***Manuscript**
Click here to download Manuscript: Dewitte_manuscript.doc
Click here to view linked References

Geoderma, Volumes 211–212, December 2013, Pages 138–153

Towards a harmonisation of the soil map of Africa at the continental scale

Olivier Dewitte (1*), Arwyn Jones (1*), Otto Spaargaren (2), Henrik Breuning-Madsen (3), Michel Brossard (4), Almami Dampha (5), Jozef Deckers (6), Tahar Gallali (7), Stephen Hallett (8), Robert Jones (8), Method Kilasara (9), Pieter Le Roux (10), Erika Michéli (11), Luca Montanarella (1); Lamourdia Thiombiano (12), Eric Van Ranst (13), Martin Yemefack (14), Robert Zougmore (15).

(1) European Commission, Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy

(2) formerly ISRIC - World Soil Information, Wageningen, The Netherlands

(3) University of Copenhagen, Department of Geography and Geology, Copenhagen, Denmark

(4) Institut de Recherche pour le Développement (IRD), UMR Eco&Sols, Montpellier, France

(5) African Union Commission, Department of Rural Economy and Agriculture, Addis Ababa, Ethiopia

(6) University of Leuven, Department of Earth and Environmental Sciences, Heverlee, Belgium

(7) University of Tunis El Manar, Department of Geology, Tunis, Tunisia

(8) Cranfield University, National Soil Resources Institute, Cranfield, United Kingdom

(9) Sokoine University of Agriculture, Department of Soil Science, Morogoro, Tanzania

(10) University of the Free State, Department Soil-, Crop- and Climate Sciences, Bloemfontein, South Africa

(11) Szent István University, Department of Soil Science and Agricultural Chemistry, Godollo, Hungary

(12) Food and Agriculture Organization of the United Nations, Subregional Office for Central Africa, Libreville, Gabon

(13) Ghent University, Department of Geology and Soil Science, Ghent, Belgium

(14) Institute of Agricultural Research for Development (IRAD), Department of Soil Water and Atmosphere Sciences, Yaoundé, Cameroon

(15) International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), West and Central Africa, Niamey, Niger

*Corresponding authors:
Olivier Dewitte
Royal Museum for Central Africa, 3080 Tervuren, Belgium
olivierdewitte@yahoo.com

Arwyn Jones
European Commission, DG Joint Research Centre, Institute of Environment and Sustainability,
21027 Ispra (VA), Italy

Abstract

In the context of major global environmental challenges such as food security, climate change, fresh water scarcity and biodiversity loss, the protection and the sustainable management of soil resources in Africa are of paramount importance. To raise the awareness of the general public, stakeholders, policy makers and the science community to the importance of soil in Africa, the Joint Research Centre of the European Commission has produced the Soil Atlas of Africa. To that end, a new harmonised soil map at the continental scale has been produced. The steps of the construction of the new area-class map are presented, the basic information being derived from the Harmonized World Soil Database (HWSD). We show how the original data were updated and modified according to the World Reference Base for Soil Resources classification system. In comparison to the initial map derived from HWSD, the new map represents a correction of 13% of the soil data for the continent. The map is available for downloading.

Keywords: Soil map, Harmonisation, Soil classification, Soil Atlas of Africa, Google Earth.

1. Introduction

In the context of major global environmental challenges such as food security, climate change, fresh water scarcity and biodiversity loss, the protection and sustainable management of soil resources are of paramount importance (Lal, 2004, 2009; Gisladottir and Stocking 2005; Millennium Ecosystems Assessment, 2005; UNEP, 2007; Vlek et al., 2008; Palm et al., 2007, 2010).

However, the importance of soil and the multitude of environmental services it provides are not widely appreciated by society at large. Soil scientists are becoming increasingly aware of a greater need to inform and educate the general public, policy makers, land managers and other scientists of the importance and global significance of soil (Hartemink and McBratney, 2008; Sanchez et al., 2009; Palm et al., 1010; Sachs et al., 2010; Bouma et al., 2012). This is particularly true in Africa where soil degradation in its diverse forms is a fundamental and persistent problem throughout the continent. Often ignored, because the observed impacts are gradual, soil degradation is a major development issue, as pressure on land, poverty and migration are mutually reinforcing (Gisladottir and Stocking 2005; Millennium Ecosystems Assessment, 2005; UNEP, 2007; Vlek et al., 2008; Lal, 2009).

While increased awareness of the role of soil is critical, many African countries lack the fundamental knowledge base on which to base policy and land management decisions. Most countries have very limited detailed mapping of their soil resources. The previous information base is of variable age and quality and only partly correlated between countries (Van Ranst et al., 2010; Grunwald et al., 2011). Most countries have a general soil map at very small scales, usually substantially smaller than 1:250,000. For many, the only national coverage is still the 1:5 M Soil Map of the World produced by FAO and UNESCO in the 1970s (FAO/Unesco 1971-1981). Detailed soil information for regional or project planning is usually not available. For example, only 15% of the Democratic Republic of the Congo has been mapped at scales of 1:50,000 to 1:500,000 (Van Ranst et al., 2010).

In this context, the Joint Research Centre (JRC) of the European Commission has initiated a project that has brought soil experts from Europe and Africa to produce the Soil Atlas of Africa (Jones et al., 2013). The main goal of the project was to produce a publication to raise awareness of the significance of soil to human existence in Africa that shows and explains the reasons for the varying patterns of soil across the continent and communicates the need to conserve and manage this increasingly threatened natural resource through sustainable management.

The heart of the Atlas is harmonised soil information at both regional and continental scales. To provide a harmonised picture of the soils in Africa, the new continental soil map has been produced. This paper describes the compilation and the processing of the soil data to complete the harmonised area-class map. The new map is displayed in the Atlas in a series of map sheets at the scale 1:3 M that cover the whole continent and the harmonisation of the map is done accordingly.

2. Original datasets

The Harmonized World Soil Database (HWSD) that has been developed by the Land Use Change and Agriculture Programme 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, 2012) has been the best continental soil map of Africa available. The new soil map is primarily derived from the HWSD.

The original HWSD data for Africa combine the FAO/Unesco Digital Soil Map of the World, or DSMW for short (FAO/Unesco 1971-1981; FAO, 1995, 2003), together with various regional SOTER (SOil and TERrain) and SOTWIS (Secondary SOTER derived from SOTER and WISE) databases (FAO, IGADD/Italian Cooperation, 1998; FAO/ISRIC, 2003; Batjes, 2007, 2008; FAO/ISRIC/UGent, 2007; Goyens et al., 2007). Figure 1A shows that the information provided by HWSD is not homogeneous. The scale of the soil information varies by region depending on the source data:

- The DSMW, mainly the Sahara and West Africa except Senegal and The Gambia, is at the scale 1:5 M;

- The SOTER database for Northeastern Africa (FAO, IGADD/Italian Cooperation, 1998) contains information at equivalent scales between 1:1 M and 1:2 M;
- The scale of the SOTER database of Southern Africa (FAO/ISRIC, 2003) and of Central Africa (Batjes, 2007; FAO/ISRIC/UGent, 2007; Goyens et al., 2007) range between 1:1 M for most countries, and 1:2 M for Angola and the Democratic Republic of the Congo;
- The SOTER database for Senegal and The Gambia is presented at scale 1:1 M (Batjes, 2008).

Although some databases have a similar scale, they can differ in resolution and differences in data density. For example, the SOTER map for South Africa is very detailed compared to the maps of other countries in the SOTER database of Southern Africa (FAO/ISRIC, 2003). Reliability of the information contained in the database is variable: the parts of the database that make use of the DSMW are considered less reliable, while most of the areas covered by SOTER/SOTWIS databases are considered to be the most reliable. For some regions, for example, the Sinai Peninsula and some areas in Namibia, HWSD contains no information. The DSMW uses the FAO-74 legend of the Soil Map of the World (FAO/Unesco, 1974) whereas SOTER/SOTWIS uses the FAO-90 soil classification system (FAO/Unesco/ISRIC, 1990). The information from DSMW and SOTER/SOTWIS are both provided according to political borders (Figure 1A).

Figure 1

At the small scales of the HWSD, the location of individual soil types cannot be delineated. Therefore, the database presents the locations of groups of soil types (also known as associations) that are referred to as Soil Mapping Units (SMUs). The criteria for soil associations and SMU delineation take into account the functioning of pedological relationships within the landscape.

Individual soil types are referred to as Soil Units (SUs). While the proportion of each SU within a SMU is specified, the location of the individual SUs is not defined. Data on soil characteristics are assigned at the SU level.

The HWSD is a raster or grid-cell database where the SMUs from the input soil datasets have been gridded to a resolution of 30 arc-seconds (nominally about 1 km). The pixel size ensures compatibility with important global inventories such as the Shuttle Radar Topography Mission (SRTM) digital elevation model and the Global Land Cover (GLC) 2000 dataset (Dewitte et al., 2012). The HWSD by necessity presents multiple grid cells with identical attributes reflecting the much coarser scale of the original vector data. For each SMU, the database records a standardised set of topsoil (0-30 cm) and subsoil (30-100 cm) characteristics for up to 9 SUs (Figure 1B). Figure 1B shows the map of soil diversity that may reflect both the actual situation (e.g. desert areas) and the level of soil survey in the area.

Although the HWSD constitutes a major contribution to the harmonisation of soil data at the continental scale, it appears from Figure 1 that it still contains numerous harmonisation shortcomings that cannot be presented as such in the Atlas (Figure 2). Boundary issues, particularly at the political level, cannot be visualised in the Atlas, as well as areas with no information. In addition to these examples of lack of harmonisation, mistakes are revealed in the analysis of the soil pattern of some regions, many river and drainage networks are not shown continuously, and major water bodies and coastline features have not been updated recently (many data shown in HWSD are historic). When zooming in the dataset, many “micro-polygons” comprising only few pixels are present, particularly in the regions of high density information, which gives an artificial “pixelated” or “noisy” pattern to the soil distribution. Cartographic judgement has been used to remove these shortcomings or at least to smooth them in order to present a more usable harmonised picture of the African soils.

Figure 2

Figure 3 identifies the steps that were followed to harmonise the HWSD information to produce the new map. There were two main production stages: (I) a raster stage related to the HWSD processing, then; (II) a polygon stage where the polygon map derived from the processed HWSD is updated. This was undertaken utilising Google Earth and several lithological and geological maps that were readily available (Table 3).

Google Earth was used as much as possible in all the regions. In the arid and semi-arid areas, much can be inferred from Google Earth since the soil surface is without vegetation or only partially covered. In regions where vegetation coverage obscures most soils, its use is less straightforward but still allows some major soil features to be delineated. Google Earth shows information that was captured by satellites at maximum a few years ago, which allows multi-temporal comparison with the HWSD data to be made.

Figure 3

The following sections describe the various data processing stages required to produce the soil maps published in the Atlas.

3. Database processing

3.1 Assigning the dominant soil type

As each pixel or cell of the HWSD can contain up to nine individual SUs, a single SU (or a soil type) is defined as dominating a particular SMU on the basis of largest areal extent occupying the SMU. While it is clear that this approach masks the diversity of soil present within an SMU and presents a simplified view of soil distribution across Africa, the final map is much clearer and easier to use. It should be emphasised that the main aim of this publication was to produce a map that introduces and highlights the diversity and importance of the soils of Africa to a new wider audience, outside of the soil science community. Specialists who need more detailed information can download the HWSD (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/).

In the HWSD, the sequence in which the SUs within the SMU are presented follows the rule that the dominant soil always has sequence number 1. As a result of a visual inspection of the database, it appears that there were several errors and inconsistencies in the dominant SU table such that the SU with the largest areal extent in the SMU is not always the one that is selected as being representative. Therefore we rechecked all the SMUs systematically to ensure that the SU with the largest areal extent is the one that represents the dominant soil type of the corresponding SMU.

A total of 147 SMUs, out of the 7327 that cover the whole Africa have been modified (blue areas in Figure 9). The determination of the dominant SU in a SMU was made on the basis of the name of the soil only, not its properties. Three types of errors or inconsistencies were detected (Figure 4):

- The SU having the actual largest areal extent is not initially ranked as the dominant one and another soil type is set as representative. The extent of this SU can be smaller or larger than 50% of the SMU extent (Figure 4 A and B);
- Two or three SUs are defined by the same soil type name but none of them is ranked as the

dominant SU. While considered together, their combined areal extent is larger than the initial dominant SU. The soil properties of the same soil type SU can be identical (Figure 4C) or can be slightly different (Figure 4D). The combined extent of these SUs can be smaller or larger than 50% of the SMU.

