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Mapping on pollution of agricultural soil as a proxy by means of magnetic susceptibility and morphological measurements in some parts of Kebbi State, northwest Nigeria

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ABSTRACT

Magnetic susceptibility (MS) and morphological measurements were carried out on surface soil samples in order to find a possible relationship and to obtain environmental implications. The samples were taken along the two parcel roads of Maidahini (A–B) and Bunza (C–D) on a square grid of 400 × 400 m^2 near the agricultural irrigation farmland soil close to the main city of Bunza area in Gwandu formation, northwestern Nigeria. MS distribution values ranged between 5.756×10^{-6} SI to 4.0×10^{-6} SI and 2.65×10^{-6} SI to 1.2×10^{-6} SI, from the two parcel roads. Geochemical analysis by means of atomic absorption spectrometry shows that the concentration of various heavy elements was higher than the mean background values for world soils. However, in view of the high values, especially that apparent mineralization was observed on each sample, the results were therefore due to the proper calibration of the equivalent used for the analysis soil samples. Spatial histogram distribution of MS shows the variation in high and low susceptibility concentrations and relate to toxic content reported near the rivers. Urban pollution and road traffic emission seem to be the main influence for these values. The results showed that magnetic measurements are sensitive, fast, inexpensive, and robust, which can be advantageously applied for studying soils affected by urban and road pollution. Thus, the study has shown that the mean spatial distribution concentrations of Fe, Mn, Cu, Ni, and Cr content were 2,378.9, 107.3, 72.8, 53.6, and 6.5, which were very high in top soil samples across the two parcel roads of Maidahini (A–B) and Bunza (C–D).

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1. Introduction

Soil pollution by heavy metals is a critical global environmental problem, and experts have estimated that more than 20 million hectares of farmlands have been contaminated, accounting for 20% of the total landmass (Bityukova et al. 1999; Hanesch and Scholger, 2002; Heller et al. 1998; Walden and Ballantyne, 2002). Cd is considered to be one of the most phototoxic metal pollutants due to its high mobility (especially in soil with low CEC and acidic pH), bioaccumulation in lower organisms, and its easily being transferred to higher tropic levels in the food chain (Lu and Bai, 2012). The toxicity of Cd pollution and its physical disturbance can influence plant survival, reproductive success, and migration (Boyko et al., 2014). Plants become inactive and they lack the ability to move actively to evade a contaminated environment. Therefore, their only chance to survive in unfavorable conditions is the

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mobilization of defense mechanisms, and evolution of tolerate genotype (Boyko et al., 2014; Wang and Qin, 2005). In this paper, the results obtained by magnetic susceptibility (MS) measurements and heavy metal analyses of agricultural farmland soil irrigated with polluted river water are presented and discussed. Our main objective is to understand the underlying processes and to quantify statistical relationships between magnetic parameters and morphological contents. Samples were taken from farmland soil irrigated with polluted water (in short we will call it wastewater) from both Maidahini parcel (A–B) and Bunza parcel (C–D) in Gwandu formation. This target area was chosen because from previous studies the degree and spatial distribution of heavy metal pollution in river sediments at Gwandu formation was known and could be related to emissions from the intercalated activities (Kogbe, 1978; Peters, 1976; Zhang et al., 2011) concerning MS of agricultural top soil on Maidahini parcel (A–B) road far from the urban activities to compare the effect of proximity to the road emission.

1.2. Location and accessibility of the study area

The study area lies between latitudes 12° 41′ to 12° 47″ N and longitudes 4° 6′ E to 4° 07″ E with an elevation of about 256 m above mean sea level. The study area covered about 1.4 km^2 and is easily accessible through a network of roads. Geomorphologically, this area is generally gentle, with occasionally tabular hills, capped by resistant sandstones and laterites deposits. The Bunza area falls within the Gwandu formation underlain by the sedimentary unit of Sokoto Basin (Kogbe, 1978; Kogbe et al., 1972). Bunza occurs in a dissected portion of the Kalgo–Bunza–Kamba Federal road (Fig. 1).

