GLOBAL SOIL PARTNERSHIP
TECHNICAL REPORT

State of the Art Report on Global and Regional Soil Information: Where are we? Where to go?

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List of abbreviations

ACLEP	Australian Collaborative Land Evaluation Program
ASSS	African Soil Science Society
AFSIS	Africa Soil Information System
ARAs	Agroecological Resource Areas
ASRIS	Australian Soil Resource Information System
CanSIS	Canadian Soil Information System
CeC	Cation Exchange Capacity
CLI	Canada Land Inventory
DN	Digital Numbers
DAAC	Distributed Active Archive Centre
DEM	Digital Elevation Models
DSM	Digital Soil Mapping
DSMW	Digital Soil Map of the World
ESBN	European Soil Bureau Network
ESDAC	European Soil Data Centre
EU	European Union
ESP	Exchangeable Sodium Percentage
EuDASM	European Digital Archive of Soil Map
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPL	General Public License
GSBI	Global Soil Biodiversity Initiative
GSIF	Global Soil Information Facilities
GSM	Global Soil Map
GSP	Global Soil Partnership
GSS	Global Soil Systems
HWSD	Harmonized World Soil Database
IIASA	International Institute for Applied Systems Analysis
INSPIRE	Infrastructure for Spatial Information in Europe
ISCW	Institute of Soil, Climate and Water
ISRIC	International Soil Reference and Information Centre
ISSCAS	Institute of Soil Science, Chinese Academy of Sciences
ISSS	International Society of Soil Science
JOSCIS	Jordan Soil and Climate Information System
JRC	Joint Research Centre
LAC	Latin America and Caribbean
LARI	Lebanese Agricultural Research Institute
LPDB	Land Potential DataBase

MENA	Middle East and North Africa
MLI	Manitoba Land Initiative
MoA	Ministry of Agriculture
NCSR	National Council for Scientific Re-search
NDVI	Normalized Difference Vegetation Index
NGOs	Non-Governmental Organizations
NIR	Near Infrared
NRI	National Resources Inventory
NRCS	National Resources Conservation Service
NSD	National Soil Database
NSDB	National Soil Database
NSMLUP	National Soil Map and Land Use Project
NSW	New South Wales
ORNL	Oak Ridge National Library
OC	Organic Carbon
PCA	Principal Component Analysis
pH	potential of Hydrogen
RDBMS	Relational DataBase Management System
SALIS	Soil and Land Information System
SCS	Soil Conservation Service
SGDB	Soil Geographic Database
SLC	Soil Landscapes of Canada
SOTER	SOil and TERrain
SOTERCAF	SOil and TERrain for Central Africa
SOTERLAC	SOil and TERrain for Latin America and Caribbean
SRTM	Shuttle Radar Topographic Mission
SSURGO	Soil Survey Geography
STATSGO	State Soil Geography
SWALIM	Somali Water and Land Information Management
TEB	Total Exchangeable Bases
TWI	Topgraphic Wetness Index
UN	United Nations
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UTM	Universal Transverse Mercator
USA	United States of America
USDA	United States Department of Agriculture
VG	Voluntary Guidelines
WG	Working Group
WISE	World Inventory of Soil Emission Potential
WSR	World Soil Resource

