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MAGNETIC SUSCEPTIBILITY AS A TOOL FOR THE DISCRIMINATION OF ANTHROPOGENIC AND LITHOGENIC HISTORY OF TOPSOILS: PRELIMINARY RESULTS FROM THE BROADER AREA OF THESSALONIKI CITY

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Abstract

In the recent years the measure of the magnetic susceptibility has been proved to be a reliable tool for the monitoring of pollution in topsoils. However the increase of magnetic susceptibility is not always correlated with polluted sources but it is possible to reflect the geological background of the area. In the present study a broad area in the southeast part of Thessaloniki city has been investigated by means of magnetic susceptibility measurements. In total 77 profiles up to 70 cm depth have been sampled. Magnetic susceptibility was measured in two different frequencies (0.47 and 4.7 KHz) and the percentage of frequency dependence was calculated. The spatial distribution of the magnetic susceptibility values was performed using GIS techniques. The results revealed the presence of two areas with high susceptibility values. These areas are investigated in details in order to distinguish the anthropogenic or the lithogenic influence.
Key words: *Environmental magnetism, soil pollution, GIS, Anthemountas river basin.*

Περίληψη

Τις τελευταίες δεκαετίες η μέτρηση της μαγνητικής επιδεκτικότητας έχει αποδειχθεί ως ένα χρήσιμο εργαλείο για τον εντοπισμό και την παρακολούθηση της επιφανειακής ρύπανσης των εδαφών. Παρόλα αυτά η αύξηση της μαγνητικής επιδεκτικότητας δεν συνδέεται πάντα με πηγές ρύπανσης αλλά είναι δυνατόν να αντανακλά το γεωλογικό υπόβαθρό της περιοχής. Στην παρούσα μελέτη έχει ερευνηθεί η ευρύτερη περιοχή νοτιοανατολικά της πόλης της Θεσσαλονίκης με τη χρήση δεδομένων μαγνητικής επιδεκτικότητας. Συνολικά έχουν συλλεχθεί δείγματα εδάφους από 77 θέσεις μέχρι το βάθος των 70 cm. Η μαγνητική επιδεκτικότητα μετρήθηκε σε δύο συχνότητες (0.47 και 4.7 KHz) και υπολογίστηκε το ποσοστό της εξαρτώμενης από τη συχνότητα επιδεκτικότητας. Η χωρική κατανομή των τιμών της μαγνητικής επιδεκτικότητας πραγματοποιήθηκε με τη χρήση τεχνικών GIS. Τα αποτελέσματα υποδεικνύουν την ύπαρξη δύο περιοχών με αυξημένες τιμές επιδεκτικότητας. Οι περιοχές αυτές μελετώνται λεπτομερειακά για να διαπιστωθεί αν η αύξηση αυτή οφείλεται σε ανθρωπογενείς ή γεωλογικές επιδράσεις.
Λέξεις κλειδιά: *Περιβαλλοντικός μαγνητισμός, ρύπανση εδάφους, GIS, Λεκάνη Ανθεμούντα.*

1. Introduction

Magnetic susceptibility indicates the degree of magnetization of a studied material when it is placed in a uniform magnetic field. Therefore, it is a very sensitive parameter to the presence of ferromagnetic minerals. Dearing (1994) reported that 0.01% of magnetite, in typical soil magnetic population, contributes about 85% to the total magnetic susceptibility. Magnetic minerals present in soils could be derived from the parent rocks (lithogenic origin) or could be originated from anthropogenic activities. When the parent rock has a weak magnetization and therefore has a negligible contribution to the magnetic properties of the soil, the measure of magnetic susceptibility can play an important role for monitoring the pollution since several toxic compounds such as heavy metals are highly increased in urban airborne materials.