Parcels A–B = Maidahini planes road.

Parcels C–D = The Bunza planes are all on extensive peneplain parcel developed on the agricultural soil yard along road proximity of the Gwandu formation (Kogbe, 1978). Alluvial deposits provide the main relief in the area.

2.2. General geological setting of the study area

Birnin Kebbi is a part of the Sokoto basin of Nigerian sector of the larger Iullemmeden Basin. The Iullemmeden Basin itself is a broader sedimentary basin covering most part of Niger and Benin Republic and parts of Mali, Algeria, and Libya. The geology of Kebbi state is dominated by two formations: Precambrian basement complex in the south to northeast and young sedimentary rocks in the north. The basement complex region is composed of very old volcanic and metamorphic rocks such as granites, schist, gneisses, quartzite, migmatites, metasediments, etc. The sedimentary region consists of Gwandu, Illo, and Rima group whose ages range from Cretaceous to the Eocene. The Gwandu group consists of massive of clay interbedded with sandstones and clay, mudstones, and siltsones, respectively. Mineral that can be formed in the state include quartz, kaolin, photolytic bauxite, clay, potassium silica, sand, and salt (Kogbe, 1979, 1981; Obaje, 2009).

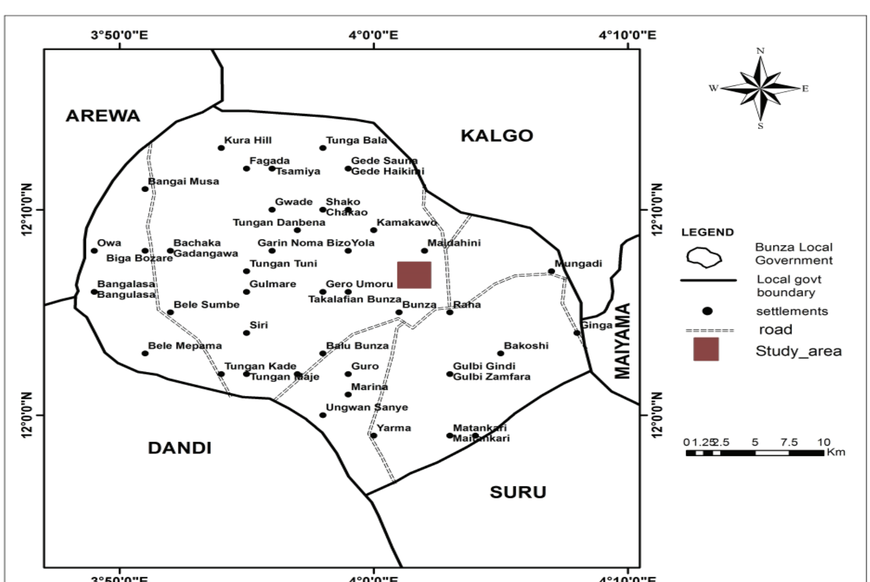


Figure 1. Location map showing the study area (Adopted from Google earth map).

3. Materials and Methods

3.1. Sampling procedure/data collection

Forty samples were collected using a parallel square grid of 500 × 500 m in each parcel road, for both Maidahini parcel (A–B) and Bunza parcel (C–D) areas of Kebbi State, NW Nigeria, 24 samples were also selected for further atomic absorption spectrometer (AAS) laboratory analysis at 20 m intervals along the four horizontals profiles located perpendicular to the main roads (i.e., 10 m on road bi-sides) (Figs. 3 and 4). Soil materials were sampled from the upper 30 cm.