- An SU is defined as a non-soil unit in the initial FAO-74 system. This SU can correspond either to DS (i.e. dunes and shifting sands) or RK (i.e. rock debris). As noted below (Section 3.2), these SUs are considered as soil types in the classification system used for the new map. In some cases, this “new” soil type corresponds to the actual dominant SU and is set as such (Figure 4E and 4F).

Figure 4

3.2 Translation to WRB

Within the HWSD, the name of the soil is given according to the legends of the FA0-Unesco 1:5 M Digital Soil Map of the World (FAO-74 system) or SOTER/SOTWIS (FAO-90 system). To harmonise these two systems and the existing JRC Soil Atlas series (Jones et al., 2005; 2010), these names have been translated to the World Reference Base for Soil Resources (WRB) classification and correlation system (IUSS Working Group WRB, 2007). The WRB serves as a common language through which the FAO-74 and FAO-90 systems can be compared and correlated.

The WRB classification system was developed under the auspices of FAO and the International Union of Soil Science, by building on the foundations of the FAO legend to create a common basis for correlating the soil resources of different countries. The WRB places all types of soil within thirty two major Reference Soil Groups (RSGs), with a series of uniquely defined qualifiers (prefixes and suffixes) for specific soil characteristics (IUSS Working Group WRB, 2007).

This section present the conversion table used to translate the FAO systems into the WRB scheme (Table 1). The table shows the major RSGs according to the application of WRB to the soils of Africa. The table correlates each WRB RSG to the related SUs in both FAO systems and gives the translation key only for the dominant SUs of the SMUs present in the continent of Africa. At the scales of the HWSD the dominant SUs of the SMUs present in the African continent comprise all but three of the WRB RSGs: Albevulisols, Anthrosols and Cryosols. The WRB system recommends that the RSGs with prefix qualifiers be used for small-scale maps (i.e. smaller than 1:1 M). This recommendation has been followed in the construction of the legend: one or two prefix qualifiers are put with each RSG to define the soil types.

Table 1

Building Table 1 presented many issues. It is based on expert knowledge of both the FAO and WRB systems, the expertise in the realisation of FAO Soil Map of the World and the SOTER methodology, and the HWSD interpretation. One of the key issues concerns the consideration of the phases . In FAO-74 and FA0-90 , phases are subdivisions of soil units based on characteristics which are significant for the use or management of the land but are not diagnostic for the separation of the soil units themselves (IUSS Working Group WRB, 2007). While noted as an additional soil characteristic in these systems , phases have to be taken into account in the WRB classification terminology (FAO names in mauve in Table 1). The WRB renaming of the SU was undertaken according to the rules presented in Table 2. To obtain the final translation we have considered in the database that the phases rule the name to the SMU if they are associated to a dominant SU that covers more than 50% of the SMU. For example, a dominant SU characterised by a petric phase

(HWSD code 3) will be renamed as a Pisoplinthic Plinthosol (PTpx) if its initial name is not a Vertisol, a Fluvisol, a Solonetz or a Gleysol. The consideration of Phases 3 and 6 allows representation of the Plinthosols in the region covered by the DSMW, since this soil group is not defined in the FA0-74 system (Table 1).

Table 2

The HWSD contains units defined as “non-soil” in the FAO systems: DS (i.e. dunes and shifting sands), RK (i.e. rock debris) and ST (salt flats) in FAO-74 and UR (urban) in FAO-90. These units are considered as soil types in WRB (FAO names in green in Table 1).

It is clear from Table 1 that most of the RSGs and soil types defined in FAO-74 and FAO-90 are also present in WRB, the symbols having been adapted accordingly. Nevertheless, some RSGs present in the FAO systems are not defined in WRB: Lithosols, Rendzinas, Xerosols and Yermosols in FAO-74 and Greyzems in FAO-90 (FAO names in blue in Table 1). And WRB contains RSGs that are not defined in FAO: Durisols, Umbrisols, Stagnosols and Technosols in both FAO systems, and Alisols, Calcisols, Gypsisols, Lixisols and Plinthosols in FAO-74. In addition, several FAO soil types do not keep their name in WRB and are inserted into other RSGs (FAO names in red in Table 1).

It has to be noted that the WRB soil types defined as `Undifferentiated´, and for which no corresponding FAO name is shown in Table 1, are soil types that were not present as such in the HWSD. Their occurrence results from the completeness of the `No Data´ areas in the original database (see Section 4.4).

For more detailed information on the major WRB RSGs present in Africa, the qualifiers used in the table and the WRB classification approach to describe and define different types of soil, the reader can refer to the Atlas (Jones et al., 2013).

4. Data update and modification

At the conclusion of the soil name translation stage, the raster database was converted to polygons to facilitate the cartographic stage (Figure 1). Cells with adjacent soil names were merged in this process. Thousands of “micro-polygons” corresponding to small terrain and soil components, which were too small to be labelled on the map sheets of the Atlas at the scale 1:3 M, were erased in order to produce ‘clean’ maps. These are indicated by the red speckle on the summary modification map (Figure 9).

At this stage, a decision was taken not to over-clean the SOTWIS data with respect to the more coarser information from the original DSMW. While the preservation of detail at the expense of cartographic harmonisation may have produced some ‘noisy’ map sheets in the Atlas, e.g. in Kenya and South Africa, we felt that it was better to highlight the lack of data in other parts of the continent.

Several major modifications were carried out to the initial data contained in the HWSD on the basis of expert knowledge, Google Earth, and several soil maps (Table 3). These maps are accessible to the public through the ISRIC - World Soil Information Database (http://library.wur.nl/isric/).

Table 3

The harmonisation steps are described below. For the sake of clarity, they are presented separately in a structured order. In practice, we often dealt with several harmonisation issues concurrently.

4.1 Phases and dunes

In addition to the renaming process performed during the previous stage (Table 1), a number of modifications were made to the polygon map using expert knowledge and the phase characteristics of the DSMW. The main modifications are related to the phases 3 and 6 (Table 2) that were used to redefine the extent of the Plinthosols in central and west Africa, and which were previously absent (the green areas in Figure 9). As an example, Figures 5 A and B illustrate the Plinthosol updates in Senegal and the neighbouring countries. When considering only the renaming through the database processing (Figure 5A), Plinthosols are absent in Senegal. At the continental scale, Plinthosols constitute a major update (Figure 9). The other modifications related to phases 4, 5 and 9 are clearly of smaller geographic extent. These changes are indicated in the red areas in Figure 9.

Figure 5

Similarly to the consideration of the phases, the update of the shifting sands and active dunes needed processing additional to the database renaming. The WRB classification defines these areas by a specific Protic Arenosol showing no horizon development (ARpr, Table 1). The shifting sands and active dunes are also specifically defined in FAO-74 (renamed from DS to ARpr, Table 1). However this specific distinction does not exist in FAO-90, shifting sands and active dunes being implicitly considered together with other sandy soils and classified as Arenosols having no meaningful characterisation (renamed from ARh to ARha, Table 1). Contrary to the FAO-74 data, a direct renaming in the database from FAO-90 to the WRB ARpr was impossible. For the areas covered by the FAO-90 data, the renaming from ARha to ARpr was done after the database processing. A systematic approach was to check with Google Earth all the ARha polygons in the areas covered by FAO-90 data to see to what extent they were related, or not, to shifting sands and active dunes and to correct obvious misclassifications. Intensive checking of the data with Google Earth also allowed new dune areas to be detected and dune areas that had moved to be reshaped. This can be seen, for example, in the Libyan – Egyptian – Sudan border region, where changes can easily be observed in the pattern of the dune polygons (Figure 5C and D). The areas of dune update are shown in yellow in Figure 9.

4.2 Boundary effects

The most visible boundary effects occur when a border delimits the two data sources DSMW and SOTWIS, showing differences in soil classification and data resolution (Figures 1 and 2). These effects are particularly striking between Libya and Egypt where, for example, two different soil names are used for the Great Sand Sea (Figure 2A). Another explicit example concerns Senegal and The Gambia where compared to the surrounding countries the density of information is far greater and the soil terminology changes across the borders (Figure 2B). The same observation can be made between Lesotho, which is only defined by a few FAO-74 soil units, and South Africa (Figure 2 E). Within SOTWIS areas, differences in data resolution are also frequent across country boundaries as exemplified in Figure 2D between Kenya and Tanzania in the Mount Kilimanjaro region. The example of Mount Kilimanjaro illustrates very well the problem that, very often, differences in soil terminology exist between SOTWIS units having similar soil forming factors but which are separated by a political border.

Figure 5 shows the harmonisation for two problem regions. In Senegal and The Gambia, the consideration of the Plinthosols was one key issue. The harmonisation required a simplification of the SOTWIS data. In the Libyan – Egyptian – Sudan border region an important part of the harmonisation relied on the update of the shifting sands and active dunes. The updates in that region resulted in an increase in density of information. The two examples in Figure 5 are ideal cases of harmonisation where plenty of information is available either from the HWSD in Senegal and The Gambia, or from Google Earth images in the Libyan – Egyptian – Sudan region (Figure 6).

Figure 6

All the political borders were checked systematically and, where feasible, the boundary effects were removed on the basis of expert knowledge. In total, modifications were brought to most of the borders between the two data sources. The borders inside SOTWIS data were also modified except for those between the countries of the horn of Africa and between Egypt and Sudan where the harmonisation in the original database is flawless. Figure 8 (C and D) shows together with the harmonisation of the drainage network, the consideration of the border issues between three SOTWIS countries. Unless otherwise stated, the changes at the borders are indicated as red areas in Figure 9.

4.3 Soil pattern

At the small scales of the HWSD, one can understand that the soil pattern of a specific region might differ slightly from one map to another since such a survey implies expert knowledge. However, independently of the boundary effects and the other harmonisation issues, mistakes were identified in soil patterns in regions of Zambia, Malawi and Lesotho. The modifications were carried out on the basis of different soil maps (Table 3). These changes are indicated as red areas in Figure 9.

4.4 No information areas

A total of 203 areas with no information are present in the HWSD derived soil map (Figure 1). Four of them are particularly large: one is located in Egypt (the Sinai Peninsula) and the other three are in Namibia (two along the ocean and one in the north of the Kalahari Basin). There are other areas of very limited extent that do not appear at a first sight in a regional map.

All the areas were completed (black areas in Figure 9). Fortunately, the larger areas are located in semi-arid and arid regions allowing a reliable use of Google Earth. Figure 7 shows an example of the completion of two of the large areas in Namibia. It can be seen that the completion were done according to the exiting soil pattern.

Figure 7

4.5 Drainage networks, water bodies and coastlines

Drainage networks, water bodies and coastlines are features easily identifiable on a map and any kind of shortcoming in their morphology can discredit the value of the soil information presented in the Atlas.

Many drainage networks and river bodies are not shown as continuous features, particularly when the drainage systems flow across political borders (Figure 8 A and C). In addition some rivers, lakes and coastlines are very dynamic features subject to morphological changes large enough to be noticeable even at the small scale of the HWSD. Being based on legacy information, some of the data used in HWSD are from several decades ago. In very dynamic environments such as river deltas and lakes with water level changes and large sedimentation rates, such periods of time are long enough to register significant changes (Figure 8 E).

In this context, the drainage networks as well as the rivers and water bodies (e.g., Congo River, Nile River, Lake Chad, Lake Volta) have been harmonised. The main coastline changes have been also considered (e.g. Nile Delta, Mozambique coast) (see Figure 8 for examples). The modifications of the drainage networks and water bodies are indicated as red areas in Figure 9 whereas the coastline updates are in pink.

Figure 8

In the former sections we detailed all the steps for the harmonisation, referring each time to a specific modified area. If we sum all the areas together the final modification picture may be shown in Figure 9. The totality of the modified areas is large, representing 13% of the continent; soil types and SMUs of the original HWSD were corrected.

Figure 9

The quality and the reliability of the modifications are difficult to quantify. However, for the areas in arid and semi-arid environments, for example at the Egyptian-Libyan border and in the Namib desert, the delineation of the soil units was clearly facilitated by the very low density or even absence of the vegetation cover. These places were harmonised at a higher resolution and are therefore more reliable.