The measurement of magnetic susceptibility is widely used during the last decades for the detection of environmental pollution of soils, sediments and dusts. Several studies have been performed indicating the enhancement of magnetic susceptibility in industrial areas, highways and urban areas. Thompson and Oldfield (1986) reported that soils near urban and industrial areas have an increased magnetic susceptibility, representative of the deposition of magnetic particles, such as, dusts of industries and fly ashes of the coal combustion. Moreover, magnetic susceptibility mapping was successfully applied in different countries for the estimation of anthropogenic pollution (Strzyszcz, 1993; Dearing et al., 1996; Scholger, 1998; Petrovsky et al., 1998, 2000; Kapicka et al., 2001; Lecoanet et al., 2001; Boyko et al., 2004; Jordanova et al., 2004; Lu and Bai, 2006; Magiera et al., 2006). Despite this big development especially in Europe, in Greece only few studies have been performed during the last decades (Scoullos et al., 1979, Sarris et al., 2009, Zananiri et al., 2010).

In this study, the preliminary results of magnetic susceptibility data obtained from the broader area of Thessaloniki City in the Anthemountas basin are presented. The main target of this work is folded: a) to investigate the spatial distribution of the results of the magnetic susceptibility of the topsoil using GIS techniques and determine the highly magnetic areas, and b) to investigate if this enhancement is due to anthropogenic or lithogenic origin.

2. Geomorphological and Geological Settings

The study area of the present work is located in the Anthemountas basin, in northern Greece at the eastern part of the Thermaikos gulf. It covers an area of 374 km^2 with high hills of semi-mountainous relief, according to Dikau's (1989) classification. The mean altitude and slope of the study area are 259 m and 20%, respectively.

From a geological point of view, Anthemountas basin is a part of the Servo-Macedonian, Circum-Rhodope and Paeonian geotectonic zone (Mountrakis, 1985). The mountainous part of the basin consists of Mesozoic ophiolithic, crystalline and carbonate rocks whereas in the lowlands Neogene and Quaternary sediments represent 65% of the formations. The Neogene sediments are mainly located at the southern part of the area and consist of sandstone-marl (sandstones, marls, sands and gravels), red-clay (clay with lenses of sands) and conglomerate series (conglomerates, gravels, sands). The Quaternary sediments are alluvial deposits (sands, gravels and clays) in the western part of the basin and terrace systems (sands, pebbles) in the east (Figure 1). Carbonate rocks outcrop in the south-central part of the basin near Agia Paraskevi and Tagarades and consist of Triassic limestones.

3. Sampling and Methodology

Soil samples have been collected from 77 different sites within the studied area. The exact positions of sampling points are shown in Figure 2. In every sampling site, a hand core drilling was used in order to obtain the soil sample. The sampling was performed in vertical profiles of maximum depth of 70cm. The collecting material of every 10 cm was homogenised and considered as one sample representative for this depth (e.g. 0-10 cm).

In total 503 samples were collected. The soil samples were dried and sieved (in order to remove all the impurities) and placed in cylindrical plastic boxes (2x2x2 cm).