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1. INTRODUCTION

1.1 Soil functions

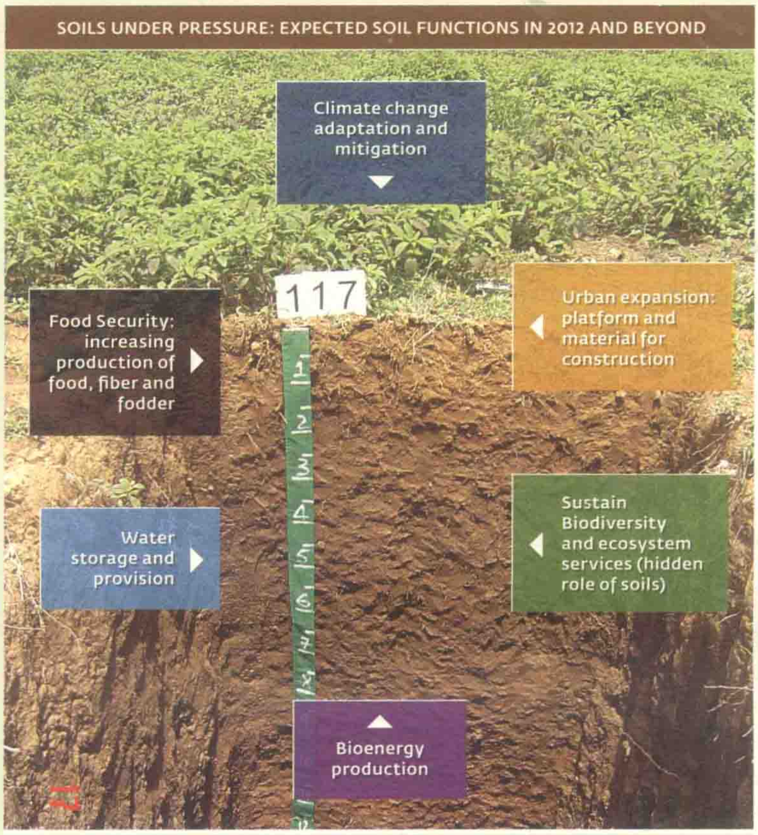
Soil is a natural body consisting of layers (soil horizons) that are composed of weathered mineral materials, organic material, air and water (Bockheim *et al.*, 2005). It is the end product of the combined influence of the climate, relief (slope), organisms (flora and fauna), parent materials (original minerals), and time. The most widely recognized function of soil is its support for food production. Farmers who use soil in crop production know very well that it is the foundation for agricultural production. This is because it is the medium in which growth of food-producing plants occurs. It supplies the plants with nutrients, water, and support for their roots. The plants, in turn, support human and animal life with food and energy. Soil also acts as a repository for seeds, germplasm, and genes for flora and fauna. In general, soil is the medium for preservation and advancement of life on earth (Brady, 1984; Foth and Ellis, 1997). Besides supplying water treatments to plants, soil also supports millions of organisms living in it. These organisms have proven useful in medicine, biodegradation and recycling of waste, as food, as well as being essential in the conversion of minerals and nutrients to readily useable formats for plants and in turn animal nutrition.

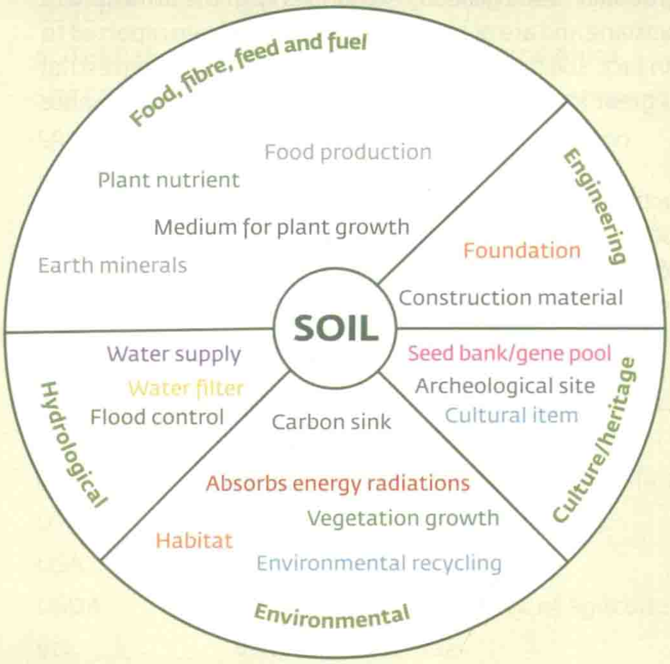
In hydrology, soil interacts with the hydrosphere as a medium that absorbs, purifies, transports, and releases water. In the hydrological cycle, the water that passes through the soil accumulates temporarily in the form of rivers, lakes/oceans/dams, soil water, and groundwater. During the storage process, soil filters the water against pollutants including natural and synthetic compounds. It also acts as a buffer against natural phenomena such as floods and soil erosion. In hydrology, the interaction of soil with the atmosphere has numerous environmental benefits. It can absorb excess energy radiation from the sun and release it gradually. Soil's gaseous exchanges with the atmosphere involve carbon dioxide, nitrogen oxides and methane and are of a magnitude that has been reported to have profound effects on the global climate. In fact, soil has been recognized as the largest terrestrial sink for carbon dioxide and consequently has great importance in mitigating the impacts of climate change (FAO, 2004).

In engineering, soil is used both as a construction material and as a foundation to support building infrastructures. Numerous engineering structures are made with soil as a primary construction material. For example, it's used to make blocks for building or used directly in construction such as in dams, mud-houses, roads, etc (Graham, 1989; Indraratna and Nutalaya, 1991). Soil importance as a foundation support cannot be overemphasized: Most structures have their foundations in the soil.

