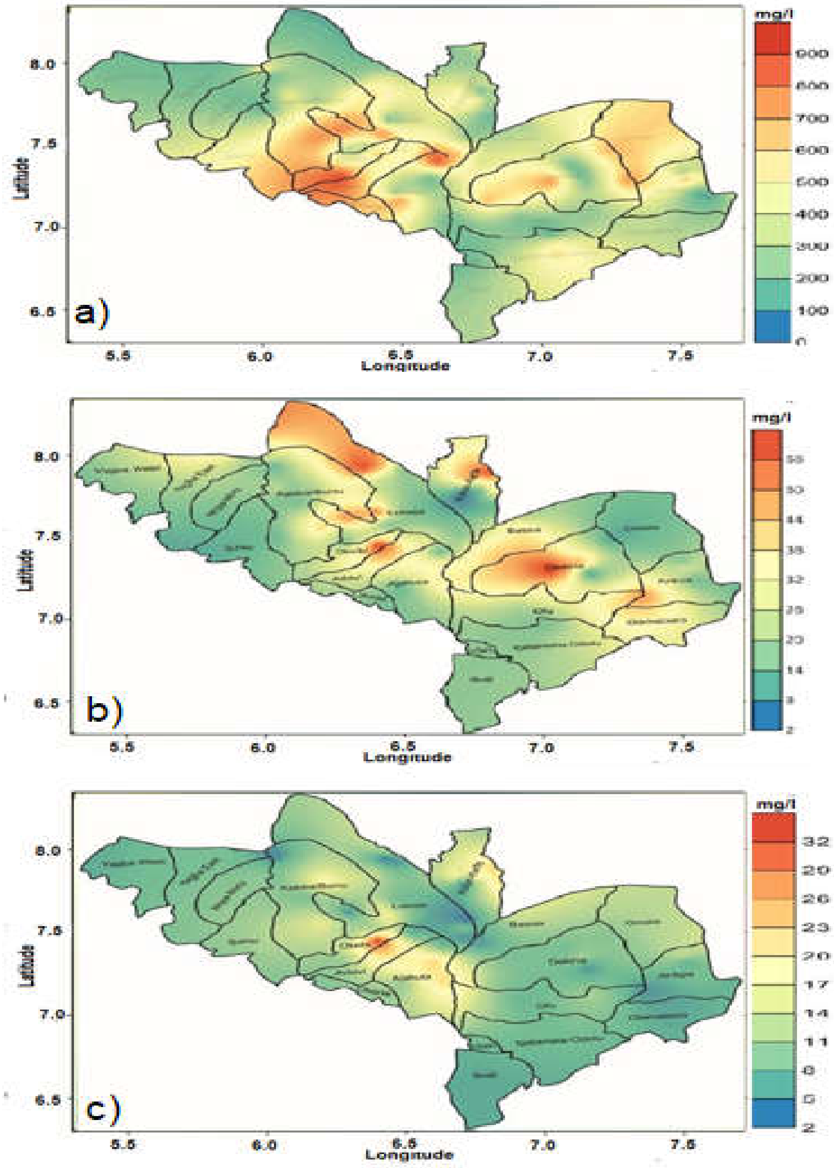

Fig. 6 Concentration of metals at the surface soil in Kogi State (a) Lead, (b) Cadmium and (c) Chromium.

The distribution of heavy metals across Kogi State surface soil can be generally attributed to anthropogenic activities within the area with Pb and Cd as the major contributors to the high magnetic susceptibility values obtained in the study area.

The source of Cd in the surface may be attributed to the abrasive vehicular wear in particular brake linings, while Pb may be attributed to petroleum products [32]. From the correlation plots, (Fig. 7) a pronounced positive and significant coefficient was found between the concentration of heavy metal elements Pb and Cd and magnetic susceptibility of about of 0.9103 and 0.9566 respectively. There is a very weak correlation with Chromium and Zinc of 0.6011 and 0.5513 respectively (Table III). From these results, it is evidence that magnetic susceptibility can be used as a guideline to find contaminated urban areas with high Pb and Cd values.

