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Soil quality — Guidance on the establishment and maintenance of monitoring programmes

Qualité du sol — Lignes directrices pour l'établissement et l'entretien de programmes de surveillance

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 7, *Impact assessment*.

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.

This second edition cancels and replaces the first edition (ISO 16133:2004), which has been technically revised. The main changes compared to the previous edition are as follows:

— Clause 2 has been updated;

— Clause 3 has been updated, definitions that were not used in the document have been deleted;

— new subclauses have been introduced regarding sampling designs (5.2.4), sampling in space (5.2.5) and in time (5.2.6);

— all examples of monitoring programmes described in Annex A have been deleted as part were outdated.

Introduction

Monitoring is the process of repetitive observation, for defined purposes, of one or more components of the environment according to pre-arranged schedules in space and time using comparable methods for environmental sensing and data collection[14][15]. Monitoring schemes are used all over the world for a large number of purposes. Soil monitoring, particularly, is a long-term undertaking. The quality and the utility of the information from the monitoring is to a large degree determined by the choice of monitoring sites and by their maintenance over the years, and by appropriate quality control at all stages of the process.

Monitoring associated with industrial (contaminated) sites can involve many specific considerations, including legal requirements. The guidance in this document is not designed or intended to cover such situations.

Soil quality — Guidance on the establishment and maintenance of monitoring programmes

1 Scope

This document gives general guidance on the selection of procedures for the establishment and maintenance of programmes for long-term monitoring of soil quality. It takes into account the large number of objectives for soil-monitoring programmes.

This document is intended to help provide a basis for dialogue between parties which might be involved in a monitoring scheme.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 15903, *Soil quality — Format for recording soil and site information*

ISO 18400 (all parts), *Soil quality — Sampling*

ISO 25177, *Soil quality — Field soil description*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11074 and the following 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
anthropogenic change
change in soil properties caused by human activities

[SOURCE: ISO 11074:2015, 5.1.1, modified — “influence on” has been replaced by “change in”]

3.2
background concentration
concentration of an element or a substance characteristic of a soil type in an area or region arising from both natural sources and anthropogenic diffuse sources such as atmospheric deposition

[SOURCE: ISO 11074:2015, 3.5.1, modified — in the definition, “an element or” has been introduced before “a substance” and “anthropogenic” has replaced “non-natural”. Note 1 to entry has been removed.]

3.3
habitat
sum of the environment of a particular species or community (e.g. in terms of soil properties, land use, climate)

[SOURCE: ISO 23611-6:2012, 3.2.2]

3.4
monitoring site
area in which investigations take place

Note 1 to entry: Such an area is usually chosen to be relatively homogenous.

[SOURCE: ISO 11074:2015, 5.1.5 modified — the following part of the definition "such an area is usually chosen to be relatively homogenous" has been moved to Note 1 to entry]

4 Monitoring objectives

4.1 General

Monitoring programmes provide baseline soil information and help in deriving soil quality values for managing soils (e.g. to verify soil quality after the implementation of remediation actions in contaminated sites).

Monitoring is also an important tool for the early detection of changes in soil properties and soil processes[16]. It, thus, has a major role in the prevention or minimization of environmental damage or the detection of environmental improvement. By the early detection of environmental impact, or the potential for such impact, a monitoring programme could help to reduce or remove the costs of reaching or maintaining a given level of environmental management, protection or quality.

Monitoring programmes can also be used to evaluate the outcome of environmental policies, to assist in the development of strategies for soil protection and environmental management. They can also serve as research platforms for the development and validation of field and analytical methods and of models of soil and related environmental processes.

The range of purposes for which soil-monitoring programmes can be designed encompasses such a vast range of time scales, variables and processes that it is not possible to give specific guidance on the design of a monitoring programme to meet all the objectives which might be covered by this diversity. The selection of sites, sampling schemes, etc. should be made following consideration of the specific objectives of the particular monitoring programme. This document identifies the principles underlying such programmes.

4.2 Examples of monitoring purposes

Some examples of monitoring purposes might include the need to establish one or more of the following:

— short-, intermediate- and long-term environmental impacts varying in magnitude, importance, duration and probability;

— changes in chemical, biological and physical soil properties (e.g. pH, adsorption processes, toxic element accumulation, radiation, compaction, erosion) and the dynamics of changes in such properties;

— effects of human impacts;

— differentiation of human impacts from inter-annual variability and longer-term climate change;

— differentiation of local contamination from long-range transport;

— evaluation of productivity;

— assessment of biological diversity;

— input of elements into the soil environment and output of elements from the soil environment;

— transport processes in the soil profile (gases; particles; elements or compounds in solution);

— calculations of uptake and retention of elements, compounds or substances by particular components of the ecosystem.

