Magnetic susceptibility measurement and heavy metal pollution at an automobile station in Ilorin, North-Central Nigeria

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Abstract

Magnetic susceptibility measurement was carried out on 26 top-soil samples randomly collected from the study area and 5 selected top-soil samples outside the station, using the Bartington MS meter linked to a computer operated using Multisus2 software. The Measurements was done at both low (0.47 kHz) and high (4.7 kHz) frequency dependent susceptibilities which was further used to calculate the frequency dependent susceptibility (XFD). The values for low frequency mass magnetic susceptibility ranges between 96.6 $\times$ 10$^{-7}$ m$^3$ kg$^{-1}$ and 146 $\times$ 10$^{-7}$ m$^3$ kg$^{-1}$ with an average value of 117.35 $\times$ 10$^{-7}$ m$^3$ kg$^{-1}$ and standard deviation of 12.22 $\times$ 10$^{-7}$ m$^3$ kg$^{-1}$. The result reveal high magnetic susceptibility values at the station compared with the values observed outside the station which ranges between 53.0 $\times$ 10$^{-5}$ m$^3$ kg$^{-1}$ and 72.3 $\times$ 10$^{-5}$ m$^3$ kg$^{-1}$ with an average value of 63.2 $\times$ 10$^{-5}$ m$^3$ kg$^{-1}$ and standard deviation of 7.01 $\times$ 10$^{-5}$ m$^3$ kg$^{-1}$. This significant magnetic enhancement indicates high concentration of ferrimagnetic minerals in the soil and thus evidence of pollution due to the activities at the station which implies that the magnetic enhancement is of anthropogenic source than pedogenic and lithogenic. Analysis of the heavy metals also reveals higher values at the station. The correlation analysis between the mass specific magnetic susceptibility and the heavy metals concentrations (i.e. Cu (R = 0.92), Fe (R = 0.88), Cr (R = 0.85), Zn (R = 0.83), Cd (R = 0.79), Mg (R = 0.72), Mn (R = 0.60), Pb (R = 0.67)) which was conducted to further investigate the relationship between the soil magnetic susceptibility values and elemental variations, demonstrated magnetic susceptibility can be used as a proxy method for assessing the pollution of these heavy metals.

1. General Introduction

Magnetic susceptibility (X) is a dimensionless quantity given by the ratio of the total magnetization induced in a material to the intensity of the magnetic field that produces the magnetization. It measures the concentration of magnetic crystals, grain size, shape and type of the magnetic minerals present in a sample (Mullins 1977, Dearing et al 1985, Beget et al 1990, Dearing 1999, Dearing et al 2001, Meglish et al 2008, Blundell et al 2009, Kanu et al 2013a and 2013b). These magnetic minerals present in soil may either be inherited from the parent rocks during the formation of the soil or because of anthropogenic activities (Ayoubi and Karami 2019, Ayoubi and Adman 2019). Pollutants released into the atmosphere by human activities eventually settle and accumulates in the soil. Accumulation of these anthropogenic particles originating from human activities such as the one taking place at the station (i.e. welding, painting, vehicular discharges and dusts, poor disposal of spare part, etc), results in significant enhancement of soil magnetic susceptibility (Kapicka et al 2002, Caggiano et al 2005, El-Hassan 2005, El-Hassan 2006).
et al 2009, Mahamed et al 2011; Mohammad et al 2012, Murdock et al 2012, Kucer et al 2012, Kanu et al 2013a and 2013b, Oluyide et al 2019). These particles usually contain heavy metals and toxic elements.

There is a growing interest in using magnetic techniques for monitoring environmental pollution. Lecoanet et al 2003 efficiently use magnetic parameters to discriminate soil contamination sources, while Yang et al (2007), Morton-Bermea et al (2009) and Mücella, (2010) and many others investigated the relationship between heavy metals contamination of soil and its magnetic susceptibility. Kanu et al (2013b) successfully investigated and applied the magnetic properties of top soil samples from parts of Jalingo, Taraba State, N-E Nigeria to assess the level of soil pollution and identify pollution hotspots using magnetic proxy parameters. Similarly, Spiteri et al (2005) studied the relationships between topsoil magnetic susceptibility and heavy metal distribution in the Lausitz region of eastern Germany and opined that magnetic susceptibility can be used as a proxy for soil heavy metals contaminations.