5. Continental soil map

The new map harmonised at the continental scale (Figure 10) shows the distribution of the major dominant soil types that can be found in Africa as defined by the Reference Soil Groups of the WRB scheme. The map comprises all but three of the WRB RSGs and illustrates a great soil diversity. The analysis of the RSG distribution (Figure 11) shows that over 60% of the soil types represent hot, arid or immature soil assemblages: Arenosols (22%), Leptosols (18%), Cambisols (11%), Calcisols (5%), Regosols (3%) and Solonchacks/Solonetz (2%). A further 20% or so are soils of a tropical or sub-tropical character: Ferralsols (10%), Plinthisols (5%), Lixisols (4%) and Nitisols (2%). 12 RSGs cover an area of less that 1% of the African land mass. This fact illustrates that a considerable number of soil types are associated with local soil forming factors such as volcanic activity, accumulations of gypsum or silica, waterlogging, etc. What is striking is that, unlike the other continents, Africa does not exhibit large expanses of prairie or steppe type soils (Kastanozems, Chernozems and Phaeozems).

The average size of the SMUs varies a lot according to the RSG (Figure 11). This can be related to the scale of the original dataset as, for example, a lot of Arenosols, Plinthosols and Ferralsols are in the DSMW part of the HWSD (Figure 1) and DSMW was also used for the phase update (Plinthosols and Durisols). Different environmental conditions could also be responsible for the SMU size (Gray et al., 2011): Arenosols contain the large dune areas in the deserts and Ferralsols are mostly associated with high rainfall areas where the very dense vegetation coverage makes soil delineation less straightforward.

Figure 10

Figure 11

In the context of raising awareness about soil, the harmonisation procedure has allowed a more accurate map to be produced. However, there is scope for future improvement because of the unequal resolution of soil data which causes differences in quality of the current dataset. The confidence of spatial data is usually difficult to quantify because it requires validation and collection of additional independent soil information, usually from the field (Kempen et al., 2009; Brus et al., 2011). This was not possible in this case but it should be possible to improve the new soil map periodically in future with inclusion of new data.

In the meantime, the confidence of the map can only be inferred qualitatively. The best procedure is to consider the information provided in Figure 1: first, the different data sources of the HWSD that show that density and reliability of the information varies according to political borders; then the number of the SU for each SMU that shows the diversity of soil information. The SMU with the highest number of SU bearing the most reliable information. The map shown in Figure 1B provides information similar to a purity map (Kempen et al., 2011).

6. The Soil Atlas of Africa

The new map is at the heart of the Soil Atlas of Africa, displayed in a series of map sheets at the scale 1:3 M, representing some forty percent of the Atlas pages.

The production of the Soil Atlas of Africa represents a unique opportunity to reach a broad range of stakeholders across Africa with a message concerning the importance of soils, the soil resource, and the multitude of services that depend on soil properties, as well as a series of statements concerning environmental changes and related issues facing the soil resource. As developed, some sixty percent of the Atlas pages are therefore dedicated to an environmental and educational function in support of the maps. Materials are provided to help contextualise the map content, highlighting and explaining the WRB map classification adopted, and to provide a narrative for each of the reference soil groups concerning their typical distribution and arrangement. The Atlas adopts a highly visual approach and is illustrated with photographs of soil profiles and associated landscapes to help readers appreciate the soil-landscape associations, and the strengths, weaknesses, opportunities and threats to these landscapes.

The Atlas places in context the mapping sections with a series of expositions concerning the role and importance of soil, descriptions of the definition of soil, soil-forming processes and where soil comes from. Topics such as parent material, topography and relief, climate, temporal influences and the impact of organisms, including humans are highlighted. Also addressed are descriptions of the soil functions and how soils contribute to the global cycles, such as that for water, carbon, nutrients, nitrogen and phosphorous, explaining the role soils play in the wider planetary cycling of materials.

Soil and land use issues are explored and exemplified and the role of soil in the provision of food and fibre is described, both for traditional and contemporary agricultural systems. One section identifies how a number of constraints come to bear on the soils of Africa, highlighting how scarce the naturally fertile soils of the continent are, after issues such as soil depth, wetness, drainage, salinity, nutrient deficiency as well as urban sprawl are taken into account. The Atlas also recognises the strong cultural and ethnographical influences that soil has exerted on the development of African society, for example as a source of raw material for construction of both property and utensils.

The soils of Africa exhibit great diversity and differentiation. Importantly, the Atlas therefore also explains how scientific methods have been developed through the years towards land characterisation and suitability assessment. Many of the key concepts in soil science, such as that of the catena, originated first amongst scientists working on developing assessments in Africa, Milne's work of the mid-1930s in then Tanganyika. Also noted, however, are the salutary lessons to learn and consequences from not applying rigorous methods to land evaluation, such as with the Tanzanian Groundnut scheme of the 1950's (Rizzo, 2006).

The Atlas concludes, following the map sections, by highlighting the degradation threats faced by the soil resources of Africa. For example the impacts manifested by climate change, erosion and population pressures. Case studies are presented highlighting small-holder scale initiatives to improve soil fertility.

Finally, the Atlas identifies the broad range of so-called 'legacy' recorded soils information available for territories across Africa, highlighting the various repositories of such information that exist, such as WOSSAC (Hallett et al, 2011, 2006), and underlines the challenges faced today in developing soil interpretative mapping for a range of end-applications. Contemporary methods for undertaking this, such as digital soil assessment are introduced.

Overall the Atlas represents a significant resource, or relevance to a broad range of end-stakeholders from schools to government ministries and from universities to the public. Overall the document draws together a unique wealth of material that helps to characterise and explain the fragile resource that African soils represent.

Together with the publication of the Atlas, the map and the corresponding datasets (modification map and associated modified HWSD) are available for downloading free of charge 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).

7. Conclusions

The new soil map of Africa represents an important contribution to the future sustainable use of soil resources of the continent. Together with the Soil Atlas of Africa it will raise awareness about the importance of soils to least for in the support of an increasing population and threatened environment. The soil map and associated database have the potential to enhance global studies on climate change, food production and land degradation for example.

The Soil Atlas of Africa Project has provided an opportunity to use the large body of legacy soil information for Africa collected over the last 60 years. The resulting harmonised soil map and database demonstrate the value of applying modern spatial analytical techniques to historic soil data to produce what is undoubtedly the best current soil information base for the African continent. Initially it is expected to satisfy the soaring demand for up-to-date and relevant soil data at international level in addition to the Africa Soil Information Service (AfSIS), which constitutes the African part (http://www.africasoils.net) of the GlobalSoilMap.net project (Sanchez et al., 2009).

The map has limitations if applied at high resolution because this would require output of data at the soil type level (SU). The soil map units (SMUs) only comprise a dominant SU together with a number of ancillary (or included) soil units but the structure is flexible enough to incorporate new soil (spatial and attribute) data as they become available. There is thus good expectation that the current resolution can be constantly improved in the future.

References

Batjes N.H., 2007. SOTER-based soil parameter estimates for Central Africa – DR of Congo, Burundi and Rwanda (SOTWIScaf, version 1.0). Report 2007/02, ISRIC - World Soil Information, Wageningen.

Batjes N.H., 2008. SOTER parameter estimates for Senegal and The Gambia derived from SOTER and WISE (SOTWIS-Senegal, version 1.0) ISRIC - World Soil Information, Wageningen.

Bouma, J., Broll, G., Crane, T.A., Dewitte, O., Gardi, C., Schulte, R.P.O., Towers, W., 2012. Soil information in support of policy making and awareness raising. Current Opinion in Environmental Sustainability 4, 552–558.

Brus, D.J., Kempen, B., Heuvelink, G.B.M., 2011. Sampling for validation of digital soil maps. European Journal of Soil Science 62, 394–407.

Dewitte, O., Jones, A., Elbelrhiti, H., Horion, S., Montanarella, L., 2012. Remote sensing for soil mapping in Africa: an overview. Progress in Physical Geography 36, 514–538.

FAO, 1995, 2003. Digital Soil Map of the World and Derived Soil Properties (Version 3.5). FAO Land and Water Digital Media Series # 1. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO, IGADD/Italian Cooperation, 1998. Soil and terrain database for northeastern Africa and Crop production zones. Land and Water Digital Media Series # 2. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO/IIASA/ISRIC/ISSCAS/JRC, 2012. Harmonized World Soil Database (version 1.2). Food and Agriculture Organization of the United Nations, Rome, Italy and IIASA, Laxenburg, Austria.

FAO/ISRIC, 2003. Soil and Terrain Database for Southern Africa. Land and Water Digital Media Series # 26. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO/ISRIC/UGent, 2007. Soil and terrain database of central Africa. FAO Land and Water Digital Media Series # 33, Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO/Unesco, 1971-1981. FAO/Unesco Soil Map of the World, 1:5,000,000 (10 volumes, 19 map sheets) Unesco, Paris, France.

FAO/Unesco, 1974. Legend of the Soil Map of the World. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO/Unesco/ISRIC, 1990. Revised Legend of the Soil Map of the World. World Soil Resources Report, Food and Agriculture Organization of the United Nations, Rome, Italy.

Gisladottir, G., Stocking, M., 2005. Land degradation control and its global environmental benefits. Land Degradation and Development 16, 99-112.

Goyens, C., Verdoodt, A., Van De Wauw, J., Baert, G., Van Engelen, V.W.P., Dijkshoorn, J.A., Van Ranst, E. 2007. Base de données numériques sur les sols et le terrain (SOTER) de l'Afrique Centrale (R.D. Congo, Rwanda et Burundi). Etude et Gestion des Sols 14, 207-218.

Gray, J.M., Humphreys, G.S., Deckers, J., 2011. Distribution patterns of World Reference Base soil groups relative to soil forming factors. Geoderma 160, 373–383.

Grunwald, S., Thompson, J.A., Boettinger, J.L., 2011. Digital Soil Mapping and Modeling at Continental Scales: Finding Solutions for Global Issues. Soil Science Society of America Journal 75, 1201–1213.

Hartemink, A.E., McBratney, A., 2008. A soil science renaissance. Geoderma 148, 123-129.

Hallett, S.H., Bullock, P., Baillie, I., 2006. Towards a World Soil Survey Archive and Catalogue. Soil Use and Management 22, 227-228.

Hallett, S.H., Baillie, I.C., Kerr, B., Truckell, I.G.,2011. Development of the World Soil Survey Archive and Catalogue (WOSSAC). Commission on the History, Philosophy and Sociology of Soil Science 18, pp14-17.

IUSS Working Group WRB, 2007. World Reference Base for Soil Resources 2006, first update 2007. World Soil Resources Reports No. 103. FAO, Rome.

Jones, A., Montanarella, L., and Jones, R. (Eds.), 2005. Soil Atlas of Europe. European Soil Bureau Network, European Commission. Publication Office of the European Union, Luxembourg. 128 pp.

Jones, A., Stolbovoy, V., Tarnocai, C., Broll, G., Spaargaren, O., and Montanarella, L. (Eds.), 2010. Soil Atlas of the Northern Circumpolar Region. European Commission. Publication Office of the European Union, Luxembourg. 144 pp.

Jones, A., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., Hallett, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Spaargaren, O., Tahar, G., Thiombiano, L., Van Ranst, E., Yemefack, M., and Zougmore, R. (Eds.), 2013. Soil Atlas of Africa. European Commission. Publication Office of the European Union, Luxembourg. 176 pp.

Kempen, B., Brus, D.J., Heuvelink, G.B.M., Stoorvogel, J.J., 2009. Updating the 1:50,000 Dutch soil map using legacy soil data: A multinomial logistic regression approach. European Journal of Soil Science 151, 311–326.

Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304, 1623-1627.

Lal, R., 2009. Soils and food sufficiency. A review. Agronomy for Sustainable Development 29, 113-133

Millennium Ecosystems Assessment, 2005. Ecosystems and Human Well-being: A Framework for Assessment. Island, Washington D.C.

Palm, C., Sanchez, P., Ahamed, S., Awiti, A., 2007. Soils: A contemporary perspective. Annual Review of Environment and Resources 32, 99–129.

Palm, C.A., Smukler, S.M., Sullivan, C.C., P.K., M., Nyadzi, G.I., Walsh, M.G., 2010. Identifying potential synergies and trade-offs for meeting food security and climate change objectives in sub-Saharan Africa. Proceedings of the National Academy of Sciences of the United States of America 107, 19661–19666.

