UDC 550.83-1029.12

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MAGNETIC SUSCEPTIBILITY AND HEAVY METALS SOIL ACCUMULATION IN UKRAINIAN URBAN AREAS

(Reviewed by the editorial board member P. Pereira)

Soil pollution is an aspect of environmental magnetism research. The main objects are heavy metals and other chemical compounds. They pollute the environment and are dangerous for human life.

Purpose. The magnetic properties of polluted soils investigation for different technogenic sources and impact on the territory.

Methodology. The field stage work includes ecological and soil research, measuring the volume magnetic susceptibility with field kappameters. Laboratory studies include measuring mass-specific magnetic susceptibility with kappameters AGICO, MS-2, magnetization measurements, measuring magnetic parameters of the hysteresis loop with rock generator and special magnetometer equipment, determination of elemental composition, and electron magnetic microscopy.

Findings. Magnetic susceptibility of polluted soils ("urbanozems") increases in the upper humus horizons (A). New magnetic particles (PM particles) tend to form during high-temperature processes. There was found a high correlation between magnetic susceptibility and the lead, zinc, and copper content in the polluted soils.

Originality. A correlation between magnetic susceptibility and soil pollutants has been described. Heavy metals often stick to the surface of ferromagnetic materials and penetrate the structure of the crystal lattice under high-technology processes, with these compounds accumulating in soils.

Practical value. Further research into soil magnetism informative value is associated with the development of an optimal soil mapping technology in urban areas. Environmental magnetic investigation is a low-cost and high-performance technology to assess the technogenic and anthropogenic impact on the environment.

Introduction

Economic power and global sociopolitical influence of modern countries are associated with developed industries. Large cities have strong impacts on the surrounding environment. Powerful megalopolises are often centers of heavy industry. They are formed within extractive or processing industrial areas and centers of geopolitical activities. Hence the necessity to conduct environmental research in these centers.

More than a half of the world's population lives in urban agglomerations. In industrially developed countries, this share is as high as 75%. In Eastern Europe, Ukraine and Moldova are at the higher end of the urbanization spectrum.

Vyzhva and Zhukov [15] mark dangerous pollution levels, with special attention being paid to the capital of Ukraine. There is high atmospheric concentration of nitrogen dioxide, lead, sulphuretted hydrogen and dust. This results from harmful emissions from the city traffic. Reva et al. [12] observed a threat of radiation, geochemical and oil pollution impacts on the environment. They propose using ecogeophysical methods based on electrical geophysical investigation of soils.

It is important to understand the mechanism of biosphere changes and functions to improve the city environment. These changes are caused by the processes of industrialization, overpopulation, environmental pollution and other adverse effects of urbanization [9].

Geophysics is an effective instrument for ecological research. Investigations into environmental magnetism are very convenient and informative methods by Evans and Heller [5], Jelenska et al. [7], who analyze soils, polluted areas, lines and sources of pollution.

The magnetic method is a high-quality indicator of the soil pollution levels. Soil magnetism can identify different sources of pollution, toxic waste accumulation, poisonous gas, active materials, pesticides, organic and inorganic toxic compounds, as well as adverse chemical processes in soils. These sources of pollution are accumulated on the soil surface, which, in turn, produces negative effects on groundwater resources. Distribution of heavy metals in soils is determined by the location of the pollution sources, wind distribution, geochemical factors and geomorphology. The magnetic anomalies and the highest accumulation levels of magnetoactive materials tend to occur in topsoil horizons [3, 14].

Soil magnetic measurements show good results in detecting and mapping different sources of urban pollution, such as the burning of fuels, iron and steel industries, coal power stations, vehicle emissions. Good results were obtained in the United Kingdom by Blundell et al. [2], in Czech Republic by Fialova et al. [6], Petrovsky et al. [11], in Germany by Blaha et al. [1]. Another source of magnetic susceptibility anomalies in soils is superparamagnetic grains of non-atmospheric origin, according to Blundell et al. [2], Mullins [10].

Liu et al. [8] used magnetic measurements and heavy metal analyses of street dust as a means of determining pollution levels. Wang et al. [16] concluded that magnetic minerals in street dust samples are PSD range magnetite in high concentration.

