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MAGNETIC PROPERTIES OF SOILS AROUND LOCAL POLLUTION SOURCES (CRETE, GREECE)

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Abstract: The main scope of the present study is to investigate the spatial and vertical distribution of the magnetic susceptibility in an area of possible industrial pollution and heavy traffic. For this purpose, a power plant with a dense traffic net around it, located in the SE section of Chania city was selected as the investigated area. In the context of the present work magnetic susceptibility measurements have been contacted in two phases. Surface soil samples have been collected in 2008 from the area under investigation and they were analyzed in order to estimate the spatial distribution of the magnetic susceptibility. Loci of high values of magnetic susceptibility within the study area gave rise to further proceed to coring up to a depth of 120cm at selected sites of the study area. GIS techniques were used for mapping the magnetic measurements on the various topographic and geological features of the area. Maps were created through interpolation algorithms indicating the spatial distribution of the above measurements. Spatial tools and statistical analysis proved the correlation between magnetic properties and the terrain attributes. Both investigations indicate high values of the magnetic susceptibility especially in the eastern part of the investigated area and along the main traffic branch.

Keywords: Magnetic susceptibility, power plant, traffic net, GIS mapping

1. Introduction

Industrial pollution is one of the most important environmental threats, with serious consequences for the future. Thus, its detailed study is of great importance. Apart from expensive and time-consuming chemical methods, several rapid and cheap proxy methods have been developed recently, one of them being based on rock-magnetic parameters.

Routinely used geochemical methods are rather time consuming, laborious in terms of sample preparation, and expensive. Therefore, any other method, although approximative, i.e. not providing absolute threshold values for contamination, but yielding fast information directly in field about relative changes between different sites, can be helpful as indicator for better targeting and selection of sampling sites for subsequent geochemical analysis. Moreover, measurements of temporal changes can serve as simple and rapid monitoring tool. One of such approximative indicators is the concentration of magnetic particles of anthropogenic origin. Magnetometry and especially magnetic susceptibility is a fast and cost-effective method for detection of environmental pollution of soils, sediments and dusts.

Magnetic minerals present in soils may be either inherited from the parent rocks (lithogenic origin), form during pedogenesis or may stem from anthropogenic activities (effluents from power plants, combustion of fossil fuel, metallurgical industries, smelters, road traffic, etc.). In the case of minor contribution of the first two sources to the magnetic properties of soils, susceptibility measurements become very important for monitoring environmental pollution, because, metallurgical dusts, fly ashes and cement dust contain relatively large amount of iron oxides and are therefore highly magnetic (Strzyszcz et al., 1996; Goluchowska, 2001).

Magnetic particles are usually deposited downwind from the industrial units on the surface of soils, streets, buildings and trees. Fly ashes with significant portion of ferromagnetic phase are produced by industrial processes; they are transported through atmospheric pathways and deposited on the ground. In soils, such particles penetrate downwards and accumulate in top layers and their increased concentration can be easily detected using surface magnetic measurements. Hansen et al. (1981) indicated that chromium manganese, cobalt, nickel, copper, zinc and beryllium are all significantly enriched in the 'magnetic' fraction of coal fly-ash. Beckwith et al. (1984) identified pollution sources in urban drainage systems using magnetic methods. Petrovsky & Elwood (1999) reviewed the application of magnetic susceptibility measurements in various ecosystems. Lately, more researchers investigate the usage of magnetic susceptibility as a tool for contaminated topsoils and sediments (Scholger, 1998; Bitykova et al., 1999; Petrovsky et al., 2001; Boyko et al., 2004; Kapicka et al., 2003, 2008; Sarris et al., 2009).

The aim of this study is to establish links between enhanced concentrations of anthropogenic magnetic particles and known sources of pollution in the catchment area. For this purpose the surface and the vertical distribution of the magnetic susceptibility is examined in an area around a local power plant with heavy traffic. This area was selected because it shows a homogenous geological structure. Therefore it is assumed that magnetic signature of anthropogenic contribution(s) should be well pronounced in the sediments and should be well correlated with heavy metals produced by the respective sources.

This study tries to document that simple and fast in situ magnetic measurements can reflect the anthropogenic influence under certain circumstances.

2. Geological and environmental setting

The study area is located at the SE section of the Chania city in Crete Island, comprising an almost flat area with slopes mainly ranging between 0 and 25%. The softness and horizontality of the geological layers contribute basically in the configuration of the low morphology of the region. A N-S orientated drainage network (Fig. 2) is present near to the local power plant.