Rizzo, M., 2006. What was left of the Groundnut Scheme? Development disaster and labour market in Southern Tanganyika 1946-1952. Journal of Agrarian Change 6, 205–238.

Sanchez, P.A., Ahamed, S., Carré, F., Hartemink, A.E., Hempel, J., Huising, J., Lagacherie, P., McBratney, A.B., McKenzie, N.J., De Lourdes Mendonça-Santos, M., Minasny, B., Montanarella, L., Okoth, P., Palm, C.A., Sachs, J.D., Shepherd, K.D., Vågen, T.-G., Vanlauwe, B., Walsh, M.G., Winowiecki, L.A., Zhang, G.-L., 2009. Digital soil map of the world. Science 325, 680-681.

Sachs, J., Remans, R., Smukler, S., Winowiecki, L., Andelman, S.J., Cassman, K.G., Castle, D., Defries, R., Denning, G., Fanzo, J., Jackson, L.E., Leemans, R., Lehmann, J., Milder, J.C., Naeem, S., Nziguheba, G., Palm, C.A., Pingali, P.L., Reganold, J.P., Richter, D.D., Scherr, S.J., Sircely, J., Sullivan, C., Tomich, T.P., Sanchez, P.A., 2010. Monitoring the world’s agriculture. Nature 466, 558–560.

UNEP, 2007. Global Environmental Outlook GEO4 - Environment for Development. United Nations Environment Programme, Nairobi, 540 pp.

Van Ranst, E., Verdoodt, A., Baert, G., 2010. Soil mapping in Africa at the crossroads : work to make up for lost ground. Bulletin des Séances d'Académie Royale des Sciences d'Outre-Mer 56, 147–163.

Vlek, P., Le, Q.B., Tamene, L., 2008. Land decline in Land-Rich Africa – A creeping disaster in the making. CGIAR Science Council Secretariat, Roma, Italy, 55 pp.

Figure captions

Figure 1. Sources of information used in the original HWSD. (A) Heterogeneity of the database: two data sources and various scales. (B) Soil diversity. The numbers from 1 to 9 indicate the number of Soil Units (SUs) within individual Soil Mapping Unit (SMU) (see text for explanation).

Figure 2. Examples of harmonisation shortcomings in HWSD illustrating the spatial distribution of the Soil Mapping Units (SMUs); each of them being represented by the dominant Soil Unit (SU). The SUs that represent the same FAO soil type are shown with the same colour. (A, B) Boundary effect between the two data sources DSMW and SOTWIS showing difference in soil classification and data resolution. (C) River network discontinuity in SOTWIS. (D) Boundary effect within SOTWIS database showing the difference of data resolution. (E) Boundary effect and “pixelated”pattern in South Africa. For each caption, the legend is the same: each soil name having

a specific colour. The colours are randomly assigned given to highlight explicitly the harmonisation shortcoming features.

Figure 3. Harmonisation steps for production of the new continental soil map of Africa.

Figure 4. Examples of SMU modifications brought to the HWSD to assign the dominant SU. For each of the six examples a map is shown locating the modified SMU (in blue) and the corresponding table caption taken directly from the original HWSD. In these tables, the SU that has sequence 1 within the SMU is not the dominant soil type. In the modified database that is used to produce the new map, these SUs are replaced by the SUs highlighted in blue in the table. For instance, in (A), HWSD is referring to a dominant SU with FRr FAO-90 soil type. In the modified database, this SMU will be defined by a dominant SU referring to LPe FAO-90 soil type (see Table 1 for the soil type definition).

Figure 5. Phase and dune update and border harmonisation. Examples for Senegal (A, B) and the Libyan – Egyptian – Sudan border (C,D). (A, C) The soil map as it appears after the database processing stage. (B, D) The soil map in its final version after all the updates and modifications. See Table 1 for the WRB legend. The star in (C) locates Figure 6.

Figure 6. Border harmonisation with the use of Google Earth along the Libyan – Egyptian border. (A) The SMU limits as they appear after the database processing stage. (B) The SMU limits in their final version after all the updates and modifications. The location of this region is shown with a star in Figure 5C. See Table 1 for the WRB legend.

Figure 7. Completion of “no information” areas. Example for two large areas in Namibia. (A, C)

The soil map and the SMU limits as they appear after the database processing stage. (B, D)) The soil map and the SMU limits in their final version after all the updates and modifications. (C, D) close-ups of the Etosha Pan Area in the Kalahari Basin in the north of Namibia showing the harmonisation with the use of Google Earth. See Table 1 for the WRB legend.

Figure 8. Harmonisation of drainage networks, water bodies and coastlines. (A, C, E) The soil map as it appears after the database processing stage. (B, D, F) The soil map in its final version after all the updates and modifications. See Table 1 for the WRB legend.

Figure 9. Summary of the modifications. The blue areas correspond to the modifications brought during the database processing stage. The other areas are the result of the processing of the polygon map. The red areas indicate all the updates and modifications other than those specified by the legend. The close-up on the Zambezi Delta shows an example of coastline update.

Figure 10. Harmonised soil map at the continental scale. The map represents the dominant SU of each SMU. World Geodetic System (WGS 84) is the coordinate system used to produce the map.

Figure 11. WRB Soil Reference Group (RSG) distribution. (A) Table with the main statistics. (B) Graphical view of the percentage of the continental area occupied by each WRB RSG. (C) Graphical view of the SMU average area for each WRB RSG.

Table captions

Table 1. Translation of FAO-74 and FAO-90 systems to WRB classification and correlation system. The RSGs are ordered alphabetically according to the codes. The division within an individual RSG follows the order of prefix qualifiers in the WRB. The FAO soil names highlighted in different colours correspond to the major changes between the systems (see text for explanation). The colour legend used for the RSGs is the one used in the Atlas.

Table 2. Soil phases considered in the WRB soil classification.

Table 3. Maps used in support for the harmonisation.

Table01

Click here to download Table: table01.xls

WRB		FAO-90		FAO-74	
Code	**Name**	**Code**	**Name**	**Code**	**Name**
ACRISOLS					
AC	Undifferentiated Acrisols				
ACfr	Ferric Acrisols	ACf	Ferric Acrisols	Af	Ferric Acrisols
ACha	Haplic Acrisols	ACh	Haplic Acrisols		
ACpl	Plinthic Acrisols	ACp	Plinthic Acrisols	Ap	Plinthic Acrisols
ACum	Umbric Acrisols	ACu	Humic Acrisols		
ALISOLS					
ALgl	Gleyic Alisols	ALg	Gleyic Alisols		
ALha	Haplic Alisols	ALh	Haplic Alisols	Ao	Orthic Acrisols
ALpl	Plinthic Alisols	Alp	Plinthic Alisols		
ALum	Umbric Alisols	ALu	Humic Alisols		
ANDOSOLS					
ANsn	Silandic Andosols	ANh	Haplic Andosols	To	Ochric Andosols
ANsnmo	Silandic Mollic Andosols	ANm	Mollic Andosols	Tm	Mollic Andosols
ANsnum	Silandic Umbric Andosols	ANu	Umbric Andosols	Th	Humic Andolsols
ANvi	Vitric Andosols	ANz	Vitric Andosols	Tv	Vitric Andosols
ARENOSOLS					
AR	Undifferentiated Arenosols				
ARab	Albic Arenosols	ARa	Albic Arenosols		
ARbr	Brunic Arenosols	ARb	Cambic Arenosols	Qc	Cambic Arenosols
ARca	Calcaric Arenosols	ARc	Calcaric Arenosols		
ARfl	Ferralic Arenosols	ARo	Ferralic Arenosols	Qf	Ferralic Arenosols
ARha	Haplic Arenosols	ARh	Haplic Arenosols		
ARpr	Protic Arenosols			**DS**	**Dunes & shifting sands**
ARwl	Hypoluvic Arenosols	ARl	Luvic Arenosols	Ql	Luvic Arenosols
CHERNOZEMS					
CHcc	Calcic Chernozems	CHk	Calcic Chernozems	Ck	Calcic Chernozems
CHlv	Luvic Chernozems	CHl	Luvic Chernozems	Cl	Luvic Chernozems
CALCISOLS					
CLha	Haplic Calcisols	CLh	Haplic Calcisols	**Bk**	**Calcic Cambisols**
				Xk	**Calcic Xerosols**
CLhaye	Haplic Yermic Calcisols			**Yk**	**Calcic Yermosols**
CLlv	Luvic Calcisols	CLl	Luvic Calcisols		
CLpt	Petric Calcisols	Clp	Petric Calcisols	**Phase 4**	**Petrocalcic**
CAMBISOLS					
CM	Undifferentiated Cambisols			**X**	**XEROSOLS**
CMca	Calcaric Cambisols	CMc	Calcaric Cambisols		
CMcr	Chromic Cambisols	CMx	Chromic Cambisols	Bc	Chromic Cambisols
CMdy	Dystric Cambisols	CMd	Dystric Cambisols	Bd	Dystric Cambisols
CMeu	Eutric Cambisols	CMe	Eutric Cambisols	Be	Eutric Cambisols
				Xh	**Haplic Xerosols**
				Y	**YERMOSOLS**
CMfl	Ferralic Cambisols	CMo	Ferralic Cambisols	Bf	Ferralic Cambisols
CMgl	Gleyic Cambisols	CMg	Gleyic Cambisols	Bg	Gleyic Cambisols
CMhaty	Haplic Takyric Cambisols			Yt	Takyric Yermosols
CMhaye	Haplic Yermic Cambisols			Yh	Haplic Yermosols
CMvr	Vertic Cambisols	CMv	Vertic Cambisols	Bv	Vertic Cambisols
DURISOLS					
DU	Undifferentiated Durisols			**Phase 9**	**Duripan**
FLUVISOLS					
FL	Undifferentiated Fluvisols	FL	Fluvisols	J	Fluvisols
FLca	Calcaric Fluvisols	FLc	Calcaric Fluvisols	Jc	Calcaric Fluvisols
FLdy	Dystric Fluvisols	Fle	Dystric Fluvisols	Jd	Dystric Fluvisols
FLeu	Eutric Fluvisols	FLm	Eutric Fluvisols	Je	Eutric Fluvisols
FLmo	Mollic Fluvisols	FLd	Mollic Fluvisols		

Table02

Click here to download Table: table02.xls

FAO		WRB		Renaming rules
Phase name*	**HWSD code**	**Name**	**WRB code**	
				Renaming occurs:
Petric	3	Pisoplinthic Plinthosols	PTpx	with all but Vertisols (VR), Fluvisols (FL), Solonetz (SN) or Gleysols (GL)
Petrocalcic	4	Petric Calcisols	CLpt	with all but Leptosols (LP), Solonetz (SN), Planosols (PL), Stagnosols (ST), Chernozems (CH), Kastanozems (KS), Phaeozems (PH), Gypsisols (GY) or Durisols (DU)
Petrogypsic	5	Petric Gypsisols	GYpt	with all but Leptosols (LP), Chernozems (CH), Kastanozems (KS) or Phaeozems (PH)
Petroferric	6	Petric Plinthosols	PTpt	with all but Vertisols (VR), Fluvisols (FL), Solonetzs (SN) or Gleysols (GL)
Duripan	9	Durisols	DU	with all soils

* If the dominant SU covers more than 50% of the areal extent of a SMU and is characterised by one of the phases in the table, then the renaming of the SU (and the SMU) into WRB will be driven according to the rules presented in the table.

