Centre for Atmospheric Research

2018 MONOGRAPH OF ATMOSPHERIC RESEARCH

Edited by A.B. Rabiu and O. E. Abiye

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National Space Research and Development Agency
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First Published in 2018

ISBN: 978-978-972-859-6

Printed in Nigeria
by Simplicity Press
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PREFACE

The Centre for Atmospheric Research was established in January 2013 with a compelling mission to improve our understanding of the behaviour of the entire spectrum of the Earth's atmosphere; promote capacity development in relevant atmospheric sciences as a way of facilitating international competitiveness in research being conducted by atmospheric scientists; and disseminate atmospheric data/products to users towards socio-economic development of the Nation. CAR's extant core research focus includes: space weather, tropospheric studies, atmospheric research software and instrumentation development, microgravity and human space technology, and atmospheric chemistry and environmental research.

Pursuant to the above, The *Monograph of Atmospheric Research* published by the Centre for Atmospheric Research (CAR), is a collection of peer-reviewed manuscripts in Atmospheric Sciences and closely related fields. This maiden edition comprises articles presented during two separate workshops; *1st National Workshop on Microgravity and Environmental Research* (26 - 29 November, 2017) and *1st National Workshop on Air Quality* (13 - 16 March, 2018). Such workshops are integral part of CAR's capacity building program and they were primarily aimed at advancing the course of atmospheric research in Nigeria towards sustainable development. The Microgravity workshop was geared towards introducing new research opportunities in space life science by simulating microgravity conditions here at the earth's surface as a means of investigation space biological environment. The Air Quality workshop was organized in collaboration with Ministry of Environment and Nigerian Meteorological Agency (NIMET). The workshop analysed current Air Quality scenario in Nigeria, explored new opportunities for collaborative research and offered novel means of improving the present quality of life of the populace without jeopardizing the chance of the future generation. Cumulatively 196 participants participated in these two workshops and about 52 articles were eventually submitted for publication consideration in this monograph. The twenty-one articles in this very monograph are the articles that eventually made it through the rigorous peer-review process. We remain grateful to the reviewers for doing thorough work on the articles.

Thus, we are very pleased to present the *2018 Monograph of Atmospheric Research* which contains twenty-one articles, including some review papers, to readers in all spheres of interest across Nigeria and beyond. It is our hope that this effort will continue and will serve as a reference to atmospheric researchers in Nigeria.

Prof. A. B. Rabiu and Dr. O. E. Abiye,
Editors

Centre for Atmospheric Research

Magnetic and metal pollution studies of top soils from residential areas of Jalingo metropolis, Taraba State, NE Nigeria

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ABSTRACT

Magnetic particles, heavy metals and other compounds generated by human activities can greatly affect soil quality and have direct implications on human health, hence the need for environmental monitoring in urban towns. Environmental magnetic proxies have been proven to provide a rapid means of assessing the degree of anthropogenic metal pollution in soils. In this study, 121 top soil samples collected from Jalingo residential areas for various environmental magnetic and geochemical measurements. Measurements of magnetic susceptibility χ and frequency dependent susceptibility χfd%, Anhysteric Remanent Magnetization ARM and Isothermal remanent magnetization IRM were performed using AGICO MFK1-FA Kappabridge, D-2000 AF Demagnetizer, Mulspin Pulse and Spinner Magnetometer respectively. Metal concentrations were measured using X-ray Fluorescence (XRF) spectrometer. Values of χ ranged from (16.07 to 1669.04) $x10^{-8}$ m^3kg^{-1}, Saturation IRM (SIRM) values ranged from (111.37 to 5693.09) $x10^{-5}$ Am^2kg^{-1}, and Susceptibility of ARM (χARM) values varied from (0.05 to 0.88) $x10^{-5}$ m^3kg^{-1}. The high values of the magnetic concentration parameters obtained implied high concentration of ferrimagnetic minerals in the soils. The average value of 7.05 ±3.33% for χfd%, indicates that the study area was dominated by a mixture of multi domain (MD) and superparamagnetic (SP) grain sizes. Low coercivity magnetic minerals e.g. magnetite dominated the samples. Enhanced concentrations of some metals (Si, P, K, Ti, Cr, Zr, Sn, Ba, Pb, Th and U) above background values were observed in the studied samples. This may result from variable sources revealed by principal component analysis. Pollution Load Index results show that the soils have been polluted. The significant positive correlations recorded between χlf, χARM and SIRM and some metals has shown that magnetic methods could be used as geochemical proxy for pollution assessment. However, χARM has proven to be the best proxy for metal concentration in Jalingo residential areas as it significantly correlated with most metals.

Key words: Environmental magnetism; magnetic susceptibility; Metal; Pollution; soil

Citation: Kanu, M. O., Meludu, O. C., Basavaiah, N. and Oniku, A. S., 2018. Magnetic and metal pollution studies of top soils from residential areas of Jalingo metropolis, Taraba State, NE Nigeria. Monograph of Atmospheric Research 2018, Edited by A. B. Rabiu and O. E. Abiye, Centre for Atmospheric Research, Anyigba, Nigeria. pp. 92-102.

INTRODUCTION

Environmental magnetism comprises the measurement of magnetic properties in environmental materials such as soils, sediments and dusts. Most often, the magnetic properties in soils are caused by mineral magnetic compounds such as iron oxides present in soils. Magnetite (Fe_3O_4) and maghemite (γFe_2O_3) are the most abundant magnetic iron oxides in soils and determine to a greater extent its magnetic characteristics with less contribution from goethite (FeOOH) and hematite (αFe_2O_3). These iron oxides in soils are inherited from parent rocks, formed during pedogenesis or from products of anthropogenic activities. Generally, the concentration of iron oxides in soils is influenced by the parent materials, biological activity, age of soil, pedogenic processes, soil temperature, physiochemical properties and anthropogenic activities (*Blundell et al., 2009*).

The simplest form in which the magnetic minerals concentration can be detected is by measurement of magnetic susceptibility (*Thompson and Oldfield, 1986*). It can be used to approximate the concentration of ferrimagnetic minerals. A soil that has elevated values of magnetic susceptibility is said to be magnetically enhanced (*Mullins, 1977*). Measurement of magnetic susceptibility (in conjunction with other magnetic parameters) has found application in the delineation of areas with concentrations of deposited anthropogenic ferrimagnetics significantly above background values (*Stryzszcz, 1993; Kapicka et al., 1999, Hoffmann et al., 1999; and Petrovsky et al., 2000*). These studies showed that in polluted areas, the magnetic susceptibility of surface soil layers is considerably higher. Magnetic susceptibility measurements of soil can be applied for the identification of polluted areas and the detailed mapping of these areas to reveal the extent of pollution (*Hanesch and Scholger, 2002*).

