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Soil and Terrain Database of Central Africa - DR of Congo, Burundi and Rwanda (SOTERCAF, version 1.0)

Vincent van Engelen
Ann Verdoodt
Koos Dijkshoorn
Eric Van Ranst

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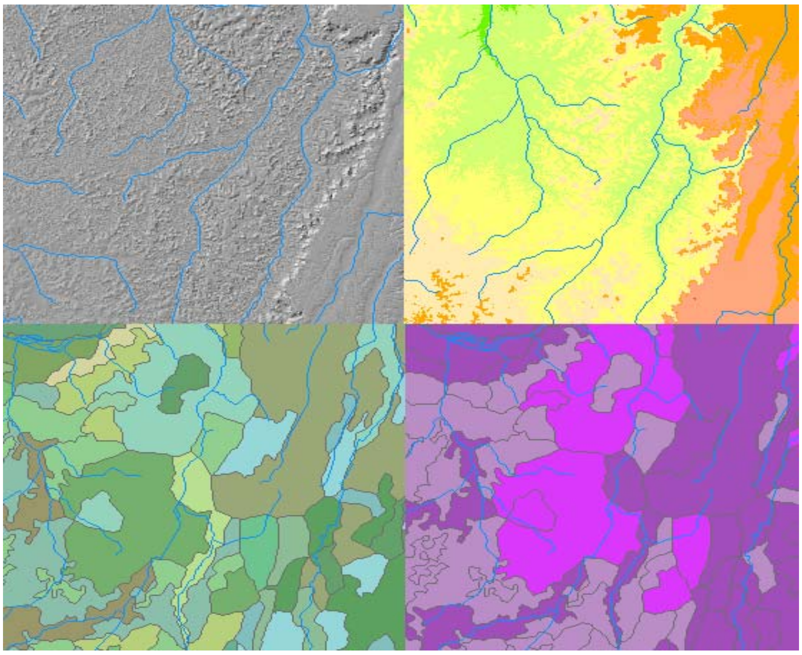

UNIVERSITEIT GENT
Department of Geology and Soil Science
Laboratory of Soil Science

Food and Agriculture Organization of the United Nations

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Inquiries:
c/o Director, ISRIC – World Soil Information
PO Box 353
6700 AJ Wageningen
The Netherlands
Telefax: +31 (0)317 471700
E-mail: soil.isric@wur.nl
Web: www.isric.org

c/o Director, AGL
FAO
Viale delle Terme di Caracalla
00100 Rome
Italy
Telefax: +39 06 570 56275
E-mail: land-and-water@fao.org

Front cover: Maps showing (clockwise from left top corner) shaded topography, elevation, SOTER landform units and relief intensity for the western part of the DR of Congo

Contents

SUMMARY

The only existing globally consistent soil resources information for the Central African region – Democratic Republic of Congo, Burundi and Rwanda - is the FAO-Unesco Soil Map of the World. This map does not reflect the present state of knowledge as new soil inventories were done after its publication. This newer information is often difficult to access, not always in a standardized format and at various scales. ISRIC was contracted by FAO to create a SOTER database for Central Africa from all existing information.

This report summarises the activities of ISRIC – World Soil Information and its subcontractor the Laboratory of Soil Science of the Ghent University within the framework of the SOTERCAF project (September, 2005 to September, 2006). The project included the compilation of a soil and terrain database of the DR of Congo at scale 1:2 M and of Burundi and Rwanda at scale 1:1 M following standardized SOTER procedures.

Materials and methods that have been used include the Space Shuttle Radar Topographic Mission digital elevation model, generating the physiography of the area, existing geological and soil maps and soil profile information.

The database of the DR of Congo is defined by pre-independence soil information at low-resolution, enhanced with landform information derived from DEM data and lithological information derived from the geological map. Reconnaissance, semi-detailed and detailed soil maps, covering about 15% of the country, were consulted to improve the delineation of the SOTER units and to characterise the soil components. A total of 144 SOTER units have been identified.

The SOTER databases of Rwanda and Burundi are based on generalization of relatively recent medium resolution 1:250,000 soil maps. Burundi has 56 SOTER units, Rwanda 41.

