SOIL MAPPING FOR AFRICA: A CONTEMPORARY PERSPECTIVE

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Abstract
The protection and the sustainable management of soil resources in Africa are of paramount importance, particularly in the context of the uncertain impact of climate change and the increase pressure of the human activities. This situation requires a demand for up-to-date and relevant soil information as well as the communication of such information to diverse audiences. These challenging issues are illustrated by focusing on two current topics: the use of coarse-resolution remote sensing for producing soil data at regional and continental scales and the Soil Atlas of Africa, an initiative of the European Commission Joint Research Center.

Keywords
Soil mapping, Africa, remote sensing, education, Soil Atlas of Africa

Résumé
Les sols d'Afrique constituent une ressource naturelle dont la protection et la gestion durable représentent un défi majeur, en particulier dans le contexte du changement global et de la pression croissante des activités humaines sur l'environnement. A cette fin, il est nécessaire de disposer d'une information sur les sols à la fois récente et fiable. Dans le cadre d'une gestion durable, la communication d'une telle information à un public non spécialisé s'avère également cruciale. Ces questions sont abordées à travers deux sujets d'actualité : l'utilisation de la télédétection basse résolution pour la production aux échelles régionale et continentale de données sur les sols et l'Atlas des sols d'Afrique, une initiative du Centre Commun de Recherche de la Commission européenne.

Mots-clés
Cartographie des sols, Afrique, télédétection, éducation, Atlas des sols d'Afrique

1. GENERAL CONTEXT

Soils are at the interface between the topography, the climate and the biology (Dietrich and Perron, 2006) and their formation occurs over a very long period of time, in some cases taking several thousands of years (Targulian and Krasilnikov, 2007). Soil thickness depends on the balance between production and erosion of soil and for soil to persist it must be replenished at a rate equal to or greater than that of erosion (Heimsath *et al.*, 1997). However, in many conventionally ploughed agricultural fields, actual erosion rates average 1–2 orders of magnitude greater than rates of soil production, erosion under native vegetation, and long-term geological erosion (Montgomery, 2007; Verheijen *et al.*, 2009).

Soils are one of the fundamental components for supporting life on the planet and for regulating climate (Lal, 2004; Millennium Ecosystems Assessment, 2005a; Palm *et al.*, 2007). Soils provide food, feed, fiber, and fuels, whilst playing an important role in determining the quality of our environment. Plants and crops are dependent on soil for the supply of water, nutrients and as a medium for growing. Soil stores, filters, buffers and transforms substances that are introduced into the environment. This capability is crucial in producing and protecting water supplies and for regulating greenhouse gas emissions. Soil is a provider of raw materials. Soil is also an important habitat and a large pool of biodiversity. Soil is a fundamental component of our landscape and cultural heritage. These functions that soils deliver to people are referred as ecosystem services (Millennium Ecosystems Assessment, 2005a).

Over the last decades the growing demand for soil-related products has come with land misuse and soil mismanagement leading to the degradation of soils (e.g., acidification, salinity, organic depletion, compaction, nutrient depletion, chemical contamination, landslides, and erosion) and many of the services they provide (Millennium Ecosystems Assessment, 2005b; UNEP, 2007; Vlek *et al.*, 2008; Lal, 2009). Established evidence links land degradation with loss of biodiversity and climate change, both as cause-and-effect (Gisladottir and Stocking 2005). Once degraded, soil resources are not renewed easily.

The African environment is diverse, ranging from deserts and seasonally dry regions in the north and the south to tropical rainforests in west and central Africa; from coastal lowlands with mangroves in the west to high mountain ranges in the east. Large parts of Africa, especially in the south and the west consist of plateaus with soils that can reach million of years old.

This diversity is reflected in the richness of African soil resources, which need to be protected for future generations. A number of threats are affecting the functioning of African soils, not only for the purpose of agricultural production, but also for other important environmental services that soil delivers to all of us. This is of particular importance once we know that many health-related problems in Africa are indirectly related to the services of soils (Sanchez and Swaminathan 2005).

For an optimal utilization of the available natural resources on a sustainable basis, particularly in the context of the uncertain impact of climate change and the increase pressure of the human activities, the availability of up-to-date and relevant soil information as well as the communication of such information to diverse audiences is very crucial for Africa (UNEP, 2007; Hartemink and McBratney, 2008; Sanchez *et al.*, 2009).

