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Harmonisation of the soil map of Africa at the continental scale

Olivier Dewitte [a,b,*], Arwyn Jones [a,**], Otto Spaargaren [c], Henrik Breuning-Madsen [d], Michel Brossard [e], Almami Dampha [f], Jozef Deckers [g], Tahar Gallali [h], Stephen Hallett [i], Robert Jones [i], Method Kilasara [j], Pieter Le Roux [k], Erika Michéli [l], Luca Montanarella [a], Lamourdia Thiombiano [m], Eric Van Ranst [n], Martin Yemefack [o], Robert Zougmore [p]

[a] European Commission, Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy
[b] Royal Museum for Central Africa, Department of Earth Sciences, Tervuren, Belgium
[c] ISRIC – World Soil Information, Wageningen, The Netherlands
[d] University of Copenhagen, Department of Geography and Geology, Copenhagen, Denmark
[e] Institut de Recherche pour le Développement (IRD), UMR Eco&Sols, Montpellier, France
[f] African Union Commission, Department of Rural Economy and Agriculture, Addis Ababa, Ethiopia
[g] University of Leuven, Department of Earth and Environmental Sciences, Heverlee, Belgium
[h] University of Tunis El Manar, Department of Geology, Tunis, Tunisia
[i] Cranfield University, National Soil Resources Institute, Cranfield, United Kingdom
[j] Sokoine University of Agriculture, Department of Soil Science, Morogoro, Tanzania
[k] University of the Free State, Department Soil-, Crop- and Climate Sciences, Bloemfontein, South Africa
[l] Szent István University, Department of Soil Science and Agricultural Chemistry, Godollo, Hungary
[m] Food and Agriculture Organization of the United Nations, Subregional Office for Central Africa, Libreville, Gabon
[n] Ghent University, Department of Geology and Soil Science, Ghent, Belgium
[o] Institute of Agricultural Research for Development (IRAD), Department of Soil Water and Atmosphere Sciences, Yaoundé, Cameroon
[p] International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), West and Central Africa, Niamey, Niger

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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. The corrections concerned boundary issues, areas with no information, soil patterns, river and drainage networks, and dynamic features such as sand dunes, water bodies and coastlines. 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.

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 (Gisladottir and Stocking, 2005; Lal, 2004, 2009; Millennium Ecosystems Assessment, 2005; Palm et al., 2007, 2010; UNEP, 2007; Vlek et al., 2008).

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 (Bouma et al., 2012; Hartemink and McBratney, 2008; Palm et al., 2010; Sachs et al., 2010; Sanchez et al., 2009). 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

* Correspondence to: O. Dewitte, Royal Museum for Central Africa, Department of Earth Sciences, 3080 Tervuren, Belgium. Tel.: +32 27695452.
** Correspondence to: A. Jones, European Commission, DG Joint Research Centre, Institute of Environment and Sustainability, 21027 Ispra (VA), Italy.
E-mail address: olivier.dewitte@africamuseum.be (O. Dewitte).

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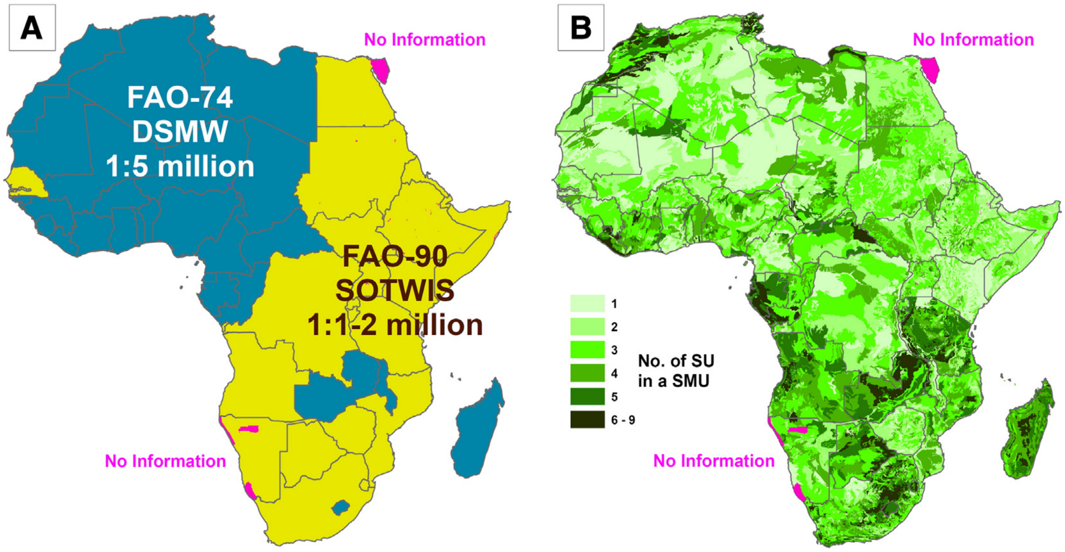

Fig. 1. Sources of information used in the original HWSD. (A) Heterogeneity of the database: two data sources and various scales. (B) Soil diversity. The numbers from 1 to 9 indicate the number of Soil Units (SUs) within individual Soil Mapping Unit (SMU) (see text for explanation).

