Overview of procedures and standards in use at ISRIC WDC-Soils (ver. 2022)

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Preface

ISRIC - World Soil Information has the mission to create and increase the awareness and understanding of the role of soils in major global issues. As an international institution we inform a wide audience about the multiple roles of soils in our daily lives; this requires scientific analysis of sound soil information. To be most useful, all data should be findable, accessible, interoperable, and reusable in compliance with so-called FAIR principles.

The purpose of this technical report is to give an overview of main procedures and standards in use at ISRIC – World Soil Information, a regular member of the International Science Council (ISC) World Data System. As a dynamic and innovative organisation, we will issue updated versions of this document when appropriate.

ISRIC is seeking collaboration with national institutes with a mission for soil resource inventories in order to further develop its world soil information services for the benefit of the international community and build its community of practice on soil data and information.

Ir Rik van den Bosch
Director, ISRIC — World Soil Information

Summary

This report serves to give an overview of main procedures and standards in use at ISRIC – World Soil Information, regular member of the International Science Council (ISC) World Data System (WDS). These cover the whole *data life cycle* from field sampling to serving quality-assessed soil data to the world community through a range of web services, examples of which are provided. Consistent workflows, procedures and *de facto* standards are used to screen (QA/QC) and standardise respectively harmonise the wide range of soil-related data that have been shared with us for consideration in our world-covering databases and soil mapping work. Ultimately, these protocols and processes are aimed at facilitating global data interoperability and citability in compliance with FAIR principles: the data should be 'findable, accessible, interoperable, and reusable'. A recent development at ISRIC has been the implementation of a community of practice (CoP) on soil data and information; the workflows, procedures and standards described in this report may be considered as resources for the evolving community of practice.

1. Introduction

ISRIC – World Soil Information is a regular member of the International Science Council (ISC) World Data System (WDS). It has a mission to 'serve the international community with information about the world's soil resources to help addressing major global issues.' This process involves all stages of the data life cycle from data sampling in the field and laboratory analyses to collation into quality-assessed databases followed by data standardisation/analysis/modelling and publication of the data. This requires adoption and (co-)development of internationally recognised standards focussing on the soil's domain.

As indicated by RDA-CODATA (2016), the 'ability of the research community to share, access, and reuse data, as well as to integrate data from diverse sources for research, education, and other purposes requires effective technical, syntactic, semantic, and legal interoperability rules and practices'. An important aspect here is that data should be 'Findable, Accessible, Interoperable, and Reusable' that is comply with FAIR principles (Wilkinson *et al.* 2016).

This document provides an overview of (main) procedures and standards in use at ISRIC (as of August 2022) as mainly developed/implemented within the workstream on 'Global Soil Information and Standards' and applied in all four workstreams (Figure 1). As an international institute dealing with world soil information, with partners, we are working towards the maintenance and development of new, internationally, recognised standards. For example, we are proactive in working groups of the International Union of Soil Science (IUSS), the Open Geospatial Consortium (OGC), GODAN (Global Open Data for Agriculture and Nutrition), and Global Soil Partnership (GSP).

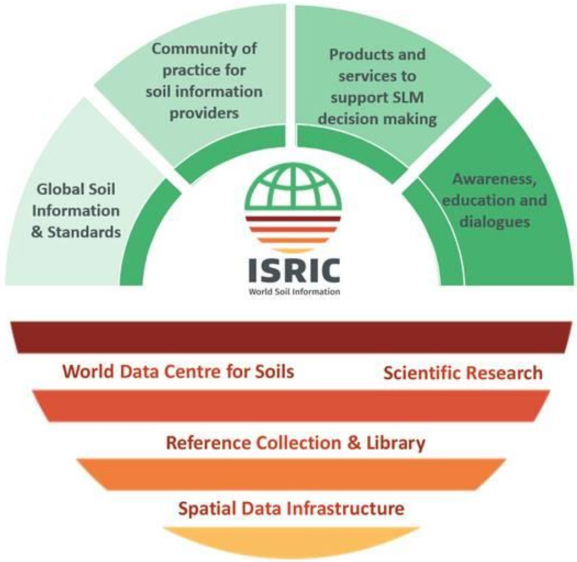

Figure 1. ISRIC's four workstreams and underpinning supporting services.

This report consists of nine Chapters, starting with an introduction (Chapter 1). Chapter two discusses standards/procedure relating to 'Data collection', involving procedures for field description, soil sampling and classification. Chapter 3 discusses laboratory analyses (wet chemistry and spectrometry-based). Procedures for taking and preparing soil monoliths and archiving these in the World Soil Museum are described in Chapter 4 under the broad title of 'Soil collection management'. Next, Chapter 5 relates to data preservation, organisation and harmonisation as well as main approaches to database development and soil mapping developed/implemented at ISRIC over the years (i.e., from traditional soil mapping to digital soil mapping) . Chapter 6 gives an overview of how we serve our digital as well as digitised resources to the international community. All soil data are prone to error that may arise along the successive stages of the life cycle, from sampling in the field to generating soil maps using digital soil mapping; our quality assurance and control practices are summarised in Chapter 7. Chapter 8 provides an overview of data policies and protocols that we follow as CTS-certified, regular member of the ICS World Data System (WDS), including procedures aimed at ensuring data privacy and handling of personal data[1]. Concluding remarks about further developments are made in Chapter 9. Appendix 1 provides a list of acronyms, while Appendix 2 provides web links to 'international standards' used in the soil domain.

ISRIC's spatial data infrastructure (SDI) is based on open software and standards, as schematised in Figure 2. Through it, we provide access to: (i) a growing range of global information products following FAIR principles, (ii) the soil reference collection and World Soil Museum, and (iii) tools and services developed to support sustainable land management decision making.