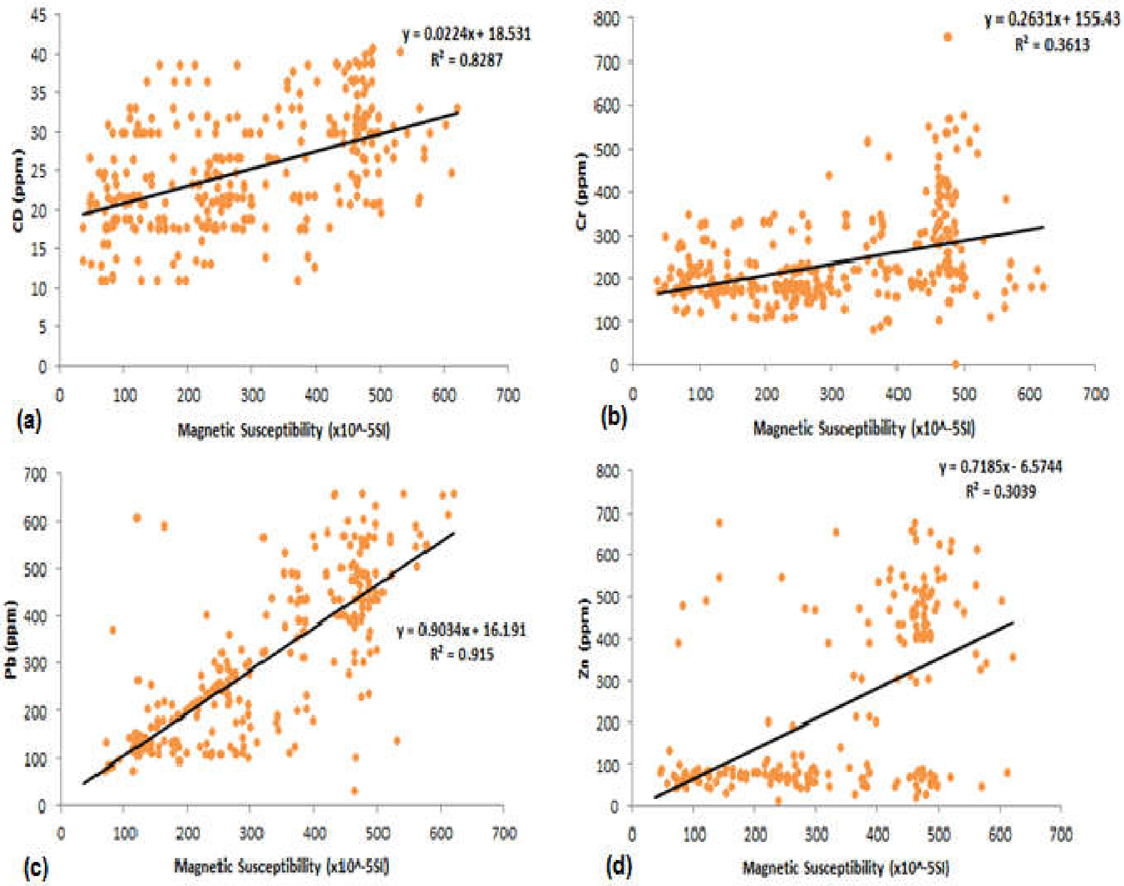

Fig. 7Correlation plots between Magnetic Susceptibility and concentration of (a) Cd (b) Cr, (c) Pb and (d) Zn at the surface soil

Table III Correlation parameters of selected heavy metals with magnetic susceptibility measurements in Kogi State

Element	Coefficient of Determination (R^2)	Correlation Coefficient (R)
Cd	0.8287	0.9103
Cr	0.3613	0.6011
Pb	0.9150	0.9566
Zn	0.3039	0.5513

IV. Conclusion

Previous studies [6, 31] showed that magnetic susceptibility variations are caused by differences in geology (lithogenic/geogenic), soil forming processes (pedogenesis) and anthropogenic input of magnetic material. The high magnetic enhancement in the top soil is attributed to anthropogenic inputs of magnetic minerals/grains. From the magnetic susceptibility results, it is observed that the soil of Kogi State has high magnetic susceptibility when compared with the background values and the parent rocks magnetic susceptibility. This indicates that anthropogenic activities results in the increased of the magnetic susceptibility observed on the soil. Spatial distributions with depth can be very useful in delineating areas were the enhancement is as a result of anthropogenic pollution from those of lithogenic origin. Additionally, the spatial distribution with depth shows that the magnetic susceptibility at the top of soil is the most affected by anthropogenic pollutants.