Click here to download Table: Table3.xls

Country	**Map**	**Scale**	**Year**	**Source**
Egypt, Namibia, Senegal, Africa	Digital Soil Map of the World	1:5.000.000	2003	FAO
Egypt	Soil Association Map of Egypt	1:4.000.000	1975	Hammad, M.A. Dr., Soil Survey Institute. Appendix 2. Soil Survey Papers no. 11., Wageningen, the Netherlands
Kenya	Exploratory Soil Map of Kenya	1:1.000.000	1980	Sombroek, W.G.; Van de Pouw, B.J.A., Republic of Kenya. Ministry of Agriculture Kenya Soil Survey, Nairobi
Lesotho	Soil Association Map of Lesotho	NI*	NI	NI
Malawi	Malawi Soil Map (Draft)	1:2.000.000	1991	SADCC, Food Security Programme, Regional inventory of agricultural resource base, Harare, Zimbabwe
Tanzania	Provisional Soils Map of Tanzania	1:2.000.000	1977	Samki, J.K., Geological Survey Department, Dodoma, Tanzania
Tanzania	Soils and Physiography. Tanzania.	1:2.000.000	1983	De Pauw, E., Ministry of Lands, Housing and Urban Development, Dar es Salaam, Tanzania FAO
Zambia	Zambia Soil Map (Draft)	1:2.000.000	1991	SADCC, Food Security Programme, Regional inventory of agricultural resource base, Harare, Zimbabwe

*NI = No Information

Figure01

Click here to download high resolution image

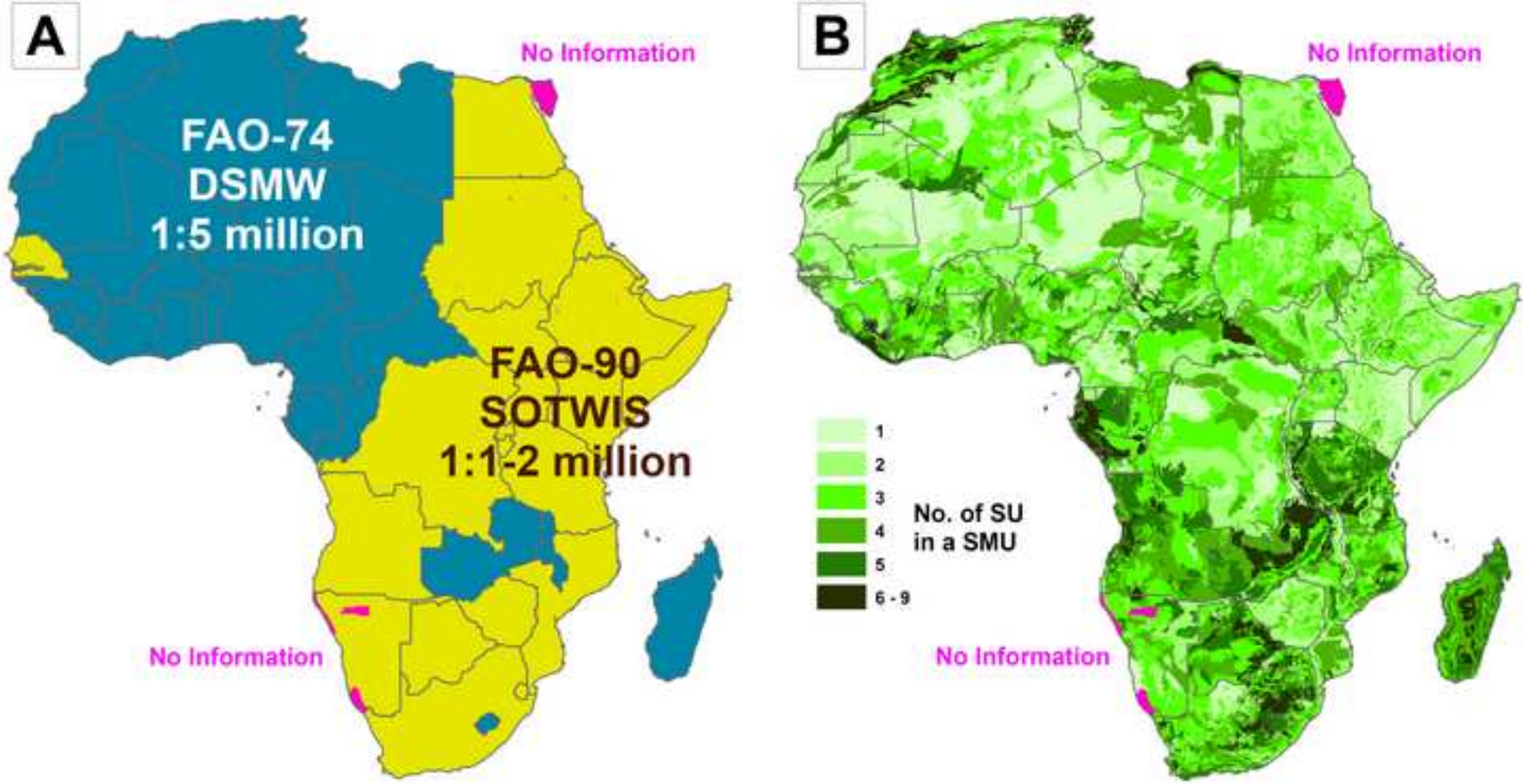


Figure02

Click here to download high resolution image

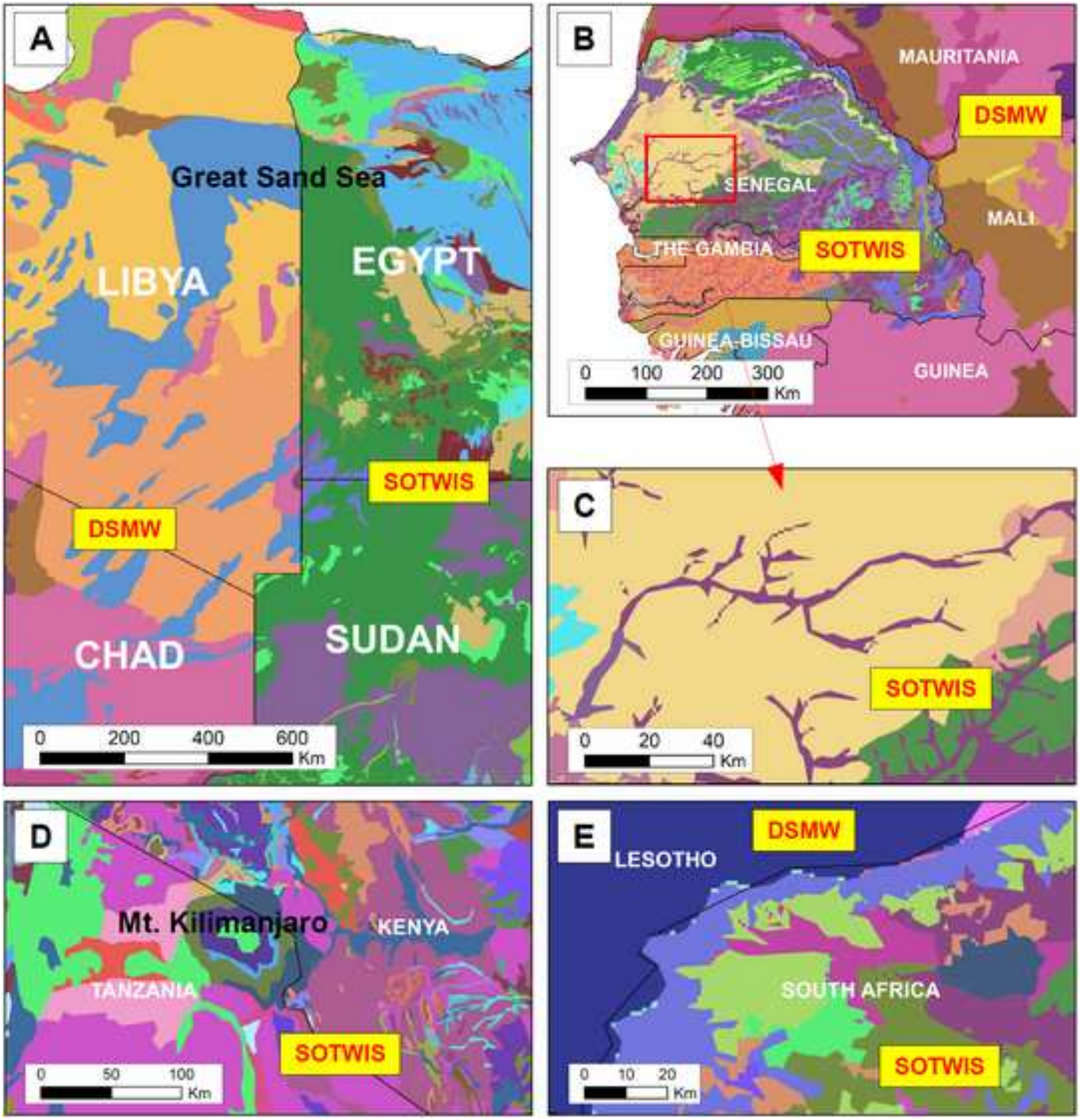


Figure03

Click here to download high resolution image

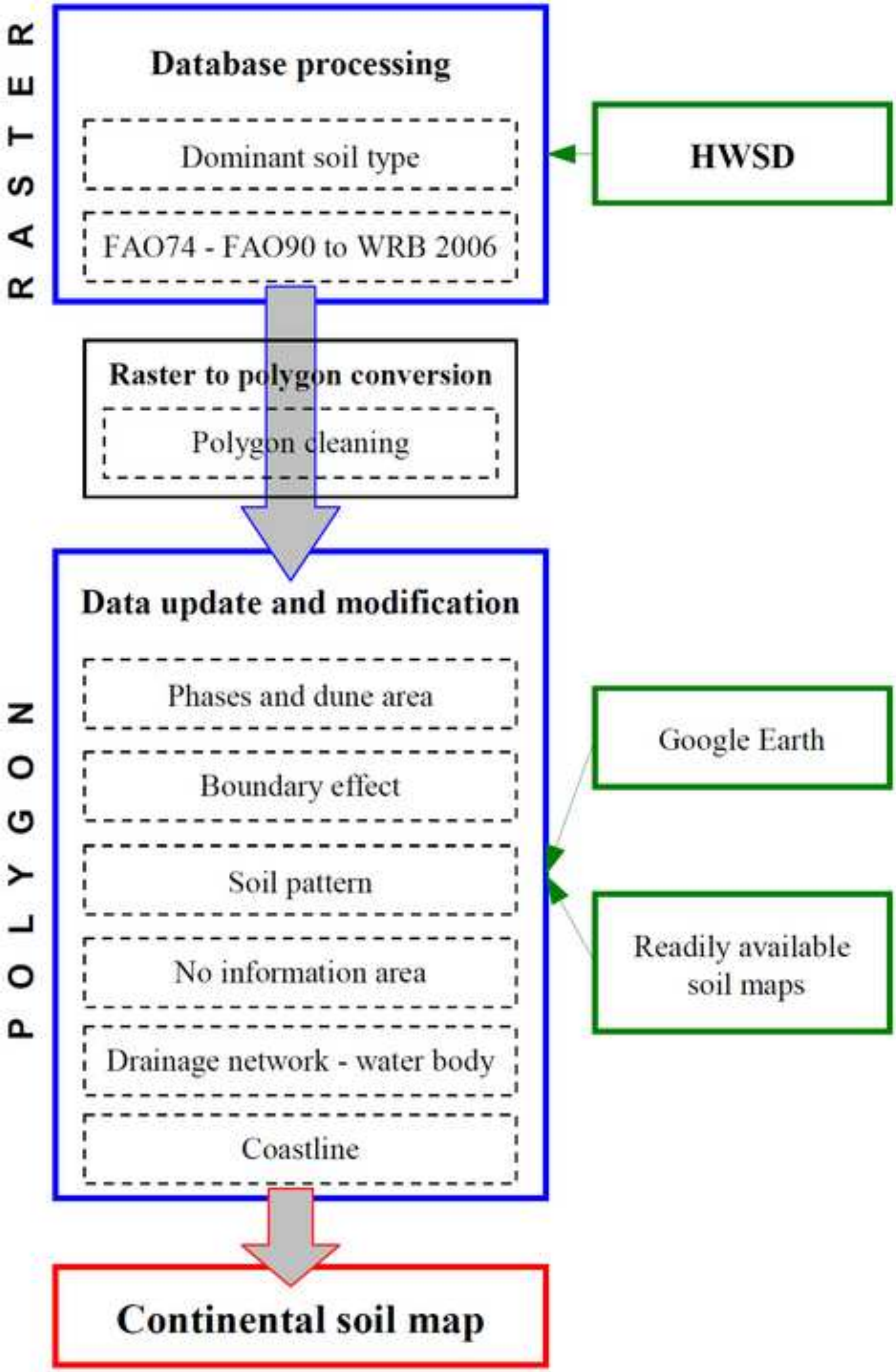


Figure04
Click here to download high resolution image

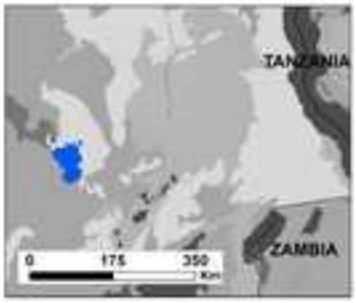
A

Soil type: FRr to LPe

SU extent: 20% to 60%

MU_GLOBAL	SHARE	SEQ	SU_SYM74	SU_SYM90
18497	20	1		FRr
18497	20	2		ACh
18497	60	3		LPe

D

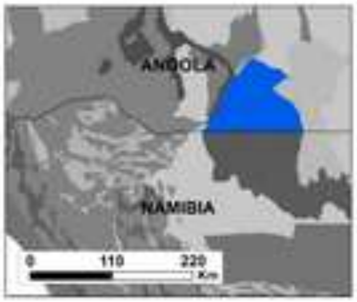


Soil type: ACh to FRh

SU extent: 34% to 66%

MU_GLOBAL	SHARE	SEQ	SU_SYM74	SU_SYM90
31439	34	1		ACh
31439	33	2		FRh
31439	33	3		FRh

B

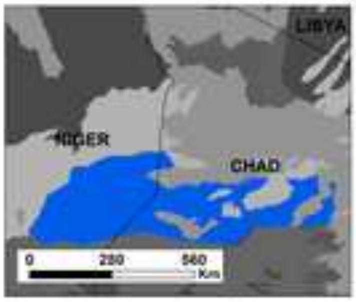


Soil type: LVk to SNk

SU extent: 10% to 30%

MU_GLOBAL	SHARE	SEQ	SU_SYM74	SU_SYM90
12019	10	1		LVk
12019	10	2		ARb
12019	10	3		VRk
12019	30	4		SNk
12019	25	5		SCk
12019	15	6		CLh