[1] https://www.isric.org/privacy-and-personal-data

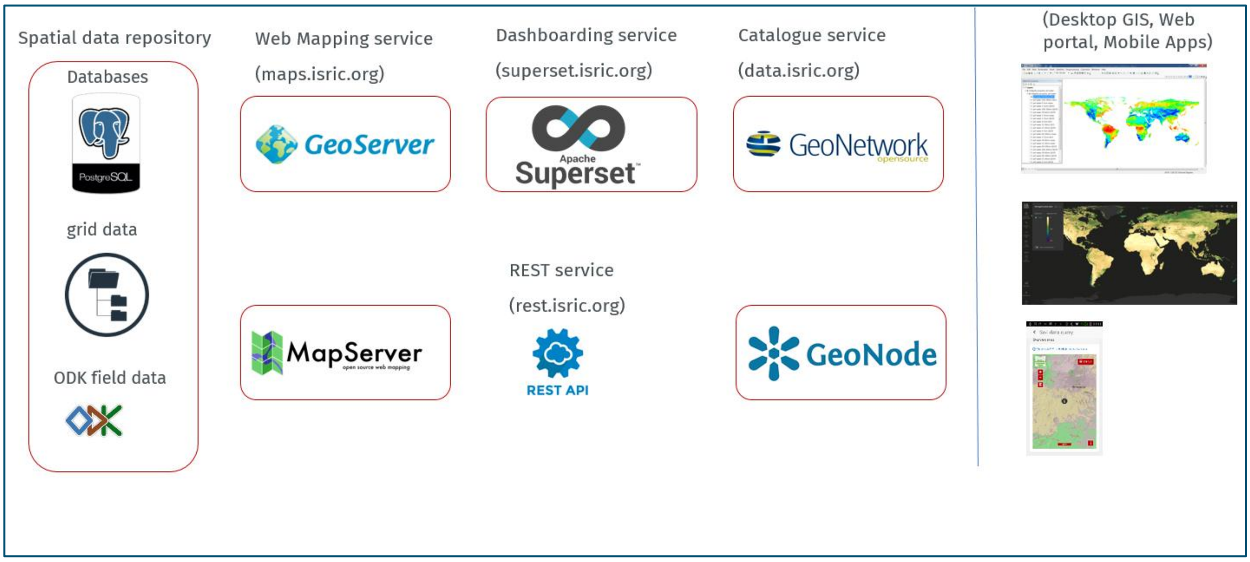

Figure 2. Main components of ISRIC's spatial data infrastructure.

Procedures and standards referred to in this report, and related webpage on 'international soil standards', may be used as resources for ISRIC's evolving community of practice (CoP[2]) on 'soil data and information' (Figure 3).

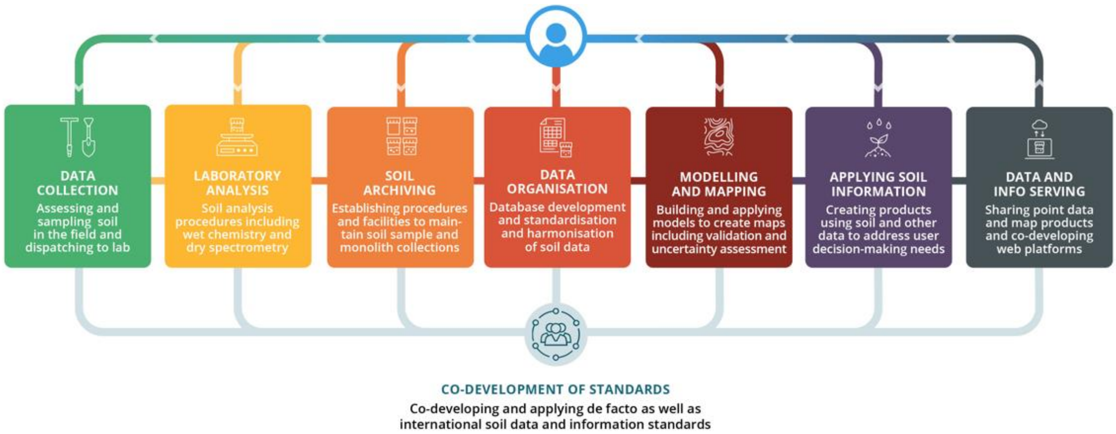

Figure 3. Main building blocks of ISRIC's Community of Practice

[2] https://www.isric.org/utilise/community-practice

2. Data collection

From its inception, ISRIC (formerly International Soil Museum) has been supporting the initiative of the UN Food and Agricultural Organization (FAO) concerning international soil characterisation in relation to the development of the Soil Map of the World (FAO-Unesco 1974; FAO 1988), its successors the Harmonised World Soil Database (HWSD, FAO *et al.* 2012) as well as an interim update thereof (WISE30sec, Batjes 2016). An important building block for this mapping work has been the use of consistent procedures for describing and sampling soils in the field.

Main procedures for field description and soil classification in use at ISRIC are described in the 'Guidelines for soil description' (FAO 2006) and 'World reference base for soil resources 2014 - International soil classification system for naming soils and creating legends for soil maps' (IUSS Working Group WRB 2015).

A concise field guide considering all field characteristics needed for WRB classification has been included in IUSS Working Group WRB (2022).

Guidelines for fieldwork and sampling protocols, as prepared for the EU Soil4Africa project, are described in Huising et al. (2022); these build upon the protocols of the 'LUCAS topsoil database' (Ballabio *et al.* 2019).

In 2020, ISRIC released the Soil Description DevTool which provides all files needed to create an Open Data Kit (ODK) form. Once uploaded and deployed, the form can be used for full soil description and assessment according to the 2006 FAO Guidelines for Soil Description; see Ruiperez Gonzalez and Janssen (2022) for details.

Further, a selection of national standards in the field of soil sampling, description and classification is presented in Hoffmann et al. (2019), see also our website.

Standard procedures for handling and preparation of soil samples for chemical and physical analyses, as developed in the framework of the Global Soil Partnership are described, in GSP-FAO (2019).

3. Laboratory analysis

3.1 Wet chemistry

Until closure of the ISRIC reference laboratory in 2001, the 'Procedures for soil analysis (6th edition)' (van Reeuwijk 2002) were used to analyse soil samples of the ISRIC soil reference collection. These procedures, as well as those of the USDA Kellogg Soil Survey Laboratory (Soil Survey Staff 2022), should be used when classifying soils according to IUSS Working Group WRB (2022).

Quality control was performed according to 'Guidelines for quality management in soil and plant laboratories' (van Reeuwijk 1998). Additional quality checks were made through round-robin tests ran by the 'Wageningen Evaluating Programmes for Analytical Laboratories (WEPAL)' (Dijk 2002). Van Leeuwen et al. (2021) demonstrated the importance of experimental measurement design and replicate measurements in the quantification of uncertainties in wet chemistry soil data.

Since 2010, soil samples collated in conjunction with the ISRIC soil exploration and sampling project (SOLEX) and newer fieldwork are sent to the National Soil Survey Center (NRCS), Lincoln NE, and analysed according to the 'Kellogg Soil Survey Laboratory Methods Manual (Ver. 5.0)' (Soil Survey Staff 2022).

According to earlier inter-laboratory comparisons, results of the ISRIC and USDA laboratories are considered to be similar for application at a broad scale (Pleijsier 1989; Vogel 1994). Presently, inter-laboratory comparisons involving a wide range of laboratories are being undertaken in the framework of GLOSOLAN (2020), as well as WEPAL (2019).

Free access to results of such comparative analyses is crucial for the desired, ultimate harmonisation of soil data collated from disparate sources (Baritz *et al.* 2014; Batjes *et al.* 2020). They are also crucial to underpin research that considers effects of measurement error in calibration and validation data to the prediction accuracy of pedotransfer functions (Cynthia van Leeuwen *et al.* 2022), digital soil mapping (Takoutsing *et al.* 2022; van der Westhuizen *et al.* 2022) and to explore the full potential of using diverse soil data (Todd-Brown *et al.* 2022).