This paper aims to illustrate these challenging issues by focusing on two current topics. The first concerns the use of remote sensing for soil mapping. Providing timely and reliable information on soils with respect to their nature, extent, spatial distribution as well as potential and threats for the whole Africa means that soil data have to be collected over large areas in quite a short period of time. To achieve this goal, remote sensing represents a unique opportunity to provide a synoptic coverage of the earth surface at regular intervals in time and to increase the efficiency of conventional soil survey methods (Dwivedi, 2001; McBratney *et al.*, 2003; Vrieling, 2006). A brief overview of the potential of remote sensing as a data source for soil mapping in Africa follows.

The second topic involves communication and education of the importance of soil as a natural resource based on the Soil Atlas of Africa, an ongoing initiative of the Joint Research Centre of the European Commission.

2. SOIL MAPPING AND REMOTE SENSING

Soil reflects or emits or transmits according to intrinsic properties of the soil material and profile such as soil texture, soil moisture, organic matter content and the mineral composition (Barnes *et al.*, 2003). Size and shape of the soil aggregates also influence the reflectance in the images. However, some limitations and problems can occur frequently while mapping soil from remote sensing:

- Mapping and categorizing soils is a complex issue which in many cases is based on soil properties that are not even visible to the naked eye and that require in-depth laboratory analyses to be carried out.
- Soil is a complex 3-D body and remote sensing only allows for a shallow penetration of soils. The surface characteristics may not be representative of the deeper soil body.
- The signal recorded by satellite imagery is the result of a combination of several properties and even if it has no consequence to classify the surface state, it can be a limitation for the study of one particular property.
- Soils are complex bodies and surface condition can vary dramatically spatially and temporally within a small area.
- Vegetation coverage obscures most soils.

Several in-depth reviews have been dedicated to remote sensing applied to mapping soil and related issues such as soil erosion, soil salinity and landslides (Dwivedi, 2001; Metternicht and Zinck, 2003; Metternicht *et al.*, 2005; Vrieling, 2006; Joyce *et al.*, 2009). Soil-related maps at regional to continental extents are usually produced with a resolution of 1 km or lower, (McBratney *et al.*, 2003). This paper focuses only on satellite-based applications that deliver spatial data at resolutions suited to this purpose. Moreover, the use of data acquired by fine spatial resolution sensors, at regional and continental levels, can be compromised by their relatively high cost, large data volume and low frequency of data acquisition. Although airborne and ground-based remote sensing systems are of great interest to soil mapping (e.g., hyperspectral imaging, LIDAR) and offer the advantage of customer control over the acquisition time, they are not discussed in this text.

2.1. Remote sensing for soil unit delineation and soil properties assessment

Remote sensing can provide detailed information on the soil themselves. A direct identification of soil units can be made through visual delineation of soil patterns, especially with optical imagery (Dwivedi, 2001). However, the use of visual interpretation techniques relies mainly on the skills of the interpreter and his knowledge on the relationships between the observable terrain characteristics and the soil units.

More automated delineations have been successfully performed, for example, through surface albedo measurements using MODIS (MODerate Resolution Imaging Spectroradiometer) imagery (Tsvetsinskaya *et al.*, 2002; Zhou *et al.*, 2003) as well as with brightness temperatures from the Special Sensor Microwave /Imager (SSM/I) (Prigent *et al.*,1999).

Remotely sensed data, even for the arid areas, are not reliable enough to support totally automatic soil delineation. Soil roughness and particularly the presence of vegetation pose serious problems in the detection of soil variations. Yet, remotely sensed data can be used as complementary and/or indirect support to soil delineation. These data are frequently inter-linked.

In this respect, measurement of soil moisture is promising. Soil moisture is heavily related to the hydraulic properties of the soil, which are defined by the soil type. Microwave measurements have been demonstrated to provide promising results in this area and give daily moisture data for the whole globe (Wigneron *et al.*, 2003; Prigent *et al.*, 2005). For example, pertinent soil moisture extractions have been obtained from passive sensors like SMMR (Scanning Multichannel Microwave Radiometer) (Vinnikov *et al.*, 1999), SSM/I (Prigent *et al.*, 1998), AMSR–E (Advanced Microwave Scanning Radiometer – Earth Observing System) (Draper *et al.*, 2009) and TRMM TMI (Tropical Rainfall Measurement Mission Microwave Imager) (Bindlish *et al.*, 2003). Active microwave sensors are also sensitive to soil moisture and, for example, good extractions were obtained with the ERS scatterometer (Prigent *et al.*, 2005; Wagner *et al.*, 2007). Soil moisture was also retrieved from visible and thermal images from VISSR (Visible and Infrared Spin Scan Radiometer) aboard Meteosat (Verstraeten *et al.*, 2006; Wagner *et al.*, 2007).