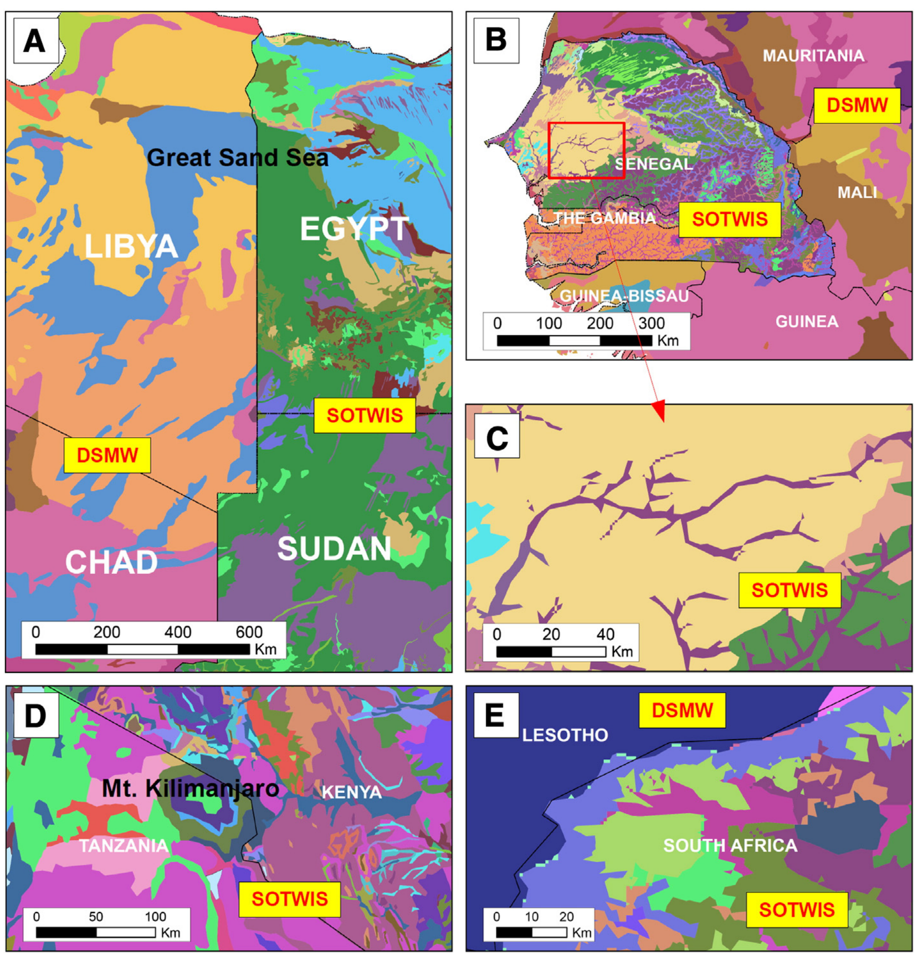

Fig. 2. Examples of harmonisation shortcomings in HWSD illustrating the spatial distribution of the Soil Mapping Units (SMUs); each of them being represented by the dominant Soil Unit (SU). The SUs that represent the same FAO soil type are shown with the same colour. (A, B) Boundary effect between the 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. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

mutually reinforcing (Gisladottir and Stocking, 2005; Lal, 2009; Millennium Ecosystems Assessment, 2005; UNEP, 2007; Vlek et al., 2008).

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 (Grunwald et al., 2011; Van Ranst et al., 2010). Most countries have a general soil map at very small scales, usually substantially smaller than 1:250,000. For many, the only consistent and harmonised national coverage is still, thirty years after its finalisation, the 1:5 M Soil Map of the World produced by FAO and UNESCO in the 1970s (FAO/Unesco, 1971–1981) which was partly based on the International Atlas of West Africa (Boulet et al., 1968). 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 together 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. The Atlas 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, a 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, 1995, 2003; FAO/Unesco, 1971–1981), together with various regional SOTER (SOil and TERrain) and SOTWIS (Secondary SOTER derived from SOTER and WISE) databases (Batjes, 2007, 2008; FAO, IGADD/Italian Cooperation, 1998; FAO/ISRIC, 2003; FAO/ISRIC/UGent, 2007; Goyens et al., 2007). Fig. 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 (Fig. 1A).

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 (approximately 1 km at the Equator). The pixel size ensures compatibility with important global inventories such as

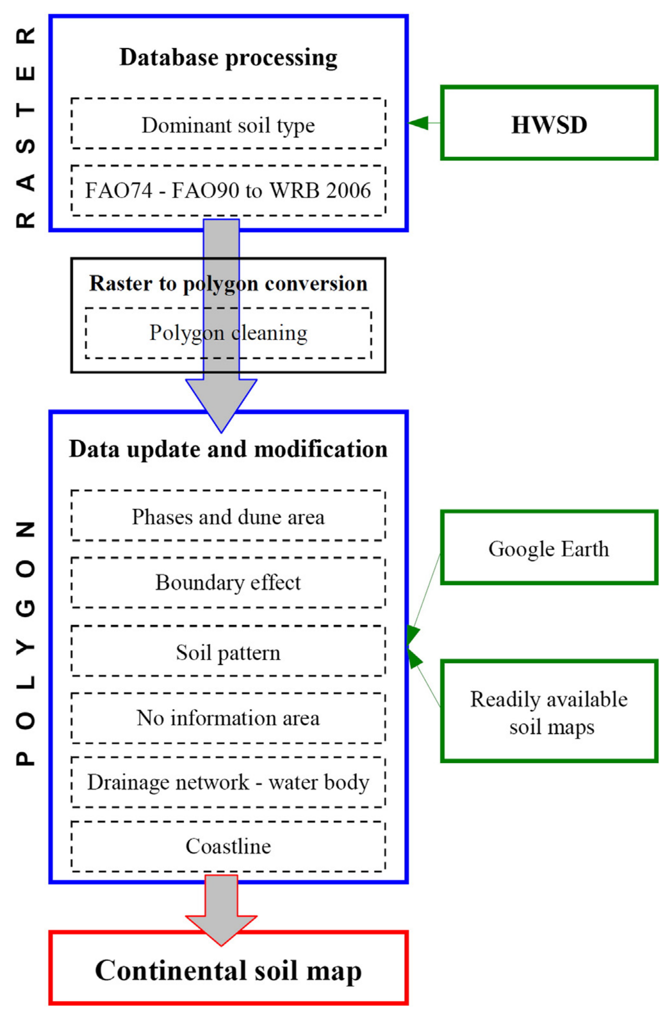

Fig. 3. Harmonisation steps for production of the new continental soil map of Africa.

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 (Fig. 1B). Fig. 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 Fig. 1 that it still contains numerous harmonisation shortcomings that cannot be presented as such in the Atlas (Fig. 2). Boundary issues, particularly at the political level, as well as areas with no information should not be presented in the Atlas. 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 to be continuous, and major water bodies and coastline features have not been updated recently. When zooming in the dataset, many "micro-polygons" comprising only few pixels are present, particularly in the regions of high density information, which gives a "pixelated" or "noisy" pattern to the soil distribution. Some of these micro-polygons are mapping artefacts. 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.

Fig. 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 through the interpretation the vegetation patterns