The magnetic method for pollution studies evolved from the growing demand for pollution data. The traditional chemical method of determination of the concentration of heavy metals are laborious in terms of sample preparation, very expensive and time consuming and cannot meet the ever increasing requirements of data on contamination levels of soils. Therefore any other method although approximate (i.e. not providing absolute threshold values for contamination), but yielding fast information directly on the field about relative changes between different sites can be helpful as indicator for better targeting and selection of samples for subsequent geochemical analysis. Magnetic measurements (in particular magnetic susceptibility) have become a generally accepted method to map spatial distribution of pollution, identify pollution sources, provide an alternative to conventional chemical analysis, because its measurements are fast , cost- effective, non destructive, sensitive, informative and can be applied as a preliminary tool to detect pollution hotspots before the application of other time consuming techniques. The integration of the traditional chemical techniques with soil magnetic susceptibility measurements maybe an interesting way of monitoring heavy metals levels in soil (*Xia et al., 2001; Hanesch et al., 2002, Schmidt et al., 2005; Wang et al., 2013*).

Studies by *Jordanova et al. (2004), Spiteri (2005), Canbay (2010), Wang et al. (2018)* and others have revealed a significant correlation between magnetic parameters and heavy metal contents in soils. This allows magnetic method to be used as an indicator for heavy metal contamination and the spatial distribution of the contaminants. The use of magnetic measurements as a proxy for heavy metal pollution is based on the fact that the origins of heavy metals and magnetic particles are genetically similar (*Lu et al., 2007*). For example, ferrimagnetic minerals (e.g. magnetite/maghemite) associated with industrial activity and traffic pollution can lodge into the lattice structure of toxic elements like Pb, Cu and Zn etc. The relationship between magnetic properties and the contents of heavy metals can be used as a proxy to determine different degrees of pollution by heavy metals in urban dust as well as in industrial soils.

The present study intends to (1) Assess the extent of metal pollution around residential areas in Jalingo Metropolis (2) Identify the various sources of pollution and (3) further examine the applicability of magnetic measurements as proxy for anthropogenic metal pollution.

MATERIALS AND METHOD

Study Area

The study was carried out in Jalingo metropolis, Taraba State, North-East Nigeria. Jalingo is located between latitude 8° 50' and 8° 55' N and between longitude 11° 17' and 11° 26' E (Fig. 1). Taraba State experiences a dry season that last for November to March and wet season that spans from April to October. Rainfall in the state is estimated at about 8000 mm per annum and according to the Nigerian National Population Commission (*NPC, 2006*), the total population of Jalingo is over 118,000. The Geology of study area is that of the basement complex rocks and is mainly composed of the migmatites, gneisses and the Older Granites (*Obaje, 2009*).

Collection and preparation of samples

Topsoil samples (about 121samples) were randomly obtained from different parts of the town. For ease of sampling and wide coverage, the town was divided into six sections, namely Awoniyi quarters (AWQ), Abuja face one (ABF1), Sintalli (STI), Mayo-Gwoi (MYG), Sabon-Gari (SGR) and Magami (MGM). The collected samples were inserted into labeled plastic containers and conveyed to the laboratory. Detailed sample preparation is given in our earlier article (Kanu *et al.*, 2017)

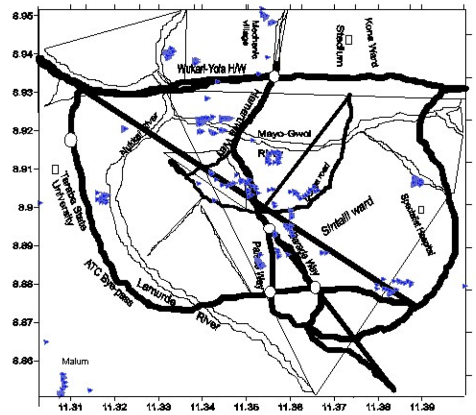

Fig. 1 Map of Jalingo showing sample locations

Magnetic Measurements

Measurement of magnetic susceptibility was performed using the Agico MFK1-FA Kappabridge instrument available at the Indian Institute of Geomagnetism, Mumbai (IIGM). Low frequency (976 Hz) and high frequency (15616 Hz) measurements were performed at an alternating field of 200 A/m. The dual frequency measurement was used to calculate the frequency dependent magnetic susceptibility using equation 1.

$$\chi_{fd}(\%) = \frac{\chi_{lf} - \chi_{hf}}{\chi_{lf}} \text{ X } 100\% \qquad (1)$$

where χlf and χhf are respectively the low and high frequency magnetic susceptibility.

To measure the Anhysteretic Remanent Magnetization (ARM), samples were first demagnetized in alternating field of 100 mT imparting a constant DC biasing field of 0.05 mT. D-2000 AF demagnetizer was used to acquire the ARM while the Molspin spinner magnetometer measured the acquired remanence. The measured ARM values were transformed to the susceptibility of ARM (χARM).

The spinner magnetometer was use to measure the Isothermal Remanent Magnetization (IRM) after magnetizing the samples using Molspin Pulse Magnetizer which can impart a maximum magnetic fields of 1 Tesla. IRM was acquired for a forward field of 20 mT and 1T. Saturation Isothermal Remanent Magnetization (SIRM) is the remanance obtained at 1T in the Molspin Pulse Magnetizer. Afterwards, DC demagnetization (reverse field) of 20, 30, 100 and 300 mT was applied. Following *Thomson and Oldfield (1986); Walden et al. (1999); Basavaiah and Khadkikar (2004); Basavaiah (2011)*, some inter-parametric ratios such as Soft IRM, Hard IRM (HIRM) and S-ratio were calculated using equations 2- 6.

$$\text{Soft IRM} = \left(\frac{SIRM - IRM_{-30mT}}{2}\right) \quad (2)$$

$$SoftIRM(\%) = \frac{SOFT}{SIRM} \times 100\% \quad (3)$$

$$HIRM = \left(\frac{SIRM - IRM_{-300mT}}{2}\right) \quad (4)$$

$$HIRM(\%) = \frac{HIRM}{SIRM} \times 100\% \quad (5)$$

$$S_{ratio} = \frac{|IRM_{-300mT}|}{SIRM} \quad (6)$$

Brief interpretation of the various magnetic parameters is given in Table 1.

X-Ray Fluorescence (XRF) Analysis:

The concentration of metals in samples was performed on 53 pre-selected samples using X-ray fluorescence spectrometer (AMATEK). Soil samples were initially powdered and packed (3 g) into plastic cups. The Turboquant Powder method was adopted. The magnetic and geochemical parameters were conducted at the Environmental Magnetism Laboratory, Indian Institute of Geomagnetism, Mumbai, India.