Surface temperature can be derived from sensors such as the AVHRR (Advanced Very High Resolution Radiometer) (Pinheiro *et al.*, 2006), NOAA HIRS-2 (High Resolution InfraRed Sounder) (Lakshmi *et al.*, 2001) and SEVIRI (Spinning Enhanced Visible and InfraRed Imager) onboard the geostationary satellite MSG (Meteosat Second Generation) (Jiang *et al.*, 2006). And models such as the Normalized Difference Vegetation Index (NDVI) calculated from the red and near-infrared channels of AVHRR have shown relationships to surface soil moisture (Prigent *et al.*, 2005; Singh *et al.,* 2004).

The soil delineation mapping techniques as reported in the sections above can also be applied to directly or indirectly identify soil properties. For example, topsoil characteristics influence the soil surface colour, and thus the spectral reflectance. Singh *et al.* (2004) established a relationship between soil colours defined by the Munsell system and an AVHRR-derived NDVI, which in turn could be applied to map soil properties such as organic matter and soil moisture.

2.2. Remote sensing for soil threats

The term “threat” is used here with reference to the definition by JTC1 (2004): “a natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. The threat (danger) can be an existing one (such as a creeping slope) or a potential one (such as a rockfall)”. Soil threats are being increasingly related to a wide range of human activities. Threats are complex and their dimension is continental. They are frequently inter-linked and when they occur simultaneously, their combined effects tend to increase the problem. The threats can induce soil degradation if they make soil lose its capacity to carry out its functions. In the subsequent sections, only the soil threats that can be detected and analyzed at the regional and continental scale are presented.

2.2.1. Soil erosion by water

Soil erosion by water is regarded as one of the most widespread forms of soil degradation and, as such, poses potentially severe limitations to sustainable development in Africa.

A visual detection of individual geomorphic features related to soil erosion by water is very limited or even impossible. The limited spatial extent of the features, even for the largest gullies, inhibits their detection using coarse-resolution satellite imagery (Vrieling, 2006). Satellite data could possibly be applied to visually delineate eroded areas such as badlands (Kumar *et al.*, 1996; Sujatha *et al.*, 2000), but their automatic extraction is more problematic and difficult (Vrieling, 2006).

Estimates of soil properties may provide necessary information that may serve as proxies to predict soil erosion. For example, soil texture and the size of particle have a significant role in erosion potential (Salisbury and D’Aria, 1992), while variations in soil moisture have the ability to affect strongly the regional runoff (Verstraeten *et al.*, 2006). Soil erosion implies the removal of top soil and subsequent decrease in organic matter, which can be assessed in the analysis of soil colour (Singh *et al.*, 2004). The analysis of changes of the surface state allows spatial and temporal assessment of erosion status.

The impacts of erosion processes on soil are generally limited by vegetation cover because it reduces rain splash and binds soils by roots. Therefore, the identification of the characteristics (or the absence) of the vegetation cover and its dynamics can help in the assessment of soil erosion (Vrieling, 2006). For example, a direct indication of the protective role of the vegetation can be obtained trough the use of vegetation indices such as AVHRR-derived NDVI (Gay *et al.*, 2002; Thiam, 2003).

Wildfire impacts on soil properties induce an increase of soil erosion before geomorphological stability is reestablished (Shakesby and Doerr, 2006). Over the past decades, spaceborne sensors for various missions have been widely used for active fire detection, burned scar mapping and fire potential danger. Examples include AVHRR (Barbosa *et al.*, 1999; Pu *et al.*, 2004), TRMM Visible and Infrared Scanner (VIRS) (Giglio, 2007) and MODIS (Justice *et al.*, 2002).

Forest clearance (or deforestation) for which fire can sometimes be used also increases the potential for soil erosion (Sidle *et al.*, 2006). Multi-temporal analysis of data provided by sensors such as SPOT Vegetation (Carreiras *et al.*, 2006), MODIS (Langner and Siegert, 2009) and AVHRR (Giri *et al.* 2003; Thiam, 2003) allows an assessment of these land cover changes.

2.2.2. Soil erosion by wind

Wind erosion is a degradation process that affects large areas in Africa and in particular the North and its desert regions (Prospero *et al.*, 2002; Engelstaedter *et al.*, 2006; Goudie, 2008). Wind erosion can be increased after wildfires (Shakesby and Doerr, 2006) and thinning of semiarid forests (Whicker *et al.*, 2008). In some places, wind erosion is the only erosion process that may act.
A variety of satellite data and derived products such as the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS) absorbing aerosol product (Prospero *et al.*, 2002), the Infrared Difference Dust Index (IDDI) of Meteosat IR-channel (Legrand *et al.*, 2001), the MODIS, MISR and Clouds and the Earth's Radiant Energy System (CERES) instruments onboard the Terra satellite (Zhang and Christopher, 2003), allows the determination of the spatial and temporal variability of dust emissions from different surfaces. Also carried by the Aqua satellite, MODIS is widely used in dust studies and, for example, allows reliable detection of hot spot of dust emission through qualitative (Washington *et al.* 2006; Lee *et al.*, 2009) and more elaborate (Bullard *et al.*, 2008) image analysis. Bullard *et al.* (2008) and Lee *et al.* (2009) established direct links between the sources of dust emission and the soil erosion induced by the wind action.