3.2. MS measurement

In situ measurements of volume MS κ were made in a grid of 500 × 500 m^2 using pocket DSM-10 MS meter κ

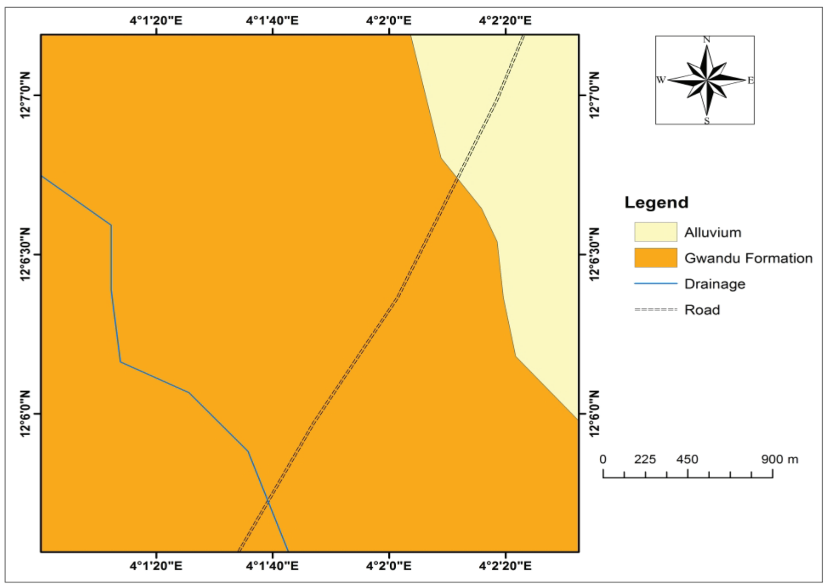


Figure 2. Geological map of the study area modified after Obaje (2009).

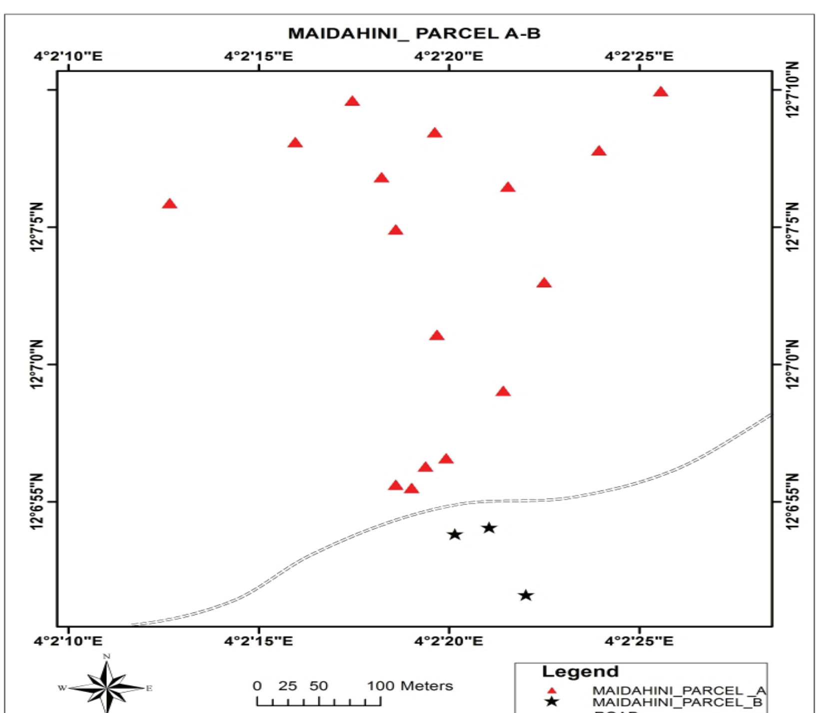


Figure 3. Distribution map of samples collected on Maidahini road parcel (A–B).

bridge making access to 90% of measuring signal, e.g., concentration of ferrimagnetic material in the top 20 mm of the land surface. In order to check reproducibility and to avoid measurement errors, each measurement represents the mean of five MS readings.