E

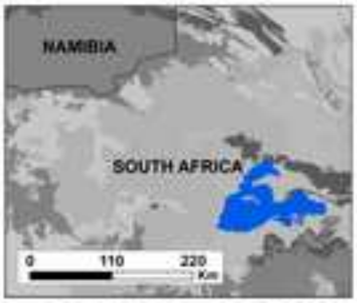


Soil type: Re to DS

SU extent: 30% to 50%

MU_GLOBAL	SHARE	SEQ	SU_SYM74	SU_SYM90
238	30	1	Re	
238	10	4	Qc	
238	10	3	Y	
238	50	2	DS	

C

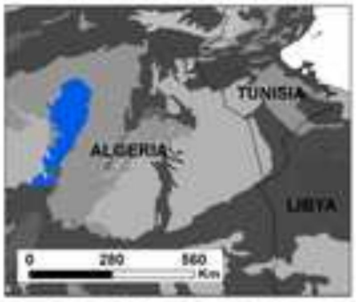


Soil type: CMc to LPq

SU extent: 44% to 56%

MU_GLOBAL	SHARE	SEQ	SU_SYM74	SU_SYM90
28823	44	1		CMc
28823	35	2		LPq
28823	21	3		LPq

F



Soil type: Y to RK

SU extent: 35% to 50%

MU_GLOBAL	SHARE	SEQ	SU_SYM74	SU_SYM90
1821	35	1	Y	
1821	15	3	Jc	
1821	50	2	RK	

MU_GLOBAL – the SMU identifier of HWSD; **SHARE** - % of the SU in the SMU; **SEQ** – the sequence of the SU in the SMU composition; **SU_SYM74** and **SU_SYM90** - SU symbol using the FAO-74 system or the FAO-90 system