2.2.3. Landslide

The possibilities and limitations of remote sensing in the inventorying and the monitoring of landslides are very similar to those detailed for the analysis of the soil erosion features produced by water. Landslides are triggered by rainfall (and also by earthquakes, sometimes in combination) and, for the largest events, their impact on the landscape can be detected through disrupted or absent vegetation cover, anomalous with the surrounding terrain. Their occurrence is generally increased after forest clearance and wildfires (Shakesby and Doerr, 2006; Sidle *et al.*, 2006). However at board scales, landslides are difficult to detect. At the global scale, Hong *et al.* (2007) used controlling factors derived from remotely sensed data such as SRTM (Shuttle Radar Topography Mission) and MODIS to compute the susceptibility to landsliding (Hong *et al.*, 2007). This model was used in conjunction with satellite-based precipitation information (NASA TRMM-based Multi-satellite Precipitation Analysis (TMPA) to detect areas with significant landslide potential due to heavy rainfall (Hong *et al.*, 2006).

2.2.4. Salinisation

Salinisation, which can be a natural process, is often associated with irrigated areas where low rainfall, high evapotranspiration rates or soil textural characteristics impeded the washing out of the salts which subsequently built up in the soil surface layers.
The presence of salt in the terrain surface affects the surface reflectance that can be detected in remotely sensed data either directly on bare soils, with salt efflorescence and crust, or indirectly through vegetation type and growth as these are controlled or affected by salinity (Metternicht and Zinck, 2003). Remote sensing has been used widely to detect and map salt-affected areas, but these mapping methods are not really adapted for coarse-resolution imageries (Metternicht and Zinck, 2003; Spies and Woodgate, 2005). The assessment of soil-affected expansion and potential salinisation risk should however be feasible with the use, as proxies, of measurements of soil moisture and land use/cover changes (e.g., Sujatha *et al.*, 2000; Li *et al.*, 2007).
Detection of irrigated areas has been done many times, notably through NDVI analysis, and provided relevant results that rely on remotely sensed images from, for example, MODIS (Thenkabail *et al.*, 2005), AVHRR (Loveland e al., 2000) and Spot VEGETATION (Kamthonkiat *et al.*, 2005).

2.2.5. Other soil threats

Other threats affecting soils include soil sealing, loss of soil organic matter, decrease of biodiversity, contamination and compaction. They can be assessed through imagery and procedures similar to those referred above.
Soil sealing is strongly related to urban expansion (e.g., Scalenghe and Marsan, 2009) which can be detected from remote sensing imagery such as AVHRR, Spot VEGETATION and MODIS imageries (Schneider *et al.*, 2003; Budde *et al.*, 2004). It may also induce compaction, contamination and decline in biodiversity (Scalenghe and Marsan, 2009).
Loss in soil organic matter is due to several factors such conversion of grasslands, forests and natural vegetation to arable land, intensive arable farming, overgrazing, soil erosion and forest (Mills and Fey, 2004).

3. COMMUNICATION AND EDUCATION: THE SOIL ATLAS OF AFRICA

To raise the awareness of the general public, policy makers and other scientists to the importance of soil in Africa, the Joint Research Centre of the European Commission is to produce the first ever Soil Atlas of Africa. This is in collaboration with the African Union Commission, the Food and Agriculture Organization of the United Nations (FAO), the Africa Soil Science Society, ISRIC – World Soil Information and scientists from both Europe and Africa.
The Atlas links the theme of soil with rural development and, at the same time, supports the goals of the EU Thematic Strategy for Soil Protection in conserving a threatened natural resource that is vital to human existence.
Not only climate change, but also desertification and loss of biodiversity are strongly affecting soils globally, making the "Soil Atlas of Africa" relevant to a much larger community of stakeholders involved in the implementation of the three "Rio-Conventions" and allowing the exploration of possible synergies among international

multilateral agreements towards global soil protection.

3.1. Content

The Atlas compiles existing information on different soil types as easily understandable maps (both at regional and continental scale) covering the African continent (fig. 1). The Soil Atlas of Africa intends to produce derived maps at continental scale with descriptive text (e.g. vulnerability to desertification, soil nutrient status, carbon stocks and sequestration potential, irrigable areas and water resources) as well as specific maps to illustrate threats such as soil erosion for instance. For each regional overview, large scale examples of soil maps and derived products are presented too.