3.3. Heavy metal analysis

The 24 collected soil samples were ground in a mechanical agate grinder until fine particles (<200 μm) were obtained and preferred for analysis by means of the acid digestion method (Li and Thornton, 1993). About 0.250 g of the soil samples were weighed and placed into Pyrex test tubes. Concentrated nitric acid (4.0 ml) and 1.0 ml concentrated perchloric acid were added. The mixtures were heated in an aluminum block until complete dryness. After the test tubes were cooled, 5% (0.8 M) nitric acid was added and heated at 60°C for 1 hour with occasional mixing. Upon cooling, the mixtures were decanted into polyethylene tubes and centrifuged at 3,500 rpm for 10 minute. Heavy metal concentrations of the solutions were measured using AAS. AAS is an analytical technique that measures the concentrations of elements. Atomic absorption is so sensitive that it can measure down to parts per billion of a gram (μgdm^{-3}) in a sample. The technique makes use of the wavelengths of light specifically absorbed by an element. They correspond to the energies needed to promote electrons from one energy level to another and higher energy levels. Atomic absorption spectrometry has many uses in different areas of chemistry.

4. Results and Discussion

4.1. Results

The magnetic properties of soil sediments investigated in this research work describes the behavior of the soil samples under the influence of an applied magnetic field created by DSM-10 susceptibility meter measured *in situ* at the surface. The behaviors as investigated are at low field and are independent of the earth's magnetic field. The analysis of the geochemical soil samples is also described below.

4.1.1. MS distribution

The MS values ranged from 3 × 10^{-6} (SI) to 2.65 × 10^{-6} (SI), with an average value of 2.825 × 10^{-6} (SI). The study area consisted basically of two sites: the Maidahini (parcel A–B) and Bunza parcel (C–D) (Figs. 3 and 4). The MS was found to depend on the amount of ferromagnetic and ferrimagnetic materials captured in each sample. The Maidahini road parcel (A–B) in which ferrimagnetic materials is well captured as revealed from the atomic absorption chemical analysis shows high MS distribution values ranging between 5.756 × 10^{-6} and 4. × 10^{-6} SI (Fig. 5a) In the Bunza parcel (C–D), the distribution of magnetic values is moderate, ranging between 2.65 × 10^{-6} and 1.2 × 10^{-6} SI (Fig. 5b). The least values of MS occur in the (B–D) parcel road samples of the then Maidahini–Bunza site B and D which was found to range between 2.65 × 10^{-6} and 1.6 × 10^{-6} SI (Fig. 5c). Fig. 6 shows the histogram

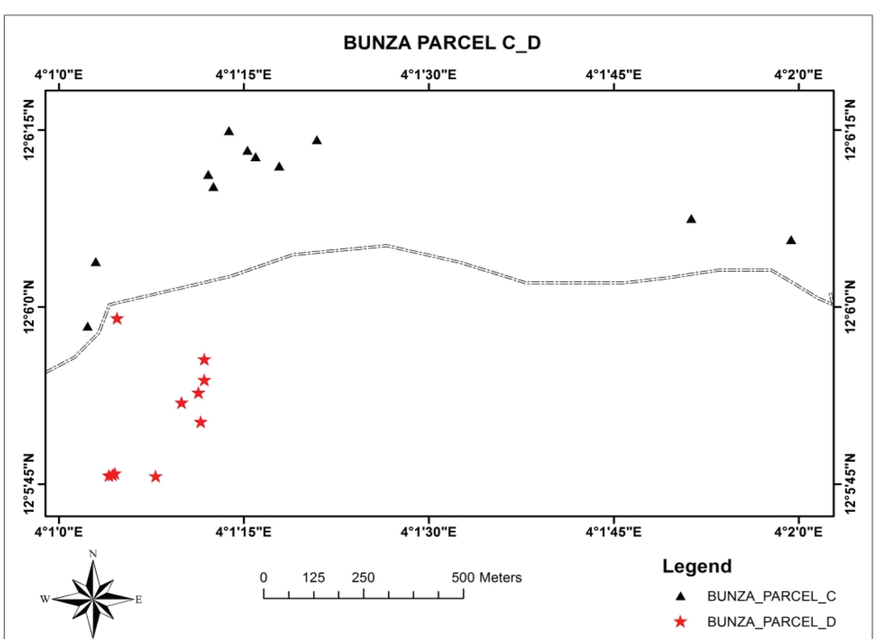


Figure 4. Distribution map of samples collected in Bunza road parcel (C–D).