Materials and methods

Figure 1 presents a map of pollution levels in Ukraine. The highest urbanization areas correspond to the areas with highest pollution levels. These are: Kyiv, Donetsk, Dnipropetrovsk, Zaporizhia and the South of Ukraine. The situation is better in Western Ukraine, these territories being moderately polluted. Black rings on the map in Fig 1 indicate the areas under investigation.

Urban geophysics is a part of environmental geophysics which deals with the ecological situation in big industrial cities and megalopolises. Urban geophysics investigates the spatial distribution of dangerous chemical compounds and pollution sources. Geophysical methods (soil science and geochemistry, electrometry and others) were used to study the effects of physical and chemical fields on urban and natural areas.

The Ecological system of megalopolis and natural areas has four basic components: air, water, soil, and vegetation. Soils play an important role in vital human activities within cities. There have been very important findings on atmospheric pollution, vegetation, soils, and water containing heavy metals and hydrocarbons. The magnetic properties of soils are the best studied. Among other objects of magnetic investigations are tree barks, leaves and other biota. These are transmitters of the anomalous ecological state, in which pollutants can be accumulated for a long period of time. Snow is an object of research, too. Air pollution investigation is of great importance because many pollutants are concentrated in the atmosphere. The direct study of the magnetic properties of air samples were performed by Spassov et al. [13] for a fast quantification of urban pollution sources in atmospheric particulate matter. The PM10 samples were collected on fibre-glass filters using a high-volume air sampler.

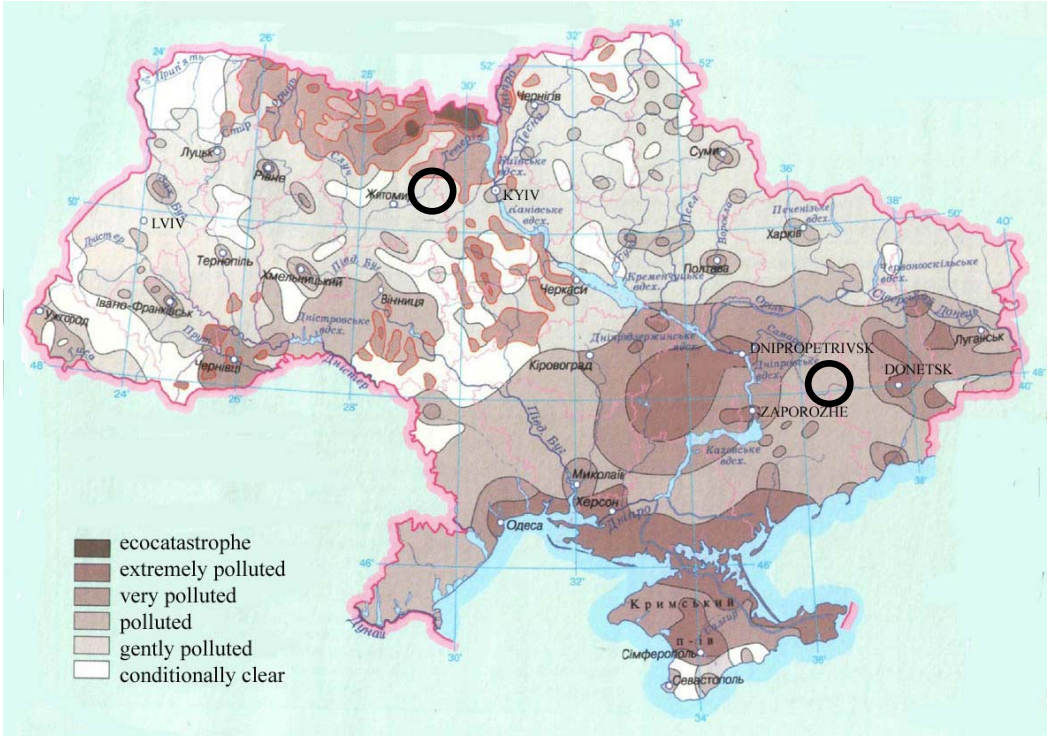

Figure 1. Map of pollution levels on the territory of Ukraine. The rings indicate the areas under study

City soils are not soils in their original meaning. Soils are unpolluted under city conditions only within forest and park areas. The specific type of soil is named urbanozem [4] (urbanosoil or anthroposols). Urbanozem is a genetically independent type of soil. It has both the natural soil and anthropogenic properties. Urban soils profile *increases* often resulting from anthropogenic accumulation of different materials. These include both household refuse and industrial waste. There are urban anthropogenic compounds in the structure of the soil. High vertical and horizontal zoning, series of buried historical, archaeological and soil layers occur in urbanozems.