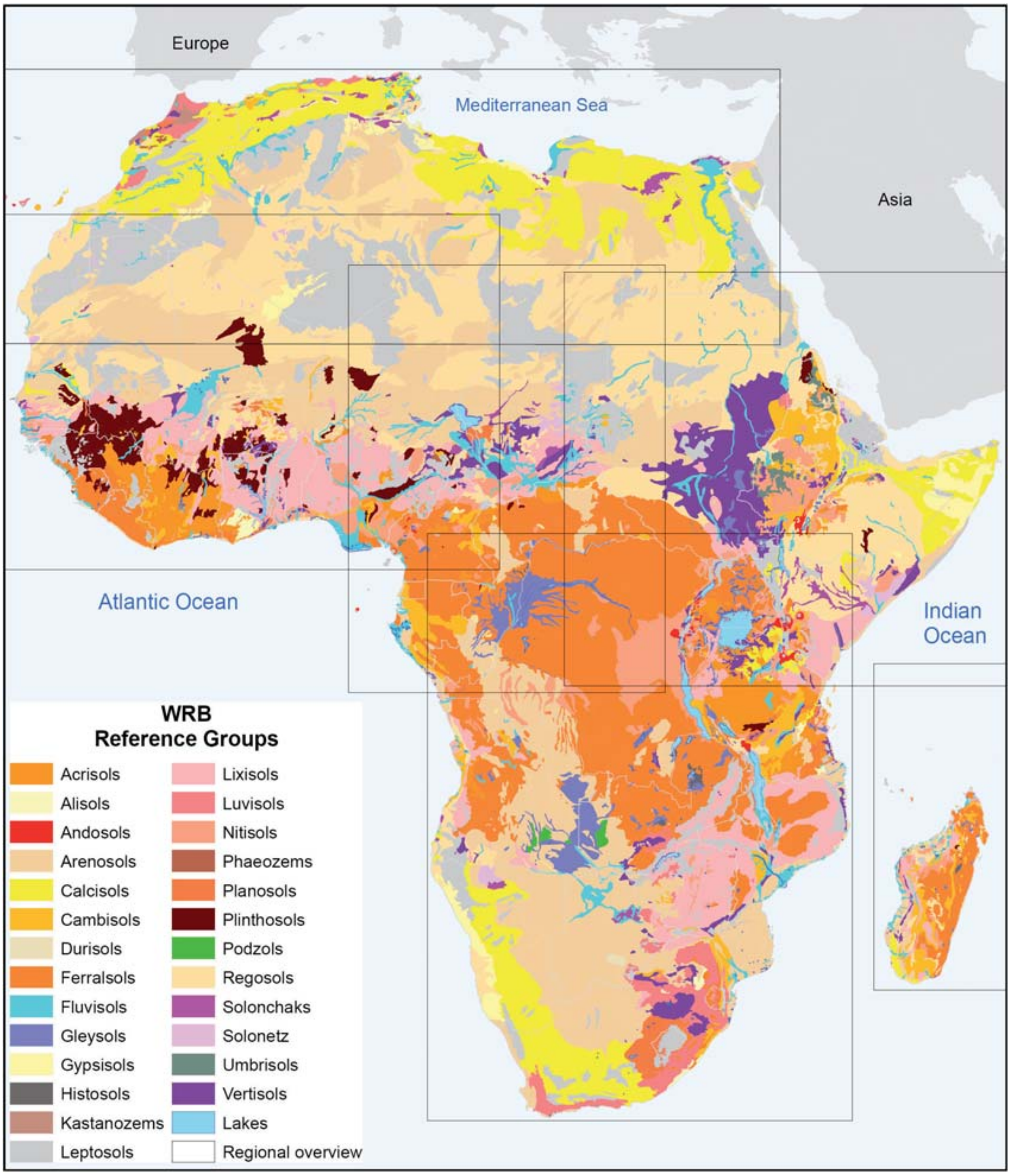

Figure 1. Distribution of the major soil types in Africa with the main regional overviews the Atlas focuses on (open quadrangles). The map shows the dominant Reference Soil Groups according to the WRB2006 classification and correlation system for Africa (IUSS Working Group WRB, 2007). The map is the updated output of the African part of the 1:5 000 000 Digital Soil Map of the World produced by FAO. The map clearly shows the zonal arrangement of soils in Africa.