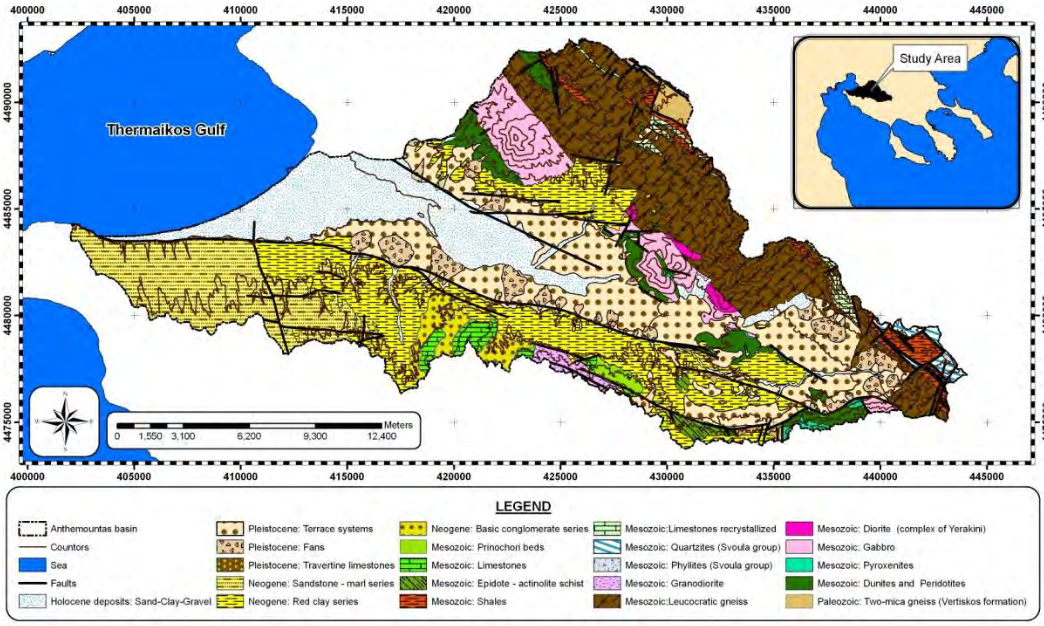

Figure 1 - Geological Map of the Anthemountas river basin.

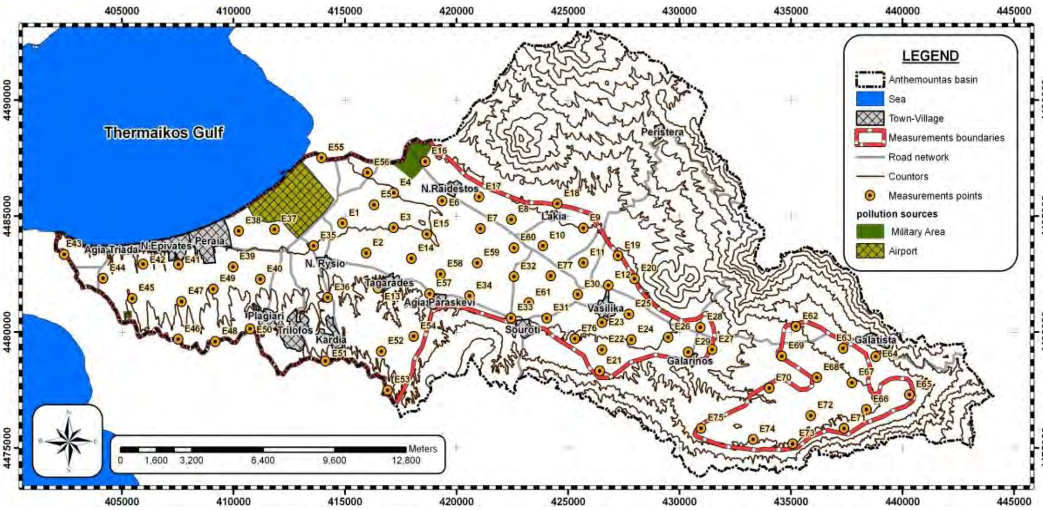

Figure 2 - Schematic map indicating the sampling locations (orange dots) and the possible pollution sources (green areas).

Magnetic susceptibility is a measure of the ease which a material can be magnetised. The volume susceptibility is defined by the relation κ=M/H, where M is the acquired magnetisation when a uniform magnetic field (H) is applied. In SI units both M and H are expressed in A/m, consequently k is dimensionless. Mass specific susceptibility χ is defined as: $\chi=\kappa/\rho$, where ρ is the density and has units m^3/kg in SI.

In the present study the measurements of the magnetic susceptibility have been performed using the Bartington MS2B sensor. As our samples were weighted before the measurements all the results are expressed as mass specific susceptibility (χ). The magnetic susceptibility was measured in low (0.47 kHz) and high (4.7 kHz) frequency, allowing the calculation of the percentage of the frequency –dependent susceptibility (χ_{fd} %) using the simple formula: χ_{fd} (%)=[(χ_{lf} - χ_{hf})/χ_{lf}]x100, where χ_{lf} and χ_{hf} is the susceptibility in low and high frequency respectively. This parameter is sensitive to magnetic grain size as it indicates the presence of superparamagnetic (SP) grain (Dearing, 1994).