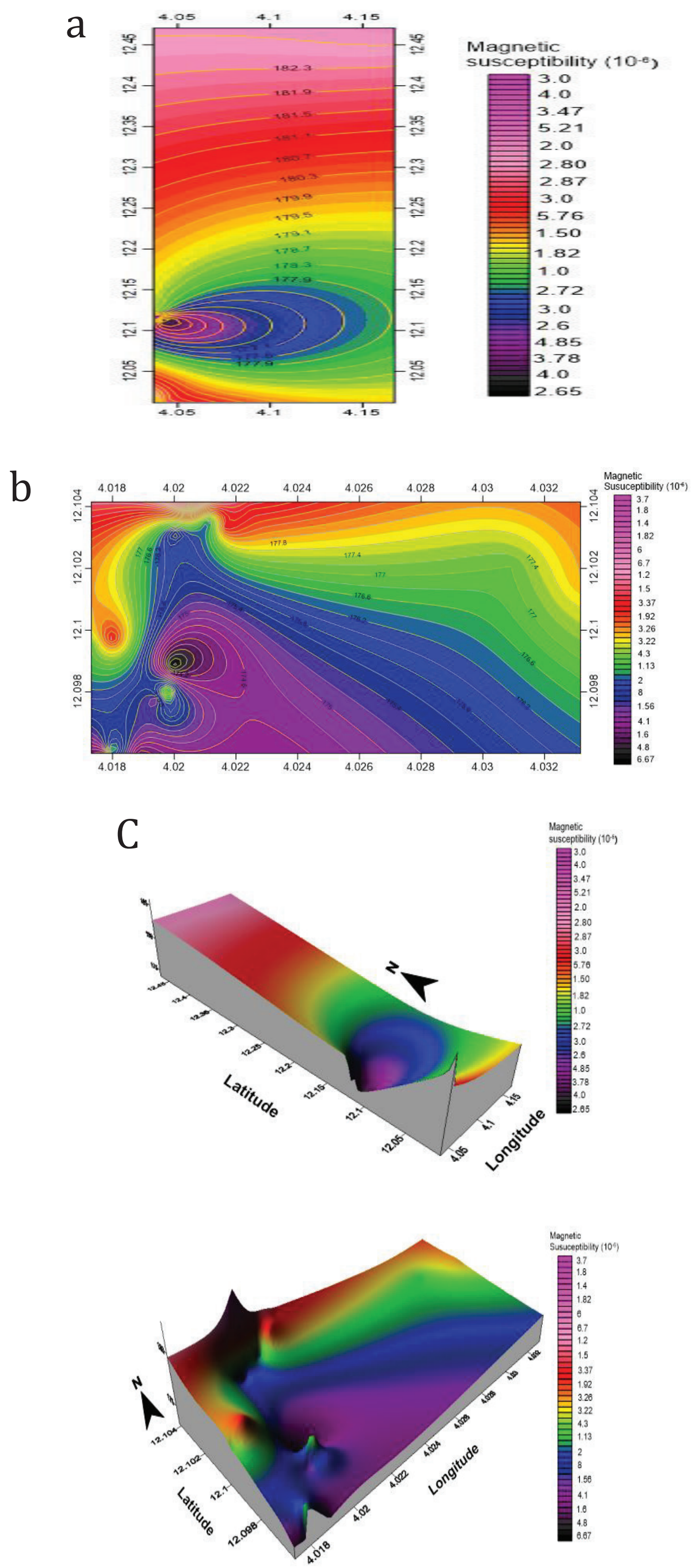


Figure 5. (a) Spatial map distribution of MS along Maidahini parcel A–B. (b) Spatial map distribution of MS along Bunza parcel C–D. (c) 3D model surface of MS distribution within the study area.

of spatial distribution plots showing the variation of MS distribution versus distance from the parcel roads within the study area and the activity concentration points are the sampled series. In both Maidahini and Bunza plain parcel roads, the MS distribution values obtained for this study are reasonable and are within the range obtained for soil sediments.