5 Monitoring programme

5.1 General considerations

It is generally not feasible to monitor all variables at all locations of the studied area. Wherever possible, consideration should be given to the monitoring of soil properties which, as well as being of specific interest themselves, might also act as a surrogate for some property or process which is otherwise difficult, time consuming or expensive to measure directly. For example, soil pH, organic matter concentration and clay content (a potential surrogate for soil hydrological behaviour) might act as factors for ranking pollutant mobility. It will be important to establish what long-term records already exist at a site before identifying additional variables for monitoring and what degree of continuity of measurement is required into the future. The close reciprocal benefits of monitoring and research on specific scientific questions should be considered.

The final series of potential monitoring options should be ranked according to their value (such as scientific relevance, sensitivity to impacts, value as an index for changes in many other environmental variables that are not measured) and feasibility (such as financial, logistic, analytical, ease of interpretation). This prioritization should be revised and updated at regular intervals. The costs of appropriate storage of samples and long-term quality assurance, such as cross-checking when improvements in analytical techniques are made, should not be underestimated.

Identification of habitat types is a key element of the monitoring plan, and is also a logical starting point for the development of an environmental monitoring strategy. It is also necessary to consider the number of sites that might be required to give appropriate spatial and temporal cover for the monitoring, and whether the site density is appropriate for all variables. It is usually impractical to establish sites that cover all combinations of soil and habitat. Consideration needs to be given, for example, to combinations that are most common or most sensitive to a given impact. It should be remembered that other research, into e.g. water quality or biodiversity, might be possible on the same site, thus adding to its value.

It is very strongly recommended that all parties to a long-term monitoring programme agree to the objectives, funding, mutual responsibilities and other relevant issues before a monitoring programme begins, and that they enter into a formal agreement which defines each party's role in the programme, including financial and legal constraints.

Some other factors that have to be considered are the following:

— partners and organizations involved, and an assessment of their objectives and long-term commitment;

— existing guides, protocols and quality standards, and the degree to which they satisfy the objectives of the programme;

— access to the sites both in terms of physical and legal aspects (a long-term commitment of owners of the monitoring sites is usually required);

— availability of sites;

— long term storage of the samples and their availability;

— effects of future changes in land use (if this is an important factor), or the landscape in the vicinity of the site(s) since changes might affect the usefulness of the site in the long term;

— the funding of the programme, and its long-term security;

— quality assurance, including documentation (see below);

— data management, accessibility of the data, intellectual property and issues of confidentiality and rights to publish.

5.2 Elements of a monitoring programme

5.2.1 Status of the monitoring sites

The history of all sites, which might be considered, should be documented. This is an essential part of any assessment of representativeness, and ensures that the chances of unexpected influences that might jeopardize the usefulness of the site, are minimized. Such assessment can involve the characterizing of present-day soil properties at representative sites. Issues such as ownership, access, etc. (see 4.1) can usually be resolved at this stage. Information about other monitoring programmes forms part of this preliminary investigation.

NOTE Guidance on the preparation of site histories is provided in ISO 18400-202.

5.2.2 Changes at the monitoring sites

The purpose of measuring change in soil properties should be clear from the start. It may also be useful to invert the question and ask what changes could be measured using such a particular site or programme design, even if all the properties might not be required at the start. Sites which allow expansion of activity for future needs can have advantages over more limited sites. It might be that one purpose of the programme is to establish changes in soil properties (e.g. pH, organic matter content, levels of toxic substances, water permeability, microbiological activity) and the dynamics of changes in such properties over shorter rather than longer time scales. This has large implications for the amount of soil sampling, and thus site disturbance, which the site might have to accommodate without having its functions seriously affected. The possibility of investigating other environmental compartments can make one site a more attractive proposition than another, especially if it interests a larger group of researchers, funders, etc.

5.2.3 Interpretation of status and changes

The data on status and changes may be used to interpret the following:

— reference/background properties;

— degradation/improvement of one or more soil characteristics and functions (and the effect of this on other soil or site properties);

— short-term and long-term environmental impact and bioavailability of extraneous inputs, applied wastes, atmospheric or water-borne substances or off-site management;

— ecological functions of soils;

— productivity functions of soils;

— influence on other environmental compartments, or of these on the soils at the site.

5.2.4 Statistical sampling design

The sampling in space of the sites has to be designed considering the statistics needed to estimate the parameters and their uncertainty[17][18]. This is a major decision for interpreting data between locations and in time (e.g. variation of a parameter, confidence intervals). Two fundamentally different sampling approaches can be distinguished, the design-based approach (e.g. random or probability sampling) followed in classical survey sampling and the model-based approach followed in geostatistics and in time series analysis[19].

In a design-based or probability sampling approach, the estimation of the statistical parameter of interest, for instance the mean or the total, and its standard error is based on the inclusion of the

probabilities of the sampling units. These probabilities are determined by the sampling design. This requires that the sampling units are selected by probability sampling (e.g. all the coordinates of the sites are randomly selected). Probability sampling is a sampling technique wherein the sites are gathered in a process that gives all the individuals in the population a known probability of being selected.