4. Results

The spatial distribution of magnetic susceptibility values from the topsoil (0-10 cm) is shown in Figure 3. The χ values exhibit a wide variation ranging from 6.4 up to 423x10^{-8} m^3/kg. The most enhanced values are observed in two areas: along a zone northwest - southeast of the studied area, and in west part indicating medium to high values (50-200 x10^{-8} m^3/kg). The lower values are found in the central part of the studied area. As it is shown in Figure 3, the high values of the topsoil in the west side revealed in an area close to the airport and in the intense urban network, an area which can be considered as a pollution source. Along the zone in the northwest-southeast edges and especially in the southeast part where the biggest anomaly is observed, no visible pollution source in the vicinity seems to be associated with this anomaly. On reverse, this zone appears to correlate with the big ophiolite outcrops following the same direction of the enhanced magnetic susceptibility values.

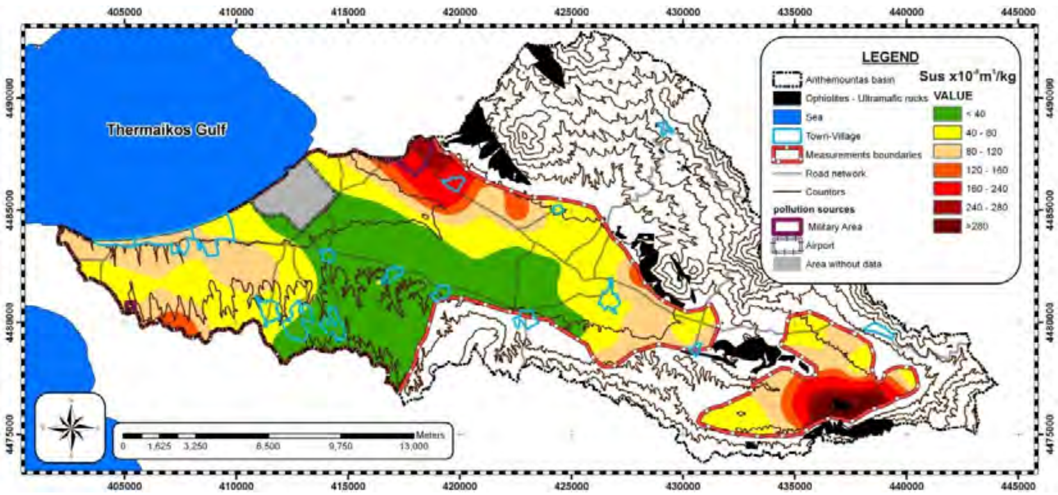

Figure 3 - Spatial distribution of the magnetic susceptibility of the topsoil (0-10cm depth).

The distribution of the χ_{fd}% for the same depth (0-10cm) shows that in the magnetically enhanced areas the percentage of the frequency dependent susceptibility is lower ranging from 0-3%, while in the central part of the area the same parameter obtains much higher values reaching even 21% (Figure 4).

The vertical distribution through the studied profiles can divided in 4 groups. The highly magnetic area in the west part present, in the majority of the samples, decreased magnetic susceptibility values with depth (Figure 5a). This is another indicator for the influence of the topsoil from different pollution sources in the area. In the other zone northwest-southeast, the vertical profiles shows more complex trends. There are samples that show increased values with depth as shown in Figure 5b and samples showing high values along the whole profile with no variation with depth. The first behavior is characteristic of soils that are influenced by the highly magnetic geological background as it is in this case the presence of the ophiolite belt. In the central part of the studied area where the lower susceptibilities are observed their vertical distribution show no significant change (Figure 5c). Finally there are only few cases throughout the whole area where the vertical profiles does not shown any reasonable change with depth which is most probable due to erroneous sampling (Figure 5d).