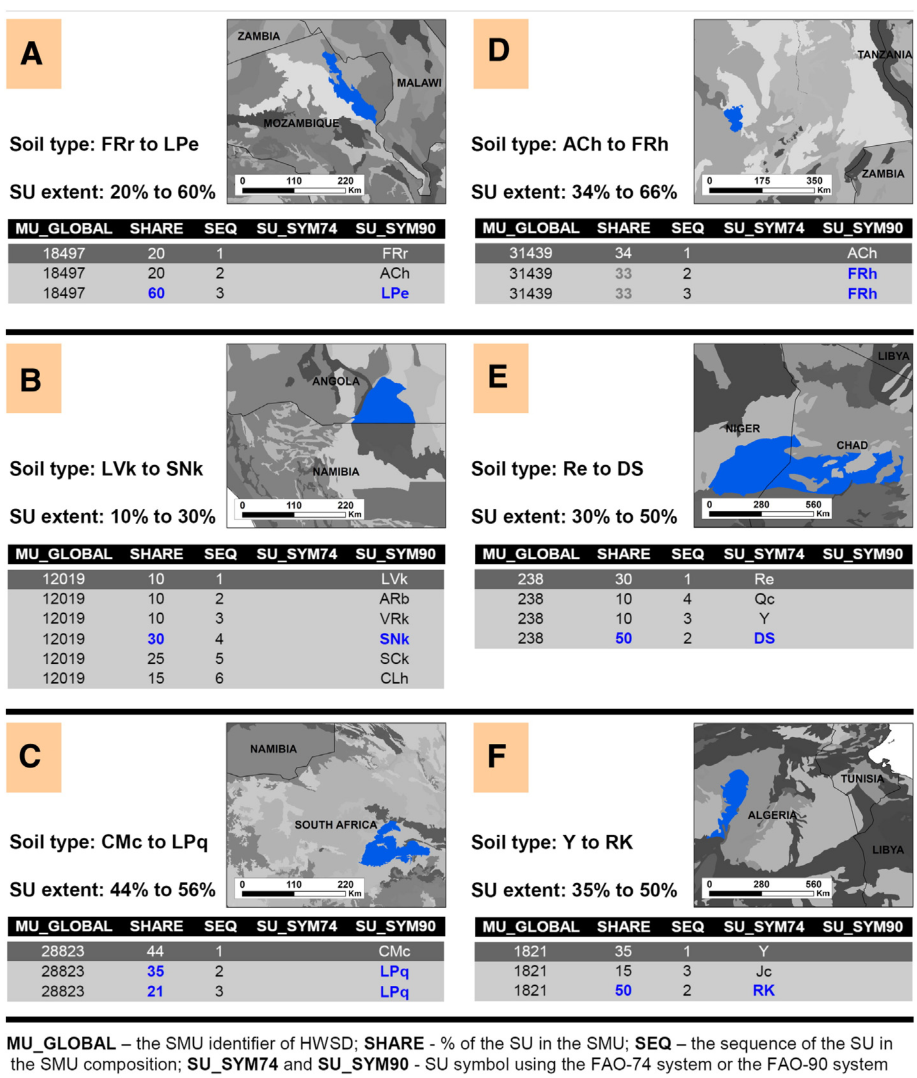

Fig. 4. Examples of SMU modifications brought to the HWSD to assign the dominant SU. For each of the six examples a map is shown locating the modified SMU (in blue) and the corresponding table caption taken directly from the original HWSD. In these tables, the SU that has sequence 1 within the SMU is 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). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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.

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		

WRB Code	WRB Name	FAO-90 Code	FAO-90 Name	FAO-74 Code	FAO-74 Name
FLsz	Salic Fluvisols	FLs	Salic Fluvisols		
FLti	Thionic Fluvisols	FLt	Thionic Fluvisols	Jt	Thionic Fluvisols
FLum	Umbric Fluvisols	FLu	Umbric Fluvisols		
	Ferralsols				
FR	Undifferentiated Ferralsols				
FRha	Haplic Ferralsols	FRh	Haplic Ferralsols	Fo	Orthic Ferralsols
FRpl	Plinthic Ferralsols	FRp	Plinthic Ferralsols	Fp	Plinthic Acrisols
FRro	Rhodic Ferralsols	FRr	Rhodic Ferralsols	Fr	Rhodic Ferralsols
FRum	Umbric/Mollic Ferralsols	FRu	Humic Ferralsols	Fh	Humic Ferralsols
FRxa	Xanthic Ferralsols	FRx	Xanthic Ferralsols	Fx	Xantic Ferralsols
	Gleysols				
GL	Undifferentiated Gleysols			G	Gleysols
GLcc	Calcic Gleysols	GLk	Calcic Gleysols		
GLdy	Dystric Gleysols	GLd	Dystric Gleysols	Gd	Dystric Gleysols
GLeu	Eutric Gleysols	GLe	Eutric Gleysols	Ge	Eutric Gleysols
GLhaar	Ahaplic Arenic Gleysols	ARg	Gleyic Arenosols		
GLmo	Mollic Gleysols	GLm	Mollic Gleysols		
GLum	Umbric Gleysols	GLu	Umbric Gleysols	Gh	Humic Gleysols
	Gypsisols				
GY	Undifferentiated Gypsisols				
GYcc	Calcic Gypsisols	GYk	Calcic Gypsisols		
GYha	Haplic Gypsisols	GYh	Haplic Gypsisols	Xy	Gypsic Xerosols
GYhaye	Haplic Yermic Gypsisols			Yy	Gypsic Yermosols
GYpt	Petric Gypsisols	GYp	Petric Gypsisols	Phase 5	Petrogypsic
	Histosols				
HSdy	Dystric Histosols			Od	Dystric Histosols
HSeu	Eutric Histosols			Oe	Eutric Histosols
HSfi	Fibric Histosols	HSf	Fibric Histosols		
HSsa	Terric Histosols	HSs	Terric Histosols		
	Kastanozems				
KS	Undifferentiated Kastanozems			K	Kastanozems
KScc	Calcic Kastanozems			Kk	Calcic Kastanozems
KSha	Haplic Kastanozems	KSh	Haplic Kastanozems		
KSlv	Luvic Kastanozems	KSl	Luvic Kastanozems	Kl	Luvic Kastanozems
	Leptosols				
LP	Undifferentiated Leptosols			RK	Rock debris
LPdy	Dystric Leptosols	LPd	Dystric Leptosols		
LPeu	Eutric Leptosols	LPe	Eutric Leptosols		
LPli	Lithic Leptosols	LPq	Lithic Leptosols	I	LITHOSOL
LPmo	Mollic Leptosols	LPm	Mollic Leptosols		
LPrz	Rendzic Leptosols	LPk	Rendzic Leptosols	E	RENDZINA
LPum	Umbric Leptosols	LPu	Umbric Leptosols		
	Luvisols				
LV	Undifferentiated Luvisols	LV	Luvisols	L	Luvisols
LVab	Albic Luvisols	LVa	Albic Luvisols	La	Albic Luvisols
LVcc	Calcic Luvisols	LVk	Calcic Luvisols		
LVcr	Chromic Luvisols	LVx	Chromic Luvisols	Lc	Chromic Luvisols
LVfr	Ferric Luvisols	LVf	Ferric Luvisols		
LVgl	Gleyic Luvisols	LVg	Gleyic Luvisols	Lg	Gleyic Luvisols
LVha	Haplic Luvisols	LVh	Haplic Luvisols	Lo	Orthic Luvisols
LVvr	Vertic Luvisols	LVv	Vertic Luvisols		
	Lixisols				
LX	Undifferentiated Lixisols				
LXfr	Ferric Lixisols	LXf	Ferric Lixisols		
LXgl	Gleyic Lixisols	LXg	Gleyic Lixisols		
LXha	Haplic Lixisols	LXh	Haplic Lixisols	Lf	Ferric Luvisols
LXpl	Plinthic Lixisols	LXp	Plinthic Lixisols	Lp	Plinthic Luvisols