Figure1. Répartition des principaux types de sol en Afrique avec en superposition une vue d'ensemble des différentes régions sur lesquelles l'Atlas se focalise. La carte montre les groupes de sol de référence dominants tels que définis sur base de la classification WRB2006 et du système de corrélation pour l'Afrique (IUSS Working Group WRB, 2007). Il s'agit d'une mise à jour de la partie africaine de la carte numérique mondiale des sols à l'échelle de 1:5 000 000 produite par la FAO. La carte illustre clairement la distribution zonale des sols en Afrique.

The Atlas illustrates the diversity of soils from the humid tropics to the arid deserts through a series of maps supported by explanatory texts, high quality photographs and descriptive graphics. The atlas illustrates the variation of soil in Africa and from an African perspective. Supporting texts describe the major soil types, together with their principal characteristics and the main soil forming processes; special attention is given to interactions between land use and soil condition.

The soil names and terminology used in the Soil Atlas are those of the World Reference Base for Soil Resources 2006 (IUSS Working Group WRB, 2007), a cooperative effort of the FAO, ISRIC-World Soil Information and the International Union for Soil Sciences to arrive at a common language for describing soils.

This Atlas highlights the diversity and richness of soil in Africa and may help the reader to understand better the characteristics and potential of various soil types in this part of the world.

3.2. The database

The maps that make up this atlas are primarily derived from the Harmonized World Soil Database (HWSD) that has been developed by the Land Use Change and Agriculture Program of IIASA (LUC) and the FAO in partnership with the ISRIC – World Soil Information and with the European Soil Bureau Network (ESBN) (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009). The database we used in the Atlas is an update version of the HWSD, according to the World Reference Base for Soil Resources 2006 classification system (IUSS Working Group WRB, 2007).

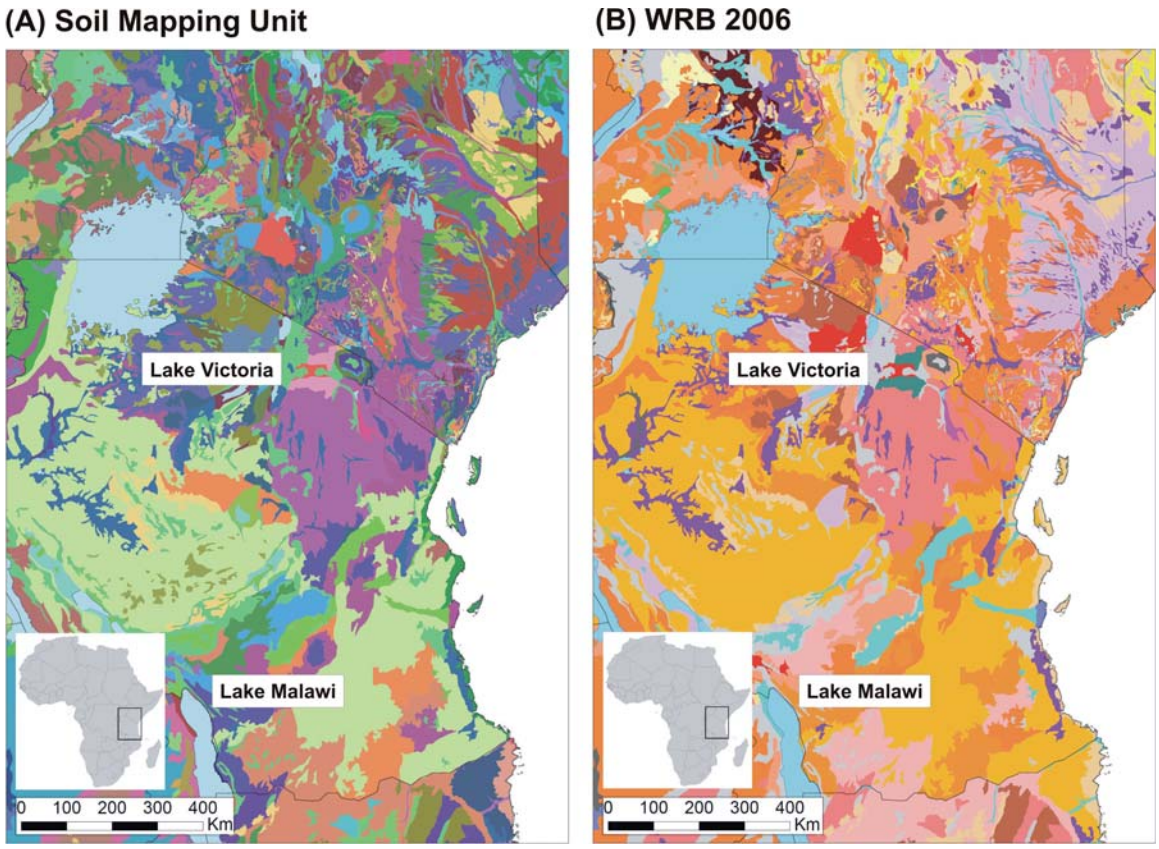

Figure 2. Example of a regional view as it is presented in the Atlas (actual display scale in the Atlas: 1:3 000 000). (A) Soil Mapping Units (SMU). A difference of resolution is clearly identifiable between the north-east of the area and the surroundings of Lake Malawi. (B) The dominant soil type represented for each SMU. The classification system is that of the World Reference Base for Soil Resources 2006 (IUSS Working Group WRB, 2007) (see figure 1 for legend).