Some 160 measured profiles have been used to characterize the soils of study region. Being based on available soil survey data, there are numerous gaps in the soil analytical data provided for the DR of Congo. Based on the availability of extensive amounts of detailed soil data, the SOTER units of Rwanda and Burundi have been characterized by well described and analysed soil profiles.

Key words: SOTER database, SOTERCAF version 1.0, Central Africa, primary soil data.

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Baert, Geert (Hogeschool Gent)
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Fernandez, Max (Royal Museum for Central Africa)
Goyens, Clémence (Ghent University)
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Mbayo Ndekanya, Doudou (Université de Lubumbashi)
Sys, Carolus (Ghent University)
Tack, Luc (Royal Museum for Central Africa)
Van de Wauw, Johan (Ghent University)
van Engelen, Vincent (ISRIC)
Van Ranst, Eric (Ghent University)
Verdoodt, Ann (Ghent University)

1. INTRODUCTION

The compilation of a Soil and Terrain database –SOTER - of Central Africa forms a part of the ongoing activities of the Food and Agriculture Organization of the United Nations (FAO) and ISRIC – World Soil Information to update the world's baseline information on natural resources. The only existing globally consistent soil resources information for this part of the world is the FAO-Unesco Soil Map of the World (FAO-Unesco 1974). A substantial part of this map does not reflect the present state of knowledge of the soils of the Central African region – Democratic Republic of Congo, Burundi and Rwanda - as new soil inventories were done after its publication. This newer information however, is often difficult to access, not always in a standardized format and at various scales. ISRIC was contracted by FAO to create from all available information a SOTER database for the region. The current activity follows similar work in Southern Africa (FAO and ISRIC 2003).

This report summarises the activities of ISRIC – World Soil Information and its subcontractor the Laboratory of Soil Science of the Ghent University from September 1st, 2005 to September 1st, 2006 within the framework of the SOTERCAF project (FAO contract PR No. 32714). The project included the compilation of a soil and terrain database of the DR of Congo at scale 1:2 M and of Burundi and Rwanda at scale 1:1 M following the standardized SOTER procedures (van Engelen and Wen 1995) and updates (Appendix 3 and 4).

The present SOTERCAF database has been compiled by merging all existing data on the soils of Central Africa. This was possible because national soil databases of Burundi, Rwanda and the DR of Congo have been created recently or are under construction. The digital soil map of Rwanda at scale 1 :50,000 and its related soil profile database was recently finalised during a project funded by the Directorate General for Development Cooperation - Belgian Technical Cooperation (DGDC-BTC), and executed by Laboratory of Soil Science of Ghent University and the *Unité des Sciences du Sol* of the Catholic University of Louvain-la-Neuve, in cooperation with the Rwandan Ministry of Agriculture (MINAGRI). The compilation of a harmonised, digital database of all existing soil maps of the DR of Congo by the Universities of Kinshasa and Lubumbashi, under the guidance of the Laboratory of Soil Science, Ghent University and funded by the Flemish Interuniversity Council – University Development Cooperation (VLIR-UOS), is in an advanced stage. With respect to Burundi, the digital soil association map by ISABU (1988), financed by the

General Administration for Development Cooperation (GADC), proved to be fundamental to the creation of the database. For the generalisation of the semi-detailed and reconnaissance maps, and for the characterisation of the non-surveyed parts of The DR of Congo, the compilers of the SOTER database could further rely on the cooperation of several experts.

The project activities were split into several steps. The first step consisted of the analysis of the SRTM90 DEM (USGS 2003), resulting in a landform map following SOTER definitions. The second step consisted of an overlay of the available lithological information with the landform units. The third activity consisted of the population of these units with available soil data. The final activity was the correlation between the three national databases and SOTER for Southern Africa.

The first activity has been executed by ISRIC, the second and third by Ghent University in close collaboration with the Royal Museum for Central Africa at Tervuren and the Hogeschool Gent. Boundary correlation between the three databases and the SOTER database of Southern Africa was done by ISRIC.

The materials and methods are described in Chapter 2, modifications of the SOTER procedures in Chapter 3, the results in Chapter 4 and conclusions are given in Chapter 5.

