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Soil quality — Guideline for the screening of soil polluted with toxic elements using soil magnetometry

Qualité du sol — Lignes directrices pour le criblage du sol pollué par des éléments toxiques en utilisant la magnétométrie du sol

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Foreword

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This document was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 3, *Chemical and physical characterization.*

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

At the time of publishing this document, the mapping of soil pollution status is generally based on geochemical methods that, despite development of new, more sophisticated and precise equipment, have apparent disadvantages, among them uncertainty, as usually there is no satisfactory information on the extent and range of pollution in the area. This results in the need of a large number of samples to be collected, followed by expensive and time-consuming chemical analysis.

Among anthropogenic soil pollutants, trace elements [potentially toxic elements (PTEs)] are the most problematic, widespread and persistent group that has accumulated in soil since the beginning of industrial revolution, mostly due to dry and wet deposition of particulates originating from emissions to the atmosphere. Due to the historical and persistent character of pollution, determination of soil quality, sources, extent and range of pollution requires large-area dense environmental monitoring network. In addition, identification of sources, pathways and extent of long-range transboundary transport of airborne trace elements creates serious technical problems and uncertainties. This has resulted in the development and broad application of soil magnetometry as easy-to-use, quick, inexpensive but sensitive and reliable screening geophysical technique based on the measurements of magnetic susceptibility in topsoil.

The method has not yet been standardized. For this purpose, a standard procedure, protocols and guidelines for the using soil magnetometry as a screening method are developed primarily to support the implementation of the two-stage optimized geophysical/geochemical method of measuring the soil spatial anthropogenic pollution with airborne trace elements from the dry and wet deposition, for further delineation of polluted soil areas to be adequately managed. The method provides data on the volume-specific magnetic susceptibility, κ, which reflects cumulative anthropogenic pollution of soil with trace elements, expressed as a PLI. The method is intended to serve as a screening and early warning system to be applied at any scale, from local to large regional one, also for the investigation of a long-range airborne element transport.

The application of this screening method alone does not allow determining the kind and concentrations of specific trace elements in soils. To carry out a more precise survey of the anthropogenic soil pollution with airborne trace elements, soil magnetometry as the screening geophysical "in situ" measurement technique (the 1st stage) is to be integrated with the classical geochemical methods (the 2nd stage) of the optimized procedure. Specifically, on the basis of geophysical methods used for screening, a relevant dense geochemical monitoring network can be applied in the areas of diagnosed elevated risk, thus reducing the number of samples and chemical analyses required.

Soil quality — Guideline for the screening of soil polluted with toxic elements using soil magnetometry

1 Scope

This document specifies methods for the measurements of magnetic susceptibility of soils (κ) as an indicator of potential soil pollution/contamination with trace elements associated with technogenic magnetic particles (TMPs) and describes related procedures, protocols and guidelines to be applied as a screening geophysical method of determination of soil pollution with trace elements. The results of measurements are used for preparing the maps of magnetic susceptibility of soils in the area of interest. From these maps, the areas of elevated and high magnetic susceptibility indicating high trace element total pollution load are discriminated for further identification of pollutants by geochemical methods.

This document is applicable to screening all TMPs-related anthropogenic emission sources including long-range transport of airborne elements, of which TMPs are carriers and indicators. Such emission sources comprise the majority of high-temperature industrial processes, where iron is present in any mineralogical form in raw materials, additives or fuels, is transformed into ferrimagnetic iron oxides (e.g. fossil solid and liquid fuels combustion, metallurgy, cement and ceramics industry, coke production, industrial waste landfills, land transport). This document is not applicable to screening anthropogenic emissions not associated with TMPs, e.g. organic pollutants or emissions from agricultural sources.

NOTE 1 Copper, zinc and other non-ferrous metal ores also contain iron (in many sulfides) as this element is abundant in almost all environments. During smelting, the iron occurring in sulfides is transformed into ferrimagnetic oxides (TMPs). However, in such cases, the proportion of TMPs and related PTEs is usually less than at coal combustion or iron metallurgy, for example, and not all PTEs are physically associated and transported by TMPs. Non-airborne elements are deposited in the close proximity of the emission source, while TMPs can be used in these cases as indicators of airborne elements and of the spatial distribution of the total element deposition from a smelter in the area.