4.1.2. Morphological measurements

This experiment was carried out in order to identify the elemental concentration obtained from soil samples for heavy metal pollution determination; results from these determinations are shown Table 1(a–d).

As seen in the tables, the soil samples from the above-mentioned areas were analyzed from their elemental concentrations. In addition, other elements in common association with the trace elements were also analyzed. The results, as presented in Table (1a–d), indicate a normal concentration for the elements Fe, Mn, Cu, Ni, and Cr. The trace element concentrations were, however, much higher than normal for avoidance of doubt, the analysis was repeated four times, each time recording the same results. However, in view of the high values, especially that apparent mineralization was observed in each sample, the results were therefore considered for further presentation.

Table 1a. Elemental concentration of Maidahini parcel A.

S/N	Samples		Elements/concentration in mg/kg				
	Sample ID	Station No	Fe	Mn	Cu	Ni	Cr
1.	MPA	001	1,977	107.3	72.8	53.6	6.5
2.	MPA	002	2,174.8	173.5	99.3	88.4	3.4
3.	MPA	003	1,603.7	36.3	69.9	40.7	5.4
4.	MPA	004	802.8	29.8	60.7	34.9	8.3
5.	MPA	005	2,168.2	140.9	145.8	95.5	3.8
6.	MPA	006	1,815.2	57.6	69.8	49.2	9.2
7.	MPA	007	1,687.8	25.8	50.6	40.9	10.1
8.	MPA	008	2,177.9	136.6	119.4	91	6.2
9.	MPA	009	2,179.3	117	126.3	92.4	2.3
10.	MPA	010	1,904.2	65.4	82.1	62.4	7.5

Table 1b. Elemental concentration Maidahini parcel B.

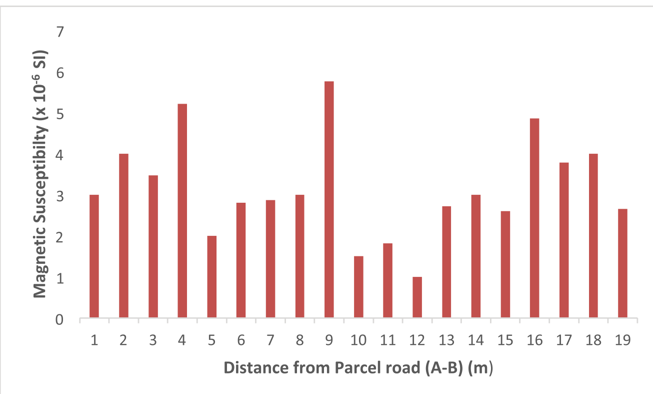
S/N	Samples		Elements/concentration in mg/kg				
	Sample ID	Station No	Fe	Mn	Cu	Ni	Cr
	MPB	001	2,086.7	89	88.5	65.1	6.2
	MPB	002	910.6	25.8	182.1	41.5	7.6
	MPB	003	2,018.3	123.9	94	63.8	4
	MPB	004	2,018.9	82.9	82.8	64.2	3

Table 1c. Elemental concentration Bunza parcel C.

S/N	Samples		Elements/concentration in mg/kg				
	Sample ID	Station No	Fe	Mn	Cu	Ni	Cr
	BPC	001	2,378.9	158.5	75.4	53.4	3.1
	BPC	002	2,286.7	299.7	387.7	86.9	2.9
	BPC	003	1,088.5	30	54.8	44.7	7.4
	BPC	004	1,685.7	40.8	65.3	52.2	6.4
	BPC	005	2,048.9	220	120.9	71.9	2
	BPC	006	2,091.6	276.4	78.5	58.4	5.6

Table 1d. Elemental concentration of Bunza parcel D.