2. MATERIALS AND METHODS

2.1 Landform

The globally available digital elevation data from the Shuttle Radar Topographic Mission (USGS 2003) consist of a GRID map available in geographic coordinates (WGS84). The GRID file supplies detailed information on the altitude at a resolution of 90 m. This dataset was used to derive physiographic units following SOTER definitions (Appendix 3), using a methodology developed by the European Soil Bureau (Dobos *et al.* 2005).

Based on an analysis of the SRTM data, ISRIC created a physiographic map of the three countries. The landform parameters initially considered were altitude, slope gradient, relief intensity and potential drainage density. After neighbourhood analysis and noise removal, the map was generalised to a minimum mapping unit size of 25 km^2 (in the field).

When analysing the geology and soil units jointly with the derived physiographic units, the limited applicability of the SRTM-derived physiographic map in areas where there is a well-known and close relationship between landscape and lithology became apparent. Consequently, the approach to map physiographic units was adapted by (1) reducing the number of parameters to slope gradient, relief intensity and altitude, and (2) increasing the generalisation to a minimum mapping unit size of 100 km^2 (in the field). The modified approach was tested and evaluated in a pilot area – the Lower Congo, with a well-known soil pattern, before it was applied to the whole area.

The final physiographic map consists of an overlay of the slope gradient and relief intensity maps, generalised to 100 km^2, with the elevation map generalised to 100 km^2. Narrow elongated features such as floodplains, ridges, valleys or strongly contrasting terrain and soil features can be delineated using this procedure.

In Rwanda, a landform map was derived from the soil associations map (Birasa *et al.* 1992) and adjusted with information from the DEM-derived physiographic map and the DTM at scale 1 :50,000 (Appendix 2), to ensure its consistency with the soil-terrain relationship drawn on the semi-detailed soil maps.

The physiographic parameters were calculated using the SOTER landform units map and the DEM. Using the Zonal Statistics module of ArcGIS©, the median values of slope and relief intensity within each SOTER unit were computed.

2.2 Hydrographic network

The drainage network has been derived from the Digital Chart of the World at scale 1:1 M (DMA 1993).

Comparison with the location of the valleys according to the SRTM data highlighted some random shifts in the drawing of the hydrographical network. Experts of the Royal Museum for Central Africa suggested using the drainage network supplied by Africover (FAO 2003) at a scale of 1:200,000. However, this dataset also showed some inconsistencies with the SRTM data and in addition needed more processing time to generalise the data to a 1:1 M scale. Consequently, it was decided to use the DCW drainage network information.

2.3 Lithological information

DR of Congo

The digital version of the geological map of Congo (Lepersonne 1974) at scale 1:2 M has been supplied by the Royal Museum for Central Africa.

The map uses stratigraphic units defined by series of depositions of variable thickness that fall in different classes, groups and types according to the lithological terminology applied by SOTER. This complicated the translation of the geological map into a lithological map. In addition, there is ambiguity in the use of the French words *schists* and *quartzites*, applying to different lithological classes of SOTER. In this report *schists* are classified as metamorphic deposits if they occur together with other metamorphous parent materials such as *quartzites*. However, if they occur together with sedimentary deposits such as calcareous rocks and sandstones, they classify as sedimentary deposits. In addition, the topography is taken into consideration, as metamorphic rocks are more resistant than sedimentary deposits and might form outstanding features in the landscape.

The lithological classification used in the revised SOTER procedures manual was used (Appendix 4).

The overlay of the derived lithological map with the SRTM and hydrographical maps shows that there have been random shifts in the positioning of the geological units. This is probably due to the limited tools available when drawing the geological map (no GPS), to minimal changes in size of the hardcopy map with time, and to subsequent digitising errors. According to the experts of the Royal Museum for Central Africa, the map has a good accuracy along the borders of the country, but the location of the valley deposits in the Central Basin is prone to significant errors.

Different approaches were suggested for the creation of the SOTER units:

- use of the lithological map as the base map and automated redefinition of the physiographic map within these units;

- use of the physiographic map as the base map and semi-automated redefinition of the lithological map; and

- combination of both maps and manual selection of the best fitting arcs constituting the boundaries of the SOTER units

The last option was selected to draw the SOTER units of the DR of Congo: a simultaneous application of GIS techniques and scientific understanding of the landscape-soil relationship.