A good relationship between magnetic susceptibility and concentration of some heavy metals in top soils has been reported by several authors (Strzyszcz and Magiera 1998, Jordanova et al 2003, Hu et al 2007, Yang et al 2007, Morton–Bermea et al 2009, Mahamed et al 2011; Brempong et al 2016). Since anthropogenic pollution usually have strong magnetic signature, this non-destructive magnetic technique looks promising in monitoring soil pollution (Mahamed et al 2011). Following the effectiveness of the integration of chemistry and magnetic properties in studies of the degree of pollution of the soil, dust, sediment and land systems, we have employed similar technique to successfully characterize and quantify the degree of pollution at an automobile station in Ilorin, Kwara State of Nigeria.

2. Materials and methods

2.1. Study area

The study area ‘Ilorin’ is situated between latitudes 8°20’ N and 8°50’ N and Longitudes 4°25’ E and 4°65’E (figure 1). Ilorin city is one of the fastest growing cities in Nigeria with a tropical wet and dry climate with mean annual rainfall of 1,200 mm (Olanrewaju, 2009). Its average annual temperature is 26.2 °C; it peaks at about 30 °C in March which marks the hottest month. Wet season is experienced from April to October and dry season from November to March.

The study area consists of Precambrian basement of south western Nigeria. The soils are formed from metamorphic and igneous rocks which are about 95%. The metamorphic rocks consist of quartztite augitegneiss, granitic gneiss, biotite gneiss and banded gneiss (Orosun et al 2019). The assortment of basement complex rocks brings about large number of ferruginous groups of soils. Therefore, ferrallitic soil type (generally deep red in colour with high clay content) is the major type of soil in Ilorin (Oyegun 1985, Orosun et al 2016a, Michael et al 2019).
2.2. Sample collection, preparation and laboratory analysis

A total of 26 samples of the top soil were collected randomly from strategic points within the study area. 5 top-soil samples were collected randomly outside the study area. The soil samples were collected in a fit rubber test container of about 10 cc each using a plastic spoon. These samples were sent to the laboratory where they were screened to remove macroscopic traces of stones, glass, rubber, hair, animal and plant matter to ensure that the materials to be analysed are free from such contaminants. The samples were air-dried at room temperature in the Laboratory for some days to reduce the mass contribution of water and to avoid any chemical reaction. The samples were air-dried at room temperature in a container of about 10 cc each using a plastic spoon. These samples were sent to the laboratory where they were stored in well labelled plastic containers for magnetic susceptibility measurements and further analysis.

Magnetic susceptibility measurement was carried on each of the collected sample using the Bartington MS2B meter linked to computer operated with Multisus2 software. For all the measurements, the sensitivity was set at 1.0. Measurements were carried out three times; first air reading, sample reading and a second air reading before and after each series for drift correction (Kanu et al. 2013b). The MS2B sensor is a handy laboratory sensor which makes use of 10 cm³ samples in plastic containers. It has the ability of taking measurements at two different frequencies i.e. at 470 Hz (low frequency) and 4700 Hz (high frequency). When the 10 cm³ cylindrical plastic bottles is in use, the accuracy of the MS2B meter is 1% (Dearing 1999). The susceptibility measurements were done at both low (470 Hz) and high (4700 Hz) frequencies which were further used to compute the frequency dependent susceptibility (\(\chi_{FD}\)).

For the geochemical analysis of the soil, we used Aqua Regia method for the digestion for trace metals in soil samples. 1 g of each soil sample was measured into a sanitized digestion flask. 3 ml of concentrated HCl and 9 ml of concentrated HNO₃ was added into the sample in the sanitized digestion flask (Orosun et al 2016b and USEPA 1986). For more details on this method, see Orosun et al (2016). The AAS technique which measures the concentrations of elements in digested samples down to parts per million of a gram (mg kg⁻¹) in a sample was carried out at ROTAS Soil-Lab in Ibadan using Buck Scientific Model 210 VGP Atomic Absorption Spectrophotometer.

3. Results and discussion

3.1. Result of magnetic susceptibility measurements

The results of the magnetic susceptibility measurement are given in tables 1 and 2.