The study area is mainly filled by recent alluvial sediments which were sampled in the context of the present study. NW-SE trending faults prevail in the wide area, away from the place that sampling has been conducted. The homogenous geological background justifies the assumption that magnetic enhancement in sedimentary samples can be attributed mostly to sources other than lithogenic.

3. Methodology

3.1. Site description and sampling

In environmental magnetism, the most often used magnetic parameter is the magnetic susceptibility (χ) which is the ratio of induced (temporary) magnetization acquired by a sample in the presence of a weak magnetic field, to the applied field itself. This is because magnetic susceptibility is concentration dependent parameter.

Samples were collected from the study area (Figs. 1a,b, 2) within a depth of 0-15 cm below the surface. GPS coordinates (in EGSA 87 system) were

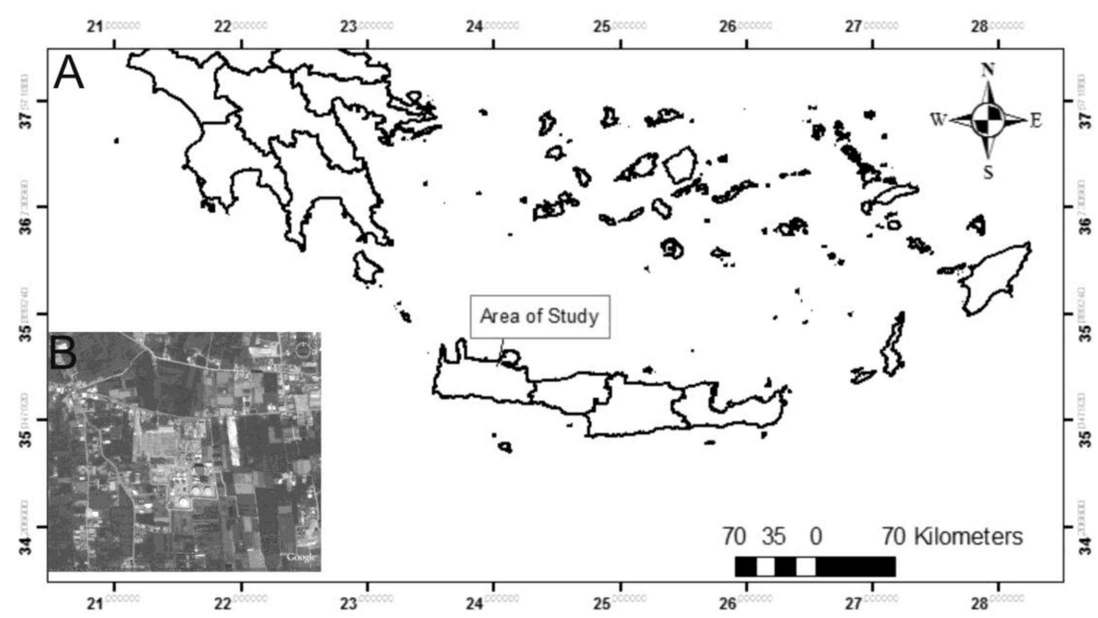


Fig. 1 (A): Location of the study area; (B) the location of the power plant in Chania, Crete. Satellite imagery from Google Earth showing the wider area of interest.

determined at each sampling site in order to be correlated with the available topographic, geological and traffic data. Additionally, coring has been performed at 10 selected sites (Fig. 3) around the local power plant and along the main road, up to a depth of 120 cm, in order to find out the relation of the magnetic susceptibility with the depth.