3.2 Soil spectrometry

New soil samples collected by ISRIC to enhance the World Soil Reference collection are increasingly analysed using spectrometry. These analyses are done at the Kellogg's Laboratory in the USA.

With our partners, we are working towards a global soil spectral library and estimation service (Benedetti and van Egmond 2021; Shepherd *et al.* 2022).

Ultimately, the ambition is to add spectrometry-derived soil property estimates to the World Soil Information Service (WoSIS) in order to complement legacy data derived from wet chemistry.

4. Soil collection management

At ISRIC activities relating to soil archiving and management of physical collections resort under the auspices of the World Soil Museum, for details see Mantel (2021). Our collection of legacy reports and maps is managed in the ISRIC soil reference library (see Section 6.1).

4.2 World Soil Museum

A collection of preserved soil profiles is a very useful visual aid in teaching soil science; it can be used also for demonstration purposes or comparative studies. A soil profile may be taken from the field preserved as a lacquer peel or as a monolith, which is subsequently prepared in the workshop so that its features are shown. Both forms are more realistic than colour photographs, drawings or paintings, although these have their value as illustrations in publications.

Since 1996, ISRIC maintains the World Soil Museum, presently located on the Wageningen Campus. On display are some 80 monoliths (Figure 4), representing a selection of our collection of over 1000 monoliths covering all major soil types of the World (FAO-Unesco 1974; FAO 1988; IUSS Working Group WRB 2015). For each soil monolith we have sample data, a full profile description, soil chemical and physical data, and information on the landscape and land-use. Since 2016, this information is managed in WoSIS our central server database.

Procedures for taking and preserving soil monoliths and preparing a soil exhibition as first described by ISM (Van Baren and Bomer 1979; Bomer and van Baren 1985) have evolved over the years. Current procedures for collection management (for physical specimens) are in line with SPECTRUM requirements, see Mantel (2021).

Figure 4. Guided tour through the ISRIC World Soil Museum.

All samples in the collection have unique barcodes for ease of reference and traceability (Figure 5). New procedures for the preservation of soil monoliths that use environmentally safe impregnants are being tested in the ISRIC workshop (Figure 6). Details are provided in the 'Collection Management Policy' for the World Soil Museum (Mantel 2021).


Figure 5. Referencing of soil samples using barcodes.


Figure 6. Testing new water-borne impregnants in the ISRIC workshop.

4.2 Global Soil Museum Network

An important development has been the establishment of the Global Soil Museum Network in 2021 (Figure 7). The network promotes a wider understanding of soil by providing a supportive and collaborative space for organizations that exhibit and teach about soils. It also provides a framework for sharing best practices around soil education, sharing tools and methods for physical and online exhibitions, and collaborating on joint (digital) collections.

A first version of the mandate and structure of the Global Soil Museum Network can be found here. A review of the world's soil museums and exhibitions has recently been published (Richer-de-Forges *et al.* 2020).

Figure 7. Announcement for the launch of the Global Soil Museum Network

5. Data organisation and harmonisation

5.1 Data preservation

As a World Data Centre, since 1989, we ensure the long-term preservation of our collection of country documentation (reports, maps and slides), soil specimens (monoliths, samples, thin sections, hand specimens), as well as geo-referenced databases (point, polygon, and grid). Many of these holdings may be consulted both on site and on-line.

A substantial section of our soil map collection was digitised in collaboration with JRC-EU in the framework of the EuDASM project (e.g. Selvarajdou *et al.* 2005). Subsequently, a wider range of scanned reports and HR maps has been made available through the ISRIC on-line library (see Batjes 2007). Digitisation of the collections is ongoing and new materials[3] are welcome!

Reports and maps are assigned unique identifiers (ISN) and registered in compliance with the Wageningen University & Research library management system (http://www.isric.org/explore/library).

[3] http://www.isric.org/explore/share

As a trusted repository, ISRIC can issue its own unique identifiers (DOI) to reports and databases that result from internal and external projects; for this we have an agreement with DataCite, the Netherlands[4].

Figure 8. ISRIC adheres to international standards for research data repositories.

We follow the certificates and standards of the International Science Council (ISC) World Data System (WDS). These are in accord with FAIR principles (Susanna-Assunta and Philippe 2016; Wilkinson *et al.* 2016), and include certification against the CoreTrustSeal trustworthy data repository requirements (https://www.coretrustseal.org/). Accordingly, ISRIC, as the World Data Centre for Soils (WDC-Soils), is listed as a trusted repository in the re3data.org registry (Figure 8).

Preferred and acceptable formats for generating and submitting data are in line with those recommended by WDS, DANS (2015), and OGC. As a general guideline, according to DANS, file formats best suited for long-term sustainability and accessibility should be: 'frequently used, have open specifications, and be independent of specific software, developers or vendors.' Different levels of support are provided for the various file formats depending on whether they are proprietary or open source.

A revised list of preferred file formats for the WDC-Soils is being elaborated to better accommodate persistent open standard (OGC) formats recommended in the soil's domain.

5.2 Database development

This section enumerates the various ways in which soil data are handled and analysed at ISRIC since the early 1990's. Increasingly elaborate data management/mapping systems have been developed

[4] https://mds.datacite.org/

that take into consideration methodological and technical developments (e.g., ITC, DSM, cloud services) over time . Most of these efforts were/are carried out in collaboration with our partners.

5.2.1 ISRIC soil information system (point)

In the 1990's the ISIS stand-alone database was specially developed to store data from the ISRIC Soil Reference collection, originally in dBase format (van de Ven and Tempel 1994; Kauffman *et al.* 1996; ISIS 2015). This collection characterises a selection of monoliths with morphological, analytical data that represent the main soil reference groups of the World.

As of 2016 the ISIS holdings are handled in WoSIS, ISRIC's central server database (Ribeiro *et al.* 2020). Standardised, quality-assessed datasets served from WoSIS, however, do not consider the whole suite of attributes considered in ISIS itself, but only a subset commonly required for global modelling (Batjes *et al.* 2019; Laura Poggio *et al.* 2021).

The full complement of ISIS holdings can be consulted on-line at http://isis.isric.org. Further, the ISIS holdings can be consulted through the ISRIC virtual soil museum at: http://wsm.isric.org.

5.2.2 SOTER world soil and terrain database (point, polygon)

SOTER aimed to establish a World Soils and Terrain Database, at scale 1:5 M, containing digitised map units and their attribute data in standardised format. The programme was implemented in 1986 by FAO, UNEP and ISRIC, under the aegis of the IUSS, to be carried out in collaboration with a wide range of national soil institutes. ISRIC played a lead role in methodology development and programme implementation, and *de facto* standard setting (Oldeman and van Engelen 1993; Van Engelen 2011; van Engelen and Dijkshoorn 2013).