The mass specific magnetic susceptibility values for the top-soil samples collected randomly within the study area are given in table 1. The values for low frequency mass magnetic susceptibility range between \(96.6 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) and \(146 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) with an average value of \(117.35 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) and standard deviation of \(12.22 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\). These values of the magnetic susceptibility measurements at the station were much higher than the observed values outside the station. This significant magnetic enhancement indicates high concentration of ferrimagnetic minerals in the soil and thus increased pollution (Kanu et al 2013b, Stryszcz and Magiera, 1998, Jordanova et al 2003, Hu et al 2007, Yang et al 2007, Morton-Bermea et al 2009 etc). The value of high frequency mass magnetic susceptibility ranges between \(90.0 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) and \(108.7 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) with average value of \(97.27 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) and standard deviation of \(4.85 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\). These values of the magnetic susceptibility fall within the range of values reported by Kanu et al (2013a and 2013b) where they carried out a preliminary assessment of soil pollution in some parts of Jalingo metropolis, Nigeria using magnetic susceptibility method and measured the magnetic susceptibility of soils of the Jalingo mechanic village in Jalingo, N-E Nigeria. Values reported by Yang et al (2007) from China, Mucella (2010) from Turkey, Mohamed et al (2011) and Ayoubi and Karami (2019) from Iran reveals high variability in the MS values but are all in the range of \(10^{-5}\) (SI) as well. The frequency dependent mass magnetic susceptibility ranges between 5.07 % and 29.36 % with an average value of 16.53 %. The results of the percentage frequency dependence susceptibility showed that only a few number of the samples have a mixture of superparamagnetic (SP) and coarse multidomains grains or superparamagnetic grains \(< 0.05 \mu\text{m}\). Sixteen samples (that is about 61%) have frequency dependent mass magnetic susceptibility \(> 14\) which indicates presence of contamination or anisotropy (Dearing 1999). Four samples (15%) are virtually SP grains as they have \(\chi_{FD}\) in the range of 12%--14%, while other samples (23%) have values in the range of 2%--10% indicating the presence of a mixture of SP and Multi Domain (MD) magnetic grains.

For the selected top-soil samples collected outside the study area, magnetic susceptibility measurements were performed at both low and high frequency. The result is given in table 2. The value for low frequency mass magnetic susceptibility ranges between \(53.0 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) and \(72.3 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) with an average value of \(63.2 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) and standard deviation of \(7.01 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\). The value of high frequency mass magnetic susceptibility ranges between \(50.6 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) and \(65.7 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) with an average value of \(59.1 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\) and standard deviation of \(5.47 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}\). The frequency dependent mass magnetic
susceptibility ranges between 3.40 % and 9.13 % with an average value of 6.71 % and standard deviation of 2.56 %. These values are very low compared with values observed at the station. This implies that the magnetic enhancement at the station is more of anthropogenic origin than lithogenic and pedogenic (Dearing, 1999).

### 3.2. Results of the geochemical analysis

The results of the geochemical analysis are given in tables 3 and 4.

Results of the heavy metals concentrations for the top-soil samples collected randomly within the station given in table 3, follows that, the mean concentration of the heavy metals of the selected top-soil decreases in the order Fe > Cr > As > Mg > Pb > Cu > Zn > Cd > Mn > Ag. The concentrations of Fe, Cr and As in the station were much higher than other selected heavy metals. This is believed to be due to gradual accumulation