Burundi and Rwanda

The geological maps of Burundi (Ministère de l'Energie et des Mines and Musée Royale de l 'Afrique Centrale 1990) and Rwanda (Theunissen *et al.* 1991) at a scale of 1:250,000 are digitally available.

The map units have been characterised and defined by a stratigraphic geological classification system. Consequently, to avoid similar translation problems as for the geological map of the DR of Congo, the lithological information was extracted from the soil association maps, having an indication of the parent material in the map legend.

Translation of the parent material into the lithological classification system of SOTER proved successful in Rwanda. The lithological information supplied by the soil association map of Burundi (ISABU 1988) does not make a clear distinction between igneous and metamorphic rocks, and metamorphic and sedimentary deposits. The information on lithology of the soil association units on these rocks was taken from the geological map.

Both lithological maps were generalised and combined with the physiographic maps to create the SOTER units maps at a scale of 1:1 M. A good match with the 1:1 M soil association map of van Wambeke (1963) exists.

2.4 Soil information

DR of Congo

The soil association map of Congo (Sys 1960) at scale 1:5M has been used to fill the soil information in the database. In addition to this national map, large-scale reconnaissance, semi-detailed and detailed soil maps of different areas covering about 15% of the country, have been consulted to extend the soil information (Appendix 1). Soil profile information was derived from Sys (1972), from databases accompanying the semi-detailed soil maps (Baert 1991; Baert *et al.* 1993) and from Beernaert (1999).

Extensive use has been made of the expertise of former soil surveyors familiar with the region in evaluating the preliminary map.

Burundi

The digital soil association map of Burundi (ISABU 1988) at a scale of 1:250,000, was used for the soil information of the SOTER units. The units on the soil association map were described as associations of two or three soil types. According to the map legend, the major soil type occupies at least 60% of the surface, and the associated soils more than 20%. These approximative numbers were retained to derive the proportions within the SOTER unit: the major soil is given 60%, the associated soils 40%. If inclusions of a third soil have been described, this ratio changes to 60/30/10.

Soil profile information was taken from the database accompanying the semi-detailed soil maps. Two additional soil profiles were taken from the database of Tessens and Gourdin (1993).

Rwanda

The soil maps of Rwanda at scale 1:50,000 were the main sources of soil information (Appendix 2). For the characterization of the soil components, representative catenas have been drawn and analysed. The semi-detailed maps were also used to quantify the extent of each soil component.

Descriptions of soil associations of Burundi and Rwanda are based on different criteria, resulting in non-matching units along their common border. These discrepancies where resolved using border correlation.

Soil profile information was taken from the extensive database accompanying the semi-detailed soil maps.

3. SOTER PROCEDURES AND CONVENTIONS

SOTER is a land resources information system. Underlying the SOTER methodology is the identification of areas of land with a distinctive, often repetitive, pattern of landform, lithology, surface form, slope, parent material, and soil. Tracts of land distinguished in this manner are named SOTER units. Each SOTER unit thus represents one unique combination of terrain and soil characteristics. Figure 1 shows a landscape with various SOTER units and the representation of a SOTER unit in the database.