Global coverage in SOTER was never achieved, for various reasons (Nachtergaele 1999; Nachtergaele and Oldeman 2002; Sanchez *et al.* 2009), but a range of databases at continental, regional and national scale were developed (see here). These databases provided the soil-geographical basis for large sections of the Harmonised World Soil Database (FAO *et al.* 2012).

In 2015, all point (profile) data from SOTER were incorporated in WoSIS (Ribeiro *et al.* 2018). The full SOTER databases themselves, including the GIS files and attribute files in MS Access® format, are available through ISRIC's Soil Data Hub (https://data.isric.org).

The SOTER data model, an empty (attribute) database that can be used to build a SOTER (Soil and Terrain) database for any given region, is available at https://www.isric.org/soter-data-model. The most recent version (v3) was created in the framework of the EU SOTER Danube project (Batjes and Ribeiro 2019).

Typically, SOTER databases are compiled in collaboration with national partners as these hold the rights to the necessary soil data. Main steps required to create the geographical and spatial components of a SOTER database have been summarised in a small report (Batjes 2022).

5.2.3 WISE world soil database (point, grid)

The WISE project, generally known as the 'World Inventory of Soil property Estimates' project, has developed homogenized sets of soil data, linked to a spatial data set, relevant for a wide range of environmental studies at global scale, such as agro-ecological zoning, assessments of crop production, soil vulnerability to pollution, soil carbon stocks and change, and soil gaseous emission potentials (Batjes and Bridges 1994; Batjes *et al.* 1997; Bouwman *et al.* 2002; Maire *et al.* 2015; Batjes 2016; Stoorvogel *et al.* 2017).

An important element of the WISE project has been to develop consistent procedures for filling gaps in measured soil (profile) data using taxotransfer rules (Batjes *et al.* 1997; Batjes 2003). These procedures have been used to fill soil analytical gaps in primary SOTER databases, thus making these suited for modelling applications (Batjes *et al.* 2007). The resulting 'SOTWIS' databases provided the soil attribute data for large sections of the Harmonised World Soil Database (FAO *et al.* 2012). An updated version of the taxotransfer rules was applied to develop the WISE30sec database (Batjes 2016).

WISE-related activities have been terminated in 2016, see here for an overview of WISE-related datasets. ISRIC's current focus is on generating soil property maps derived from digital soil mapping (Hengl *et al.* 2014; L. Poggio *et al.* 2021).

All point holdings from WISE were incorporated in WoSIS in 2015 (Ribeiro *et al.* 2018).

5.2.4 Africa soil profile database (point)

The Africa Soil Profiles Database (AfSP) is a compilation of soil profile records from a wide range of sources (Leenaars, van Oostrum*, et al.* 2014). The database itself was compiled in support of the Africa Soil Information System (AfSIS 2016) in conjunction with the GlobalSoilMap project. Soil attribute values in AfSP are standardised according to SOTER conventions and evaluated according to routine rules. As of 2015, all point holdings from AfSP have been incorporated into WoSIS (Ribeiro *et al.* 2018), and the AfSP itself is no longer maintained.

5.2.5 World soil information service (point)

From 2015 ISRIC has been developing a centralised and user–focused server PostgreSQL-database, known as ISRIC World Soil Information Service (WoSIS), that draws on contributions from many data providers. The aims are to:

1. Safeguard world soil data 'as is' (especially for soil legacy data).
2. Share soil profile data upon their standardisation and harmonisation.
3. Provide quality-assessed input for a growing range of environmental applications.

WoSIS includes the holdings from all our former stand-alone databases (i.e., ISIS, WoSIS, AfSP and SOTER). Any duplicate profiles have been removed/flagged in the process, see Ribeiro et al. (2018). Subsequently, these holdings have been augmented with contributions from a wide range of international partners.

Ultimately, the quality assessed and standardised respectively harmonised 'shared' data are made available to the international community through several web services and in various formats (Ribeiro *et al.* 2018; Batjes *et al.* 2020). An important aspect of WoSIS is the development of consistent procedures for describing disparate soil analytical method descriptions under a common (*de facto*) standard using 'operational definitions' in which analytical methods are grouped according to their main characteristics. This work is partly carried out in support of Pillar 5 (Harmonisation) of the Global Soil Partnership (FAO-GSP 2014a).

The initial list of soil properties served from WoSIS was based on the GlobalSoilMap (2015) specifications, but has since been expanded to include a wider range of soil properties (Batjes *et al.* 2020), see here for a short overview. At present, we serve standardised soil data (over 200,000 points) for large parts of the world (Figure 9).

Related procedures and standards include 'ISO 2016. ISO/TC 190 - Soil quality (standards catalogue), and 'ISO 28253:2013 Soil quality -Digital exchange of soil-related data', which considers ISO 19156 observations and measurements (OM) for use in soil science (see also Cox and David 2011; OGC 2013).

Additional information can be found at FAQ – WoSIS.

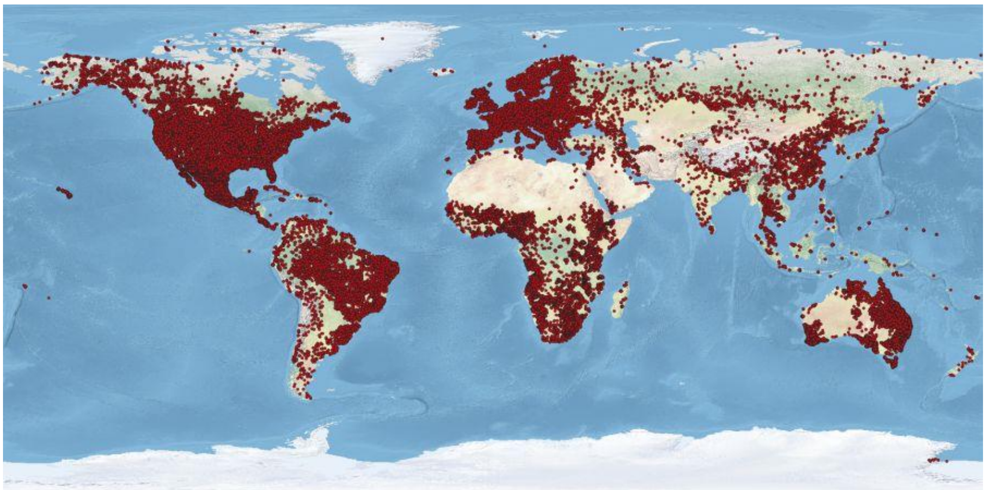

Figure 9. Location of soil profiles provided from WoSIS via WFS (December 2021)

5.2.6 Soil property mapping (SoilGrids)

SoilGrids™ predictions (Figure 10) are generated at ISRIC as a result of international collaboration. SoilGrids™, a system for automated soil mapping based on global soil profile and covariate data, produces a collection of updatable soil property and class maps of the world. It uses machine learning and statistics (L. Poggio *et al.* 2021). Currently, products are generated at three resolutions (i.e., SoilGrids5000m, SoilGrids1000m, SoilGrids250m) to accommodate a diverse user community. For example, SoilGrids^{TM} predictions can be used to support mapping activities of the Global Soil Partnership, in data scarce regions (Montanarella and Vargas 2012; Omuto *et al.* 2012; FAO-GSP 2014b; L. Poggio *et al.* 2021).