In order to investigate urban soils, Kyiv was divided into a few key areas. 120 samples were taken to analyze magnetic susceptibility of the soils and the heavy metals content. Donetsk is the main city of the Donetsky coal-field, which is the driving force behind the industrial development of the city. Its population is about 1 million people. The values of the magnetic susceptibility of the urbanozem soils in different districts of Donetsk were obtained for 50 samples.

To measure magnetic susceptibility, we used the Bartington MS2 and AGICO Kappabridge.

Results and discussion

Research into soils of the capital of Ukraine (Kyiv) and the main industrial center of Ukraine (Donetsk) shows a close correlation between magnetic susceptibility of soils, heavy metals concentrations, and the sampling area. The distribution of the urbanozem soils magnetic susceptibility in different districts of Donetsk is presented in Table 1.

Figure 2 presents the distribution histogram of average magnetic susceptibility values for Donetsk region.

Table 1

The distribution of magnetic susceptibility of the urbanozem soils in different districts of Donetsk

№	District	Street	MS*10^{-9} m^3/kg
1	Kirovskiy	Fruktovaya	1934
2	Leninskiy	Leninskaya	3303
3	Leninskiy	Pintera	607
4	Proletarskiy	Razdolnaya	1063
5	Voroshilovskiy	Komsomolskiy Ave.	1173
6	Voroshilovskiy	Teatralniy Ave.	2531
7	Kalininskiy	Vladichanskogo	2078
8	Kievskiy	Universitetskaya	1694
9	Kuibishevskiy	Yugoslavskaya	7755
10	Budenovskiy	Zasulich	652
11	Kievskiy	Prosp. Kievskiy	2071

The registered values of magnetic susceptibility on the territory of Donetsk are between 2 and 50 times higher than those observed for natural soil types. The lowest magnetic susceptibility (MS=600-700*10^{-9} m^3/kg) was registered in Leninskiy and Budenovskiy districts of Donetsk. The most probable values of magnetic susceptibility (MS=1000-3000*10^{-9} m^3/kg) are in Kirovskiy, Voroshilovskiy, Kalininskiy, and Kievskiy districts of Donetsk. The highest values of magnetic susceptibility registered on the territory of Donetsk were in Leninskiy and Kuibishevskiy (Yugoslavskaya Street) districts. And the most considerable anomalies were found in the chemical plant zone (MS=7000-8000*10^{-9} m^3/kg).

The average values of magnetic susceptibility for the soils of different districts of Donetsk ranged between 1000-3000*10^{-9} m^3/kg. This is 2 to 6 times higher than in non-polluted soils. The soil samples with magnetic susceptibility of up to 6000*10^{-9} m^3/kg were collected in Kuibishevskiy (Yugoslavskaya Street) district. The left asymmetry was composed with the samples from Leninskiy and Bude-

novskiy districts of Donetsk. The magnetic susceptibility is 600-700*10^{-9} m^3/kg.

The correlation coefficients between magnetic susceptibility and heavy metals content in Kyiv urbanozems are presented in Table 2. The investigations were conducted in 5 zones of Kyiv with different levels of anthropogenic and technogenic impact.The highest correlation coefficients were between magnetic susceptibility and Zn, magnetic susceptibility and Pb, lower for Cu. An increase in MS values accounts for the growth of Pb, Cu and Zn concentrations in soils.

For example, the correlation between Ln MS and LN Pb for Kyiv Koncha-Zaspa area is presented in Fig.3. The correlation coefficient value is 0.9, this being the highest among the statistical samples.