| S/N   | Latitude | Longitude | Mass (g) | $X_{LF} \times 10^{-5}$ (SI) | $X_{HF} \times 10^{-5}$ (SI) | $X_{FD}$ (%) |
|-------|----------|-----------|----------|-------------------------------|-------------------------------|--------------|
| 8.48074 N | 4.60412E | 13.01     | 118.00   | 96.80                         | 17.97                         |
| 8.48078 N | 4.60423E | 14.02     | 110.00   | 98.40                         | 10.55                         |
| 8.48090 N | 4.60427E | 14.30     | 114.00   | 92.00                         | 19.30                         |
| 8.48090 N | 4.60425E | 14.80     | 122.00   | 98.00                         | 19.67                         |
| 8.48071 N | 4.60415E | 13.22     | 106.00   | 98.40                         | 7.17                          |
| 8.48082 N | 4.60434E | 13.02     | 127.40   | 90.00                         | 29.36                         |
| 8.48062 N | 4.60429E | 14.52     | 102.60   | 97.40                         | 5.07                          |
| 8.48066 N | 4.60447E | 13.43     | 121.00   | 96.00                         | 20.67                         |
| 8.48093 N | 4.60414E | 13.36     | 128.80   | 99.80                         | 22.52                         |
| 8.48075 N | 4.60422E | 14.06     | 121.20   | 98.00                         | 18.65                         |
| 8.48095 N | 4.60432E | 13.45     | 116.40   | 93.00                         | 20.10                         |
| 8.48081 N | 4.60430E | 12.88     | 124.00   | 102.40                        | 17.42                         |
| 8.48081 N | 4.60427E | 13.67     | 108.80   | 90.00                         | 17.28                         |
| 8.48080 N | 4.60425E | 13.76     | 104.20   | 98.00                         | 5.95                          |
| 8.48080 N | 4.60422E | 13.48     | 96.60    | 90.00                         | 6.83                          |
| 8.48065 N | 4.60424E | 13.98     | 122.00   | 98.00                         | 19.67                         |
| 8.48065 N | 4.60419E | 14.08     | 138.60   | 104.60                        | 24.53                         |
| 8.48064 N | 4.60417E | 14.24     | 146.80   | 108.40                        | 26.16                         |
| 8.48093 N | 4.60423E | 13.38     | 102.40   | 88.60                         | 13.48                         |
| 8.48095 N | 4.60404E | 13.68     | 108.80   | 92.50                         | 14.98                         |
| 8.48085 N | 4.60440E | 13.24     | 106.80   | 96.40                         | 9.74                          |
| 8.48088 N | 4.60430E | 13.26     | 104.80   | 97.40                         | 7.06                          |
| 8.48090 N | 4.60437E | 13.22     | 133.00   | 102.00                        | 23.31                         |
| 8.48090 N | 4.60435E | 13.98     | 128.00   | 102.60                        | 19.84                         |
| 8.48091 N | 4.60442E | 13.82     | 124.00   | 100.80                        | 18.71                         |
| 8.48092 N | 4.60428E | 13.92     | 114.80   | 99.00                         | 13.76                         |

Min 12.88 96.60 90.00 5.07
Max 14.80 146.80 108.40 29.36
Median 13.68 117.20 98.00 18.31
Mean 13.68 117.40 97.30 16.53
SD 0.49 12.20 4.90 6.63
CV 3.58 10.39 5.04 40.11

| S/N   | Latitude | Longitude | Mass (g) | $X_{LF} \times 10^{-5}$ (SI) | $X_{HF} \times 10^{-5}$ (SI) | $X_{FD}$ (%) |
|-------|----------|-----------|----------|-------------------------------|-------------------------------|--------------|
| 1     | 8.40255° N | 4.62662°E | 13.00    | 66.0                         | 60.6                         | 8.18         |
| 2     | 8.40258° N | 4.62468°E | 14.02    | 72.3                         | 65.7                         | 9.13         |
| 3     | 8.40680° N | 4.62046°E | 14.30    | 53.0                         | 50.6                         | 4.53         |
| 4     | 8.40880° N | 4.61688°E | 13.80    | 62.0                         | 60.2                         | 3.40         |
| 5     | 8.40990° N | 4.61432°E | 14.10    | 62.8                         | 58.4                         | 8.30         |

Min 13.00 53.0 50.6 3.40
Max 14.30 72.3 65.7 9.13
Median 14.02 62.8 60.2 8.18
Mean 13.84 63.2 59.1 6.71
SD 0.51 7.0 5.5 2.56
CV 3.68 11.08 9.31 38.15

Table 1. Magnetic Susceptibility of selected top-soil within the study area.