Figure05

Click here to download high resolution image

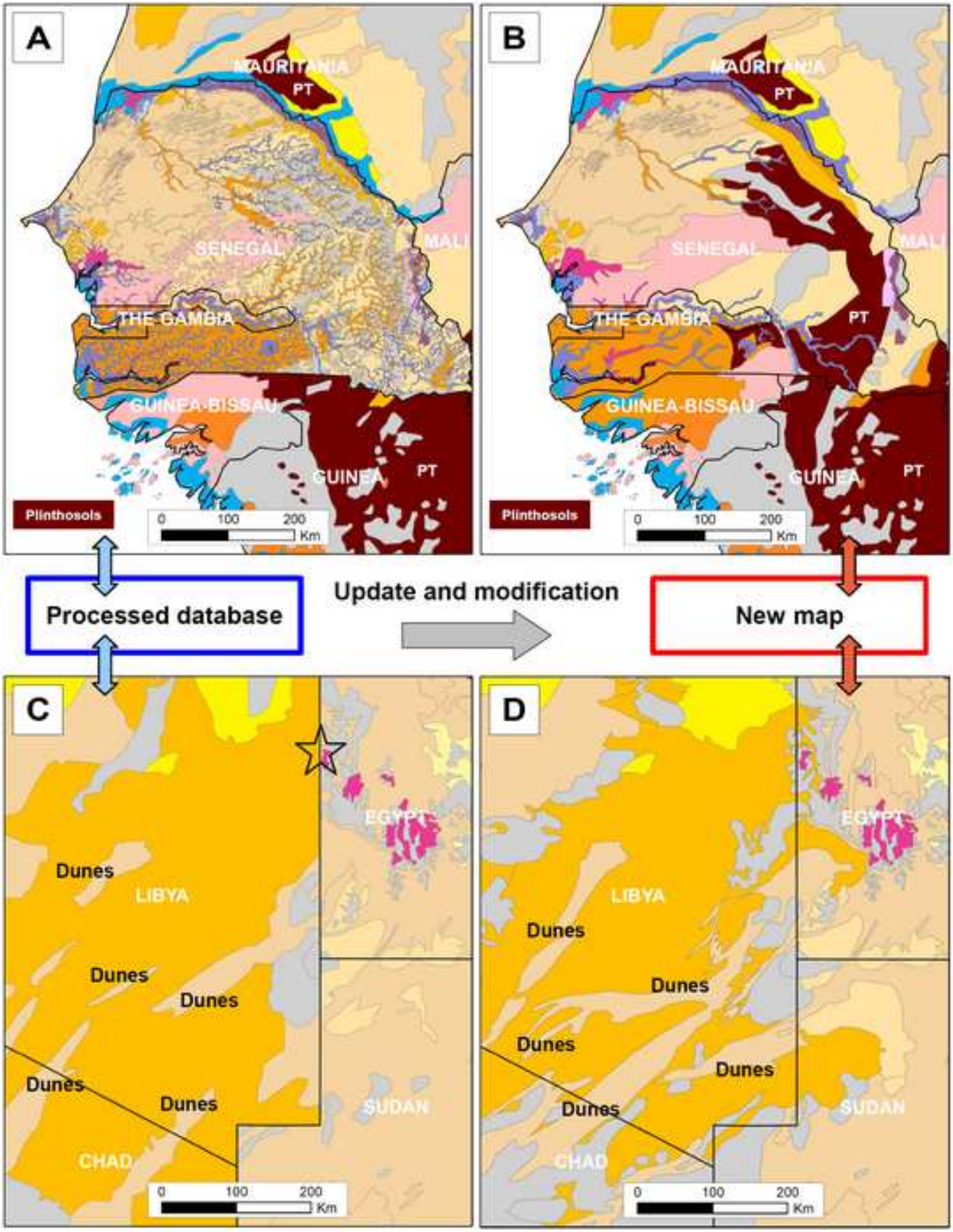


Figure06

Click here to download high resolution image

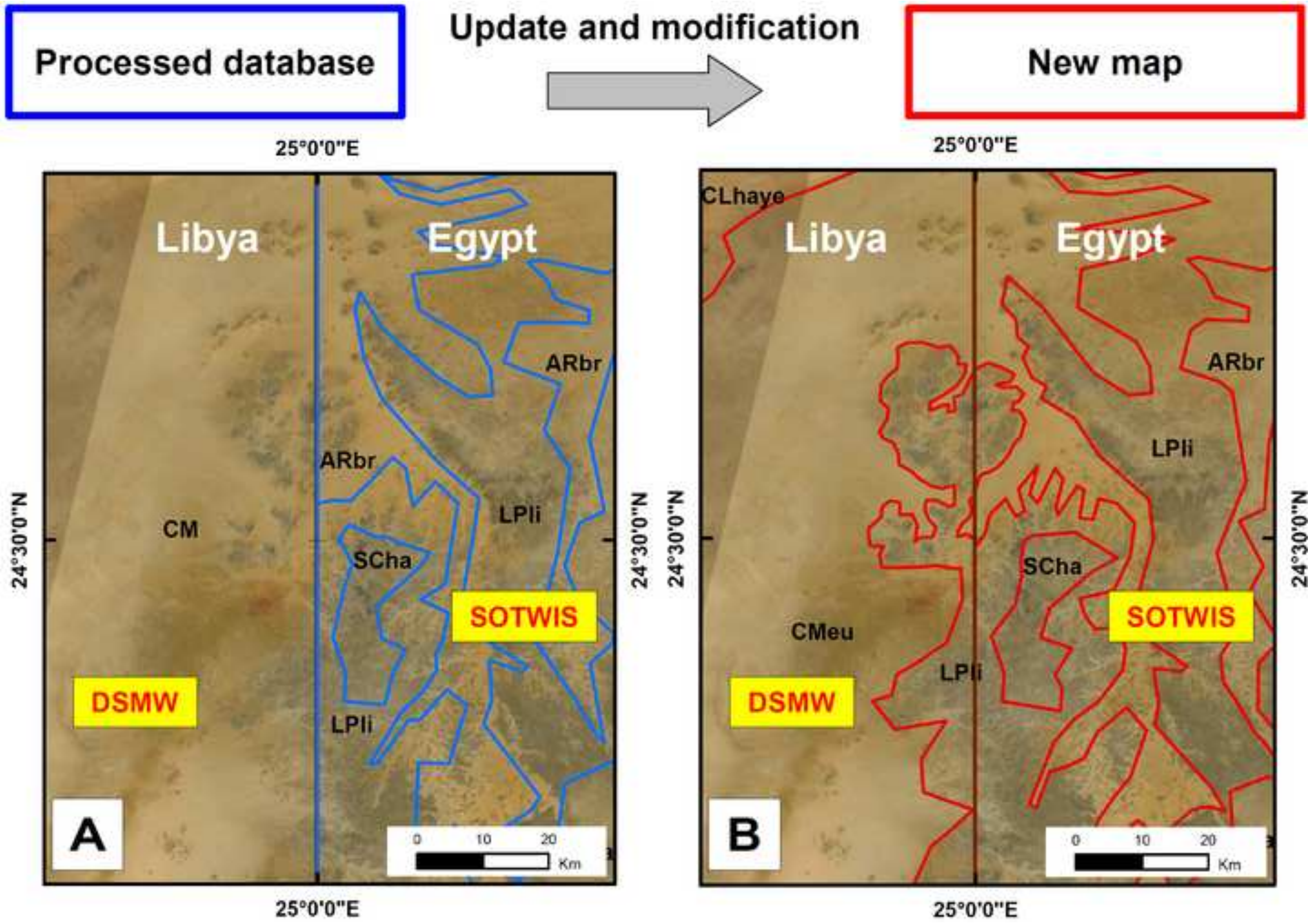


Figure07

Click here to download high resolution image

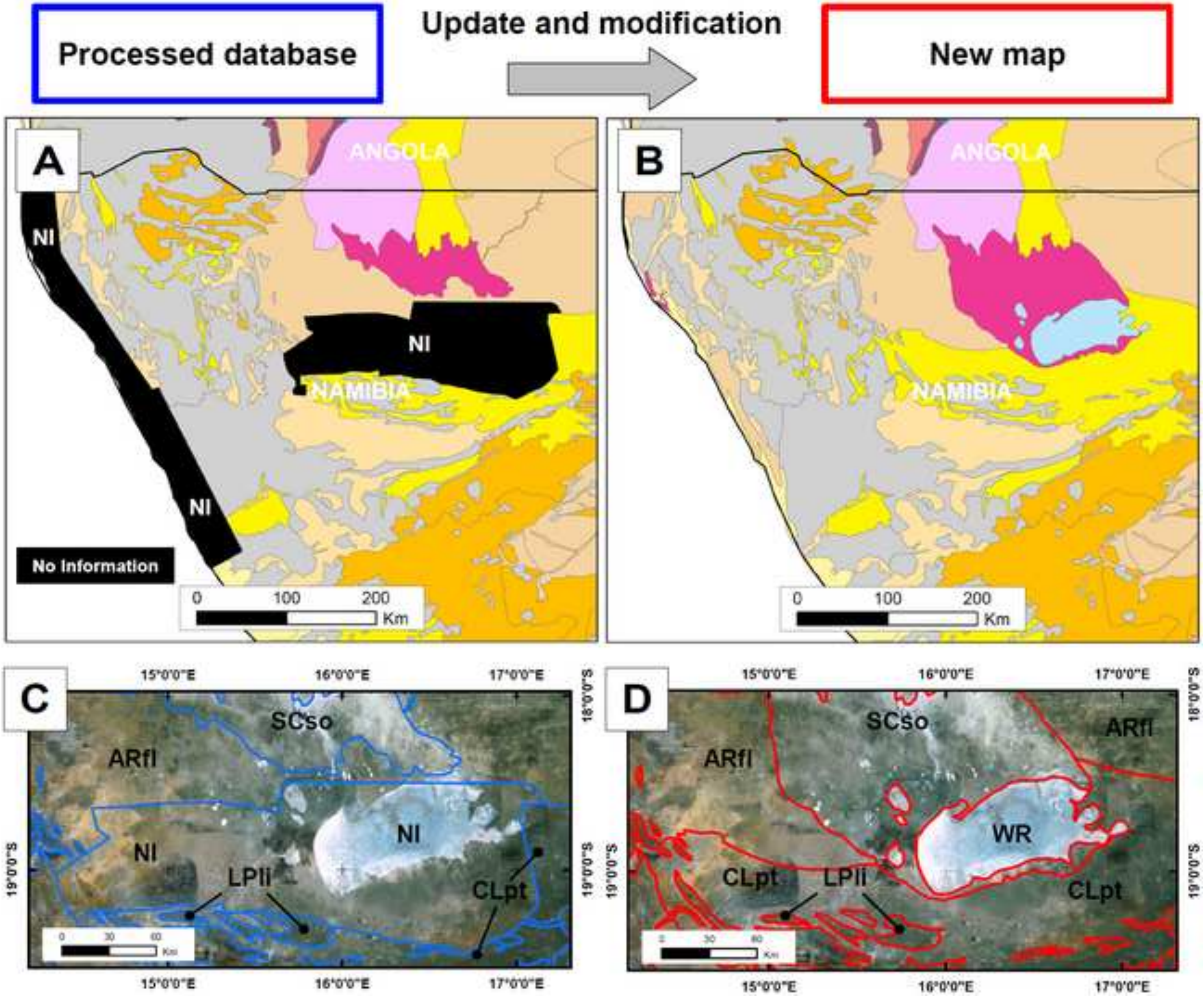
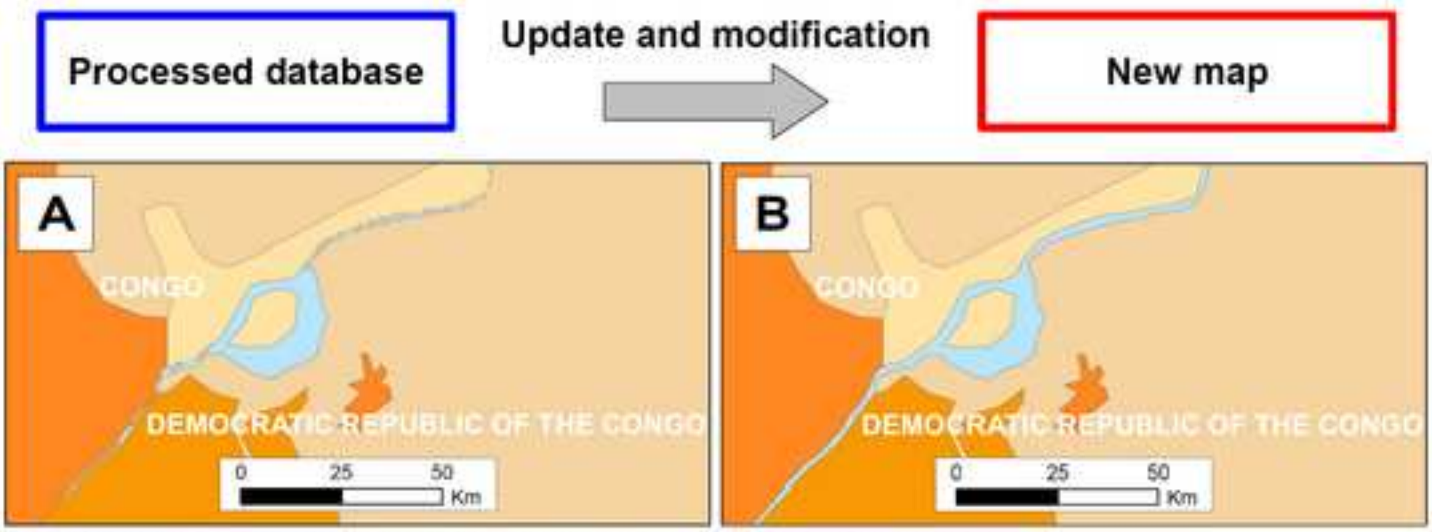
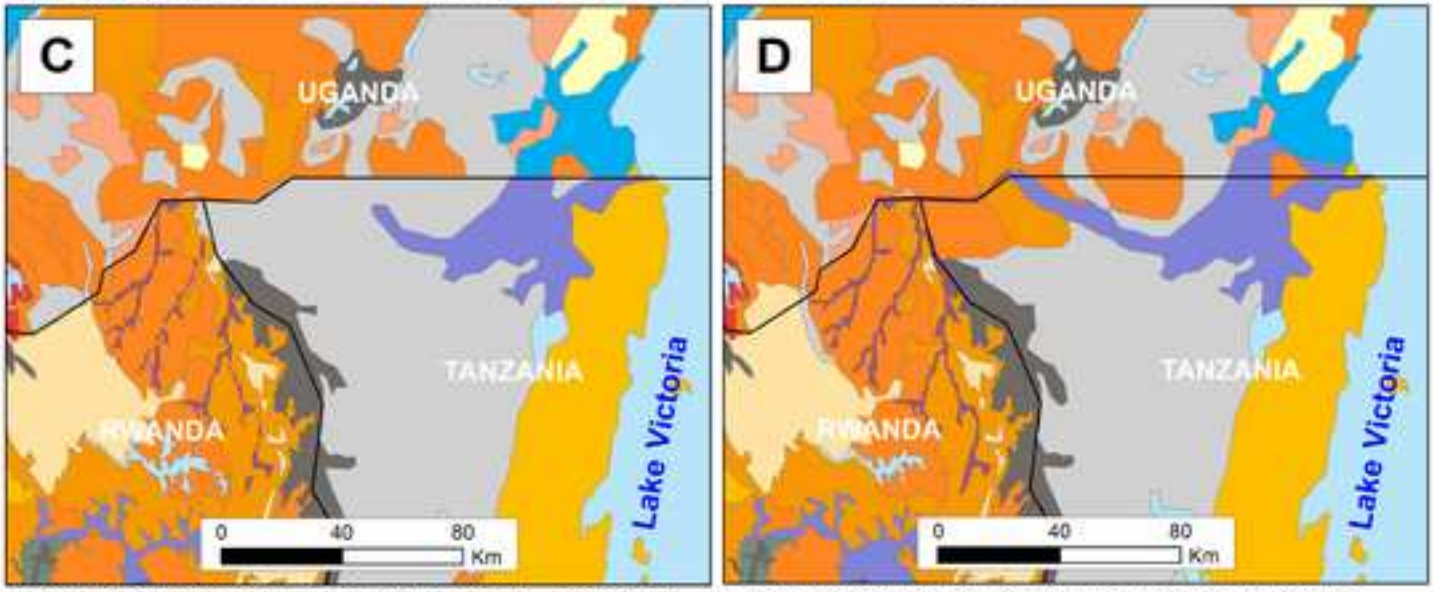


Figure08

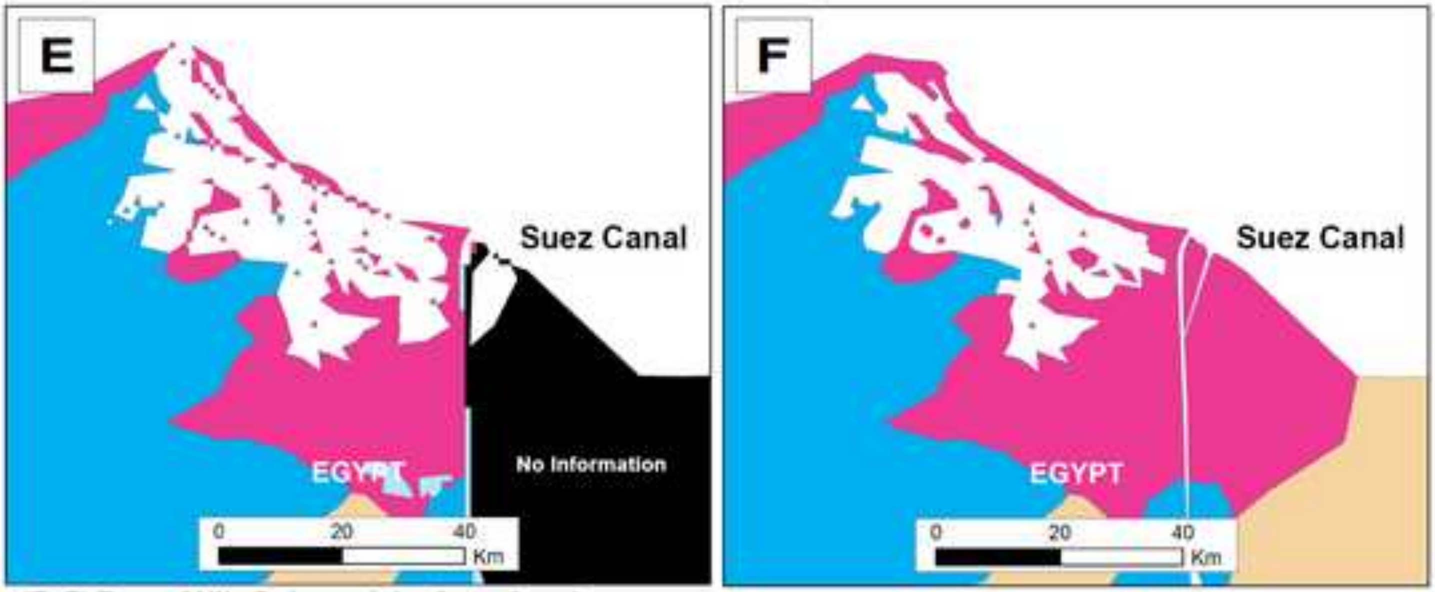
Click here to download high resolution image



(A, B) Congo River in the Brazzaville, Kinshasa and the Malebo Pool Region



(C, D) Drainage network in the Rwanda – Tanzania – Uganda border region to the west of Lake Victoria