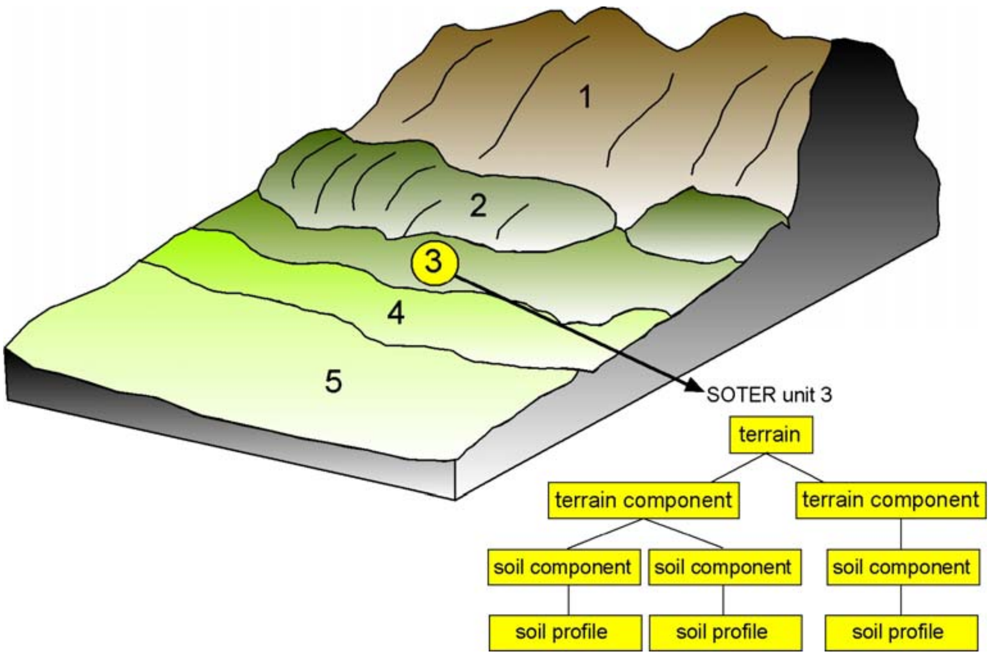

Figure 1. SOTER units in the landscape and their components in the database

The criteria for the discrimination between undulating and rolling land – has been set at 10% in accordance with the Guidelines for Soil Description (FAO 2006). Previously, the limit was set at 8% (van Engelen and Wen 1995). The 10% limit has also been applied in the neighbouring SOTER database of Southern Africa (FAO and ISRIC 2003).

The definition of landform and lithological units has been slightly changed with respect to the original SOTER definitions (van Engelen and Wen 1995) using criteria given in Appendix 3 and 4.

The SOTER guidelines state 15% as minimum for the proportion of the terrain and soil components of a SOTER unit, but here a minimum of 10% has been applied to allow inclusion of components that, although relatively small, are strongly contrasting to the dominant ones. Soils covering less than 10% of the SOTER unit are not listed in the database and are added to the soil component with a similar classification at major soil group level within the same terrain component. Soil components covering less than 10% of a unit and having no equivalent soil component at soil group level (no soil component with equivalent major soil group) were omitted and the percentage added proportionally to the remaining soil components. The Revised Legend (FAO *et al.* 1988) has been used as the reference for harmonization at soil component level. The soil classification according to the World Reference Base for Soil Resources (IUSS *et al.* 1998) has been added to the profile table. The latest version of WRB (IUSS Working Group WRB 2006) could not be included as it was published after the compilation stage of the project.

Country boundaries were made congruent to those of the Digital Chart of the World at scale 1:1 M (DMA 1993).

Cross-border harmonization was focussed on SOTER units along the border between The DR of Congo and Angola. As the reliability of the soil pattern is higher in the Bas Congo area than in the adjacent Angolan territory, the harmonization has resulted a modifications in the Angola part of version 1.0 of the SOTERSAF database (FAO and ISRIC 2003). An updated version of the latter will be made available from the ISRIC website at: http://www.isric.org.

4. RESULTS

4.1 General

The SOTER-GIS files are presented in ArcInfo© format as coverage and export file with geographic coordinates in decimal degrees and with datum WGS84. Also SOTER attribute data have been stored in a relational database system in MSAccess© format using the standardized SOTER input module (Tempel 2005). A number of thematic maps – landform, lithology, dominant soils and number of soil components per SOTER unit – are presented as ArcInfo© shape files.

4.2 DR of Congo

The database of the DR of Congo at scale 1:2 M is mainly defined by pre-independence soil information at low-resolution, enhanced with landform information derived from SRTM90 DEM data and lithological information derived from the geological map. About 15% of this vast country is covered by more detailed soil survey information that allowed improvements of the spatial pattern and contents of the mapping units. For example, new information for the Bas-Congo area (Figure 2, Appendix 1) that was until now not digitally available has been included. A total of 147 SOTER units have been identified, compared with 45 soil mapping units on the 1:5 M source map of Sys (1960). The major increase in detail occurs in areas with recent detailed surveys.

SOTER units are further characterized in the attribute database: most units consist of two components – terrain and soil components (Figure 1 and Table 1). The number of soil components (322) is not matched with the number of profiles. Several profiles are considered representative for different soil components while about half of the soil components do not have a measured profile in particular for those areas that are only covered by the pre-independence soil survey. The number of profiles is 96 due to a low paucity of accessible data. The profile density is 1 per 24,000 km^2 for the whole national territory but it is substantially higher in the recently surveyed areas.