Table 2. Magnetic susceptibility of selected top-soil outside the study area.
from various pollution sources over time, including automobile exhaust and other related activities in
the station. Higher concentrations of Mn and Fe in the station are likely to have come from metallurgical sources
such as steel, iron and poor disposal of spare parts. The increased concentration of Cu and Zn could also be
related to the activities at the station, since it may result from deterioration of automobile parts. Besides, Zinc is
often used in the tyres fabrication and Cu is a familiar element in vehicle brake lining, thrust bearing and
remaining parts of the engine (Mohamed et al 2011, Kanu et al 2013a and 2013b; Canbay, 2010, Kucer et al
2012, Lu et al 2007; Mücella, 2010, Duan et al 2009; Durza, 1999). Zn compounds are expansively utilized as anti-
oxidants and also as agents for improving dispersant for motor oil (Lu et al 2007). We did similar analysis for the
top-soil samples collected randomly outside the study area (presumed virgin/control soil) and the result given in
table 4 shows that the mean concentration of the selected heavy metals are much lower than their respective
concentrations at the station. This also reveals that the higher values observed at the station could be due to the
anthropogenic inputs ( Mohamed et al 2011, Kanu et al 2013a and 2013b, Strzyszcz and Magiera, 1998,
Jordanova et al 2003, Hu et al 2007, Yang et al 2007, Morton-Bermea et al 2009). The results of the heavy metals
analysis at the mechanic station despite higher than the measured values outside the station, are still lower than
the values reported by Isinkaye (2018) where he measured the distribution and multivariate pollution risks
assessment of heavy metals around abandoned iron-ore mines in North-central Nigeria. The calculation of
coefficient of variation (CV) also reveals the variability in the distribution of the magnetic susceptibility and the
heavy metals in the study area. CV <= 20% indicates little variability, 20 < CV <= 50% implies moderate
variability, while 50% < CV <= 100% indicates high variability and CV value greater than 100% is regarded as
exceptionally high variability (Isinkaye, 2018). From the results, the low frequency magnetic susceptibility ($X_{LF}$)
and all the heavy metals (except Ag) show low variability in the soil.

### 3.3. Pearson correlation analysis

The Pearson correlation coefficients between the heavy metals concentrations and MS values and between
different elements are presented in table 5.
Table 4. Concentration of heavy metals of selected top-soil outside the study area in ppm.

| S/N | Latitude       | Longitude      | Mg  | Mn  | Ag  | Zn  | Cd  | Pb  | Cu  | Fe  | As  | Cr  |
|-----|----------------|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1   | 8.40255° N     | 4.62662° E     | 4   | 3.4 | ND  | 7.4 | 3.8 | 19  | 12  | 220 | 32  | 55  |
| 2   | 8.40258° N     | 4.62468° E     | 4.2 | 3.8 | ND  | 8.8 | 3.5 | 18  | 12  | 212 | 30  | 60  |
| 3   | 8.40680° N     | 4.62046° E     | 4.2 | 3.6 | 2   | 8.2 | 3.5 | 19  | 10  | 224 | 35  | 52  |
| 4   | 8.40880° N     | 4.61688° E     | 4.2 | 4   | 2   | 8   | 4   | 19  | 10  | 242 | 35  | 50  |
| 5   | 8.40990° N     | 4.61432° E     | 4.6 | 3.4 | ND  | 8.2 | 4.2 | 19  | 11  | 225 | 35  | 52  |
| Min |                |                | 4   | 3.4 | ND  | 7.4 | 3.5 | 18  | 10  | 212 | 30  | 50  |
| Max |                |                | 4.6 | 4   | 2   | 8.8 | 4.2 | 19  | 12  | 242 | 35  | 60  |
| Mean|                |                | 4.24| 3.64| 2   | 8.12| 3.8 | 18.8| 11  | 224.6| 33.4| 53.8|
| SD  |                |                | 0.22| 0.26| 0   | 0.50| 0.31| 0.44| 1   | 10.99| 2.30| 3.89|
| CV  |                |                | 5.19| 7.14| 0   | 6.16| 8.16| 2.34| 9.09| 4.89 | 6.89| 7.23|

ND = Not detectable.
operated using Multisus2 software. The measurements were done at both low area and 5 selected top-soil samples outside the station, using the Bartington MS meter linked to a computer. Magnetic susceptibility measurement was carried out on 26 top-soil samples randomly collected from the study location and activities of Automobile repair stations. If possible, the stations should be sited far away from residential areas or any drinking water source.

4. Conclusion

Magnetic susceptibility measurement was carried out on 26 top-soil samples randomly collected from the study area and 5 selected top-soil samples outside the station, using the Bartington MS meter linked to a computer operated using Multisus2 software. The measurements were done at both low (0.47 kHz) and high (4.7 kHz) frequency susceptibilities which was further used to calculate the frequency dependent susceptibility (\(X_{\text{FD}}\)). The results reveals high magnetic susceptibility values at the station compared with the values observed outside the station. This significant magnetic enhancement indicates high concentration of ferrimagnetic minerals in the soil and thus evidence of pollution due to the activities at the station. It also implies that the magnetic enhancement is of anthropogenic source than pedogenic and lithogenic. Analysis of the heavy metals also reveals higher values at the station.