WRB		FAO-90		FAO-74	
Code	Name	Code	Name	Code	Name
Nitisols					
NT	Undifferentiated Nitisols	NTh	Haplic Nitisols		
NTdy	Dystric Nitosols			Nd	Dystric Nitosols
NTeu	Eutric Nitosols			Ne	Eutric Nitosols
NTro	Rhodic Nitisols	NTr	Rhodic Nitisols		
NTum	Humic Nitisols	NTu	Humic Nitisols		
Phaeozems					
PHgl	Gleyic Phaeozems	PHg	Gleyic Phaeozems		
PHha	Haplic Phaeozems	PHh	Haplic Phaeozems	Hh	Haplic Phaeozems
PHlv	Luvic Phaeozems	PHl	Luvic Phaeozems	Hl	Luvic Phaeozems
		GRh	Haplic Greyzems		
Planosols					
PL	Undifferentiated Planosols			W	Planosols
PLdy	Dystric Planosols	PLd	Dystric Planosols	Wd	Dystric Planosols
PLeu	Eutric Planosols	PLe	Eutric Planosols	We	Eutric Planosols
PLsc	Solodic Planosols			Ws	Solodic Planosols
PLum	Umbric Planosols	PLu	Umbric Planosols		
Plinthosols					
PT	Undifferentiated Plinthosols				
PTab	Albic Plinthosols	PTa	Albic Plinthosols		
PTeu	Eutric Plinthosols	PTe	Eutric Plinthosols		
PTpt	Petric Plinthosols			Phase 3	Petric
PTpx	Pisoplinthic Plinthosols			Phase 6	Petroferric
PTum	Humic Plinthosols	PTu	Humic Plinthosols		
Podzols					
PZ	Undifferentiated Podzols				
PZcb	Carbic Podzols	PZc	Carbic Podzols	Ph	Humic Podzols
PZgl	Gleyic Podzols	PZg	Gleyic Podzols		
PZha	Haplic Podzols	PZh	Haplic Podzols		
Regosols					
RG	Undifferentiated Regosols			R	Regosols
RGca	Calcaric Regosols	RGc	Calcaric Regosols	Rc	Calcaric Regosols
RGdy	Dystric Regosols	RGd	Dystric Regosols	Rd	Dystric Regosols
RGeu	Eutric Regosols	RGe	Eutric Regosols	Re	Eutric Regosols
Solonchaks					
SC	Undifferentiated Solonchaks			Z	Solonchaks
				ST	Salt flats
SCcc	Calcic Solonchaks	SCk	Calcic Solonchaks		
SCgl	Gleyic Solonchaks	SCg	Gleyic Solonchaks	Zg	Gleyic Solonchaks
SCha	Haplic Solonchaks	SCh	Haplic Solonchaks	Zo	Orthic Solonchaks
SChaty	Haplic Takyric Solonchaks			Zt	Takyric Solonchaks
SCso	Sodic Solonchaks	SCn	Sodic Solonchaks		
Solonets					
SN	Undifferentiated Solonetz	SN	Solonetz		
SNcc	Calcic Solonetz	SNk	Calcic Solonetz		
SNgl	Gleyic Solonetz	SNg	Gleyic Solonetz		
SNha	Haplic Solonetz	SNh	Haplic Solonetz	So	Orthic Solonetz
SNmo	Mollic Solonetz	SNm	Mollic Solonetz		
SNst	Stagnic Solonetz	SNj	Stagnic Solonetz		
Stagnosols					
STlv	Luvic Stagnosols	LVj	Stagnic Luvisols		
STlx	Lixic Stagnosols	LXj	Stagnic Lixisols		
STmo	Mollic Stagnosols	PHj	Stagnic Phaeozems		
Technosols					
TC	Undifferentiated Technosols	UR	Urban		
Umbrisols					
UMcm	Cambic Umbrisols	CMu	Humic Cambisols	Bh	Humic Cambisols

WRB		FAO-90		FAO-74	
Code	Name	Code	Name	Code	Name
Vertisols					
VR	Undifferentiated Vertisols			V	Vertisols
VRcc	Calcic Vertisols	VRk	Calcic Vertisols		
VRha	Haplic Vertisols	VRe	Eutric Vertisols	Vc	Chromic Vertisols
VRhams	Haplic Mesotrophic Vertisols	VRd	Dystric Vertisols		
VRpe	Pellic Vertisols			Vp	Pellic Vertisols
Miscellaneous Categories					
WR	Water Body				

and their position in the landscape. Google Earth shows information that was captured by satellites at most a few years ago, which allows multi-temporal comparison with the HWSD data.

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 7,327 that cover the whole Africa have been modified (blue areas in Fig. 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 (Fig. 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 (Fig. 4A and B);
- Two or three SUs are defined by the same soil type name but none of them is ranked as the dominant SU (Fig. 4C and D). 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 or can be slightly different. 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 (Fig. 4E and F).

3.2. Translation to WRB

Within the HWSD, the name of the soil is given according to the legends of the FAO-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).

Table 2
Soil phases considered in the WRB soil classification.

FAO		WRB		Renaming rules
Phase name[a]	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

[a] 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.

Table 3
Maps used in support for the harmonisation.

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	1:250.000	1979	Carroll, P.H. et al. Soils of Lesotho. The Office of Soil Survey. Cons. Div., MA, Lesotho
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

The conversion of the FAO systems into the WRB scheme is presented in Table 1, which correlates each WRB RSG to the related SUs in both FAO systems but 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:

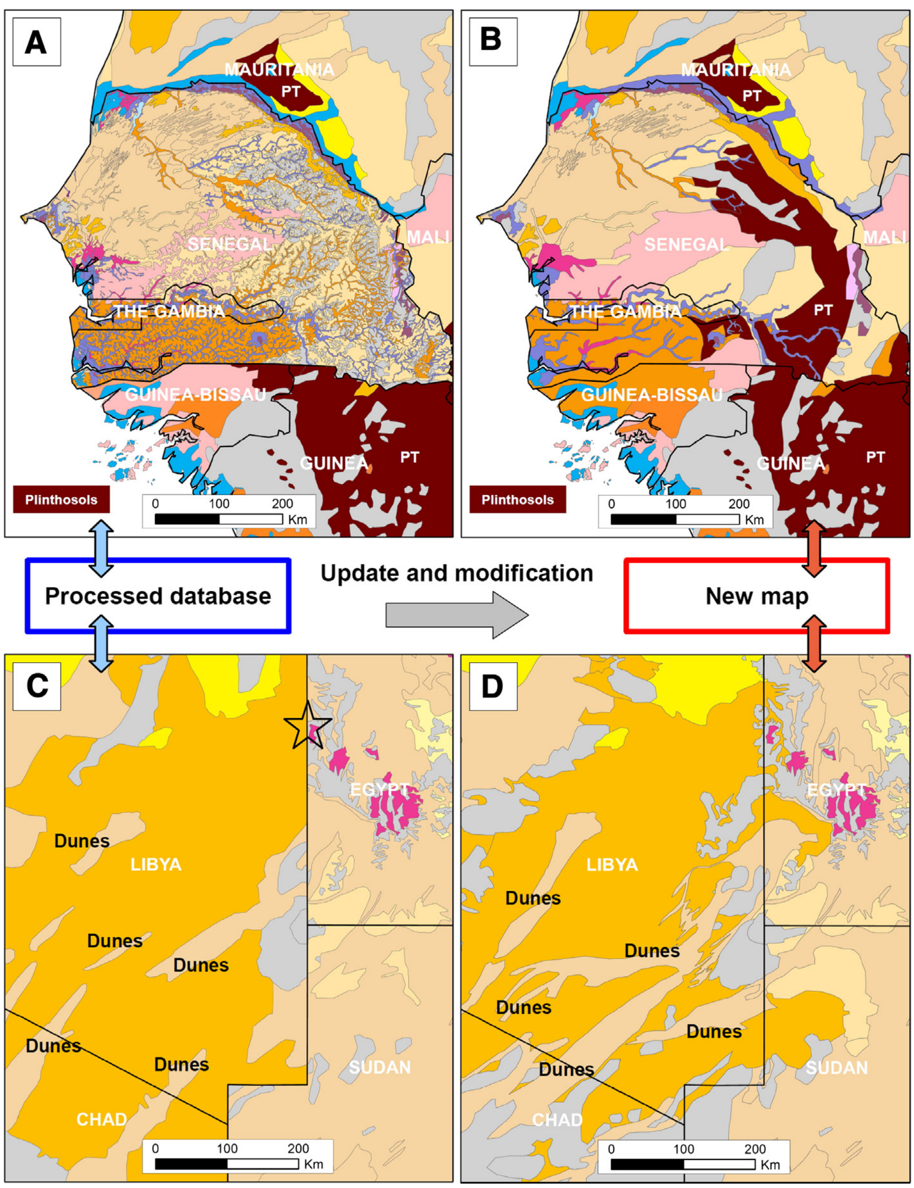

Fig. 5. Phase and dune update and border harmonisation. Examples for Senegal (A, B) and the Libyan–Egyptian–Sudan border (C,D). (A, C) The soil map as it appears after the database processing stage. (B, D) The soil map in its final version after all the updates and modifications. See Table 1 for the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

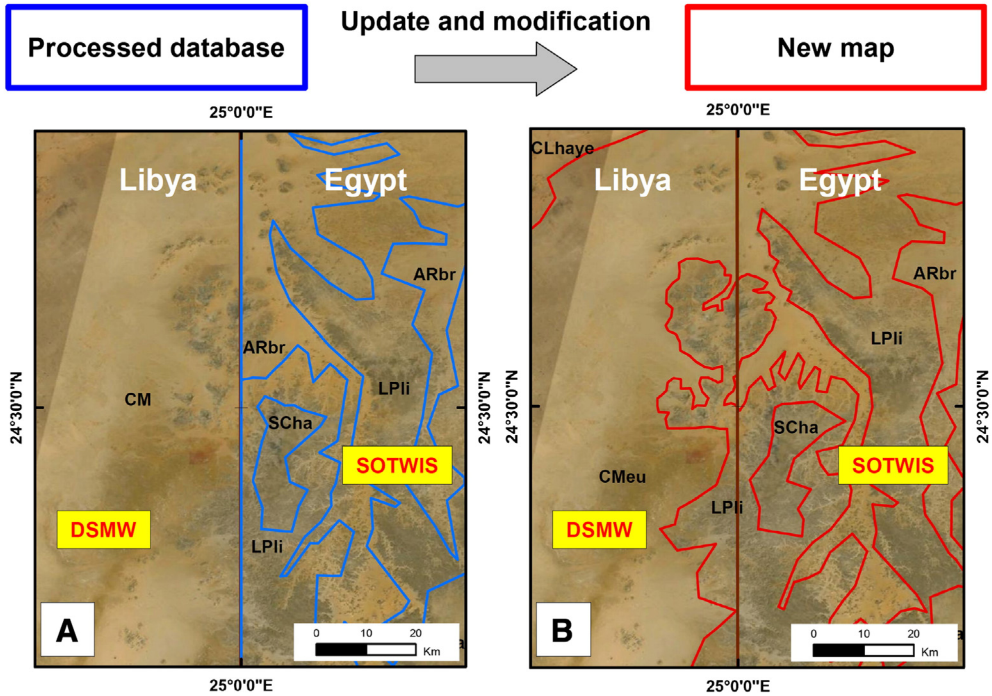

Fig. 6. Border harmonisation with the use of Google Earth along the Libyan–Egyptian border. (A) The SMU limits as they appear after the database processing stage. (B) The SMU limits in their final version after all the updates and modifications. The location of this region is shown with a star in Fig.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

Albeluvisols, 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) (IUSS Working Group WRB, 2010). 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.

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).

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).

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 (Fig. 1). Cells with adjacent soil names were merged in this process. The conversion gives a map of 30,554 polygons that can be categorized in three groups: soil, water body, and sea and ocean area; these groups containing, respectively, 26,204, 3,951 and 399 polygons.

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 overwritten with their surrounding map units in order to produce 'clean' maps. These are indicated by the red speckle on the summary modification map (Fig. 9). These polygons are smaller than the minimum legible delineation (MLD), which, according to the definition of Vink (1975), is 0.25 cm^2 on the map. For a 1:3 M scale, MLD is 225 km^2. The map contains 20,500 polygons smaller than 225 km^2 (i.e. 80% of the total number), most of them being located in the SOTWIS regions (Fig. 1).

At this stage, a decision was taken not to over-clean the SOTWIS data with respect to the coarser information from the original DSMW