Analytical results for most of the soil profiles are far from complete. They were sometimes determined by methods that are not current anymore: for example only exchangeable cations Ca and K were determined using 0.05N HCl extraction for all profiles taken from Sys (1972).

Table 1. Details of SOTER units and their components per country

Country	Area (10^3 km^2)	SOTER units	Terrain components	Soil components	Profiles
Burundi	27	56	131	187	20
DR of Congo	2,337	147	295	322	96
Rwanda	25	41	56	91	51
Total	2,390	244	482	600	167

4.3 Rwanda and Burundi

The SOTER databases of Rwanda and Burundi at scale 1:1 M are based on generalization of relatively recent medium resolution 1:250,000 soil maps, complemented in Rwanda with detailed soil maps at scale 1:50,000. Extensive soil profile databases for both countries exist.

Burundi has 56 SOTER units, further subdivided into 131 terrain components and 187 soil components. Rwanda has 41 SOTER units mostly consisting of only one terrain component. Most terrain components have two soil components. There are 20 soil profiles for Burundi and 51 for Rwanda.

The profile density is 1 per 1350 km^2 in Burundi, and 1 per 510 km^2 in Rwanda.

Analytical methods (Birasa *et al.* 1992; ISABU 1988; Tessens and Gourdin 1993) are in line with internationally accepted procedures (van Reeuwijk 2002).

5. CONCLUSIONS

The generation of a physiographic layer from the SRTM DEM using the method developed by Dobos *et al.* (2005) did not fit well with the existing soil pattern and needed some revision by limiting the DEM-derived parameters to three (elevation, relief intensity and slope) by deleting potential drainage density.

The revised soil information of the DR of Congo at scale 1:2 M shows an unbalanced picture: there is a low resolution for the major part of the country that was surveyed before independence. However, for those areas where new surveys were done, the database has a much better spatial resolution. At the same time, the database contains previously non-digital soil profile information for those newly surveyed areas. Additional profile information is needed for the area where soil components are only characterised by taxonomic names.

The soil and terrain information of Burundi and Rwanda at scale 1:1 M is of a much higher spatial reliability as it is based on recent semi-detailed survey information. Sufficient soil profile information accompanies the spatial units.

Gaps in the analytical data should be filled using taxonomy-based taxotransfer rules (Batjes, 2003, 2004). Results from non-standard analytical procedures used in the older profiles of the DR of Congo should be updated.

The SOTER database of Central Africa has required a harmonization and standardization of all accessible terrain and soil information. The result is a spatial database of the area with previously inaccessible soil data that further extends the existing SOTER database of the continent.

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APPENDICES

Appendix 1: Soil maps of The DR of Congo

Soil surveys carried out in The DR of Congo since 1948 are shown in Figure 2 and detailed in Table 2.