So based on the results of this study it follows that the study area is polluted as a result of the activities at the station (i.e. welding, painting, vehicular discharges and dusts, poor disposal of spare part, etc) and the strong correlation observed between the heavy metals and magnetic susceptibility indicated a strong affinity of heavy metals to magnetic materials. Hence, since the MS method is cost effective, fast and can cover a very large area in a short time, it becomes very essential and should be utilized as a preliminary method/tool to identify polluted spots before applying the geochemical method that is time consuming and expensive.

Considering the significant magnetic enhancement and heavy metals pollution at the station, we recommend that the government of Nigeria via the environmental protection agency should monitor the location and activities of Automobile repair stations. If possible, the stations should be sited far away from residential areas or any drinking water source.

Table 5. Pearson correlation coefficient (R) matrix between heavy metals and magnetic susceptibility.

| Element | Mg   | Mn   | Ag   | Zn   | Cd   | Pb   | Cu   | Fe   | As   | Cr   | X_{LF} |
|---------|------|------|------|------|------|------|------|------|------|------|--------|
| Mg      | 1    | 0.8847 | 0.1493 | 0.7968 | 0.8642 | 0.6855 | 0.6915 | 0.8605 | 0.2499 | 0.7902 | 0.7215  |
| Mn      | 1    | 0.1783 | 0.9423 | 0.8602 | 0.8683 | 0.8683 | 0.9723 | 0.3659 | 0.9508 | 0.6042 |         |
| Ag      | 1    | 0.1228 | 0.1808 | 0.1303 | 0.1370 | 0.1174 | 0.2044 | 0.1811 | 0.1095 |         |         |
| Zn      | 1    | 0.9713 | 0.9631 | 0.9571 | 0.9671 | 0.2181 | 0.9719 | 0.8305 |         |         |         |
| Cd      | 1    | 0.8904 | 0.8938 | 0.9857 | 0.4604 | 0.9751 | 0.7942 |         |         |         |         |
| Pb      | 1    | 0.9957 | 0.9091 | 0.2675 | 0.9405 | 0.6712 |         |         |         |         |         |
| Cu      | 1    | 0.9143 | 0.2884 | 0.9442 | 0.9230 |         |         |         |         |         |         |
| Fe      | 1    | 0.1789 | 0.9869 | 0.8816 |         |         |         |         |         |         |         |
| As      | 1    | 0.2659 | 0.1140 |         |         |         |         |         |         |         |         |
| Cr      | 1    | 0.8506 |         |         |         |         |         |         |         |         |         |

The correlation analysis between the mass specific magnetic susceptibility and the heavy metals concentrations was conducted to further investigate the relationship between the MS values and elemental variations (see table 5). The results were classified according to the correlation coefficient R (Yu and Hu 2005), as follows:

- \(0.8 \leq |R| \leq 1\) suggests a strong correlation;
- \(0.5 \leq |R| \leq 0.8\) suggests a significant correlation;
- \(0.3 \leq |R| \leq 0.5\) suggests a weak correlation; and
- \(|R| < 0.3\) suggests an insignificant correlation.

The resulting correlation analysis demonstrated that concentrations of Cu (\(R = 0.92\)), Fe (\(R = 0.88\)), Cr (\(R = 0.85\)) and Zn (\(R = 0.83\)) were strongly correlated with MS, where as Cd (\(R = 0.79\)), Mg (\(R = 0.72\)), Mn (\(R = 0.60\)), Pb (\(R = 0.67\)) gives significant correlation with MS. But As (\(R = 0.1140\)) and Ag (\(R = 0.1095\)) shows insignificant correlation.

The correlation between magnetic susceptibility measurements and heavy metals content reveals a good relation between ferrimagnetic oxides and heavy metals in the studied station. This relationship is believed to be as a result of the fact that heavy metals are adsorbed onto surface of pre-present ferrimagnetics in the environments or are subsumed into the lattice structure of the ferrimagnetics during combustion process (Hanesch and Scholger 2002, Morton-Bermea et al 2009, Mohamed et al 2011). A strong and positive correlation between the selected heavy-metal and also with Magnetic susceptibility was observed for most of the selected elements, indicating a common pollution source. Thus, high correlation coefficients between Magnetic susceptibility measurements and heavy-metal content can be used as an indicator of pollution level.
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Conflict of interests

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