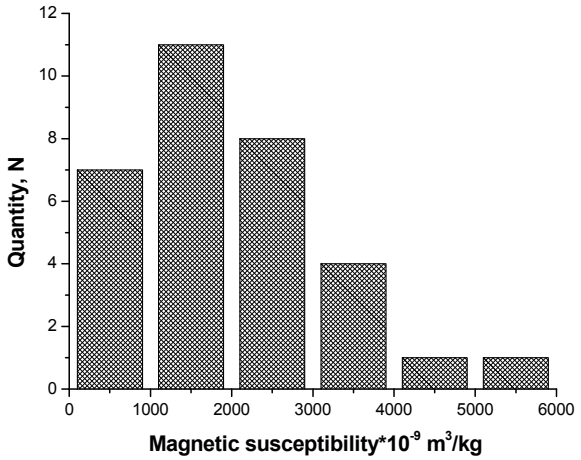

Figure 2. The distribution histogram of average magnetic susceptibility values for the soils of Donetsk districts

Table 2

The correlation coefficients between magnetic susceptibility and heavy metals content in Kyiv soils

Area	*Heavy metals*		
	Cu	**Zn**	**Pb**
Koncha-Zaspa	0.5	0.9	0.9
Kiyv-Dniprovskiy	0.8	0.7	0.8
Darnitsa	0.3	0.9	0.4
Svatoshino-Pusha-Vodytsa	0.8	0.6	0.6
Golosievo	0.5	0.9	0.9

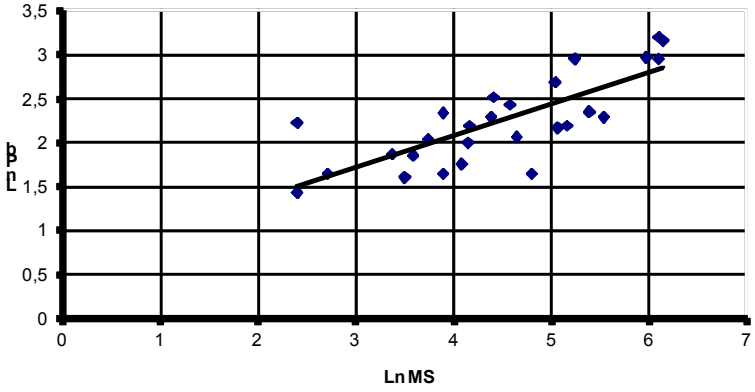

Figure 3.The regression between Ln MS and LN Pb for Koncha-Zaspa area, Kyiv

The positive correlation can be explained in terms of the single factor causing an increase in both parameters. A good example would be alphitite, which accumulates heavy metals and magnetic materials. According to Spassov et al. [13], some heavy metals are readily absorbed into the surface of iron oxides. Heavy metals have a high affinity towards iron oxides. They tend to occur as particulate matter smaller than 10 μm (PM10) or may penetrate their crystal lattice under high-temperature technological processes (fly ash).

Conclusions

The registered values of magnetic susceptibility on the territory of Donetsk were 2-50 times higher than those for natural soil types.

1. For the territory of Kyiv, the highest correlation coefficients were between magnetic susceptibility and Zn, magnetic susceptibility and Pb, lower for Cu. An increase in MS values accounts for the growth of Pb, Cu and Zn concentrations in soils.

2. Positive correlation between magnetic susceptibility and heavy metals content can be put down to the presence of particulate matter smaller than 10 μm (PM10) which may penetrate the crystal lattice under high-temperature technological processes.

3. We have emphasized the necessity for urban geophysical investigations on the territory of big industrial cities and megalopolises, with Ukrainian cities examples used as an illustration. The magnetic properties of city soils – urbanozems, snow and air – correlate with industrial dust, heavy metals and other city pollutants. The magnetic method has proved to be appropriate, low-cost and quick for this type of investigation.

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Received by Editorial Board on 30.08.13

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МАГНІТНА СПРИЙНЯТЛИВІСТЬ ТА НАКОПИЧЕННЯ ВАЖКИХ МЕТАЛІВ У ГРУНТАХ УРБАНІЗОВАНИХ ТЕРИТОРІЙ УКРАЇНИ

Дослідження забруднення ґрунтових покривів є частиною вивчення магнетизму навколишнього середовища. Основними об'єктами досліджень є важкі метали у ґрунтах та їх хімічний склад. Відповідні небезпечні речовини накопичуються у ґрунтах та водночас є небезпечними для життєдіяльності людини.

Мета. Дослідження магнітних властивостей забруднених грунтів при різних техногенних джерелах впливу на навколишнє середовище.