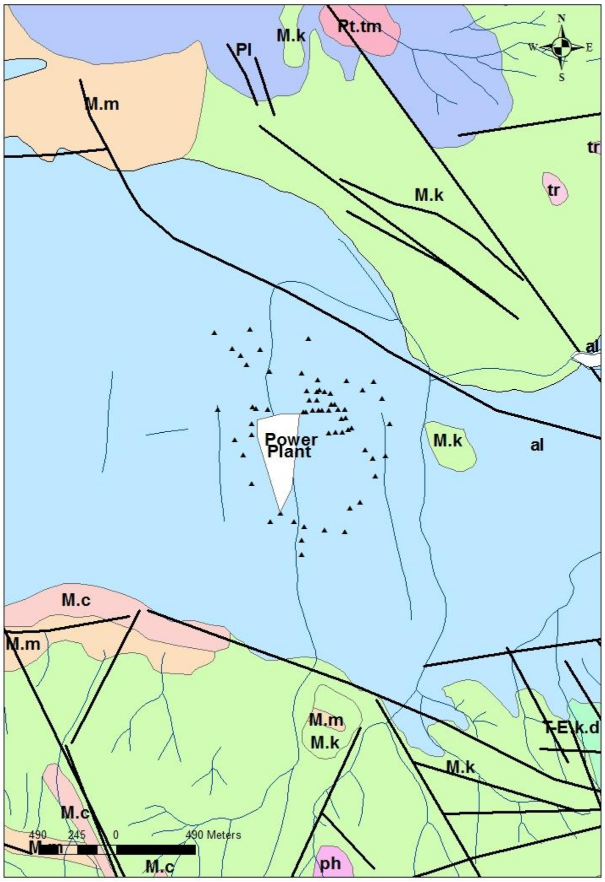


Fig. 2. Geological map of the wider area. Sympols: al-alluvial sed., tr-terra rosa, Pt.tm-marls, sands and conglomerate, Pl-Pliocene sediments, M.m, M.k-Miocene sediments, Black line-fault, blue line-drainage net, Black triangle-sample location.

3.2. Magnetic measurements

Since our samples were of unknown density, mass specific measurements seemed to be more appropriate compared with those based on specific volume. Bartington MS2 susceptibility meter was employed for measuring magnetic susceptibility in two frequencies (f_{low}= 0.43KHz and f_{high}= 4.3KHz). The samples were air-dried and sieved at 2mm in order to remove rock fragments. A sample of 10 cm^3 tightly packed Manganese Carbonate powder (χ= 99.2x10^{-6} emu/gr) was used for calibration of the instrument. The consistency of the instrument calibration was checked by measuring the susceptibility of the calibration sample in the beginning and end of the measuring session. The contribution of the plastic container was measured for 10 pieces and the average value was subtracted from all measurements. 200 samples were generally analyzed.

3.3. GIS techniques

Digitization techniques and GIS were applied for the presentation of the spatial distribution of magnetic susceptibility measurements and the geological features (the geological formations of the region available by 1:50000 scale geological maps of the Institute of Geological and Mineral Exploration, IGME) . Faults, rivers, and the main and secondary roads were also digitized and fused to the Geographical Information System component of the project. Gridding of the data was carried out using the inverse distance weighted method. Similar interpolation methods were used for creating surfaces of the spatial distribution of magnetic measurements.

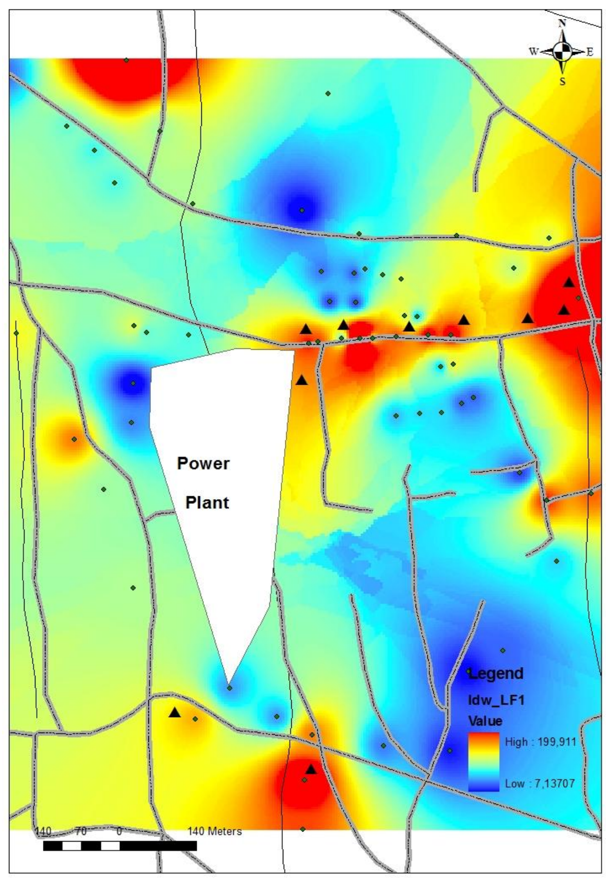


Fig. 3. Mapping of the low field magnetic susceptibility (LFS) in 10^{-6} m^3/Kg. Bullets represent the sample location, black triangle the coring locations, thin solid lines the drainage net and dashed line the traffic net.