RESULTS AND DISCUSSION

Mineral magnetic data

The results obtained from magnetic measurements are presented in Table 2. Results of χ varied greatly between samples with moderate to high values that ranged from 16.07 to 1669.04 x 10^{-8} m^3kg^{-1} (average, 124.42 x 10^{-8} m^3kg^{-1}). According to Thompson and Oldfield (1986) and Dearing *et al*. (1996), variations in magnetic susceptibility are caused by variations in geology (lithogenic/geogenic), pedogenesis and anthropogenic inputs

Table 1: Environmental Magnetic Parameters and Interpretation

Symbol	Parameter Description	Dependent on/indicative of
χ	Mass specific susceptibility (m^3kg^{-1})	Concentration of ferrimagnetic minerals in a sample and grain size
χfd	Frequency dependence of susceptibility (%)	Grain size. It determines the concentration of SP grains in sample
ARM	Anhysteric Remanent Magnetization (Am^2kg^{-1}) or (Am^{-1})	Concentration of Single Domain (SD) ferrimagnetic minerals
χARM	Susceptibility of ARM (m^3kg^{-1})	Concentration of SD ferrimagnetic minerals in the range (0.02-0.4 μm)
SIRM	Saturation Isothermal Remanent Magnetization (=Mrs) (Am^2kg^{-1}) or (Am^{-1})	Concentration of all minerals in the sample that carry remanence and grain size
Ms	Saturation Magnetization (Am^2kg^{-1}) or (Am^{-1})	Concentration
Bcr	Remanent coercive force (mT)	Grain size, mineralogy (ferrimagnetic vs antiferromagnetic)
Bc	Coercive force (mT)	Grain size, mineralogy (ferrimagnetic vs antiferromagnetic)
Tc	Curie temperature (°C)	Mineralogy
Tm	Morin transition temperature (°C)	Mineralogy (hematite)
Tv	Verwey transition temperature (°C)	Mineralogy (magnetite)
Mrs/Ms & Bcr/Bc	Day plot	Grain size
IRM_{-300mT}/ SIRM	S-ratio	Mineralogy (ferrimagnetic vs antiferromagnetic)
ARM/SIRM	Magnetism ratio	Grain size, concentration of SD remanence carrying particles
χARM/χ	Susceptibility ratio	Grain size. High ratios indicate presence of Stable SD (SSD) grains
SIRM/χ	Ratio of SIRM to susceptibility (10^3 Am^{-1})	Concentration, grain size, mineralogy
χ/Ms	Ratio of susceptibility to Saturation magnetization (mA^{-1})	Grain size
Soft IRM	Soft Isothermal Remanent Magnetization (Am^2kg^{-1}) or (%)	Concentration of magnetically 'soft' ferrimagnetic mineral
HIRM	Hard Isothermal Remanent Magnetization (Am^2kg^{-1}) or (%)	Concentration of magnetically 'hard' canted antiferromagnetic mineral

(Source: Maher, 1988; Walden et al., 1999; Basavaiah, 2011)

of magnetic materials. The variation of magnetic susceptibility obtained in this study may not be attributed to effect of geology, since all the samples were collected within the same geologic setting. The enhancement of magnetic susceptibility in the topsoil might be due to *in -situ* conversion of a small proportion of weakly magnetizations of iron oxide and hydroxide in the soil to strongly magnetic form which can only be maghemite or magnetite (*Mullins, 1977*); anthropogenic loadings due to remote emissions sources, local brewing activities and scattered refuse dumps; and the presence of bacterial magnetite.

The average value of χ (124.07 x 10^{-8} m^3kg^{-1}) obtained for Jalingo urban topsoil is comparable to that obtained by Jiang *et al.* (2010) in Baoshan District urban topsoil (147 x 10^{-8} m^3kg^{-1}) and Hanzhou city (128 x 10^{-8} m^3kg^{-1}) by Lu and Bai (2008). Higher mean χ value of 240.53 x 10^{-8} $m^3kg^{-1}$was obtained in Jalingo road side soils (Kanu *et al.*, 2017). This clearly indicates higher pollution along the major roads from vehicular sources. The highest values of χ were obtained around the AF1 and STI areas of the town where local brewing activities and repairs of automobiles are respectively carried out. The results of χ for the various sections of the town were summarized in a box plot of Fig. 2a. Other concentration dependent parameters (χARM, SIRM etc.) were equally high showing that ferrimagnetic minerals dominate the samples. χfd% ranged from 0.07 to 15.74% with an average value of 7.05 ±3.33%, indicating that the residential areas were dominated by MD and SP grain sizes. The variations of χfd% within the different sections of the town were summarized in a box plot (Fig. 2b). Higher values of χfd% are observed in AWQ and SGR areas. This implied that samples in these areas are dominated by MD grain sizes, an indication of high anthropogenic activities (Li *et al.*, 2014)

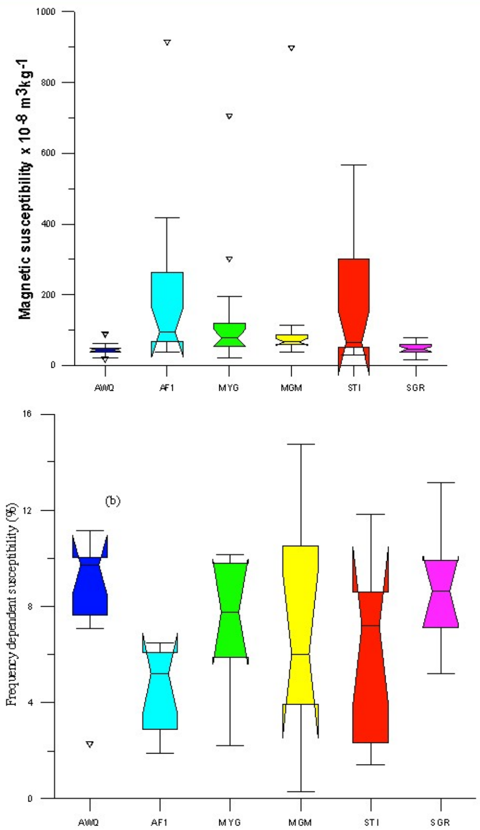

Fig. 2: Notched Box-Whisker plot of (a) χ and (b) χfd% of the different Sampling Sites of Jalingo Residential Areas

Table 2: Magnetic Properties of Jalingo Residential Areas (n = 121)

Magnetic Property	Unit	Min	Max	Mean	S.D	CV %
χ	x 10^{-8} m^3kg^{-1}	16.070	1669.040	124.421	206.188	165.7
χfd%	%	0.070	15.74	7.05	3.33	46.9
ARM	x10^{-5} Am^2kg^{-1}	2.033	34.860	7.962	4.590	57.7
χARM	x10^{-5} m^3kg^{-1}	0.051	0.876	0.200	0.115	57.7
χARM/χ	Dimensionless	0.361	6.349	2.649	1.139	43.0
χARM/χfd	Dimensionless	2.786	3779.509	88.913	361.273	06.3
SIRM	x10^{-5} Am^2kg^{-1}	111.365	5693.089	695.787	828.822	119.1
ARM/SIRM	Dimensionless	0.004	0.037	0.016	0.007	43.6
SIRM/χ	kA/m	3.411	11.543	6.722	1.413	21.0
S-100	Dimensionless	0.415	1.000	0.692	0.131	18.9
S-ratio	Dimensionless	0.854	1.000	0.911	0.089	09.7
Soft IRM	x10^{-5} Am^2kg^{-1}	31.721	2659.538	298.510	351.352	117.7
SOFT %	%	16.53	49.65	43.24	5.40	12.5
HIRM	x10^{-5} Am^2kg^{-1}	0.001	556.96	34.15	65.99	193.2
HIRM %	%	0.00	45.33	4.45	4.431	99.6

S.D = Standard Deviation. CV = Coeffi[illegible] Variation

The mean value of the S-ratio (0.91 ± 0.09) which was very close to one implied that the samples were composed of magnetically soft ferrimagnetic mineral. The ratio of the Soft IRM to HIRM was about 10:1 indicating that low coercivity ferrimagnetic minerals (e.g. magnetite or maghemite) controlled the samples. Higher value of the ratio SIRM/χ compared to χARM/χ is a further proof that MD grains dominate SD grains.