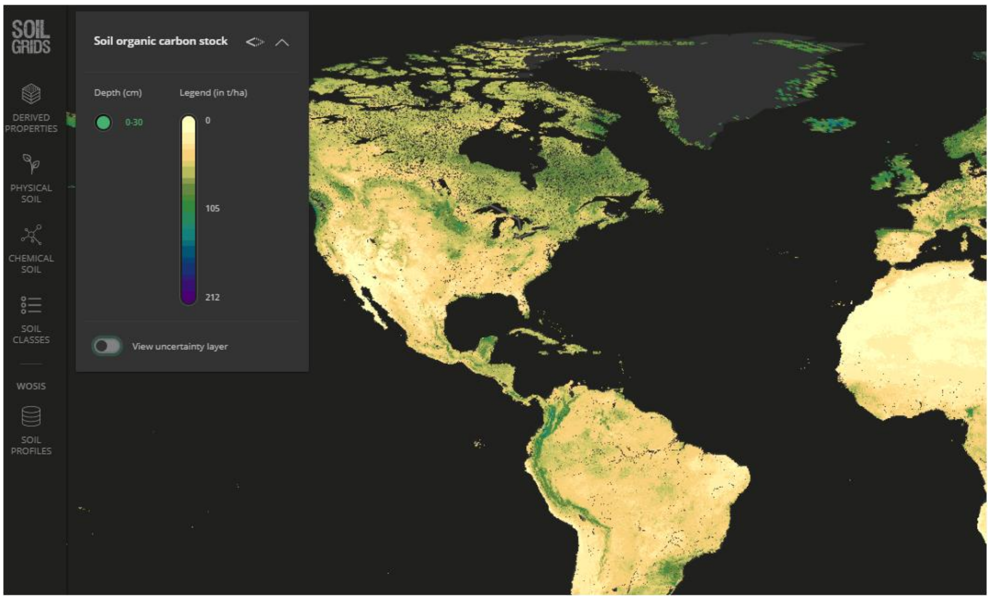

Figure 10. Screenshot of a SoilGrids250m map (https://www.soilgrids.org).

SoilGrids is based on Free and Open Source Software (Linux, PHP, Latex, R, GDAL, GRASS, SAGA GIS, PostgreSQL, Postages, Python and similar). A description of the computational infrastructure for SoilGrids is provided in de Sousa et al. (2020). Additional information can be found at FAQ – SoilGrids.

6. Data and information serving

6.1 ISRIC on-line library

Our reference collection of (scanned) maps and reports is accessible through the ISRIC Soil Reference library (http://www.isric.org/explore/library), see Figure 11. This facility is hosted by the Wageningen UR-Library based on a service level agreement.

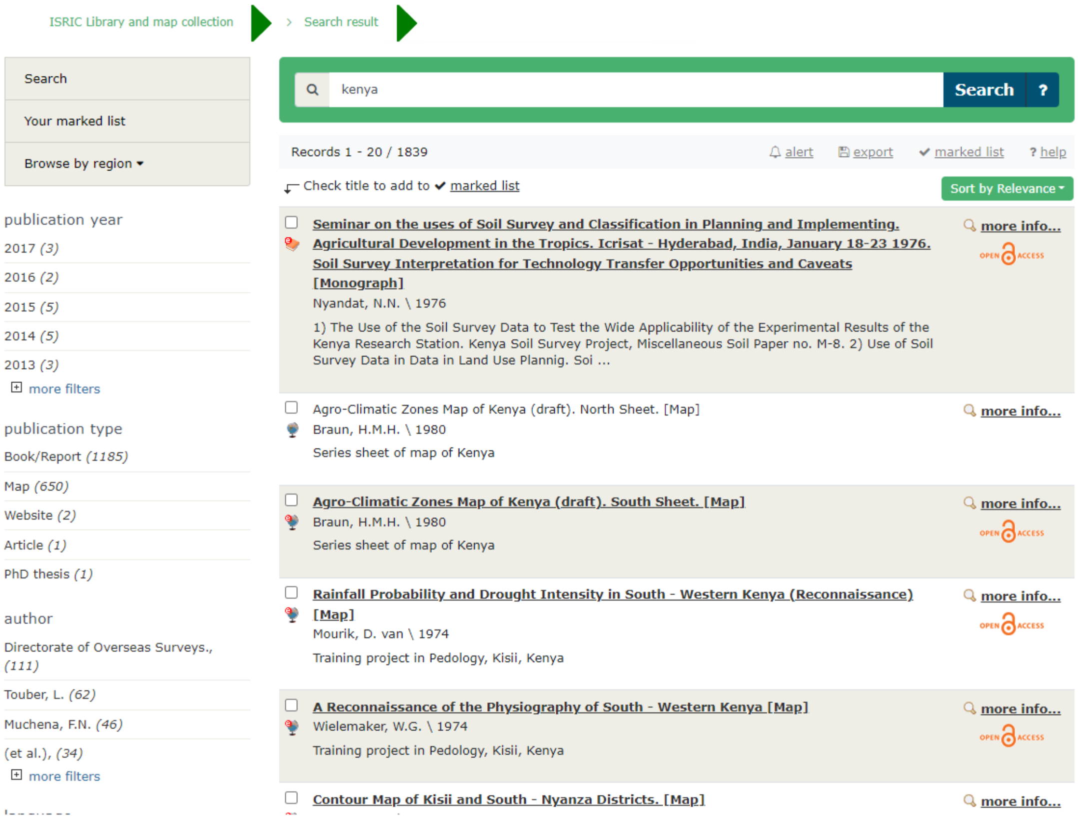

Figure 11. Screenshot of library holdings for Kenya

6.2 Virtual Soil Museum

The ISRIC World Soil Museum can also be visited online (Figure 12). Through the WSM web-platform our collection of reference soil profiles from around the world can be visited virtually, with their associated properties queryable though a central station as well as tablets.

The collection, including the objects in the collection storage – normally off limits to visitors – can also be visited online. As the collection is expanded, the scope of the virtual tour will be gradually extended.