(E, F) East of Nile Delta and the Suez Canal

Figure09

Click here to download high resolution image

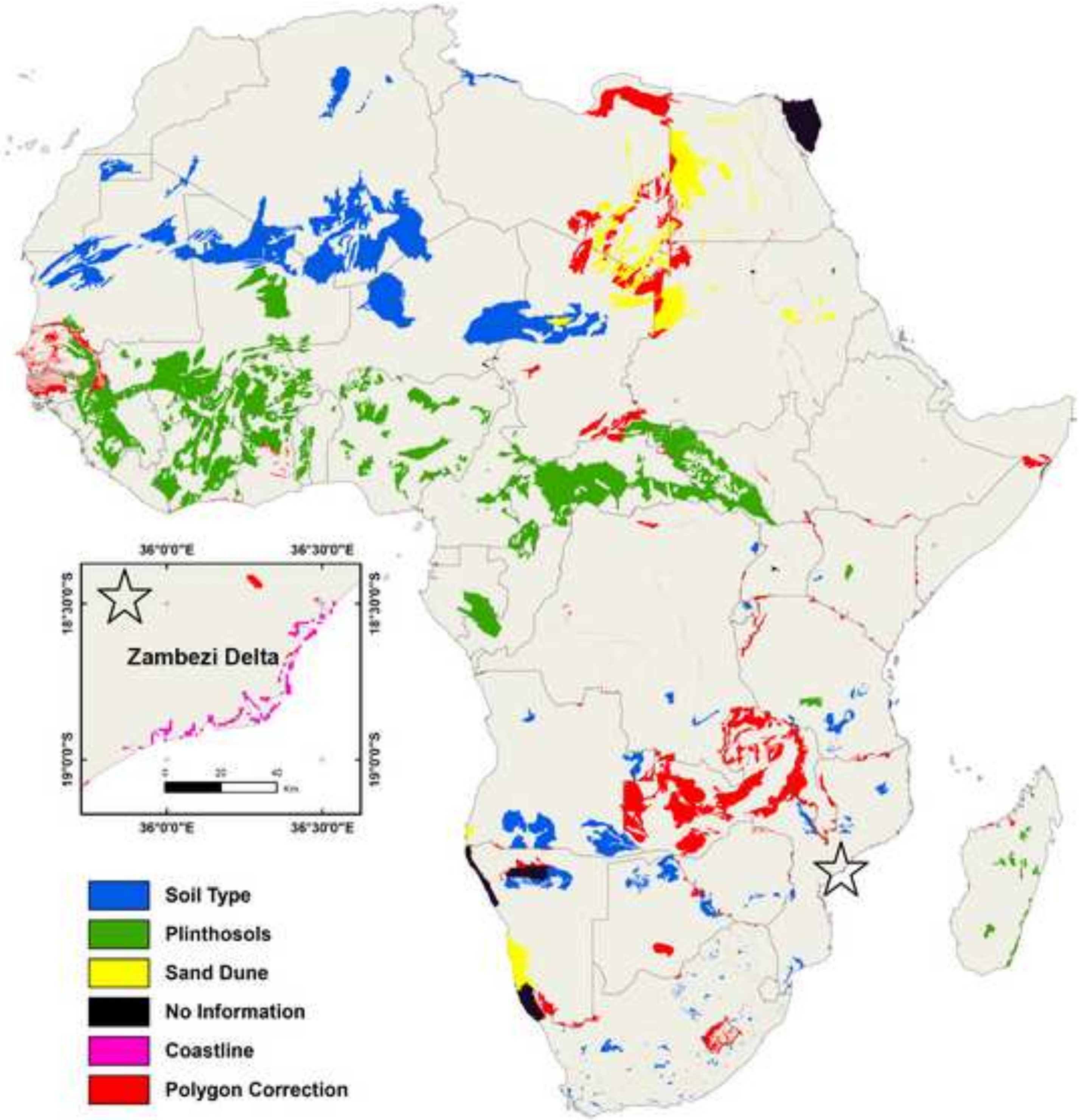


Figure10

Click here to download high resolution image

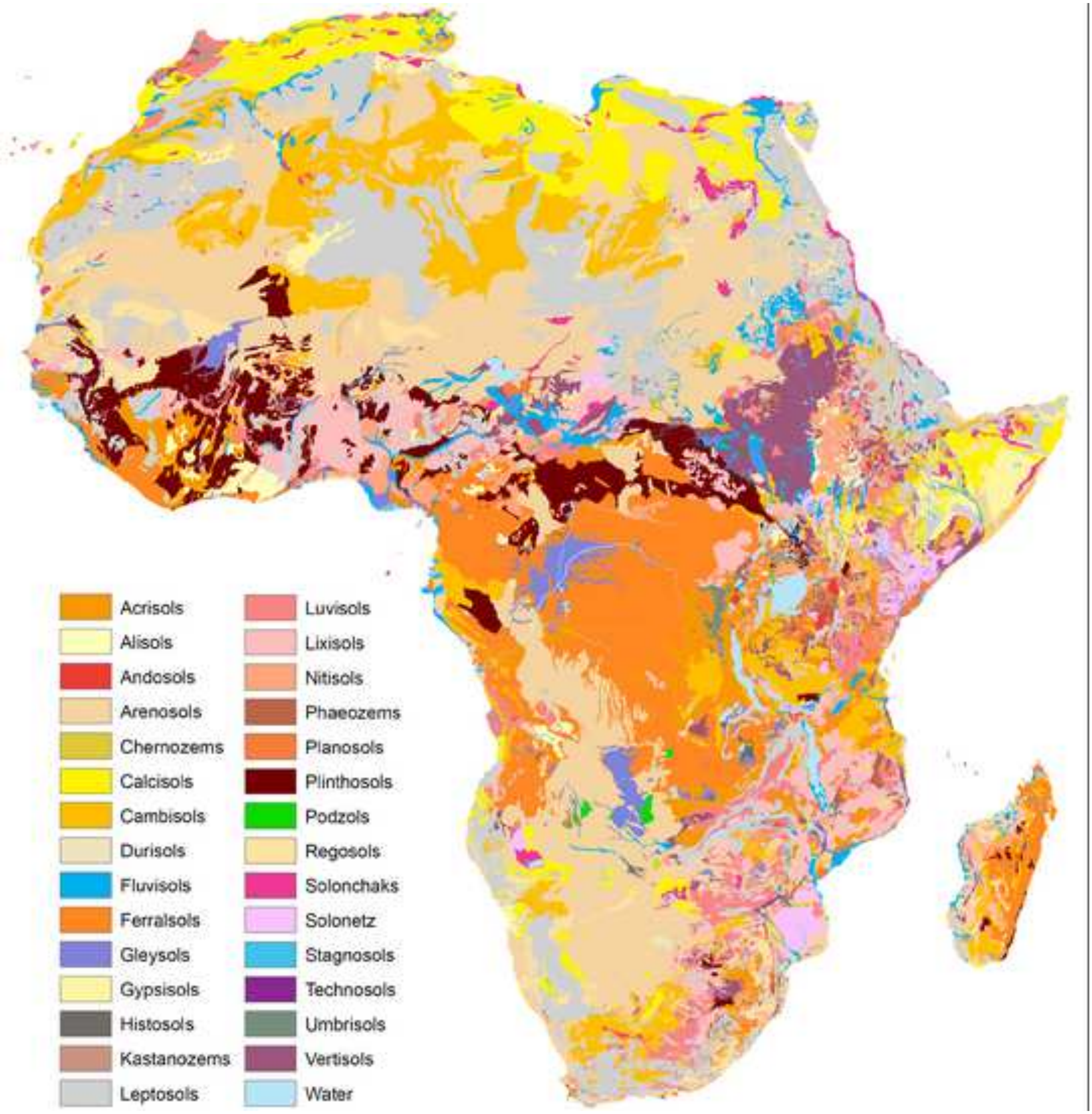
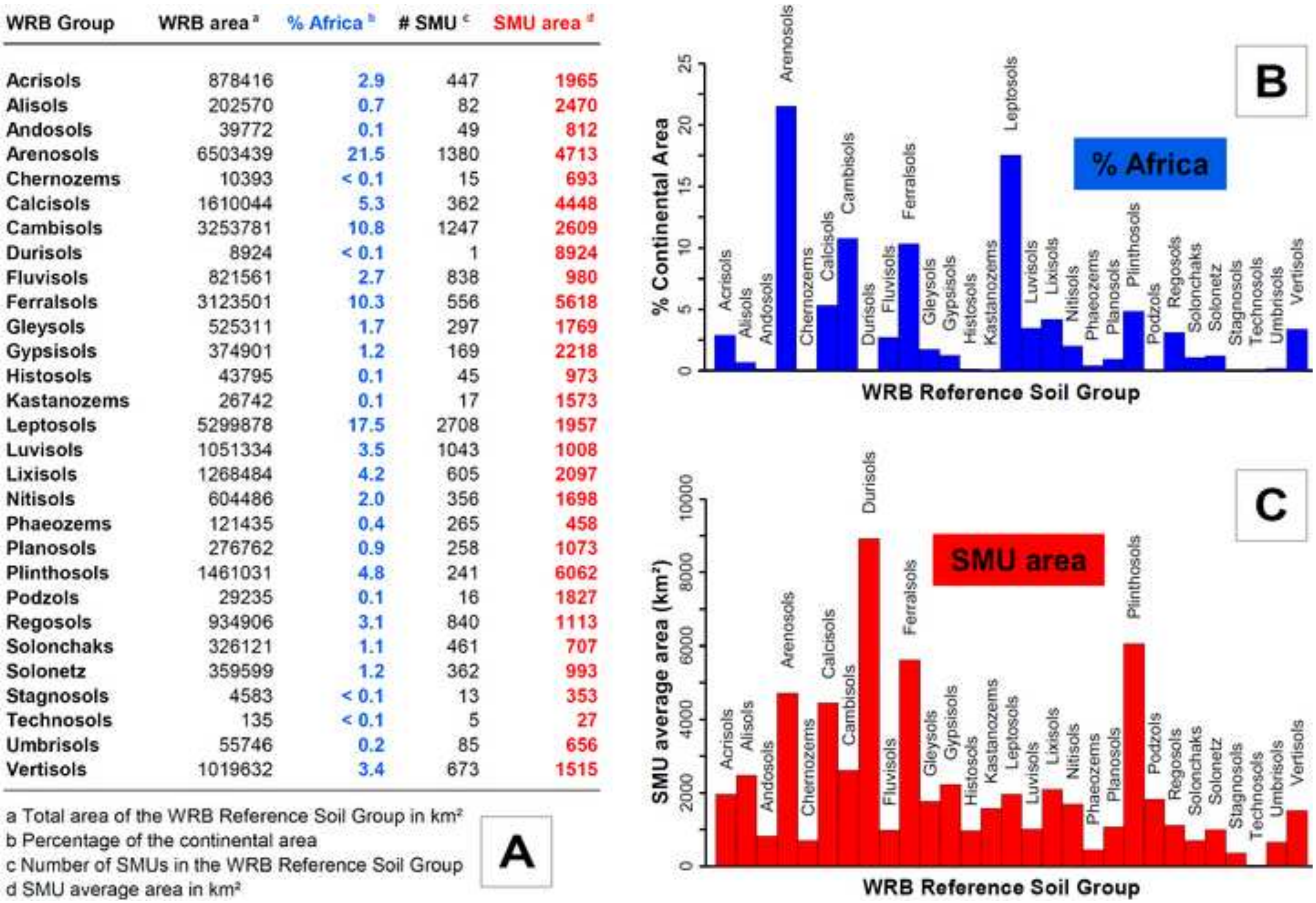


Figure11

Click here to download high resolution image



WRB Group	WRB area [a]	% Africa [b]	# SMU [c]	SMU area [d]
Acrisols	878416	2.9	447	1965
Alisols	202570	0.7	82	2470
Andosols	39772	0.1	49	812
Arenosols	6503439	21.5	1380	4713
Chernozems	10393	< 0.1	15	693
Calcisols	1610044	5.3	362	4448
Cambisols	3253781	10.8	1247	2609
Durisols	8924	< 0.1	1	8924
Fluvisols	821561	2.7	838	980
Ferralsols	3123501	10.3	556	5618
Gleysols	525311	1.7	297	1769
Gypsisols	374901	1.2	169	2218
Histosols	43795	0.1	45	973
Kastanozems	26742	0.1	17	1573
Leptosols	5299878	17.5	2708	1957
Luvisols	1051334	3.5	1043	1008
Lixisols	1268484	4.2	605	2097
Nitisols	604486	2.0	356	1698
Phaeozems	121435	0.4	265	458
Planosols	276762	0.9	258	1073
Plinthosols	1461031	4.8	241	6062
Podzols	29235	0.1	16	1827
Regosols	934906	3.1	840	1113
Solonchaks	326121	1.1	461	707
Solonetz	359599	1.2	362	993
Stagnosols	4583	< 0.1	13	353
Technosols	135	< 0.1	5	27
Umbrisols	55746	0.2	85	656
Vertisols	1019632	3.4	673	1515

a Total area of the WRB Reference Soil Group in km²
b Percentage of the continental area
c Number of SMUs in the WRB Reference Soil Group
d SMU average area in km²

Background dataset fig09

Click here to download Background dataset: fig09_high.pdf

Background dataset fig10
Click here to download Background dataset: fig10_high.pdf

Cranfield University

CERES Research Repository **https://dspace.lib.cranfield.ac.uk/**

School of Applied Sciences (SAS) (2006-July 2014) Staff publications (SAS)

Towards a harmonisation of the soil map of Africa at the continental scale

Dewitte, Olivier

2013-12-31T00:00:00Z

Dewitte O, Jones A, Spaargaren O, et al., (2013) Harmonisation of the soil map of Africa at the continental scale. Geoderma, Volume 211-212, December 2013, pp. 138-153

http://dx.doi.org/10.1016/j.geoderma.2013.07.007

Downloaded from CERES Research Repository, Cranfield University