Relationship between some mineral magnetic properties

Table 3 shows the Pearson correlation coefficient obtained for the magnetic properties of the Jalingo residential area (JRA). The results revealed significant positive correlation at 1% confidence level between the concentration dependent magnetic parameters. For example χ and χARM (r = 0.634), χ and SIRM (r = 0.957), χ and Soft IRM (r = 0.977), SIRM and χARM (r = 0.658) and so on. The grain size dependent parameters were likewise positively correlated with each other. Some examples are χfd% and χARM/χ (r = 0.679, $P < 0.01$), χfd% and ARM/SIRM (r = 0.688, $P < 0.01$), etc. Inverse relationship was observed between concentration dependent parameters and the grain size parameters, indicating anthropogenic influence. HIRM was also found to be significantly correlated with concentration dependent parameters showing that hard antiferromagnetic magnetic mineral also influences the magnetic properties of the topsoil samples.

The relationships between some mineral magnetic properties are shown in Fig. 3. The χfd% versus χ plot show inverse relationship and gives an indication of anthropogenic influence. Other figures are in agreement with previous discussions. That is, the concentration dependent parameters positively correlated with each other and inversely proportional to the grain size parameters.

Results of geochemical parameters

The descriptive statistics of the elemental concentration is shown in Table 4. Results showed that Al, Si and K had the highest concentration. However, the mean values of the elements indicated that Si, P, K, Ti, Zr, Sn, Ba, Hg, Pb, Th and U exceeded their geochemical background concentration. This could be resulting from external influences such as vehicular emissions, wastes, painting materials, long distance travel of air particulate etc. Fig. 4 displayed the box plot showing the variation of selected elements within the different sampling sites in Jalingo residential areas. It was observed that the concentration of Pb was highest in AF1 and STI regions while Zn was lowest in AWQ and highest in AF1. Also, between the different areas, there was no noticeable difference in Ti, Mn and Ni concentrations. Fe was lowest in AWQ and highest in AF1 and STI while Ca was higher in AF1 and MYG but lowest in AWQ and MGM.

In Fig. 5, the relationships between selected geochemical parameters were expressed graphically. The relationship between the normalizing element (Fe) and some selected elements (Mn, Al, Ni, Cu, Cr, Th) showed positive correlations indicating similar source (s) of origin.

Relationship between magnetic properties and Metal concentration in JRA

In the Jalingo residential area (JRA), correlation analyses performed between geochemical and magnetic parameters are presented in Table 5. The effectiveness of using magnetic parameters as proxy for soil pollution in JRA was assessed by the extent at which magnetic parameters correlated well with metal contents. It is expected that since some of these elements share similar origin with magnetic minerals, the increase in one should lead to the increase in the other and vice versa. The concentration dependent parameters (χlf and SIRM) showed significant correlation with Al, K, Fe, Zr, Th and U. This implied that magnetic methods can be used as a proxy to the concentration of these elements. It also implied that the source of these metals in the residential top soils is anthropogenic.

χARM is a concentration dependent parameter which is found to (in addition to the above mentioned elements) correlate significantly with Mg, Al, Ti, Cr, Mn, Fe, Ni, Cu, Zr, Th and U. The strong significant correlation between χARM and these elements implies that in the JRA samples, χARM is a better magnetic parameter to be used as soil pollution proxy parameter. The grain size magnetic parameters (χfd%, χARM/χ, ARM/SIRM, and SIRM/χ) showed negative correlation with elements which were positively correlated with the concentration dependent parameters. This indicated that these metals were of anthropogenic origin. The close relationship found between Si and χfd% clearly indicated that the presence of Silicon in the surface soils was mainly from weathering or pedogenetic activities. Fig. 6 is a plot of selected geochemical and magnetic parameters correlations from the JRA.

Assessment of environmental quality

Contamination factor (CF) and Pollution load index (PLI)

The Pollution Load Index (PLI) proposed by Tomlinson *et al* (1980) is used to assess the toxicity status of soil or sediment samples. The PLI is obtained from the relation given in equation 7.

$$PLI = \sqrt[n]{(CF_1 \times CF_2 \times \ldots\ldots\ldots CF_n)} \qquad (7)$$

where $CF_{metal} = \frac{C_{metal}}{C_{background}}$ is the contamination factor. It is the ratio of individual metal concentrations (C_{metal}) to the corresponding background values ($C_{background}$). The background value for each metal is obtained from the reference site or the lowest value measured for individual metal (this is adopted for the present study).

The results of contamination factor (CF) are shown in Table 6. Following the classification scheme of *Hakanson (1980)*, the soils are moderately contaminated with Al, Si, Fe, Ni, and Pb. Ti Mn and Cu are in class 3, indicating considerable contamination while Ca and Zn show very highly contamination. The quality of the environment can be assessed by the Tomlison pollution index. In Table 6, PLI varied between 1.49 and 4.81(average, 2.89 ± 0.89). The average PLI value is ˃ 1.0, implying that the samples were moderately polluted (*Singh et al. (2003)*).

Table 3: Pearson Correlations between some Mineral Magnetic Properties of JRA.

	χfd%	χ	χARM	χARM/χ	SIRM	ARM/ SIRM	SIRM/χ	S-ratio	Soft IRM	HIRM
χfd%	1.000	-0.329**	-0.114	0.679**	-0.389**	0.688**	0.037	0.081	-0.402**	-0.328**
χ	-0.329**	1.000	0.634**	-0.557**	0.957**	-0.458**	-0.491**	0.036	0.977**	0.360**
χARM	-0.114	0.634**	1.000	-0.171	0.658**	-0.017	-0.412**	-0.074	0.674**	0.339**
χARM/χ	0.679**	-0.557**	-0.171	1.000	-0.604**	0.917**	0.326**	0.046	-0.605**	-0.358**
SIRM	-0.389**	0.957**	0.658**	-0.604**	1.000	-0.541**	-0.358**	-0.066	0.990**	0.535**
ARM/ SIRM	0.688**	-0.458**	-0.017	0.917**	-0.541**	1.000	-0.031	0.110	-0.530**	-0.391**
SIRM/χ	0.037	-0.491**	-0.412**	0.326**	-0.358**	-0.031	1.000	-0.181*	-0.399**	0.156
S-ratio	0.081	0.036	-0.074	0.046	-0.066	0.110	-0.181*	1.000	-0.025	-0.318**
Soft IRM	-0.402**	0.977**	0.674**	-0.605**	0.990**	-0.530**	-0.399**	-0.025	1.000	0.473**
HIRM	-0.328**	0.360**	0.339**	-0.358**	0.535**	-0.391**	0.156	-0.318**	0.473**	1.000