S/N	Samples		Elements/concentration in mg/kg				
	Sample ID	Station No	Fe	Mn	Cu	Ni	Cr
	MPD	001	1,345.3	42.3	56.6	39.8	9.9
	MPD	002	2,262.8	190.1	112.8	82.6	3.7
	MPD	003	1,320.6	31.8	59.9	45.2	12.2
	MPD	004	1,829.9	51.7	72.9	52.8	5



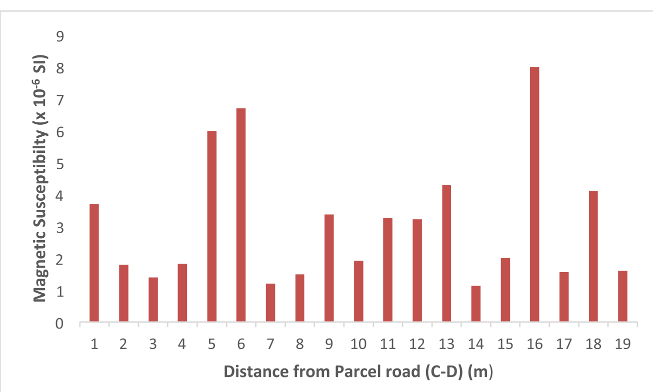


Figure 6. (a) Histogram plots showing MS variations versus distance from parcel road (A–B). (b) Histogram plots showing MS variations versus distance from parcel road (C–D).

The accuracy of the results is due to the proper calibration of the equipment used for the analysis.

4.2. Statistical analysis of heavy metals in soil

In Maidahini parcel (A–B) concentrations of Fe, Mn, Cu, Ni, and Cr, contents in top soil were 1,977, 107.3, 72.8, 53.6, and 6.5 mg/kg, respectively.

In Bunza parcel (C–D), the mean concentrations of Fe, Mn, Cu, Ni, and Cr were 2,378.9, 158.5, 75.4, 53.4, and 3.1, respectively. As a common element, the concentration of Fe was very higher throughout in the soil samples across the two parcel roads. The Maidahini parcel (A–B) contains 63.2% of the total heavy metals content than the in soils measured in the Bunza parcel (C–D) away from road. This result indicates that top soils near the road have higher concentrations of heavy metals than the top soils away from the road due to vehicular emission and anthropogenic activities.

4.3. Correlation between MS and heavy metal analysis of soil contents

A graph of each heavy metal contents present in each road parcel of agricultural soils is plotted against magnetic susceptibilities measured in the same parcels of soils. Correlation coefficients, for each heavy metal of agricultural soils, are calculated and analyzed. According to the correlation analysis of each parcel of soil, all heavy metals analyzed show positive correlations with MS values (Fig. 6a and b). Heavy metal content of Fe in both parcels of soils show relativity strong positive correlation coefficients (0.6085) with MS when compared to the rest of other heavy metals. Heavy metals such as Fe, Mn, Cu, Ni, Cr, and Cr showed significant values (< 0.0012) of correlation coefficients with magnetic susceptibilities in both parcels. The rest of the metals such as Fe, Mn, Cu, Cr, and Ni gave inconsistent values (≤0.02) of correlation coefficient with magnetic susceptibilities in both parcels.

6. Conclusion

Our results demonstrate that MS has a good correlation with heavy metals, and thus this parameter can be used as a proxy for soil pollutions; however, remnant magnetic parameters are better indicators for heavy metal pollutions than MS within the area of study. Also, morphological measurements were used for monitoring the contents of toxic metals in top soils within Maidahini–Bunza parcel roads. The result of the AAS analysis shows that the most abundant minerals of high concentration are iron (Fe), copper (Cu), nickel (Ni), chromium (Cr), and manganese (Mn). This study shows that MS can be used as a proxy for mapping high concentrations of heavy metals in agricultural top soils.

7. Recommendations

Further research work is recommended to be carried out in the nearby streams or dams to check if the top soils believed to be washed away by erosion or weathering processes are clearly deposited in the nearby streams or dams which serve as water sources for agricultural farming for the people of Maidahini–Bunza community.

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