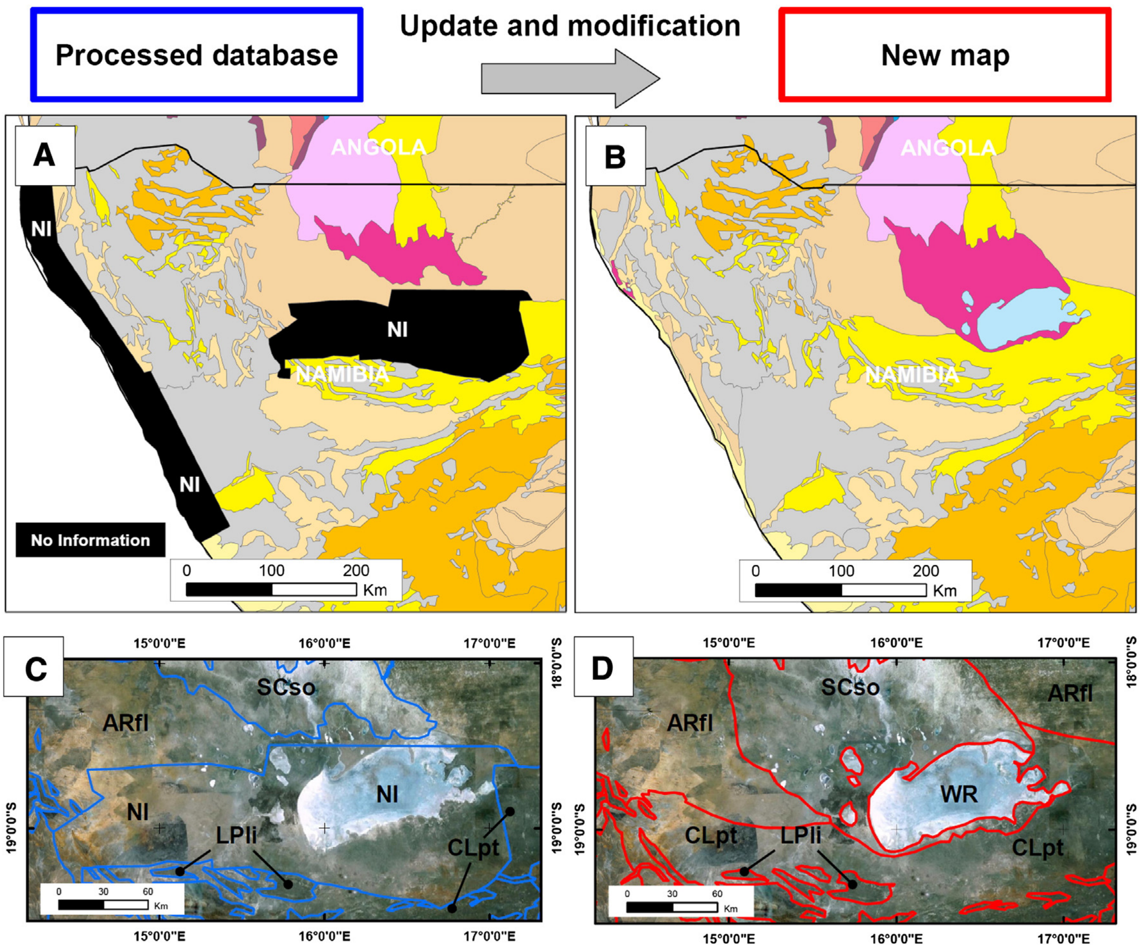

Fig. 7. Completion of “no information” areas. Example for two large areas in Namibia. (A, C) The soil map and the SMU limits as they appear after the database processing stage. (B, D)) The soil map and the SMU limits in their final version after all the updates and modifications. (C, D) close-ups of 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.

(Fig. 1). 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. Some parts of the map are therefore at a much finer effective scale than 1:3 M.

In total, 12,800 soil polygons smaller than 225 km^2 (out of 20,500 in the initial map) were overwritten; 12,000 of them (out of 14,300) having an area smaller than 25 km^2 (i.e. the MLD for a 1:M scale map) and 6,800 (out of 7,000) being smaller than 1 km^2 (i.e. approximately the size of a pixel at the Equator). Most of these polygons are located in South Africa, Senegal and Kenya.

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/).

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 Fig. 9). As an example, Fig. 5A and B illustrate the Plinthosol updates in Senegal and the neighbouring countries. When considering only the renaming through the database processing (Fig. 5A), Plinthosols are absent in Senegal. At the continental scale, Plinthosols constitute a major update (Fig. 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 Fig. 9.

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 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

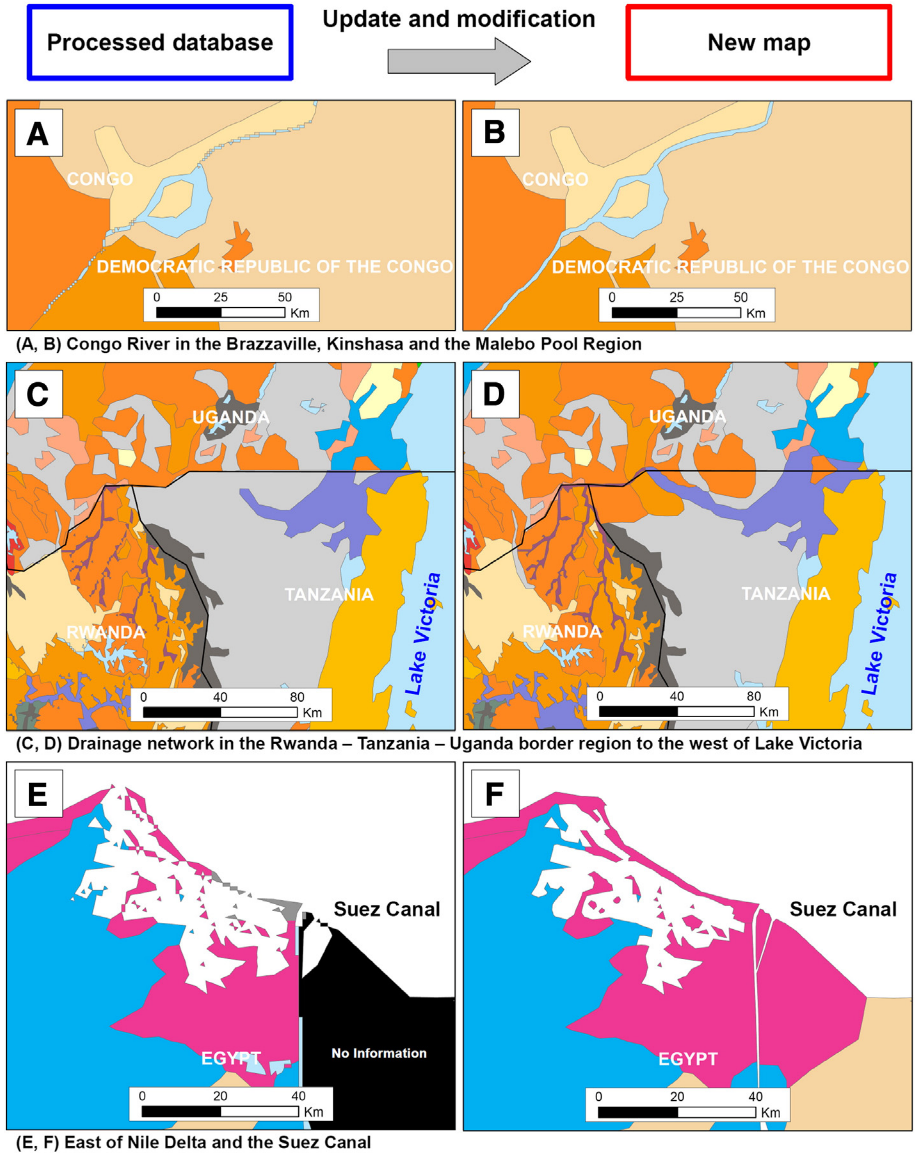

Fig. 8. Harmonisation of drainage networks, water bodies and coastlines. (A, C, E) The soil map as it appears after the database processing stage. (B, D, F) The soil map in its final version after all the updates and modifications. See Table 1 for the WRB legend.

seen, for example, in the Libyan–Egyptian–Sudan border region, where changes can easily be observed in the pattern of the dune polygons (Fig. 5C and D). The areas of dune update are shown in yellow in Fig. 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 (Figs. 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 (Fig. 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 (Fig. 2B). The same observation can be made between Lesotho, which is only defined by a few FAO-74 soil units, and South Africa (Fig. 2 E). Within SOTWIS areas, differences in data resolution are also frequent across country boundaries as exemplified in Fig. 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.