Bold values indicate significant correlation coefficient (*p < 0.05; **P < 0.01, two tailed)

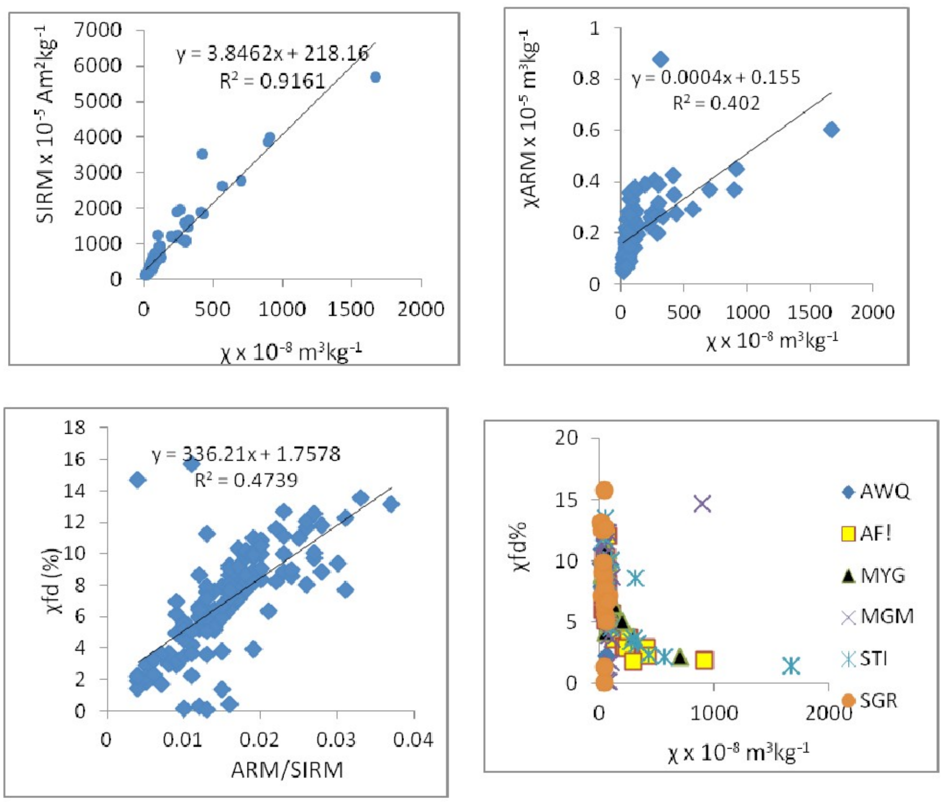

Figure 3: Scatter plots of selected Mineral Magnetic Parameters of Jalingo Residential Area.

Table 4: Concentration of metals measured in mg/kg in JRA (n = 53) in mg/kg. The average background value for each metal obtained from Turekian and Wedepohl (1961) are in parenthesis

Metals	Min	Max	Mean	S.D
Na (9600)	100.00	9280.00	4168.72	2315.11
Mg (15000)	<20.00	4238.00	1176.53	975.27
Al(80000)	44690.00	110000.00	66609.62	13351.76
Si(73000)	292300.00	385500.00	347784.91	23382.76
P(700)	176.30	4257.00	1018.02	738.72
K(26600)	23220.00	54770.00	40837.92	7463.18
Ca(22100)	793.00	40420.00	8275.28	8035.36
Ti(4600)	1230.00	12160.00	5357.96	2233.74
Cr(90)	<1.0	38.90	6.40	8.26
Mn(850)	81.60	658.10	318.83	138.92
Fe(47200)	3927.00	26640.00	9991.17	5377.02
Ni(68)	2.50	18.40	7.02	2.81
Cu(45)	2.10	14.30	6.54	3.12
Zn(95)	9.00	241.20	61.89	47.96
Br(4)	<0.20	4.20	0.91	0.80
Zr(160)	150.30	8932.00	1980.70	1875.30
Sn(6)	9.30	20.50	15.69	2.16
Ba(580)	711.40	2106.00	1112.67	243.47
Hg(0.4)	<0.50	1.80	0.82	0.48
Pb(20)	19.60	765.70	47.19	100.91
Th(12)	3.50	220.00	37.83	39.83
U(3.7)	<1.00	27.20	6.95	5.99

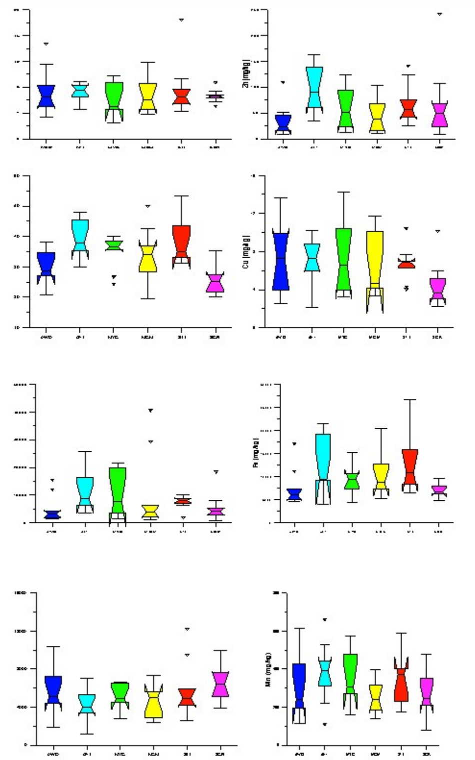

Figure 4: Box Plots Displaying Variation of selected Geo-chemical Parameters in JRA

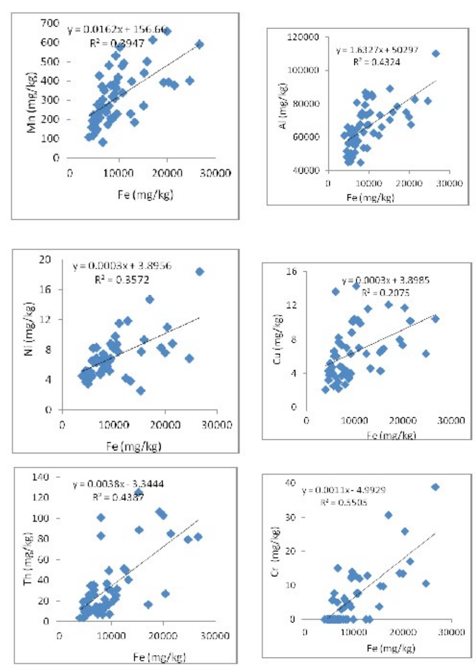

Fig. 5: Relationship of selected Element with the Concentration of Fe in JRA

Enrichment factor (EF)

Anthropogenic impact on the soils and sediments can be estimated by calculating the enrichment factor (*EF*) of metal concentrations higher than background levels. The EF is calculated following (*Kanu, 2017*) as given in equation 8.

$$EF_x = \frac{\left(\frac{C_x}{C_{ref}}\right)_{sample}}{\left(\frac{C_x}{C_{ref}}\right)_{background}} \quad (8)$$

where $\left(\frac{C_x}{C_{ref}}\right)_{sample}$ is the ratio of the metal x concentration to a normalizing element (aluminum is used for this study) in the sample and $\left(\frac{C_x}{C_{ref}}\right)_{background}$ *is* their background concentration in a suitable reference material.