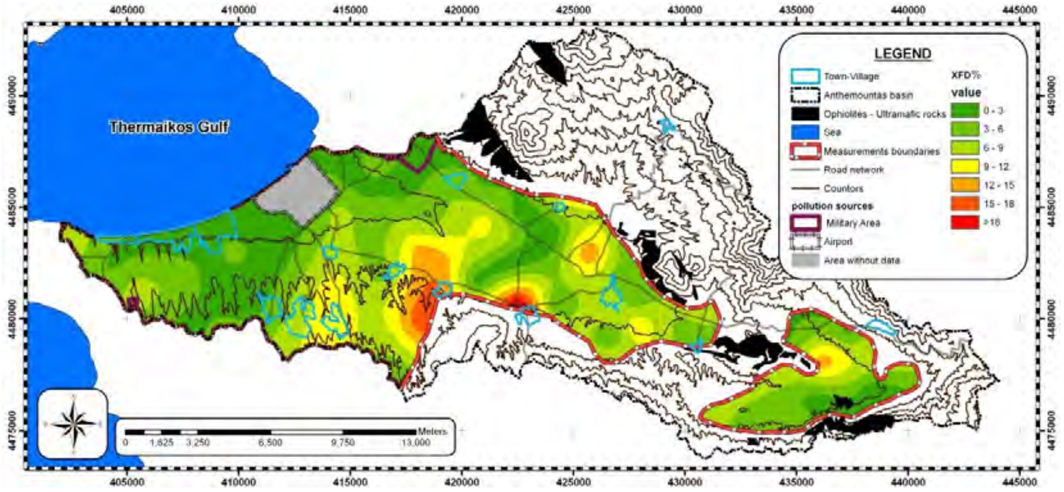

Figure 4 - Spatial distribution of the frequency dependent susceptibility (χ_{fd}).

5. Discussion

The studied area is a complex area since it compiles urban areas and pollution sources with a rich geological background. The spatial distribution of our results revealed the presence of enhanced magnetic areas. As it is shown from the vertical profiles in some cases the χ values are decreased with depth while there are cases where the opposite phenomenon is observed.

These different trends with depth are characteristics in soils influenced by near surface pollution and by strong geological background respectively. Several authors have studied and compared there two types of vertical distribution leading to the same conclusions. Maher (1986) investigated several types of soils in order to characterize them by the mineral magnetic measurements. Examples of soils developed on doleritic parent rock showed a steady increase in χ with depth accompanied with a correspondent decrease in χ_{fd}.

Furthermore, soils that have been affected from atmospheric pollution showed the reverse behavior; decreased values of χ with depth followed with increased χ_{fd}. Similar results concerning the variation of χ and χ_{fd} in vertical soils profiles from China have been reported by Lu and Bai, (2006). Magiera et al., (2006) tried to discriminate the lithogenic and anthropogenic influence on topsoil using magnetic susceptibility measurements. The study of the vertical profiles showed again increased χ values with depth in the forest soils and decreased in the polluted areas. They conclude that the anthropogenic origin of enhanced topsoils can be confirmed by the following observations: anomalies in χ close to industrial and urban areas, strongest enhancement of the topsoil located in the topsoil (uppermost 8 cm), topsoil enhancement in forest is higher than in arable field of the same area, χ enhancement is accompanied by increased heavy metal content.

Following the observations of Magiera et al., (2006) and compare them with the available data in the present study we can conclude that the west part of our studied area can be considered as polluted from local pollution sources originated either from the intense human activities or the airport. In order to reinforce this observation the difference between the χ values of the topsoil and the bottom χ values is calculated. The spatial distribution of this difference is presented in Figure 6. High positive values are observed in the west part of the plot, confirming the anthropogenic influence by the presence of highly magnetic horizons in the upper most part of the soil close to urban areas.

The second enhanced area (northwest-southeast zone) is more complex since both urban zones and the ophiolite belt zone are present. As Magiera et al., (2006) reported the lithogenic origin of enhanced topsoil can be confirmed by: a) localization of observed anomaly in areas remote from urban sources of pollution, b) the χ values increase gradually with depth, c) topsoil χ values are significantly lower than the measured in an arable field and d) heavy metal content is low and no correlated with χ.