Frequency dependent susceptibility helps us to discriminant magnetic grains due to anthropogenic sources from those that originate from lithogenic processes. Mostly emission for vehicles and industries are ultrafine particle (Super-paramagnetic) in nature with diameter less the $0.03\mu m$. From the results obtained, it is clearly that the major contributor to the surface magnetic susceptibility in Kogi State aroused from the continuation deposition of magnetic grains from anthropogenic sources. The results from the geochemical analysis indicate the high concentration of Pb, and Cd at the surface soil. These concentration are more than the allow concentration and hence poses a risk to the environment. The positive and pronounced correlation between Pb and Cd make the magnetic susceptibility measurement a reliable tool in quick evaluation of contaminated areas by these metals.

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References

[1] J. W. Doran, M. A. Liebig and D. P. Santana. ”Soil Health and Global Sustainability”. In: Proceedings of the 16th World Congress of Soil Science. Montepellier, France, 20–26 August, 1998.

[2] R. Gobinath, G.P. Ganapathy, E. Gayathiri, Ashwini Arun Salunkhe, Hamid Reza Pourghasemi, Chapter 18 - Ecoengineering practices for soil degradation protection of vulnerable hill slopes, Editor(s): Hamid Reza Pourghasemi, Computers in Earth and Environmental Sciences, Elsevier, 2022.

[3] J. W. Doran and S. Stamatiadis. ‘Soil Health as an indicator for a Sustainable Land Management; Summary Findings of an International Workshop. Agronomy Abstracts, Salt Lake City. Utah meeting (1999).

[4] H. H. Bennett ‘Soil conservation’ Soil Conservation 1939 Google Scholar

[5] A. Musy and M. Soutter. ”Physique du sol” (Presses polytechniquesetuniversitairesromandes, Lausanne), 1991 (in French).

[6] S. S. Jatto, P. O. Sule and L. A. Ahmed. “3-Dimensional Surface Magnetic Susceptibility Distribution with Depth to Investigate Anthropogenic Pollutants Boundary in Abuja Metropolis”. Geology, Geophysics and Environment; vol.42 (4); 443-448. 2016.

[7] F. Lagroixand and S. K. Banerjee,”Paleowind directions from the magnetic fabric of loess pro ¢ les in central Alaska”. Earth Planet. Sci. Lett. 195, 2002.

[8] S. A. Banwart. ‘Save our Soils. Nature 474, 151-151. (2011).

[9] F. B. Fatoye and N. D. Gideon. ”Geology and Mineral Resources of the Lower Benue Trough, Nigeria”. Advances in Applied Science Research Journal. Vol.4; No. 6. 2014.

[10] Kogi State Ministry of Solid Mineral and Development (KSMSMD). Guide to Investment Opportunities in Solid Mineral Sector of Kogi State. 2004.

[11] F. B. Fatoye. ”Geology and Minerals Resources of Kogi State”. Nigerian International Journal of Multidisciplinary Sciences and Engineering. Vol. 9, No. 7. 2018.

[12] R. A. Sutherland and C. A. Tolosa. ”Multi-element analysis of road-deposited Sediment in an Urban Drainage Basin, Honolulu, Hawaii”. *Environmental Pollution*, 110(3), 483-495. 2000.

[13] A. D. K. Banerjee. ”Heavy Metal Levels and Solid Phase Speciation in Street Dusts of Delhi, India”. *Environmental Pollution*, 123(1), 95-105. 2003.

[14] S. Charlesworth, M. Everett, R. McCarthy, A. Ordonez and E. A. De Miguel. ”Comparative Study of Heavy Metal Concentration and Distribution in Deposited Street Dusts in a large and a small Urban Area: Birmingham and Coventry, West Midlands, UK”, *Environmental International,* 29, 563-573. 2003.

[15] P. Gautam, U. Blaha and E. Appel. ”Magnetic susceptibility of dust-loaded leaves as a proxy of traffic-related heavy metal pollution in Kathmandu City, Nepal”. *Atmospheric Environment*, 39(12), 2201-2211. 2005.