The average value of the EF calculated in the present study indicated that most metals have been enriched with enrichment factor > 1(Table 6), indicating anthropogenic influence. However, following the classification of Loska and Wiechula (2003), the soils are minimally enriched by Fe, Ni, and Pb; moderately enriched by Ti, Mn and Cu and significantly enriched by Si, Ca and Zn.

Principal Component Analysis (PCA)

In order to assess the relationships and likely sources that contributes to the concentrations of some elements, PCA was performed. PCA analysis using SPSS 20 revealed four components, representing four sources of pollution in the study area. (Table 7). Only variables with loadings > 0.5 are used in each PC. Based on the 4 PCs considered, the communalities shown by the variables varied from 50.0% for Sn to 93.0 %

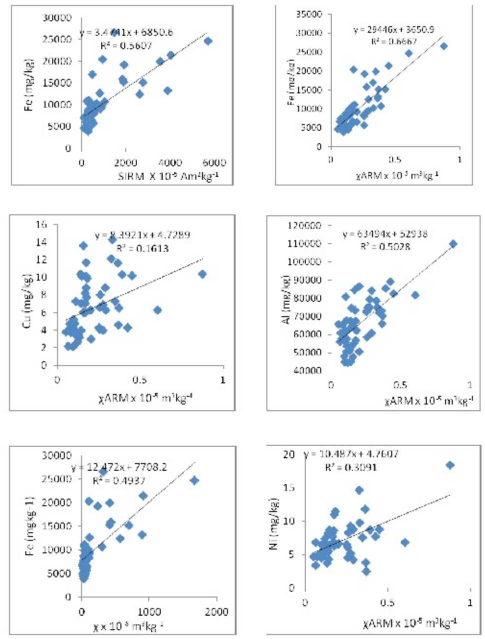

Figure 6: Scatter Plot between Selected Magnetic and Geochemical Parameters for JRA

Table 5: Pearson Correlation Statistics between Magnetic and Geochemical Properties

	χfd%	χ	χARM	χARM/χ	SIRM	ARM / SIRM	SIRM/χ	Soft IRM	HIRM
Mg	-0.287*	0.167	0.390**	-0.076	0.181	-0.071	0.004	0.204	0.114
Al	-0.241	0.353**	0.709**	-0.120	0.379**	0.026	-0.321*	0.391**	0.330*
Si	0.308*	-0.136	-0.378**	0.077	-0.162	0.048	0.006	-0.192	-0.078
P	-0.211	0.044	0.003	-0.111	0.075	-0.249	0.282*	0.081	0.041
K	-0.279*	0.385**	0.159	-0.285*	0.442**	-0.295*	-0.175	0.407**	0.439**
Ca	-0.370**	-0.044	-0.107	-0.144	-0.007	-0.224	0.192	0.002	-0.023
Ti	0.067	0.188	0.495**	0.093	0.146	0.256	-0.286*	0.189	-0.037
Cr	-0.115	0.193	0.645**	-0.109	0.251	0.039	-0.179	0.263	0.254
Mn	-0.206	0.201	0.587**	-0.095	0.293*	0.020	-0.151	0.287*	0.397**
Fe	-0.405**	0.684**	0.817**	-0.490**	0.749**	-0.351*	-0.412**	0.754**	0.582**
Ni	-0.014	0.007	0.556**	0.087	0.045	0.219	-0.084	0.067	0.110
Cu	-0.073	0.098	0.402**	-0.071	0.148	-0.020	-0.051	0.158	0.129
Zn	-0.311*	0.078	0.064	-0.240	0.169	-0.313*	0.186	0.154	0.258
Zr	-0.409**	0.431**	0.361**	-0.479**	0.470**	-0.401**	-0.348*	0.471**	0.401**
Pb	-0.010	-0.023	-0.013	0.042	-0.013	-0.044	0.194	-0.011	-0.031
Th	-0.500**	0.510**	0.503**	-0.541**	0.572**	-0.443**	-0.405**	0.565**	0.520**
U	-0.439**	0.495**	0.513**	-0.489**	0.553**	-0.396**	-0.390**	0.549**	0.504**

*Significant correlation coefficient (*p < 0.05; **P < 0.01, two tailed) are indicated by bold values*

Table 6: Summary Statistics of Pollution Assessment Indices for JRA Top Soils (n= 53)

	Descriptive statistics for CF and PLI				**Descriptive statistics for EF**				
	Min	**Max**	**Mean**	**S.D**		**Min**	**Max**	**Mean**	**S.D**
Al	1.00	2.42	1.49	0.30	Al	1.00	1.00	1.00	0.00
Si	1.00	1.32	1.19	0.08	Si	2.91	9.20	5.99	1.49
Ca	1.00	50.97	10.44	10.13	Ca	0.86	36.16	7.06	6.98
Ti	1.00	9.87	4.36	1.82	Ti	0.73	8.07	3.01	1.37
Mn	1.00	8.07	3.91	1.70	Mn	0.73	5.88	2.62	1.05
Fe	1.00	6.78	2.54	1.37	Fe	0.73	3.44	1.66	0.67
Ni	1.00	7.36	2.81	1.13	Ni	0.64	3.34	1.89	0.63
Cu	1.00	6.81	3.11	1.48	Cu	0.73	6.07	2.10	1.01
Zn	1.00	26.80	6.88	5.33	Zn	0.78	22.26	4.73	4.00
Pb	1.00	39.07	2.41	5.15	Pb	0.85	36.60	1.81	4.88
PLI	**1.49**	4.81	**2.89**	**0.89**					

Table 7: Variable loading to the principal components 1 – 4; bold numbers indicates significant loadings of variables to the respective components