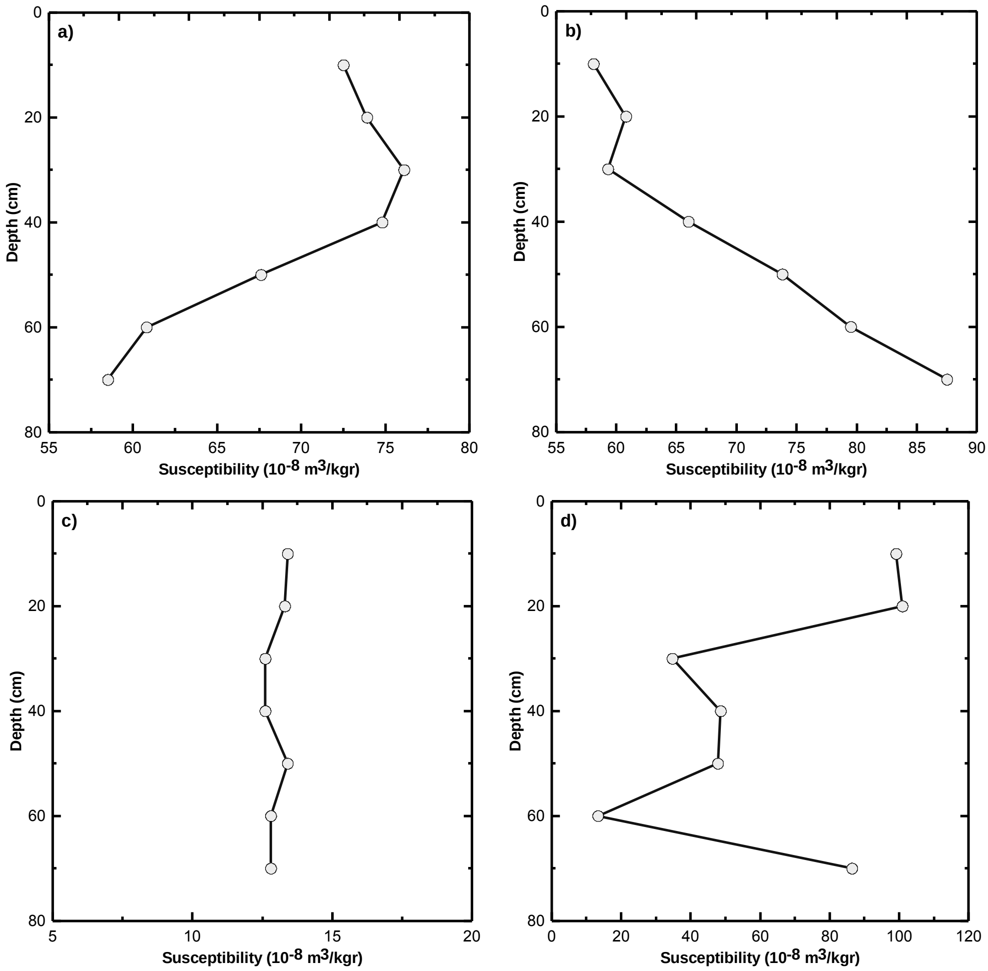

Figure 5 - Vertical profiles of magnetic susceptibility. Typical examples of the enhanced magnetically area in the west part (a), along the northwest-south east part (b), from the central part with the lower values of susceptibility (c) and wrong sampling (d).

From the above observations only the first two are available in the present study and only the first one is fulfilled. As it is already mentioned above, the vertical distribution of χ values is not uniform in this zone. Some of the samples display similar trend as Magiera et al., (2006) reported (that is increase with depth) but also no big changes in the vertical profiles are observed. This dual behavior is recorded in Figure 6 where no clear indication on the lithogenic influence of the soils is observed. If the geological influence was dominant, this zone should be characterized by high negative values (green color in Figure 6). The mixture that is observed reflects the complexity of the area. A possible plausible explanation for the big positive anomaly in the northern part of the zone can be the vicinity of the sampling point to an urban area and also close to the highway.