[16] Yin J., Allen A.G., Harrison R.M., Jennings S.G., Wright E., Fitzpatrick M., Healy T., Barry E., Ceburnis D. and McCusker D. (2005). Major Component Composition of Urban PM10 and PM2.5 in Ireland. *Atmospheric Research*, 78(3-4), 149-165.

[17] M. A. Anagnostopoulou and J. P. Day (2006). ”Lead Concentrations and Isotope Ratios in Street dust in major Cities in Greece in Relation to the use of Lead in Petrol”. *Science of the Total Environment*, 367(2-3), 791-799. 2006.

[18] C. A. Booth, V. Shilton, M. A. Fullen, J. Walden, A. T. Worsley and A. L. Power. ”Environmental Magnetism: Measuring, Monitoring and Modelling Urban Street Dust Pollution”. In: J.W.S. Longhurst and C.A. Brebbia (Eds) *Air Pollution XIV*. Wessex Institute of Technology (WIT) Press, Southampton 333-342. 2006.

[19] T. Haugland, R. T. Ottesen and T. Volde. ”Lead and Polycyclic Aromatic Hydrocarbons (PAHs) in surface Soil from day care centres in the city of

Bergen, Norway”. *Environmental Pollution*, 153(2), 266-272. 2007.

[20] T. Yang, Q. Liu, H. Li, Q. Zeng and L. Chan. ”Anthropogenic Magnetic Particles and Heavy Metals in the Road dust: Magnetic identification and its implications”. *Atmospheric Environment*, 44(9), 1175-1185. 2010.

[21] K. L. Verosub and A. Roberts. ”Environmental Magnetism: Past, Present and Future”. Journal of Geophysical Research, 100, 2175-2192. 1995.

[22] B. A. Maher, C. Moore and J. Matzka. ”Spatial Variation in Vehicle-derived Metal Pollution identified by Magnetic and Elemental Analysis of Roadside Tree Leaves”. Atmospheric Environment 42 (2), 364–373. 2008.

[23] Lecoanet, F. Leveque and J. P. Ambrosi. ”Combination of Magnetic Parameters: an efficient way to Discriminate Soil-contamination Sources (south France)”. *Environmental Pollution* 122, 229–234. 2003.

[24] W. O’Reilly. ”Magnetic Mineral in the Crust of the Earth”. Reports Prg. Phys., 39, 857-908. 1976.

[25] N. Basavaiah and S. K. Aniruddha. ”Environmental Magnetism and its Implication towards Palaeomonsoon Reconstruction”. Journal of Indian Geophysics Union, 8 (1), 1-14, 2004.

[26] B. E. Kogo, E. N. Gajere, J. K. Ogunmola and J. O. Ogbole. ”Neutron Activation Analysis of Soil Samples from Different Parts of Abuja Metropolis”. Middle-East Journal of Scientific Research 4 (4), 254-262. 2009.

[27] C. B. Longpia, E. C. Ashano and B. G. Pam. “Geophysical Investigation for Engineering Site Development around Galadimawa-Aleita Area, Abuja, North Central Nigeria”. Journal of Applied Geology and Geophysics, 1(6), 1-11. 2013.

[28] I. M. Idehai, A. O. Egai and M. E. Okiotor. ”Comparative Assessment of the Geotechnical Properties of Residual Soils in part of Awka and Abuja of Nigeria”. Nigerian Journal of Technology (NIJOTECH), 33(4), 595-603. 2014.

[29] H. Preetz, S. Aftleder, V. Henning and I. Jan. ‘Classification of Soil Magnetic Susceptibility and Prediction of Metal Detector Performance; case study of Angola. Conference Proceedings of SPIE. Vol. 7303, 730312. 2008.

[30] [32]. J. A. Dearing. ”Environmental Magnetic Susceptibility” Using the Bartington MS2 System, Chi Publishing, Kenilworth, U. K, 104. 1999.

[31] S. B. Michal. ‘Application of Magnetic, Geochemical and Micro-morphological Methods in Environmental Studies of Urban Pollution Generated by Road Traffic.’ PhD Dissertation, Department of Physics, University of Helsinki. 2012.

[32] W. Birmili, A. G. Allen, F. Bary and R. M. Harrison ‘Trace Metal Concentrations and Water Solubility in Size-fractionated Atmospheric Particles and influence of Road Traffic’. *Environmental Science and Technology*, 40, 1144–1153, 2006.