Fig. 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 Fig. 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 (Fig. 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

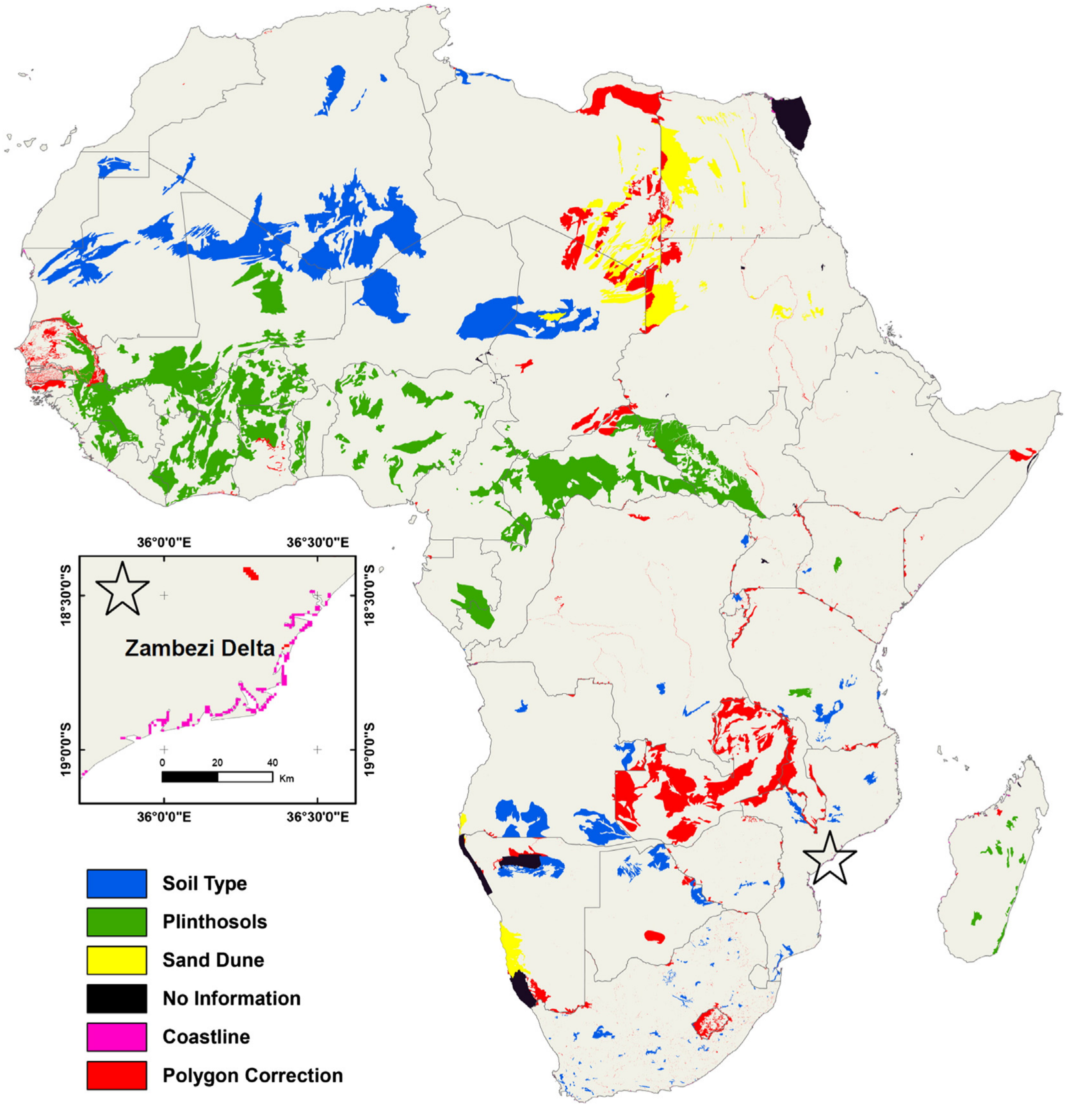

Fig. 9. Summary of the modifications. The blue areas correspond to the modifications brought during the database processing stage. The other areas are the result of the processing of the polygon map. The red areas indicate all the updates and modifications other than those specified by the legend. The close-up on the Zambezi Delta shows an example of coastline update. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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. Fig. 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 Fig. 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 information for these countries is from the DSMW (Fig. 1) and some mistakes were due to the poor resolution of the data; Lesotho, for example, being defined mainly by two polygons. In addition, in Zambia and Malawi, experts familiar with this region noticed several inconsistencies in the general north–south distribution of the soils. The modifications were carried out on the basis of different soil maps at more detailed scales (Table 3). These changes are indicated as red areas in Fig. 9.

4.4. No information areas

A total of 203 areas with no information are present in the HWSD derived soil map (Fig. 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 Fig. 9). Fortunately, the larger areas are located in semi-arid and arid regions allowing a reliable use of Google Earth. Fig. 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 existing soil pattern.