Soil is a source of all life. Its interaction with various aspects of life is summarized in Figure 1.1.

Figure 1.1 Importance and interaction of soil with aspects of life





Life support services

- The soil renews, retains, delivers nutrients and provides physical support for plants;
- It sustains biological activity, diversity, and productivity;
- The soil ecosystem provides habitat for seeds dispersion and dissemination of the gene pool for continued evolution.

Provisioning services

- Soil is the basis for the provision of food, fibre, fuel and medicinal products to sustain life;
- It holds and releases water for plant growth and water supply.

Regulating services

- The soil plays a central role in buffering, filtering and moderation of the hydrological cycle;
- It regulates the carbon, oxygen and plant nutrient cycles (such as N, P, K, Ca, Mg and S) affecting the climate and plant production;
- Soil biodiversity contributes to soil pest and disease regulation. Soil micro-organisms process and break-down wastes and dead organic matter (such as manure, remains of plants, fertilizers and pesticides), preventing them from building up to toxic levels, from entering water supply and becoming pollutants.

Cultural services

- Soil provides support for urban settlement and infrastructure;
- In some cultures, soils may also be of specific spiritual or heritage value.
- Soils are the basis for landscapes that provide recreational value.

1.2 Importance of soil information

Soil is derived from weathering products of rocks and the decayed remains of plants and animals that once lived in or on the Earth. It is composed of four major components: minerals, organic matter, air, and water. The proportion of each of these components together with other factors such as climate, vegetation, time, topography, and, increasingly, human activities are important in determining the type of soil at any location in the landscape. For a long time, scientists have endeavoured to develop appropriate and efficient methods for predicting the spatial distribution of soils and their occurrence in the landscape. Soil mapping is the term often used to describe the process of understanding and predicting the spatial distribution of soils. It is a process that involves collecting field observations (including recording soil profile descriptions), analysing soil properties in the laboratory, describing landscape characteristics, and, ultimately, producing soil maps. Soil maps are the most widely used end-products of the soil mapping process since they illustrate the geographic distribution of soil types, soil properties (such as physical, chemical, and biological properties), and landscape characteristics.

Data coming from a soil mapping exercise can be classified as either primary data or secondary data. Primary data are those that have been obtained directly from observations or measurements in the field or in a laboratory. Secondary data are data that have been inferred or derived from the primary data. Examples of secondary data are the soil maps themselves, soil quality ratings, degradation assessments, pedotransfer functions, suitability indices, hydrologic soil groups, textural classes, etc. Secondary and primary soil data together form *Soil Information*. Soil information has a variety of uses worldwide such as assessing soil for its adequacy for a variety of applications, assessing and monitoring natural phenomena, determining productivity, and planning. Some of the major categories of these uses include:

- **Agronomic assessment:** Soil information is used to develop recommendations for best management practices, including determining the need for, and amount of, fertilizers, or other inputs, improving soil productivity, assessing land suitability for crop production, estimating crop yields, determining irrigation needs and scheduling, selecting appropriate crop types, calculating productivity, etc.
- **Engineering applications:** Soil information is used in urban planning, evaluation of construction materials, site selection, foundation design, design of water conveyance and flood control structures, etc.
- **Hydrology and Hydrogeologic assessments:** Including groundwater prospecting, groundwater and surface flow characterization, water pollution, modelling floods and droughts,
- **Environmental assessments:** As assessment of natural phenomenon including climate modelling, land degradation assessment, sediment transport and deposit into water bodies, global circulation, vegetation dynamics, modelling heat and carbon sinks, pollution control, environmental impacts, reclamation, remediation, etc.
- **Policy decisions:** Especially for national planning, resources allocation, economic development, when, where, and what crop or vegetation to promote, conservation of natural resources, formulation of laws and regulation of use of natural resources, preservation of environment, etc.

These uses have various levels of data demand in terms of accuracy, scale/spatial extent, temporal resolution, and details in metadata.