Методика. Польовий етап робіт включає еколого-ґрунтознавчі роботи, вимірювання об'ємної магнітної сприйнятливості польовими капаметрами, відбір зразків ґрунтів. Лабораторні дослідження складаються з вимірювання питомої магнітної сприйнятливості лабораторними капаметрами типу AGICO, MS2, вимірювання намагніченості, магнітної жорсткості, параметрів петлі гістерезису за допомогою рок-генератора і спеціальної магнітометричною апаратури, визначення елементного складу, електронна магнітна мікроскопія. Останнім етапом виступає комплексний аналіз та інтерпретація отриманої інформації.

Результати. Наведено результати вивчення магнітних властивостей забруднених ґрунтів території Києва та Донецька. Виявлено, що магнітна сприйнятливість заражених ґрунтових покривів – урбаноземів, може підвищуватися у багато разів у верхніх гумусних горизонтах. Вивчення магнітної мінералогії показує, що в процесі високотемпературних реакцій відбувається формування нових магнітних частинок величиною до 10 мкм (PM частинки). Відзначені високі коефіцієнти кореляції між магнітною сприйнятливістю і вмістом в заражених ґрунтах свинцю, цинку, міді.

Наукова новизна. Встановлено зв'язок між магнітною сприйнятливістю і техногенним навантаженням на урбанізовані території України. Важкі метали часто приклеюються до поверхні феромагнетиків, потрапляють до структури їх кристалічної решітки в процесі високотемпературних техногенних процесів, а потім ці сполуки накопичуються у ґрунтах.

Практична значимість. Наступні дослідження інформативності магнетизму ґрунтів в екології пов'язуються з розробкою оптимальної технології картування ґрунтових покривів урбанізованих територій магнітними методами. Екомагнітне дослідження є експресною, дешевою і високоефективною технологією оцінки техногенного впливу на навколишнє середовище.

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МАГНИТНАЯ ВОСПРИИМЧИВОСТЬ И НАКОПЛЕНИЕ ТЯЖЕЛЫХ МЕТАЛЛОВ В ПОЧВАХ УРБАНИЗИРОВАННЫХ ТЕРРИТОРИЯ УКРАИНЫ

Исследование загрязнения почвенных покровов является часть магнетизма окружающей среды. Основными объектами, которые загрязняют окружающую среду и при этом опасны для жизни человека, а также фиксируются магнитными методами, выступают тяжелые металлы и некоторые другие химические соединения.

Цель. Изучение магнитных свойств почв загрязненных вследствие техногенного влияния на территорию различных источников.

Методика. Полевой этап работ включает эколого-почвоведческие работы, измерение объемной магнитной восприимчивости полевыми капаметрами, отбор образцов почв. Лабораторные исследования состоят из измерения удельной магнитной восприимчивости лабораторными капаметрами типа AGICO, MS-2, измерения намагниченностей, магнитной жесткости, параметров петли гистерезиса с помощью рок-генератора и специальной магнитометрической аппаратуры, определение элементного состава, электронная магнитная микроскопия. Последним этапом выступает комплексный анализ и интерпретация полученной информации.

Результаты. Приведены результаты изучения магнитных свойств загрязненных почв Киева и Донецка. Выявлено, что магнитная восприимчивость зараженных почвенных покровов – урбаноземов, может повышаться во много раз в верхних гумусных горизонтах. Изучение магнитной минералогии показывает, что в процессе высокотемпературных реакций происходит формирования новых магнитных частиц величиной до 10 мкм (PM частицы). Отмечены высокие коэффициенты корреляции между магнитной восприимчивостью и содержанием в зараженных почвах свинца, цинка, меди.

Научная новизна. Установлена связь между магнитной восприимчивостью и техногенной нагрузкой на урбанизированные территории Украины. Тяжелые металлы часто приклеиваются к поверхности ферромагнетиков, попадают в структуру их кристаллической решетки в процессе высокотемпературных техногенных процессов, а затем эти соединения накапливаются в почвах.

Практическая значимость. Последующие исследования информативности магнетизма почв в экологии связываются с разработкой оптимальной технологии картирования почвенных покровов урбанизированных территорий магнитными методами. Экомагнитные исследования являются экспрессной, дешевой и высокоэффективной технологией оценки техногенного влияния на окружающую среду.