Figure 2. Exemple d'une vue régionale telle que présentée dans l'Atlas (l'échelle réelle de publication est de 1:3 000 000). (A) Unités de cartographie des sols (SMU). On note clairement une différence de résolution entre le nord-est de la région et les environs du lac Malawi. (B) Sol dominant pour chaque SMU. La classification des sols est basée sur le World Reference Base for Soil Resources 2006 ((IUSS Working Group WRB, 2007) (la légende est montrée sur la figure 1).

The HWSD original data for Africa combines existing regional and national updates of soil information (SOTER and SOTWIS (Secondary SOTER databases) databases) with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World (FAO/Unesco 1971-1981). The spatial resolution of the Soil Mapping Units (SMU) varies by region depending on the source data (fig. 2). The best resolution represents approximately a 1:1 million map scale and can be found in Eastern and Southern Africa, which is included in the SOTWIS database.

The HWSD raster database has a resolution of about 1 km (30 arc-seconds), which ensures compatibility with important inventories such as Global Land Cover 2000/2005 data available at 30 arc seconds (http://www-tem.jrc.it/glc2000/). The HWSD by necessity presents multiple grid cells with identical attributes occurring in individual soil mapping units as provided on the original vector maps. The database shows the composition of each SMU, and standardized soil parameters for top- and subsoil. A SMU can have up to 9 soil type/topsoil texture combination records in the database. The derived soil properties (provided for topsoil (0-30 cm) and subsoil (30-100 cm) separately) have been derived from analyzed profile data obtained from a wide range of countries and sources.

The series of maps of the Atlas cover the whole continent and illustrate the varying pattern of different soil types at the scale 1:3 000 000. The maps represent the dominant soil type of each soil mapping unit (fig. 2). Maps of soil properties (texture, mineralogy, organic carbon, pH, cation exchange, base saturation, etc) of the dominant soil types are also presented (fig. 3).