1.3 Need for analysis of soil information

Soil information exists at various spatial scales. Users of this information need to know the potential and limitations of available soil data at the various scales, where soil data is archived and whether there are any access restrictions or information gaps, and opportunities for collaborative work to improve soil information. To this end, a workshop on soil information was organized under Pillar 4 of the Global Soil Partnership "Towards Global Soil Information: activities within the GeoTask Global Soil Data" (http://www.fao.org/fileadmin/templates/GSP/downloads/GSP_SoilInformation_WorkshopReport.pdf). A key outcome of this workshop was the recognition of a need for assessing the state of the art of global and regional information. The present document represents an attempt to assemble relevant information on existing soil data at various scales throughout the world and on-going regional and global soil mapping initiatives. It aims at a) increasing users' awareness on existing soil data and information, b) encouraging informed and accurate application of it, c) understanding user needs in terms of soil data and information and d) understanding demands on soil data and information under the challenges of food security and climate change. The document is organized into four broad sections:

- **Existing soil legacy data and information**
  Existing soil data is a key factor to build accurate soil information. There is a huge reservoir of existing legacy soil data in many countries in the form of soil maps, soil profile descriptions and analyses. Given the time and resources invested in gathering this soil information, it's important to acknowledge these existing datasets and exploit their potential. This document reviews legacy soil data and highlights how this data can be accessed.
- **Soil user needs**
  Knowledge of soil data requirements of the soil user community and related stakeholder groups is important because soil information is generated to benefit the intended users. This document conducted an online survey on user requirements. Although the survey was not exhaustive, it gave highlights on the general nature of information expected from soil scientists and soil maps.
- **State of the art on methods and tools for digital soil mapping**
  Digital soil mapping (DSM) is a new technological advancement that seeks to fulfil the increasing worldwide demand in spatial soil data through more rapid and accurate production and delivery of soil information and increased coverage and improved spatial resolution of mapped areas. New tools and methods are constantly being developed to support DSM. This document explores these tools to highlight their potential for improving user access to accurate soil information.
- **On-going global and regional soil mapping initiatives**
  Several endeavours are being made globally, and in different regions, to coordinate soil information generation, share soil data and improve access to soil information. These endeavours need to be identified and catalogued, acknowledged, and, if possible, coordinated more effectively.

2. SOIL LEGACY DATA AND INFORMATION

The term legacy soil information is used for all existing soil information collected to characterize or map soils. The majority of such information was collected by soil surveys that included landscape and site descriptions, soil profile morphological descriptions and laboratory analysis of the main chemical, physical and biological soil properties. This information has typically been synthesized in paper soil maps that consist of polygons (soil mapping units) containing a description of soil units named and characterized by a national or international soil classification. Detailed, sometimes geo-referenced, information on the sampled soil profiles (point information) has been frequentlycollected and published in reports that accompany soil maps. In recent years there has been a considerable effort to capture this information in digital form (databases, digital maps) and some organizations have compiled and harmonized this local and national soil information at regional to global scales. In addition, for ease of combination with other kinds of information layers in GIS, some soil maps have been rasterized to a regular grid. Global soil maps and databases usually contain information on soil properties associated with the soil units described as being present in the polygons of the map, while global soil profile databases contain information on the soil classification unit they belong to. It is therefore somewhat arbitrary to subdivide the available soil information into categories of "mapped" and "point" information or in "global", "regional" or "national" information as these are often interrelated. We focus first on information presented at a global scale that is of particular interest to global policy makers and modellers. Next the availability of soil information, both in map and soil profile forms, at regional and at national scale is discussed. Detailed local soil surveys, which represent the bulk of soil information collected to date, are not discussed. One of the best general websites that lists the achievements of soil survey to date can be found at: http://www.itc.nl/~rossiter/research/rsrch_ss.html