In rare cases, some soils are developed on bedrock exhibiting geogenically high magnetism, which can cause false-positive results. This influence can, however, be easily indicated by measurements of magnetic susceptibility along soil profiles. This method is not applicable when the bedrock exhibits extremely high magnetic signals.

NOTE 2 Such cases are rare.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
topsoil
upper part of a natural soil that is generally dark coloured and has a higher content of organic matter and nutrients when compared to the (mineral) horizons below, excluding the humus layer

Note 1 to entry: For arable land, topsoil refers to the ploughed soil depth, while for grassland it is the soil layer with high root content.

3.2
subsoil
natural soil material below the *topsoil* (3.1) and overlying the parent material

Note 1 to entry: All or much of the original rock structure has been obliterated by pedogenic processes.

3.3
technogenic magnetic particles
different mineral forms of iron oxides exhibiting magnetic properties that are components of anthropogenic emissions from high-temperature technologic processes and are carriers of airborne trace elements

3.4
soil magnetometry
geophysical survey technique used for mapping spatial variations in the magnetic properties [mostly *magnetic susceptibility* (3.5)] of *topsoil* (3.1) and *subsoil* (3.2)

3.5
magnetic susceptibility
measure of the ability of a material to be magnetized expressed in SI magnetic units, which is proportional to the concentration of *technogenic magnetic particles* (3.3) in *topsoil* (3.1), indicating cumulative anthropogenic contamination of soil with trace elements

3.6
mass magnetic susceptibility
magnetic susceptibility (3.5) divided by density of sample material, measured in a laboratory when the mass of measured sample is known

3.7
frequency dependence of magnetic susceptibility
χ_{fd}
parameter revealing presence of superparamagnetic particles, being the result of natural (pedogenic or biogenic processes)

3.8
magnetic susceptibility mapping
development of 2D or 3D maps with the use of measured data of *magnetic susceptibility* (3.5) in the area of interest correlated with pollution load index

3.9
pollution load index
dimensionless index showing cumulative anthropogenic pollution of soil with trace elements used to validate results of *magnetic susceptibility* (3.5) screening

3.10
contamination factor
ratio of specific metal concentration in soil and its background value in soil

3.11
natural background concentration
concentration of a substance that is derived solely from natural sources (i.e. of geogenic origin) commonly expressed in terms of average, a range of values or a natural background value

Note 1 to entry: For the practical purposes of this document, this is mean element concentration in subsoil measured in soil cores collected from studied area.

3.12
soil core
core collected from an uppermost soil layer (min. 200 mm long and 35 mm in diameter)

3.13
boundary depth
depth in soil profile where *magnetic susceptibility* (3.5) stabilizes after decreasing from its maximum value, indicating the transition from the polluted layer to unpolluted part of soil profile

4 Symbols and abbreviated terms

PTE	potentially toxic trace element
TMP	technogenic magnetic particle
C_e	element concentration in a sample
$C_{Bl\text{-}e}$	baseline value for an element *e*
CF_e	contamination factor
PLI_{SITE}	pollution load index
κ	magnetic susceptibility
χ	mass magnetic susceptibility
χ_{fd}	frequency dependence of magnetic susceptibility

5 Fundamentals

5.1 Screening principle

Magnetic iron oxides are components of industrial and urban dusts emitted to the atmosphere and deposited on the soil surface. Anthropogenic emission sources of pollution containing technogenic magnetic particles (TMPs) comprise metallurgy, combustion of fossil fuels, coke industry, cement and ceramic industry, land transport, waste landfill sites and others.

Volume-specific magnetic susceptibility κ is directly proportional to the concentration of magnetic particles within the sensor penetration area and reflects cumulative anthropogenic contamination of soil with PTEs. High interdependence between the total historic dust dry and wet deposition, and magnetic susceptibility has been well confirmed. Magnetic susceptibility can be measured quickly and accurately in trace amounts as validated in Annex D. Magnetic susceptibility mapping of an area of interest based on the measurements of magnetic susceptibility in topsoil (soil surface and uppermost horizons), correlates with cumulative anthropogenic pollution with airborne trace elements expressed as pollution load index (PLI). Annex A describes the relation between magnetic susceptibility and trace element contamination taking place in topsoil.