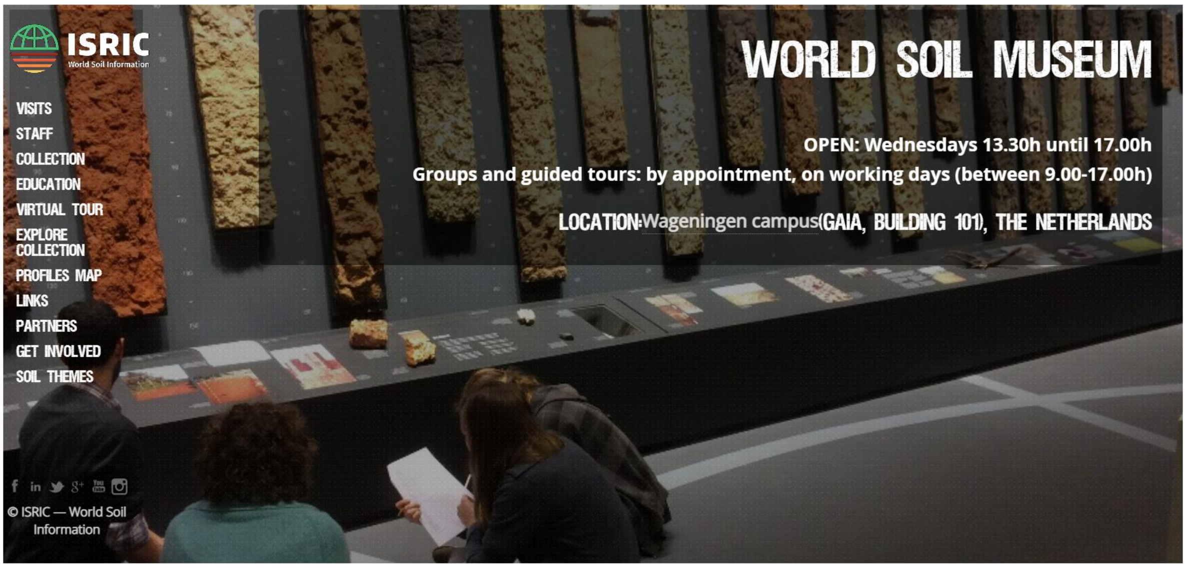

Figure 12. Screenshot of the entry page to the virtual World Soil Museum.

6.3 Soil data hub

Metadata for geo-referenced datasets hosted at ISRIC are managed by a GeoNetwork 3.10.10 instance that implements the ISO 19115 standard, defining metadata sections, entities and elements (Figure 13; http://data.isric.org/). The system is commonly referred to as 'ISRIC soil data hub'.

With GeoNetwork, a user can search for data content and easily obtain information about a specific dataset. The download of data is done directly from this system and allows users to choose between multiple file formats (e.g., GeoTIFF and shapefiles) using various procedures .

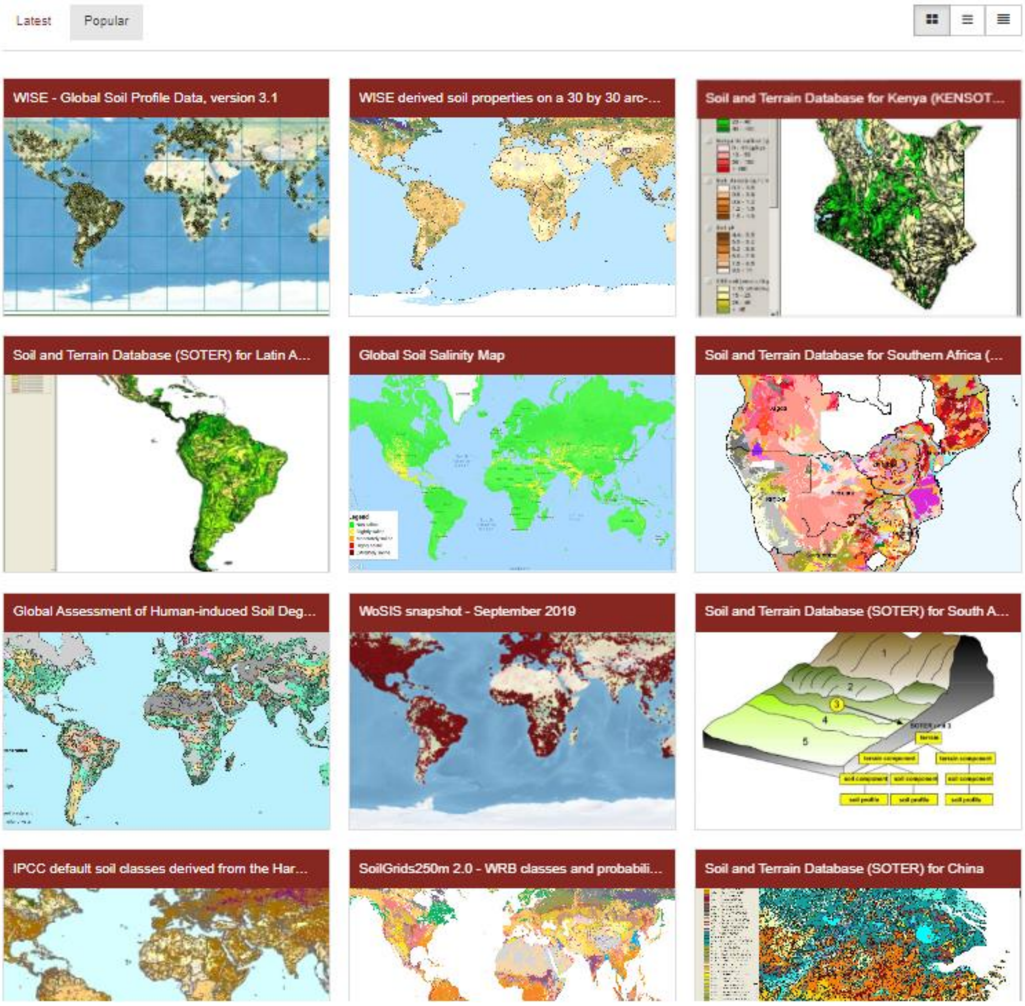

Figure 13. Example of products served through the ISRIC data hub.

GeoNetwork provides a Catalogue Web Service (CWS), which is an important part of our Spatial Data Infrastructure (SDI), and a requirement for interoperability with, for example, the Global Earth Observations System of Systems (GEOSS[5]) and ICSU-WDS[6].

6.4 SoilGrids/WoSIS web portal

The SoilGrids/WoSIS web platform allows to visualise, query and download of world soil data. It accesses data from SoilGrids 250m (Figure 14) and the underpinning soil profile data as derived from WoSIS (Figure 15).