Parameters	Components				Communality
	1	2	3	4	
χfd%	**-0.438**	**0.556**	**0.401**	**0.101**	**0.672**
χ	**0.593**	**-0.650**	0.291	0.153	0.883
χARM	**0.831**	-0.088	0.429	0.033	0.884
SIRM	**0.649**	**-0.656**	0.219	0.175	0.930
ARM/SIRM	-0.286	**0.793**	0.333	-0.175	0.853
Al	**0.726**	0.102	0.182	-0.357	0.698
Si	**-0.698**	-0.232	0.419	0.417	0.890
Ca	0.296	0.037	**-0.794**	-0.298	0.809
Ti	**0.522**	0.376	0.418	0.021	0.621
Cr	**0.796**	0.356	-0.023	0.110	0.772
Mn	**0.924**	-0.179	0.152	-0.062	0.913
Fe	**0.709**	**0.583**	0.091	-0.027	0.852
Ni	**0.637**	0.390	-0.197	0.284	0.678
Cu	0.409	0.030	**-0.611**	0.205	0.583
Zn	0.192	**0.542**	-0.065	0.255	0.500
Pb	0.083	0.186	-0.282	**0.788**	0.601
Eigen Value	5.718	2.987	2.131	1.312	
Total Variance (%)	35.740	18.666	13.317	8.201	
Cumulative Variance (%)	35.740	54.406	67.723	75.925	

for SIRM, hence all parameters have been adequately covered by these principal components. PC1 shows close association between χ, χARM, SIRM, Al, Si, Ti, Mn, Fe and Ni, which explain over 36% of the total variance. This may indicate elements of anthropogenic origin. χ, SIRM and Ni are found to be significant in more than one PCs implying multiples sources of origin in Jalingo urban soils. The second PC (PC 2) is comprised of χfd%, χ, SIRM, ARM/SIRM Ni and Sn which explains 19% of the total variance. This suggests the presence of weathered material from parent rocks. The Concentration of Sn and Ni in Jalingo soils may be resulting from weathering of parent rocks. PC 3 constitutes 13% of the overall variance and contains Ca and Zn which suggests anthropogenic input. Zn has been found to originate from vehicular related activities such as brake linings and wear/tear of tires (*Zhang et al., 2009*). Ca is linked to cementing/construction materials. PC 4 contains Pb which constitutes 8 % of the total explained variance. This may suggest evidence of strong anthropogenic input, basically from emissions from vehicles and power generators and colour paints

CONCLUSIONS

By following the results of this study, the conclusions reached are:

There is enhancement in the magnetic signal of the top soils which suggest increased contamination in JRA. The soils are dominated by mixture of MD and SP magnetic grain sizes as revealed by χfd% values. Low coercivity, soft magnetic minerals e.g. magnetite, maghemite or pyrhotite dominate the soil. Si, P, K, Ti, Cr, Zr, Sn, Ba, Pb, Th and U have been enhanced above background value indicating anthropogenic influence. Enrichment factor calculation indicated that all samples have been enriched at variable degrees above natural value. Sources of enhancement are either anthropogenic (from vehicular/ industrial emissions, paints and construction/cement materials) or lithogenic (from weathering of parents rock). Significant positive correlation between χlf, χARM and SIRM and some metals shows that there is great potential for the use of environmental magnetic methods as proxy for soil pollution assessment.

Acknowledgement

The authors appreciate the Director, Indian Institute of Geomagnetism (IIG) for granting access to the Environmental Magnetism laboratory where all measurements were taken. The assistance rendered by the Environmental Magnetism Research Group is also appreciated.

Conflict of interest

The author declares no conflict of interest.

REFERENCES

Alargarsamy, R. (2009) Environmental Magnetism: An Application in the Continental Shelf Sediments of India. *Mar. Environ. Res*. 68 (2): 49-58.

Basavaiah N. (2011) Geomagnetism: Solid Earth and Upper Atmosphere Perspectives: Springer publisher, Netherland.

Basavaiah N. and Khadkikar S. (2004) Environmental Magnetism and its Application towards Paleomonsoon Reconstruction. *Journal of Indian Geophysical Union*, **8**: 1–14.

Blundell, A., Dearing, J. A., Boyle, J. F. and Hannam, J. A. (2009) Controlling factors for the spatial variability of soil magnetic susceptibility across England and Wales. *Earth-Science Reviews,* 95: 158 – 188.

Booth, C. A., Walden, J., Neal, A. and Smith, J. P. (2005) Use of Mineral Magnetic Concentration data as Particle Size Proxy: A Case Study using Marine, Estuarinr and Fluvial Sediments in the Carmarthan Bay Area. South wales, UK. *Science of the Total Environment*, 347: 241-253.

Canbay, M. (2010) Investigation of the relation between heavy metal contamination of soil and its magnetic susceptibility. *International Journal of Physical Sciences*, vol. 5(5): 393-400

Chan, L. S., Ng, S. L., Davis, A. M., Yim, W. W. S. and Yeung, C. H. (2001) Magnetic properties and heavy metal contents of contaminated seabed sediments of Penny's Bay, Hong kong, *Mar. Pullut Bull.* 42: 569-583

Dearing, J. A., Dann, R. J. L., Hay, K., Lees, J.A., Loveand, P. J., Maher, B. A., and O'Grady, K. (1996) Frequency dependent susceptibility measurements of environmental materials. *Geophys. J. Int.*, vol. 124, 228-240

Goddu, S., R., Appel, E., Jordanova, D., and Wehland, R. (2004): Magnetic properties of road dust from Visakhapanam (India) relationship to industrial pollution and road traffic. *Phys. Chem. Earth*. 29: 985 -995.

Hakanson, L. (1980) Ecological Risk Index for Aquatic pollution control. A sedimentological approach, *Water Res*, 14: 975-1001

Hanesch, M. and Scholger, R. (2002) Mapping of heavy metals loadings in soils by means of magnetic susceptibility measurements. Environ. Geol. 42, 857-870. Doi: 10.1007/s00254-002-0604-1

Hoffmann, V. (2005): Magnetic screening/monitoring in different scales. Abstract of Bilateral Sino-German Sympossium, Innovative Methods and Strategies for Characterization and Risk Assessment of Polluted Soils and Sediments, May 26-31, Nanjing, China

Hoffmann, V., Knab, M. and Appel, E. (1999) Magnetic susceptibility mapping of roadside pollution. *Journ. of Geochem. Explor.* 66: 313-326.

Jiang, Q., Hu, X. F., Wei, J., Li, S. and Li, Y. (2010) Magnetic properties of urban topsoil, Boashan District, Shanghai and its environmental implication. 19th World Congress of Soil Science, 1-6 August, Brisbane, Australia.

Jordanova, N., Hoffmann, V. and Thomas Fehr, K. (2004) mineral magnetic characterization of anthropogenic magnetic phases in the Danube river sediments (Bulgarian part). *Earth Planet. Sci. Lett*. 221: 71 – 89.