4. Results and Discussion

The distribution of the low frequency field magnetic susceptibility susceptibility (LFS) is presented in Figure 3. The susceptibility values corresponding to the topmost samples of cores are not included in this figure. High susceptibility values, indicating possibly polluted sites, are generally detected in the eastern part of the study area, almost parallel to the orientation of the wind currents and along the main road. Additionally some samples, characterized by relative high χ, are indicated across the main branches of the drainage system.

LFS was measured in two phases, i.e. in different days, in order to estimate the influence of the background noise in the laboratory. Figure 4 presents the correlation (R^2=0.8) of the LFS measurements. A 20% influence of the background noise is expected on the measurements. The correlation between LFS and HFS (high frequency field magnetic susceptibility susceptibility) is high as it is expected.

Vertical susceptibility distribution in soil profiles is measured in order to distinguish between lithogenic and anthropogenic contributions to measured topsoil susceptibility values. Figure 5 presents the correlation (R^2=0.91) of the surface susceptibility values around to coring locations with the corresponding values from topmost samples of cores. Figures 6a,b,c show the distribution of the mean low frequency measured magnetic susceptibility, mean high frequency measured magnetic susceptibility and frequency dependent susceptibility in relation to depth, resulting from ten corings up to a depth of 120cm near to the power plant and the main road where high surface susceptibility values were observed. Relative high LFS and HFS values (Fig. 6a,b) are indicated at depths ranging between

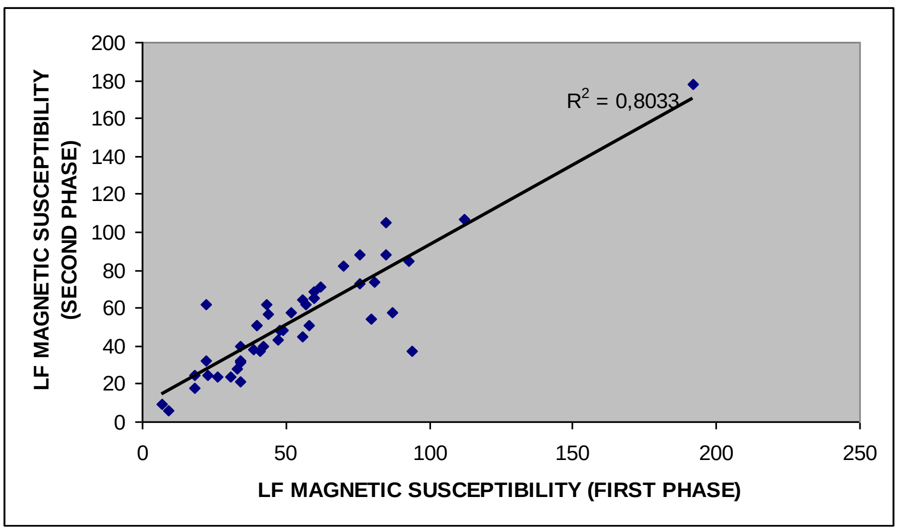


Fig. 4. Correlation of the LFS (10^{-6} m^3/Kg) measured in two phases.