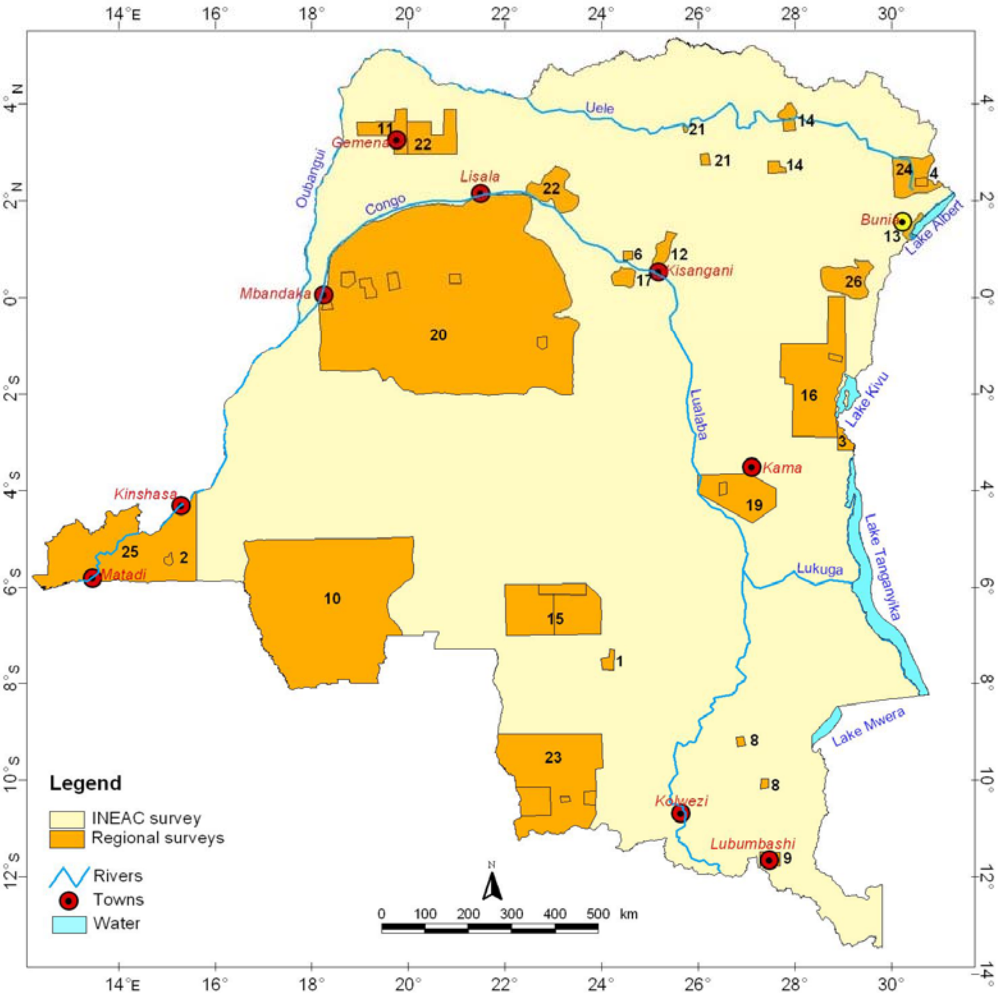

Figure 2. Location of soil surveys in DR of Congo (Source: Van Ranst *et al.* 2006)

Table 2. Details of soil maps of the DR of Congo

#	Name	Sheet	Scale 1 :	Year
1	Carte des Sols du Katanga	Kaniama	100,000	1948
2	Carte des Sols du Bas-Congo	Mvuazi	50,000	1949
3	Carte des Sols du Sud Kivu	Vallée de la Ruzizi	100,000	1950
4	Carte des Sols de la Province Orientale	Région de Nioka	50,000	1952
6	Carte des Sols de la Province Orientale	Yangambi	50,000	1953
8	Carte des Sols du Katanga	Vallée de la Lufira	100,000	1954
9	Carte des Sols du Katanga	Lubumbashi	60,000	1956
10	Carte des Sols de Bandundu	Kwango	100,000	1955
11	Carte des Sols de l'Equateur	Ubangi	100,000	1956
12	Carte des Sols de la Province Orientale	Bengamisa	100,000	1955
13	Carte des Sols de la Province Orientale	Région du Lac Albert	100,000	1952
14	Carte des Sols de la Province Orientale	Uele	100,000	1956
15	Carte des Sols des Deux Kasai's	Kasai	200,000	1958
16	Carte des Sols du Nord et Sud Kivu	Dorsale du Kivu	500,000	1957
	Carte morpho-pédologique de la plaine de Ruzizi		50,000	1992
17	Carte des Sols de la Province Orientale	Yanonge-Yatolema	100,000	1958
19	Carte des Sols de Maniema	Maniema	250,000	1960
20	Carte des Sols de l'Equateur	Tshuapa	100,000	1958
21	Carte des Sols de la Province Orientale	Uele-Babua	40,000	1956
22	Carte des Sols de l'Equateur	Ubangi	100,000	1968
23	Carte des Sols du Katanga	Zone de la Haute Lulua	200,000	1960
24	Carte des Sols la Province Orientale	Mahagi	200,000	1959
25	Carte des Sols du Bas Congo	Kinshasa	200,000	1991
		Inkisi	200,000	1991
		Luozi	200,000	1991
		Mbanza Ngungu	200,000	1991
		Kai Mabaku	200,000	1991
		Matadi	200,000	1991
		Banana	200,000	1991
		Tshela	200,000	1991
26	Carte des Sols du Nord Kivu	Nord Kivu et Lac Edward	200,000	1970

Appendix 2: Soil and relief maps of Rwanda

All soil maps are at scale 1:50,000 and have been published in 2000 by the Laboratory of Soil Science, Ghent University.