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

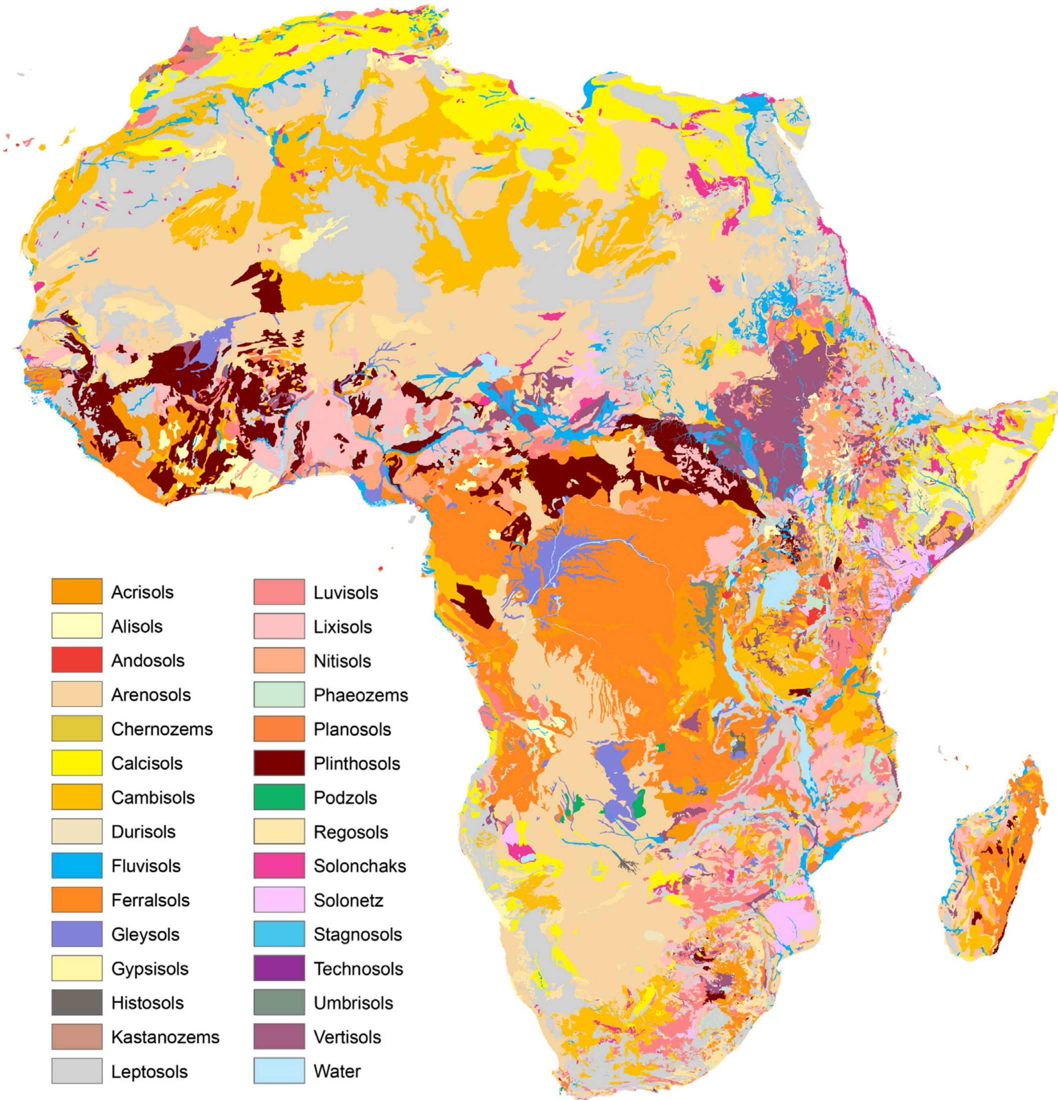

Fig. 10. Harmonised soil map at the continental scale. The map represents the dominant SU of each SMU. World Geodetic System (WGS 84) is the coordinate system used to produce the map.

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 (Fig. 8A and C). In addition some rivers, lakes and coastlines are 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 (Fig. 8E).

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 Fig. 8 for examples). The modifications of the drainage networks and water bodies are indicated as red areas in Fig. 9 whereas the coastline updates are in pink.

The large number of water bodies in the initial map derived from HWSD was due to an artificial fragmentation of the river network. Through the harmonisation, we went from 3,951 to 251 water bodies. The occurrence of 399 sea and ocean areas enclosed with soil polygons in the initial map was also due to cartographic artefacts. The modification of the coastlines removed all of them except two that are in the Nile Delta.

At the conclusion of the harmonisation, the new map contains 13,689 polygons: 13,436 sol, 251 water body, and 2 sea and ocean. This represents a reduction of 12,768 polygons from the initial map.

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 is shown in Fig. 9. The totality of the modified areas is large, representing 13% of the continent; soil types and SMUs of the original HWSD were corrected.

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 (Fig. 10) shows the distribution of the major dominant soil types that can be found in

WRB Group	WRB area [a]	% Africa [b]	# POL [c]	POL 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 polygons in the WRB Reference Soil Group
d Polygon average area in km²

A

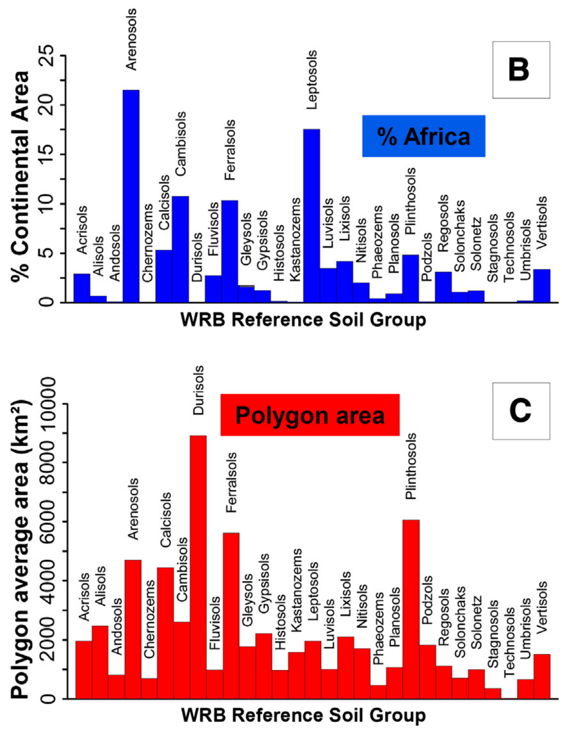

Fig. 11. WRB Soil Reference Group (RSG) distribution. (A) Table with the main statistics. (B) Graphical view of the percentage of the continental area occupied by each WRB RSG. (C) Graphical view of the polygon average area for each WRB RSG.

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 (Fig. 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. 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 polygons varies considerably according to the RSG (Fig. 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 (Fig. 1) and DSMW was also used for the phase update (Plinthosols and Durisols). Different environmental conditions could also be responsible for the polygon 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.

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 (Brus et al., 2011; Kempen et al., 2009). 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 Fig. 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 bears the most reliable information. The map shown in Fig. 1B provides information similar to a purity map (Kempen et al., 2009).

The new map is at the heart of the Soil Atlas of Africa (Jones et al., 2013), displayed in a series of map sheets at the scale 1:3 M, constituting some forty per cent of the Atlas pages. The published Atlas, the Soil Map of Africa that it contains and the corresponding datasets (modified map and associated modified HWSD) are available for downloading free of charge from the portals of the European Commission Joint Research Centre SOIL Action (http://eusoils.jrc.ec.europa.eu/).

6. 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 in the support of an increasing population and threatened environment. The soil map and associated database also have the potential to enhance global studies on climate change, food production and land degradation for example. The explanation of the decisions that were made to produce the map will be useful to others who are attempting to harmonise legacy soil data sources to provide a usable information base.

The Soil Atlas of Africa Project utilised 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). However, the resulting map highlights the need for applying new mapping techniques and collecting new data in Africa to meet 21st century soil information needs.

It is important to recognise that the map has limitations if applied at high resolution because, to be meaningful, this would require data at the soil type (SU) level. The soil mapping units (SMUs) on the current map only comprise a dominant SU together with a number of ancillary (or included) soil units for which the precise spatial distribution is not known. But the structure is flexible enough to incorporate new soil (spatial and attribute) data as they become available and there is good expectation that the current resolution can be constantly improved in the future.

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