In a model-based approach, the statistical inference is based on a model of the spatial variation (e.g. using a grid design will require a variogram as a model). Randomness is introduced via the model, which is a stochastic model, i.e. it contains a random error term.

5.2.5 Selection of sites in space

The sites should be selected so that they are suitable for the objectives of the programme with respect to geology, soil type, vegetation and land use, topography, climate and ecological habitat. Other important criteria are anthropogenic changes and natural background conditions (e.g. trace element levels, acidity, salinity, buffer capacity). Other important considerations are the objectives of the programme with respect to the statistical outputs, e.g. mapping or global statistics (see also 5.2.4).

The choice of geographical distribution of monitoring sites might be influenced by the degree of pre-existing knowledge of the landscape or soil pattern. Where relatively little is known, regular grids are often the most appropriate, although this can imply considerable preliminary investigation to establish the variability of the area in question. In general, there are four main choices in the selection of geographical distribution. They are listed below without priority.

— **Regular grid.** The sites are selected using a regular grid. In order to provide representative data, this approach generally requires a large number of sites. The interval between the grid points is very dependent on the size of the area of interest. This is profitable both for mapping soil properties and for estimating spatial means or totals of these properties.

— **Cluster random sampling.** A cluster is a group of population sites that serve as sampling units. If one population site of a cluster is selected, then all other sites are also selected.

— **Stratified approach.** This is based on a stratification of soils according to land use and/or soil type, or soil horizon, on soil parent material, or soil extent, or distance from potential contamination sources, etc. This is profitable for estimating spatial means or totals of these properties only. Appropriate stratification and allocation of sample sizes to the strata will usually lead to higher precision and lower cost of estimation.

— **Hypothesis-oriented approach**. The selection of the location is not randomly chosen but evaluated on the basis of their ability to detect and quantify impacts hypothesized to result from specific human activities.

In order to make efficient use of available resources, it is always important to consider the possibilities to integrate the sites with other monitoring programmes. Both synergistic and disturbing effects (e.g. caused by sampling activities or experimental treatments) should be considered if sites are to be used for different monitoring programmes.

5.2.6 Resampling in time

Making decisions on where and when to make observations, boils down to choosing a sampling design in space and time. Such designs can be categorized on the basis of their structure in the space time domain. Four basic design types are given in References [18] and [19].

— **Fully independent**, where the individual combinations of sampling locations and sampling times, here referred to as sampling events, have no imposed ordering in space or time.

— **Static**, where the set of sampling locations remains fixed through time, but the observations at these locations are not made at the same times.

— **Independent synchronous**, where the observations are made at the same times, but not at the same locations.

— **Static-synchronous**, where observations are ordered in both space and time (synchronized as well as co-located).

These basic design types have their own pros and cons with respect to operational costs and statistical efficiency (see References [18] and [19]).

5.3 Sampling and measurement

5.3.1 General

A sampling and measurement plan is an important part of a monitoring programme. Such a plan should include procedures described in 5.3.2 to 5.3.7.

5.3.2 Site design and identification

The chosen site(s) should allow the range of measurements appropriate for the objectives of the soil-monitoring programme, and any other monitoring activities which add value to this programme. The layout of the site should allow repeated representative sampling, without compromising the overall functioning of the site or the soils within it. The site should be protected from unwanted external disturbances.

The choice of sampling points within the monitoring site depends on several factors. The sampling point might have to allow for the digging of soil-profile pits, the installation of soil instruments, repeated sampling by augers or other sampling devices, possibly the introduction of designed experiments, for example to test the effect of different cropping regimes on the properties monitored, and so on. These factors shall be estimated at the preliminary stage, and the site design modified to include them. If none of these larger factors needs to be allowed for, the sampling point may be located at the centroid of the monitoring site.

5.3.3 Soil and site description

Soil and site description should be performed in accordance with ISO 25177 and ISO 15903.

5.3.4 Sampling

Sampling includes for example the sampling strategy, sampling techniques, labelling, transport and storage. Sampling shall be done in accordance with the ISO 18400 series. Careful thought should be given to sampling schemes so as to cause minimum disturbance to the site and its properties.

5.3.5 Field and laboratory measurements

Field and laboratory measurements should be selected according to the objectives.

It is strongly recommended that the following minimum data set of chemical and physical parameters be included, as many of these underpin the interpretation of soil data in the wider context: pH, organic carbon content, cation exchange capacity, electrical conductivity, dry matter content, particle size distribution and bulk density. There is no recommended minimum data set for biological parameters, as the choice depends on the objectives. Standardized methods should be used wherever possible.

NOTE The relevant International Standards for the recommended minimum data set are given in the Bibliography.

5.3.6 Specimen banking

Depending on the purposes of the monitoring programme, it may be necessary to bank samples. In case of banking, a specified portion of each sample should be stored for future needs following the guidance in ISO 18512 as appropriate. Sufficient sample should be taken so as to allow re-analysis of many of the properties for an extended period into the future, in order to compare time series analysis without any