[5] http://www.geoportal.org/

[6] https://www.icsu-wds.org/services/data-portal

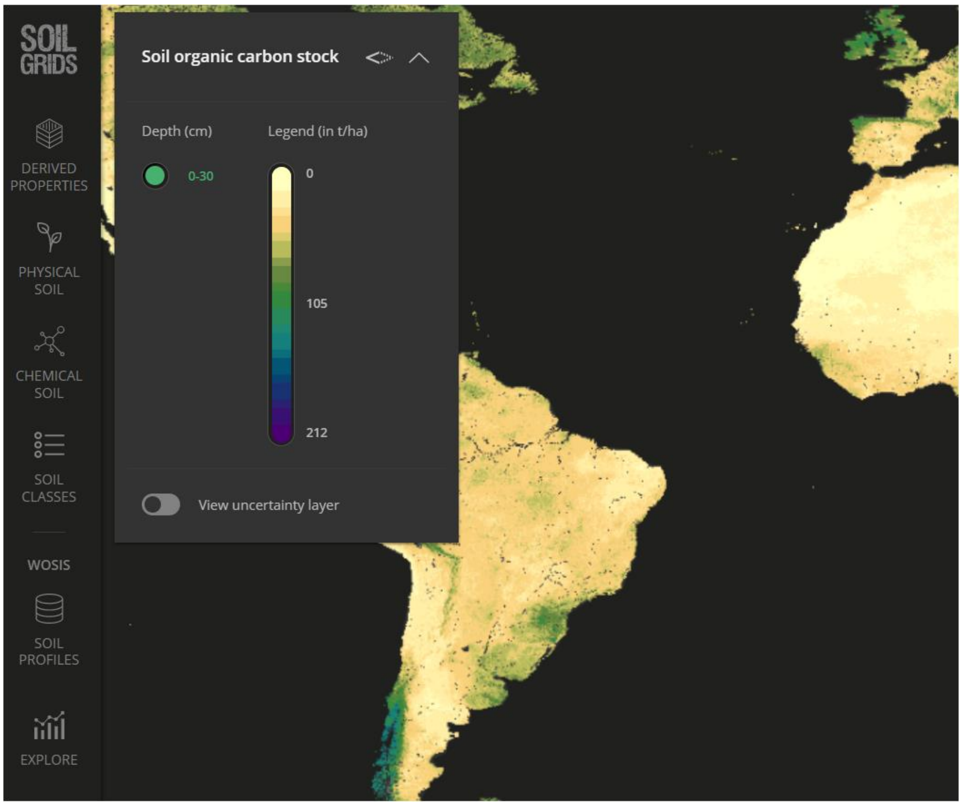

Figure 14. Example of SoilGrids maps visualised using the SoilGrids/WoSIS web platform.

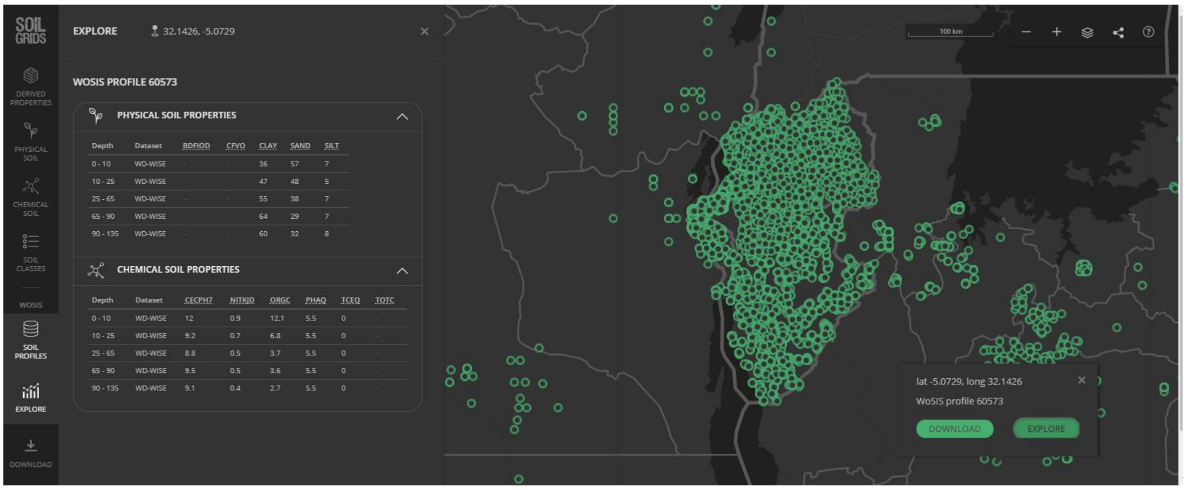

Figure 15. Example of WoSIS point data visualised using the SoilGrids/WoSIS web platform

The latest SoilGrids release can also be accessed through the following services:

- WMS: access for visualisation and data overview
- WCS: best way to obtain a subset of a map and use SoilGrids as input to other modelling pipelines.
- WebDAV: download the complete global map(s) in VRT format. Each map has three elements:

- a master VRT file;
- an OVR file with overviews for faster visualisation;
- a folder with the GeoTIFF tiles.

Further, SoilGrids predictions are available on Google Earth Engine as community contributed datasets. See here for more details.

6.5 Towards a global soil information system

ISRIC is actively contributing to various international activities aimed at ultimately achieving global interoperability of soil data. For example, in conjunction with our eSOTER, AfSIS, GlobalSoiMap and WoSIS-related work (Ritchie 2016), and much progress has been made. However, concerted work is still needed to bring the various approaches to a common mark-up language for soils ('soilML') (e.g. GS Soil 2008; INSPIRE 2015; GODAN 2016; Wilson 2016).

In its capacity of Soil Data Facility for the GSP, from 2016 to 2021, ISRIC contributed to the development of GLOSIS (Global Soil Information System). In particular, it presented a number of implementing units and enumerated some of the technologies on which GLOSIS may depend (de Sousa *et al.* 2021); the broad aim is to have an implementation that is lightweight, cheap and easy to deploy by data holders, while at the same time relieving data providers from technical details.

Much of our work on data-interoperability is being continued within the framework of international projects, such as EJP Soil (European *et al.* 2020; de Sousa *et al.* 2021; Van Egmond *et al.* 2021).

7. Quality assurance and control

All ISRIC products are submitted to rigorous, routine in-house checks prior to their distribution; nonetheless, they are unlikely to be free or errors (see FAQ WoSIS, FAQ SoilGrids). Users may report potential 'bugs' and suggest improvements in the data or software using various automated procedures, for example through a Git-repository hosting service[7] and several Google groups[8].

Typically, measures for uncertainty or accuracy assessments are described in technical reports and/or manuscripts for external peer-review (e.g. Heuvelink 2014; Leenaars, Kempen*, et al.* 2014; Batjes *et al.* 2017; Laura Poggio *et al.* 2021; Cynthia van Leeuwen *et al.* 2022), in compliance with common scientific practice.