5.2 Screening work processes

This screening method consists of two or three steps. All measurements may be performed either in the field only (two-step procedure), or as field and laboratory works (three-step procedure):

— field measurements and works;

— laboratory measurements;

— data mapping.

The next step is related to the use of screening measurement data maps with delineated potentially polluted areas for the targeted soil sampling within the proper geochemical analysis of soil pollution status:

— soil sampling for geochemical analysis.

5.3 Field measurements and works

Field measurements and works to be carried out are as follows:

— surface measurements of magnetic susceptibility of topsoil;

— in situ measurements of magnetic susceptibility along soil profiles (optional);

— topsoil core sampling for laboratory measurements of magnetic susceptibility along soil profiles.

5.4 Laboratory measurements

Magnetic susceptibility is measured along soil profiles in a laboratory.

5.5 Data mapping

Data mapping to be completed are as follows:

— magnetic susceptibility mapping of the area;

— delineation of contaminated sites for further geochemical analysis.

5.6 Soil sampling for geochemical analysis

Soil sampling is necessary, in case geochemical analysis is additionally arranged. See 7.5.

6 Apparatus

The following equipment and devices are used.

6.1 Field equipment

6.1.1 Field magnetic susceptibility loop sensor.

6.1.2 GPS.

6.1.3 Datalogger coupled with GPS or laptop.

6.1.4 Topsoil core sampler.

6.1.5 Plastic tubes for the topsoil core sampler.

6.1.6 Hammer.

6.1.7 Field core magnetic susceptibility meter (optional).

6.1.8 Laptop coupled with a field core magnetic susceptibility meter (optional).

6.2 Laboratory equipment

6.2.1 Dual-frequency laboratory magnetic susceptibility sensor.

6.2.2 Laboratory core magnetic susceptibility meter.

6.3 Data mapping

6.3.1 Visualization, contouring and surface modelling software.

NOTE Software used for terrain modelling, bathymetric modelling, landscape visualization, surface analysis, contour mapping, 3D/2D surface mapping, gridding and volumetrics.

7 Procedures

7.1 Measurement network

The main purpose of surface measurements of magnetic susceptibility is the determination of spatial distribution of pollution with trace elements. Basic measurements of magnetic susceptibility (κ) in the area of interest are performed in the field in a possibly regular network that is designed as discussed in Annex B.2. The grid density is selected depending on the size of an area to be screened, and the availability of preliminary information concerning possible sources and extent of anticipated pollution, but no less than 1/7 to 1/10 of the surveyed area, at the distance ratio DR approximately 1:1 to 1:2 between basic measurement points.

In the areas of identified elevated magnetic susceptibility, additional measurements should be performed close to about every third basic point, at the considerably smaller distance ratio DR approximately 1:5 to 1:10.

Within delineated areas of magnetic susceptibility higher than the average for the area, dense measurements should be carried out. The measurement points may be sited in irregular distances.

7.2 Measurements of magnetic susceptibility at the topsoil surface

Magnetic susceptibility (κ) at the topsoil surface is measured in the field with a portable hand magnetic susceptibility loop sensor in network points. The geographic position of each measurement point is recorded with GPS as is shown in the scheme in Annex B.1. Within about 2 m radius around the GPS position, at least 11 measurements (odd number) of magnetic susceptibility shall be taken. The soil surface shall be available for a sensor, thus a thick vegetation or litter in the measurement point should be racked aside.

The time needed for a single measurement is approximately 1 s.

The measurement results can be downloaded from a datalogger coupled with GPS and are ready for analysis. The downloaded table for a single measurement includes coordinates and measured values of soil magnetic susceptibility.

NOTE Extraordinary high values of magnetic susceptibility (outliers) can be caused by the occasional occurrence in topsoil layer of metallic artefacts. The possible impact of artefacts is eliminated by the rejection of the highest and the lowest values from the measured set of results when calculating mean value for a single point.