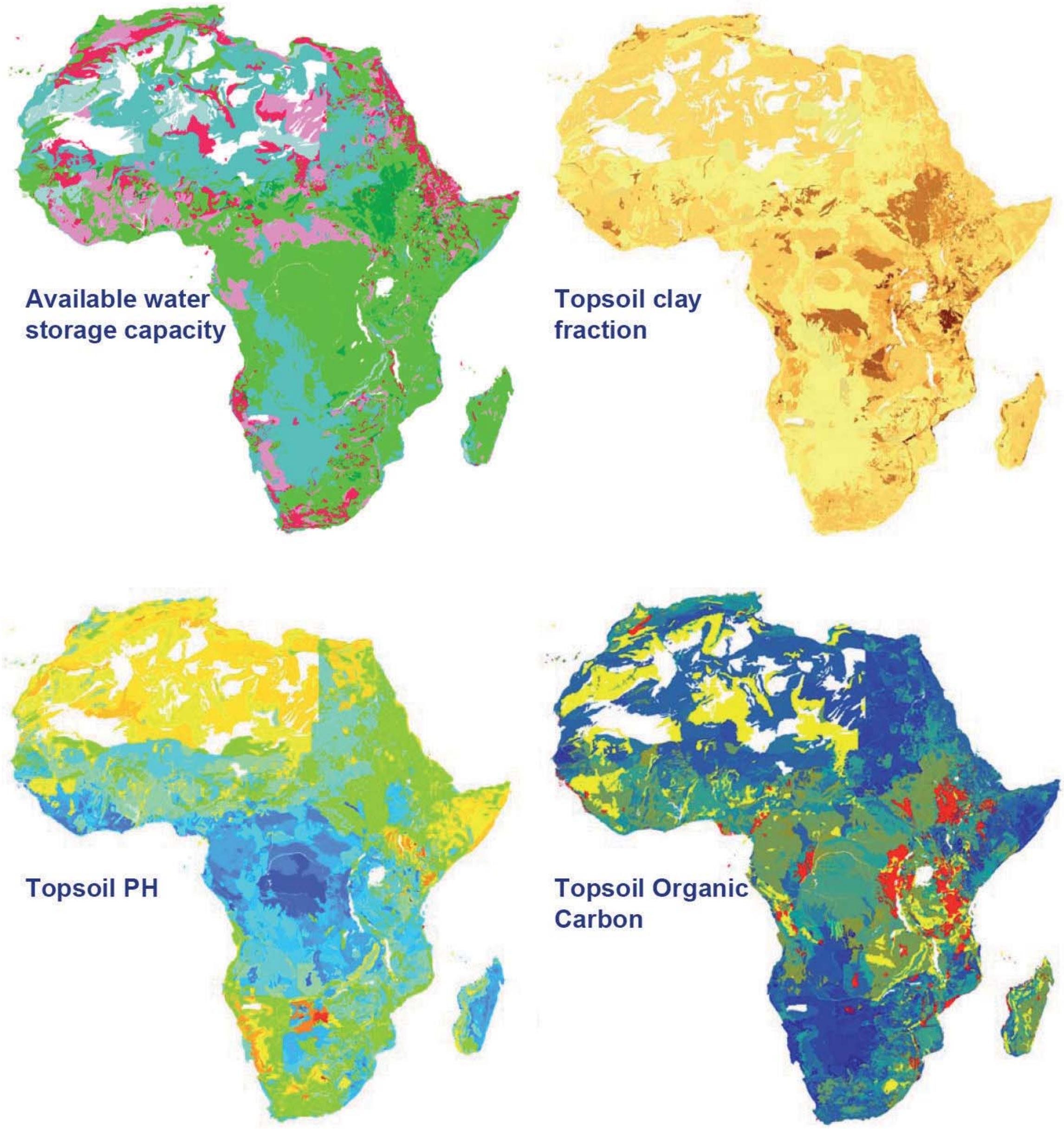

Figure 3. Examples of soil property maps derived from the database used for the Soil Atlas of Africa.

Figure 3. Exemples de cartes de propriétés des sols dérivées de la base de données utilisée pour l'Atlas des sols d'Afrique.

3.3. Making soil information available

The Atlas will be published as a hardcover book containing 174 A3 pages, which will allow soils maps to be displayed at the A2 scale. Both French and English versions of the Atlas will be edited. The Atlas will be sold at a low cost and will be for free for educational purposes (Schools and Universities). A digital version on CD and eventually freely downloadable on internet will also be available.

Together with the publication of the Atlas, associated datasets on soil characteristics for Africa will be made available. These datasets will be useful for making broad distinction among soil types and provide general trends at the global and regional scales but have limitations when applied at higher levels of resolution. Since soils mapped and related properties are based on the dominant soil unit, even though the area is comprised of several soil types, there is an overestimation of the extent and the importance of the dominant soil.

The datasets will be made accessible for free downloading from the portals of the SOIL Action (http://eusoils.jrc.ec.europa.eu/) and the ACP Observatory for Sustainable Development (http://acpobservatory.jrc.ec.europa.eu). The datasets will also be included in the African-European Georesources Observation System (AEGOS) project (http://www.aegos-project.org/) which aims at setting-up a pan-African information system containing and making accessible data and knowledge on African geological resources and contributing to the Global Earth Observation System of Systems (GEOSS) (http://www.earthobservations.org/).

The atlas is also expected to satisfy the soaring demand for up-to-date and relevant soil information at the international level like for the Africa Soil Information Service (AfSIS) (http://www.africasoils.net/) which constitutes the African part of the GlobalSoilMap.net project (Sanchez *et al.*, 2009).

4. CONCLUSION

In the context of the sustainable use of soil resources in Africa, two current topics that concern (1) the production by coarse-resolution spaceborne remote sensing of soil information at regional and continental scales and (2) the communication to a wider audience of the importance of soil through the Soil Atlas of Africa project are presented.

Coarse-resolution spaceborne remote sensing offers an ideal support for soil mapping. Through the review of multispectral, thermal infrared, passive and active microwave imaging, the paper shows that many sensors help in the delineation of soils themselves, in the assessment of some of their key properties and identification of threats such as water and wind erosion, landsliding and salinisation. However, the use of remotely sensed imagery for mapping soils can be problematic if applied alone and often requires the use of ancillary data (e.g., soil topography, vegetation, soil properties maps, climate and lithology) and field observations.

In a wider context, remote sensing is complementary to digital soil mapping (DSM). DSM frequently requires indirect information from remote sensing and vice-versa (McBratney *et al.*, 2003). In that sense, together with the publication of the Atlas, the production of datasets on soil characteristics is an additional value.

The production and the diffusion of soil information have a large potential with regard to setting-up of international initiatives and future satellite missions (Committee on Earth Observation Satellites (CEOS), http://www.ceos.org/).

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