[7] https://github.com/ISRICWorldSoil/SoilGrids250m/issues

[8] https://groups.google.com/forum/#!forum/global-soil-information ; https://groups.google.com/forum/#!forum/isric-world-soil-information

8. Data policies

We are a CoreTrustSeal certified, regular member of the ICS World Data System. As WDC-Soils, ISRIC's information handling and sharing is based on a number of policies that are accessible through our website. A short summary of their purpose is provided below:

- Data and Software Policy: This policy describes our procedures with respect to the management and citation of data, as well as the access and use of software developed by ISRIC.

- Collection Management Policy: To ensure the quality of the reference collection and provide accountability, ISRIC has been working towards compliance with Spectrum procedures of museum collection management. There are 21 procedures in Spectrum. These are discussed in the policy in relation to the management of the ISRIC soil reference collections. Spectrum procedures for the curation of the soil reference collection will be implemented over the coming years in prioritized phases.

- Digital Data Preservation Policy: Describes the policy of ISRIC with respect to the preservation of its digital soil resources (sensu datasets).

- Data Management Protocol: Describes the procedures and processes of ISRIC with respect to the management and long-term preservation of data produced by the centre.

- Privacy and Personal Data statement: ISRIC takes the protection of your privacy very seriously and strives to provide services that are transparent, reliable, and focused on the individual. The personal data that is collected through the website as well as in the framework of (inter)national collaboration projects is processed in accordance with the 'General Data Protection Regulation' (GPDR), consolidated text Regulation (EU) 2016/679.

9. Concluding remarks

We continuously improve the scope and management of our physical and digital collections, web services and workflows for handling and processing soil data (e.g., WoSIS and SoilGrids).

Our activities are aimed at facilitating global data interoperability and citability in compliance with FAIR principles: all data should be 'findable, accessible, interoperable, and reusable'.

New procedures and standards of relevance to ISRIC's mission and activities will be incorporated in subsequent releases of this document.

Acknowledgements

This report summarises work undertaken by many colleagues in the framework of internal and external projects and draws heavily on materials from the ISRIC website.

Appendix 1 - Acronyms and web links

AfSIS: Africa Soil Information Service, http://africasoils.net/

AfSP: Africa Soil Profile Database, http://www.isric.org/projects/africa-soil-profiles-database-afsp

AGROVOC: Multilingual agricultural thesaurus, http://aims.fao.org/vest-registry/vocabularies/agrovoc-multilingual-agricultural-thesaurus

CC: Creative Commons (licences), https://creativecommons.org/

DANS: Data Archiving and Networked Services, https://dans.knaw.nl/en/deposit/information-about-depositing-data?set_language=en

DataCite: A leading global non-profit organisation that provides persistent identifiers (DOIs) for research data, https://www.datacite.org/

EUROVOC: EU's multilingual thesaurus, http://eurovoc.europa.eu/

FAO: Food and Agriculture Organization of the United Nations, http://www.fao.org

GeoNetwork: Open--source catalogue application to manage spatially referenced resources, http://geonetwork-opensource.org/

GEOSS: Global Earth Observation System of Systems (GEOSS), http://www.geoportal.org/

GitHub: web-based Git repository hosting service, https://en.wikipedia.org/wiki/GitHub

GLOSIS: Global Soil Information System, under development GSP, https://www.fao.org/global-soil-partnership/areas-of-work/soil-information-and-data/en/

GODAN: Global Open Data for Agriculture & Nutrition, http://www.godan.info/

GSM: GlobalSoilMap, http://www.globalsoilmap.net/

GS Soil: http://inspire.ec.europa.eu/SDICS/gs-soil

GSP: Global Soil Partnership, http://www.fao.org/global-soil-partnership/en/

ICSU: International Council for Science, http://www.icsu.org/

INSPIRE: http://inspire.ec.europa.eu/

INSPIRE, code list register: http://inspire.ec.europa.eu/codelist

ISIS: ISRIC Soil Information Service, http://isis.isric.org

ISO standards catalogue (ISO/TC190 – Soil quality): http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=54328

IUSS: International Union of Soil Sciences, http://www.iuss.org/

IUSS WG SIS: IUSS Working Group Soil Information Standards, http://www.soilinformationstandards.org/

IUSS WG WRB: IUSS Working Group WRB, http://www.iuss.org/index.php?article_id=516

JRC: Joint Research Centre – European Commission, http://driver-project.eu/content/jrc-joint-research-centre-european-commission

NRCS: Natural Resources Conservation Service (USA), https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/

OdBL: Open Database License, http://opendatacommons.org/licenses/odbl/

OGC: Open GeoSpatial Consortium, http://www.opengeospatial.org/

OGC Standards and Supporting Documents: http://www.opengeospatial.org/standards

OSGeo: Open Source Geospatial Foundation, http://www.osgeo.org

Re3data.org: Registry of Research Data Repositories, http://www.re3data.org/

RDA: Research Data Alliance, https://www.rd-alliance.org/

SDI: Spatial Data Infrastructure, https://en.wikipedia.org/wiki/Spatial_data_infrastructure

SDF: Soil Fata Facility (for the Global Soil Partnership), https://tinyurl.com/yb5qky79

SOiL EXploration and Sampling for Science and Education, http://www.isric.org/projects/soil-exploration-sampling-sciences-education

SOTER: Soil and Terrain database, http://www.isric.org/projects/soil-and-terrain-database-soter-programme

WDC-Soils: World Data Centre for Soils, a regular member of ICSU-WDS, https://www.icsu-wds.org/community/membership/regular-members/@@member_view?fid=isric-wdc-soils

WDS: World Data System, an Interdisciplinary Body of the International Council for Science, https://www.icsu-wds.org/

WISE: World Inventory of Soil Emission Potentials, http://www.isric.org/projects/world-inventory-soil-emission-potentials-wise

WOSIS: World Soil Information Service, http://www.isric.org/data/wosis

* All URLs last accessed on 25 August 2022.

Appendix 2 – Index to websites on international soil standards

ISRIC maintains a dedicated webpage[9] which aims to evolve towards a comprehensive catalogue of 'international' standards in the soils domain. The index of this webpage has been reproduced below for additional information:

- Overviews
- Collection Management Plans
- Soil glossaries
- Soil description and sampling
- Soil classification
- Laboratory methods
- Data quality
- Standardisation/harmonisation of disparate soil data
- Digital soil mapping
- Spatial data specifications
- Soil data interoperability
- Soil-related vocabularies
- Soil proximal sensing
- OGC standards
- Soil-related ISO standards
- FAIR guiding principles

[9] https://www.isric.org/international-soil-standards

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