2.1 Soil maps and soil profile databases at global scale

2.1.1 The FAO-UNESCO Soil Map of the World

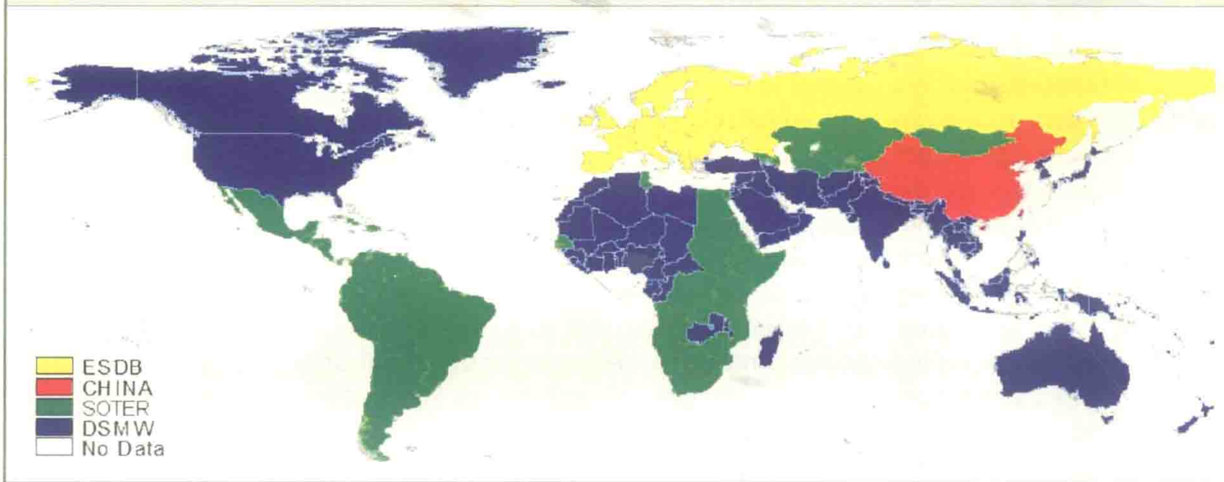
The FAO-UNESCO Soil Map of the World (FAO-UNESCO, 1971-1980) is presently the only, fully consistent, harmonized soil inventory at the global level which is readily available in digital format. It was published between 1974 and 1980 in 19 separate sheets at a mapping scale of 1:5 million. The map was based on information contained in some 11000 separate large-scale maps. Its development started as a project originated by a motion of the ISSS at the Wisconsin congress in 1960. It was first digitized by ESRI in vector format in 1984. The paper map contains 26 major soil groups, which are further subdivided into 106 individual soil units (FAO-UNESCO, 1974). The map was later digitized by FAO (1995) with a grid resolution of 5' x 5' (or 9 km x 9 km at the equator) (Nachtergaele, 2003). The digitized version, known as Digital Soil Map of the World (DSMW), contains a full database in terms of composition of the soil units, topsoil texture, slope class, and soil phase in each of its more than 5000 mapping units. The map is downloadable at: http://www.fao.org/geonetwork/srv/en/resources.get?id=14116&fname=DSMW.zip&access=private.

Transformations of the DSMW to reflect other soil classification systems such as the USDA Soil Taxonomy (Eswaran and Reich, 2005) and the World Reference Base for Soil Resources (FAO/EC/ISRIC, 2003) have also been published, but do not contain any additional information compared to the original map.

2.1.2 The Harmonized World Soil Database

The Harmonized World Soil Database (HWSD, FAO/IIASA/ISRIC/JRC/CAS, 2006), contains a digital soil map of the world, with soil units classified in the Revised FAO Legend (FAO 1990) at a fixed grid resolution of 1km by 1km, with associated soil properties and soil qualities. This digital global dataset is not fully harmonized, as it is based 40% on the original DSMW and 60% on regional and national updates undertaken after the DSMW was completed. (Figure 2.1)

Figure 2.1 Main legacy soil data sources for HWSD



(Source: Nachtergaele et al.,2012)

It should be acknowledged that the 1km grid resolution used in the DSMW parts of the database is not fully justified given the lower resolution of the base material used in the DSMW part of the map. Presently, the HWSD contains over 16000 mapping units, which are used to link to a database of soil attribute data. The result is a 30 arc-second raster database consisting of 21600 rows and 43200 columns with each grid cell linked to the harmonized soil property data. This linkage of mapping units to the soil attribute data offers the opportunity to display or query the database in terms of soil units or in terms of selected soil parameters (such as Organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry both for topsoil as subsoil layers). Although not fully harmonized and consistent, the HWSD contains the most up-to-date and consistent global soil information that is currently available and continuously updated. The Harmonized World Soil Database v1.2, is downloadable at: http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/. In addition, the website contains freely downloadable software for visualising, querying, and retrieving the data. Figure 2.2 is an example of the database as visualized through the data viewer.

2.1.3 The WISE global soil profile database

The International Soil Reference and Information Centre (ISRIC) World Inventory of Soil Emission Potential (WISE) International soil profile database is presently the only freely available and comprehensive repository of global primary data on soil profiles. ISRIC was established in 1966 with a focus of serving the international community with information about the world's soils. Through its WISE project, ISRIC has consolidated select attribute data for over 10,250 soil profiles, with some 47,800 horizons, from 149 countries in the world. Profiles were selected from data holdings provided by the Natural Resources Conservation Service (USDA-NRCS), the Food and Agriculture Organization (FAO-SDB), and ISRIC itself (ISRIC-ISIS).