Kanu, M. O., Basavaiah, N., Meludu, O. C. and Oniku, A.S. (2017) Investigating the potential of using environmental magnetism techniques as pollution proxy in urban road deposited sediment, *Int. J. Environ. Sci. Technol.* 14: 2745-2758, DOI: 10.1007/s13762-017-1356-5

Kapicka, A., Petrosvsky, E., Ustjak, S. and Machackova, K. (1999) Proxy mapping of fly-ash pollution of soils around a coal -burning power plant: a case study in the Czech Republic. *J. Geochem. Explor*. 66, 291-297

Lepland A., Stevens R. L. (1996) Mineral magnetic and textural interpretations of sedimentation in the Skagerrak, eastern North Sea. *Mar Geol* 135:51–64

Li, H., Haitao, X. Q., Zhang, W. R, Yang, Y., Liu, Z., Hailong, W. H., Wang, G. Y. (2014) Magnetic properties as proxies for the evaluation of heavy metal contamination in urban street dusts of Nanjing, Southeast China, *Geophysical Journal International*, Vol. 199 (3): 1354–1366, https://doi.org/10.1093/gji/ggu253

Loska, K. and Wiechula, D. (2003) Application of principle component analysis for the estimation of source of heavy metal contamination in surface sediments from Rybnik Reservoir, *Chemo*, 51: 723-733

Lu, S. G., Bai, S. Q. and Xue, Q. F. (2007) Magnetic Particles as Indicators of Heavy Metals Pollution in Urban Soils: A case Study from the City of Luoyang, China. *Geophys. Journ. Inter. 171: 603 – 612.*

Lu, S. G. and Bai, S. Q. (2008) Magnetic Characterization and Magnetic Mineralogy of the Hangzhou Urban Soils and its Environmental Implications. *Chinese Journal of Geophys. Vol 51. No. 3, pp. 549 – 557.*

Maher, B. A. (1998) Magnetic properties of modern soils and Quaternary Loessic Paleosols: Paleoclimatic implications. *Paleogography, Paleoclimatology, Paleoecology*, 137: 25-54.

Mullins, C. E. (1977) Magnetic susceptibility of the soil and its significance in soil science: a Review. *J. Soil Sci*., 28: 223-246.

Obaje, N. G. (2009) Geology and mineral resources of Nigeria, lecture notes in Earth sciences 120, DOI: 10.1007/978-3-540-92685-6, Springer-Verlag Berlin Heidelberg, 216pp

Oldfield, F., Yu, L. (1994) The influence of particle size variations on the magnetic properties of sediments from the north-eastern Irish Sea. *Sedimentology* 41:1093–1108

Petrovsky, E., Kapicka, A., Jordanova, N., Knab, M. and Hoffmann, V. (2000) Low field magnetic susceptibility: A proxy method of estimating increased pollution of different environmental systems, *Environmental Geology*, 39: 312-331

Rosler W. and Blaha U. (2005) Shallow vertical sections-magnetic proxies and heavy metals. Abstract of Bilateral Sino-German Sympossium, Innovative Methods and Strategies for Characterization and Risk Assessment of Polluted Soils and Sediments, May 26-31, Nanjing, China

Sangode, S. J., Vhatkar, K., Patil, S. K., Meshram, D.C., Pawar, N. J., Gudadhe, S.S., Badekar, A. G. and Kumaravel, V. (2010) Magnetic Susceptibility Distribution in the Soils of Pune Metropolitan Region: Implications to Soil Magnetometry of Anthropogenic Loading. *Current Science,* Vol. 98, No. 4, PP. 516 -527.

Scholger, R. (1998) Heavy metal pollution monitoring by magnetic susceptibility measurements applied to sediments of the River Mur (Styria, Austria), *Eur. J. Environ. Eng. Geophys*., 3: 25-37

Schmidt, A. Yarnold, R., Hill, M. and Asmore, M. (2005) Magnetic susceptibility as proxy for heavy metal pollution: A site study, *Journal of Geochemical Exploration* 85(3): 109-117

Singh, A. K., Hasnain, S. I. and Banerjee, D. K. (2003) Grain size and geochemical portioning of heavy metals in sediments of the Danoder River - a tributary of the lower Ganga, India, *Environmental Geology*, 39, 90-98.

Spiteri, C., Kalinski, V., Rosler, W., Hoffmann, V., Appel, E. and MAGPROX team (2005) Magnetic screening of a pollution hotspot in the Lausitz area, Eastern Germany: correlation analysis between magnetic proxies and heavy metal contamination in soils, *Environmental Geol*, 49: 1-9

Strzyszcz, Z. (1993) Magnetic properties of soils in the areas influenced by industrial emissions. In: Schullin, R. (Ed.), Soil monitoring: Early detection and surveying of soils contamination and degradation. Birkhäuser, Basel, Switzerland, pp. 265-269

Thompson, R. and Oldfield, F. (1986) Environmental Magnetism. Allen and Unwin, London.

Tomlinson, D. L., Wilson, J. R., Harris, C. R. and Jeffrey, D. W. (1980) Problems in the assessment of heavy metals levels in estuaries and the formation of a pollution index. *Helgol. Wiss. Meeresunters*, 33: 566-575.

Turekian, K. K. and Wedepophl, K. H. (1961) Distribution of the elements in some major units of the Earth's Crust. *Geol. Soc. Am. Bull*., **72**: 175-192.

Venkatachalapathy, R., Veerasingam, S., Basavaiah, N., Ramkumar, T., and Deenadayalan, K. (2011) Environmental magnetic and geochemical characteristics of Chennai coastal sediments, Bay of Bengal, India, *J. Earth Syst. Sci*., 120 (5): 885-895

Walden, J., Oldfield, F., and Smith, J. (eds.) (1999) Environmental Magnetism: A Practical Guide, Technical Guide, No. 6, Quaternary Research Association London, 243pp

Wang, B., Xia, D. S., Yu, Y., Jia, J. and Xu, S. (2013) Magnetic records of heavy metal pollution in urban topsoil in Lanzhou, *China, Chin Sci Bull*, 58:384-395, doi: 10.1007/s11434-012-5404-8

Wang, G., Liu, Y., Chen, J., Ren, F., Chen, Y., Ye, F. and Zhang, W. (2018) Magnetic Evidence for heavy metal pollution of topsoil in Shenghai, China, *Frontiers of Earth Science*, 12(1): 125-133

Zhang, X. Y., Qiao, Lin, F., Wong, F., Mike, T. F., Feng, X. L., and Wang, K. (2009) Identification of soil heavy metal sources from anthropogenic activities and pollution assessment of Fuyang County, China. *Environmental Monitoring and Assessment* **154***:* 439-449*.*

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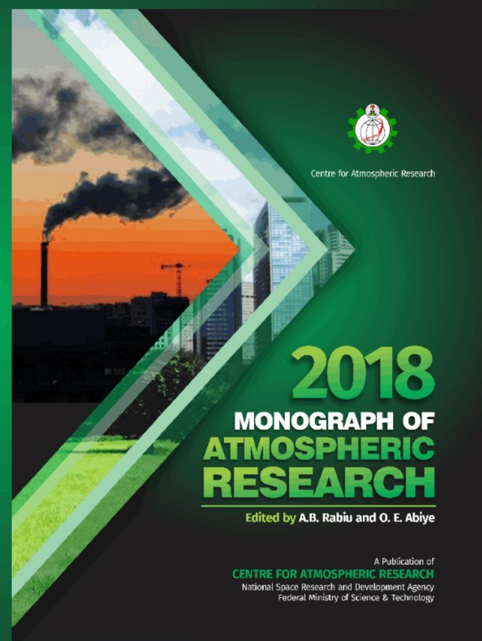

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ISBN 978-978-972-859-6