The most interesting part is the south edge of the zone where both high positive and high negative values are observed. This area is remote from any industrial or urban area, so the ophiolithic influence in the χ values should be expected. This is confirmed only in the north and south ends where high negative values are displayed. In contract in the middle of this area two (2) high positive values are recorded, indicating the enhancement of χ in the upper most part of the soil. This area consists of arable soils. The main cultures in those areas are corn, cotton and vegetables and characterized by high demands in fertilizers, whereas the excessive use of the fertilizers reflected in the nitrates concentration in the groundwater exceeding 50 mg/L (Kazakis, 2013). The use of the fertilizers possible affects the χ_{lf} values (Figure 3) in the agricultural area, as well as the difference between the top and bottom soil (Figure 6) creating these high values, which are recorded in the southeast part of the study area.

On the other hand, Magiera et al., (2006) showed that in arable soils the observed topsoil χ is higher that the nearby forest soil. During the ploughing of arable soil, ferromagnetic minerals from the parent rock are transported upward, while in the forest soil they are concentrated in the bottom of the studied soil cores. So, it seems that ploughing plays an important role in the distribution of the magnetic minerals and consequently can be an alternative explanation for this 'unexpected' behavior of the soils in the present study.

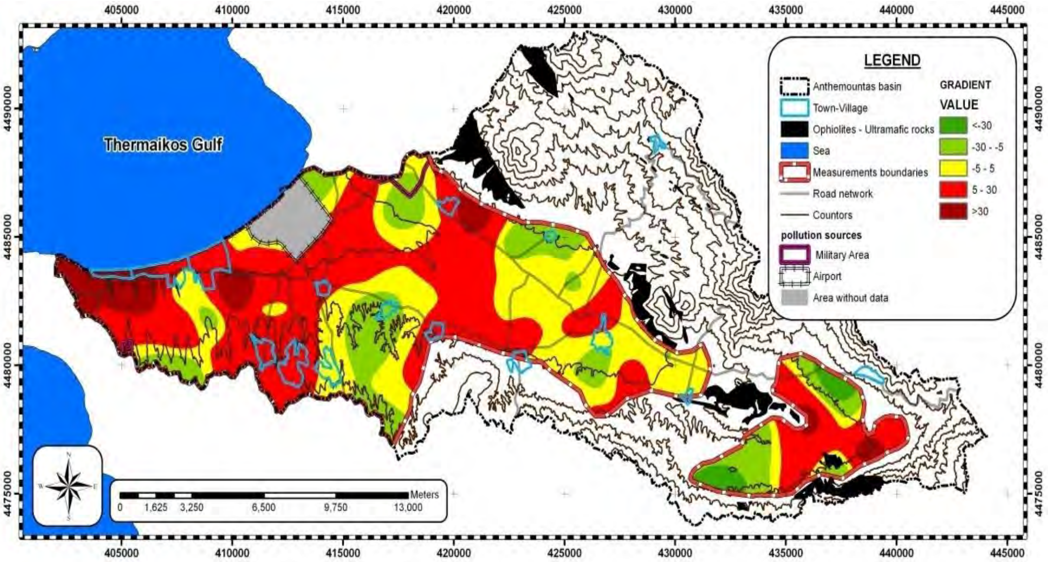

Figure 6 - Distribution of the difference between the topsoil and the bottom soil from all studied locations.

6. Conclusions

Magnetic susceptibility measurements of soils have been performed in the Anthemountas river basin close to Thessaloniki City. The spatial distribution of χ (mass specific susceptibility) indicates areas with big magnetic anomalies. The first one is located west of the studied area and characterised by high values of χ in the topsoil samples, indicative for their anthropogenic origin. The second enhanced area is a zone northwest–southeast of the studied area which appears more problematic. This area is remote from any industrial or urban area, so the magnetic anomalies should be attributed to the presence of ophiolithic rocks, which are rich in ferromagnetic minerals.

In order to confirm the above results a more detailed sampling should be performed especially in the more problematic areas. Moreover heavy metal analysis will validate our assumptions and will certain enlighten the research regarding the possible sources of pollution.

The mapping of magnetic properties of soils can be very helpful for outlining areas affected by different pollution sources. However, as our preliminary results shows, the enhancement of the magnetic properties is not always lead to the pollution sources, hence, the geology of the area has to be seriously considered when interpreting the data. This is essential for the discrimination of anthropogenic contribution from the natural magnetic effects.

7. Acknowledgments

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