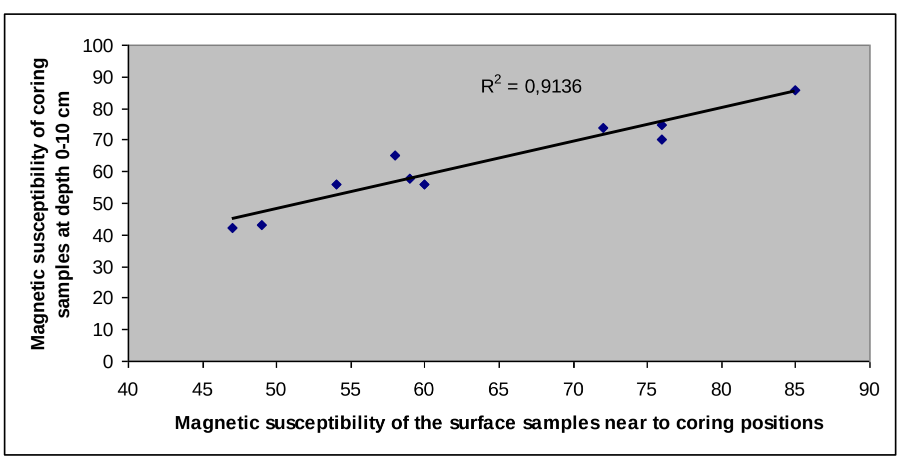
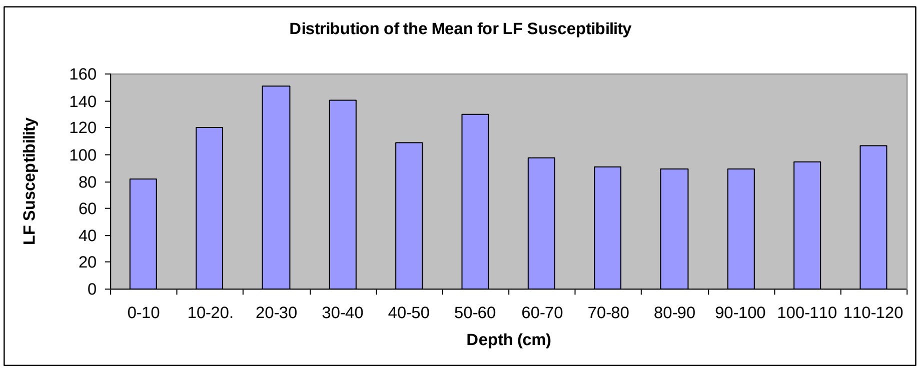


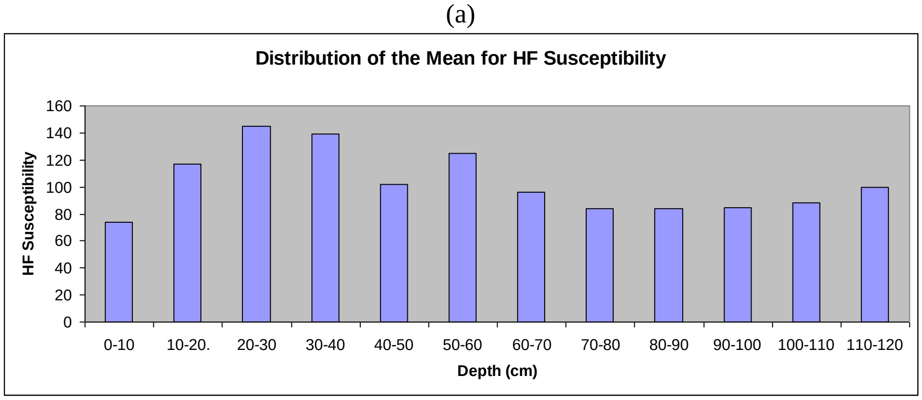
Fig. 5. Correlation of the LFS (10^{-6} m^3/Kg) measured in the two campaigns.

20 and 40cm. The relative deep penetration could be possibly explained by the fact that around the power plant mainly agricultural fields are located, and most of them are cultivated. Therefore polluted dusts can penetrate easier in greater depths. The frequency dependent susceptibility (χ_{fd}) which is given by the following relation: $\chi_{fd} = (\chi_{low}-\chi_{high}/\ \chi_{low})$ %, where χ_{low} and χ_{high} refer to mass specific magnetic susceptibility measured at low and high frequency. Frequency-dependent susceptibility (FDS) reflects variations in magnetic grain size from the single domain to superparamagnetic state (Dearing et al., 1996, Kapicka et al., 2003). FDS values in the present case (Fig. 5c) are varying between 4% and 12% (highest values at depths ranging between 60 and 80cm). This suggests that the fined grain sizes have strong contribution to susceptibility due to magnetite formation during pedogenesis.