- Carte pédologique de Kagitumba, feuille 1 (ISBN 90-76769-01-X)
- Carte pédologique de Birunga, feuille 2 (ISBN 90-76769-02-8)
- Carte pédologique de Kirambo, feuille 3 (ISBN 90-76769-03-6)
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Appendix 3: Revised SOTER definition of landform

1st level	2nd level	gradient (%)	relief intensity (m km^{-2})	potential drainage density (PDD)
L level land	**LP** plain	<10	<50	0-25
	LL plateau	<10	<50	0-25
	LD depression	<10	<50	16-25
	LF low gradient footslope	<10	<50	0-10
	LV valley floor	<10	<50	6-15
S sloping land	**SE** medium-gradient escarpment zone	10-30	100-150	<6
	SH medium-gradient hill	10-30	100-150	0-15
	SM medium-gradient mountain	15-30	150-300	0-15
	SP dissected plain	10-30	50-100	0-15
	SV medium-gradient valley	10-30	100-150	6-15
T steep land	**TE** high-gradient escarpment zone	>30	150-300	<6
	TH high-gradient hill	>30	150-300	0-15
	TM high-gradient mountain	>30	>300	0-15
	TV high-gradient valley	>30	>150	6-15

Notes: PDD = potential drainage density is the number of ‘receiving’ pixels within a 10 by 10 pixels window.

Appendix 4: Revised SOTER definition of lithology

major class		group	type
I	igneous rock	**IA** acid igneous	**IA1** granite **IA2** quartz-diorite/grano-diorite **IA3** syenite **IA4** rhyolite, dacite
		II intermediate igneous	**II1** andesite, trachyte, phonolite **II2** diorite, diorite-syenite
		IB basic igneous	**IB1** gabbro **IB2** basalt **IB3** dolerite/diabase
		IU ultrabasic igneous	**IU1** peridotite **IU2** pyroxenite **IU3** ilmenite, magnetite, ironstone,
		IP pyroclastic	**IP1** tuff, tuffite **IP2** volcanic scoria/breccia **IP3** volcanic ash **IP4** ignimbrite
M	metamorphic rock	**MA** acid metamorphic	**MA1** quartzite **MA2** gneiss, migmatite, granulite **MA3** slate, phyllite **MA4** schist
		MB basic metamorphic	**MB1** slate, phyllite **MB2** (green)schist **MB3** gneiss rich in ferro-magnesian minerals **MB4** metamorphic limestone(marble) **MB5** amphibolite **MB6** eclogite
		MU ultrabasic metamorphic	**MU1** serpentine, greenstone

major class		group	type
S	sedimentary rock (consolidated)	**SC** clastic	**SC1** conglomerate, breccia
			SC2 sandstone, greywacke, arkose
			SC3 siltstone, mudstone, claystone
			SC4 shale
			SC5 ironstone
		SO organic	**SO1** limestone, other carbonate rocks
			SO2 marl and other mixtures
			SO3 coals, bitumen & related rocks
		SE evaporites	**SE1** anhydrite, gypsum
			SE2 halite
U	sedimentary rock (unconsolidated)	**UR** weathered residuum	**UR1** bauxite, laterite
		UF fluvial	**UF1** sand and gravel
			UF2 clay, silt and loam
		UL lacustrine	**UL1** sand
			UL2 silt and clay
		UM marine and estuarine	**UM1** sand
			UM2 clay and silt
		UC colluvial	**UC1** slope deposits
			UC2 lahar
		UE **a**eolian	**UE1** loess
			UE2 sands
		UG glacial	**UG1** morainic deposits
			UG2 glaciofluvial sands
			UG3 glaciofluvial gravel
		UO organic	**UO1** rainwater-fed moor peat
			UO2 groundwater-fed bog peat
		UA anthropogenic	**UA1** redeposited natural materials
			UA2 industrial/artisanal deposits
		UU unspecified	**UU1** unspecified sediments