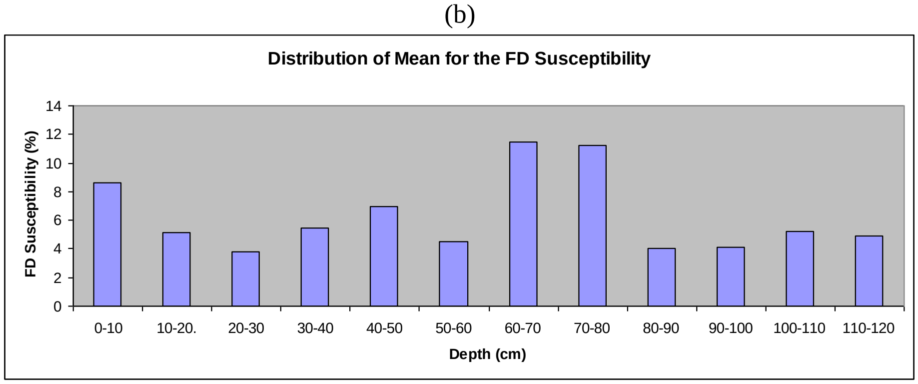
To eliminate the effect of diagenetic formation of magnetic particles during the sample storage, magnetic susceptibility of raw wet material, measured immediately after sampling, was compared with measurements on the same samples during some days of drying at room temperature. No changes in mass-specific magnetic susceptibility suggest that iron minerals are already stable and no further oxidation or precipitation takes place (Fig. 7).



(a)



(b)



(c)

Fig. 6. Distribution of the Mean for (a) LFS (10^{-6} m^3/Kg), (b) HFS (10^{-6} m^3/Kg) and (c) FDS resulting from 10 corings up to a depth of 120cm.

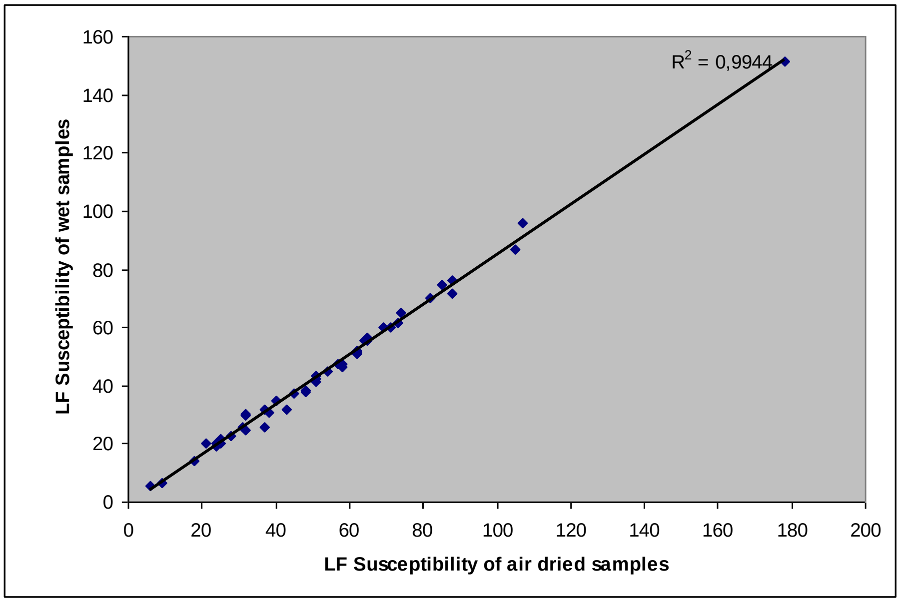


Fig. 7. Correlation of LFS (10^{-6} m^3/Kg) for wet and air-dried samples.

5. Conclusions

In the present work, magnetic susceptibility measurements were conducted around a power plant with a dense traffic net, located in the SE section of Chania city in Crete, in order to examine if the study area is an interesting place for further pollution research.

The main transmission factor seems to be the wind. High values of the magnetic susceptibility χ are orientated east of the power plant and along a major branch of the traffic net. The vertical susceptibility distribution in soil profiles indicates increased values at depths ranging between 10 and 60cm. Frequency dependent susceptibility is moderate and variable, possibly indicating the dominance of SP ferromagnetic minerals and non negligible pedogenesis.

The spatial distribution of magnetic susceptibility in both campaigns verifies the influence of anthropogenic activities and confirms that magnetic susceptibility measurements provide the basis for an environmental study in polluted areas.

In concluding, the study area is of interest and further magnetic analyses (thermomagnetic curves, IRM, ARM, hysteresis loops) as well chemical analyses are proposed in order to examine the possibly polluted sites. In any case, the application of magnetic methods should not be overestimated. Results obtained in one specific region may not be simply transferrable to another region. Instead, detailed analysis should be carried out in order to establish basic correlations (if existent) between various magnetic parameters and concentrations of heavy metals. Only if such relationship is evident, magnetic measurements can be used in tracing and observing future temporal and spatial variations of metal contamination.

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