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World Soil Information

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Front cover: Shoreline of Lake Malawi near Mbamba Bay in Tanzania (photo: J.A. Dijkshoorn).

ISRIC Report 2016/01

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Preface

ISRIC – World Soil Information has the mission to create and increase the awareness and understanding of the role of soil in major global issues. As an international institution, we inform a wide audience about the multiple roles of soils in our daily lives; this requires scientific analysis of sound soil information. In its capacity of World Data Centre for Soils, ISRIC is seeking collaboration with national institutions that provide soil resource inventories in order to build capacity and further develop world soil information services for the benefit of the international community.

This report presents and discusses the national Soil and Terrain (SOTER) database for the Republic of Malawi at scale 1:1 million. This GIS database may be used for a range of broad scale applications and assessments.

The SOTER programme was initiated in 1986 by the Food and Agricultural Organization of the United Nations, the United Nations Environment Programme and ISRIC under the aegis of the IUSS. Implementation was carried out in collaboration with national institutes. Under the programme, soil and terrain databases were compiled for Latin America and the Caribbean, Central and Eastern Europe, Southern Africa, Central Africa, as well as a number of specific countries. In 2008, these SOTER databases were incorporated in the Harmonized World Soil Database, a collaborative activity led by FAO, IIASA, ISRIC, JRC and ISCCAS. The newly developed SOTER database for Malawi may be considered in a future update of the HWSD product in the framework of the Global Soil Partnership.

Rik van den Bosch
Director, ISRIC – World Soil Information

Summary

This report describes the methodology that was used to compile the national Soil and Terrain (SOTER) database for the Republic of Malawi at scale 1:1,000,000. The GIS database provides generalized information on landform, parent material and soil conditions in digital format. The base information used to compile the database, including information on physiography, soils, agro-climate, land use and vegetation, was derived from the Land Resources Evaluation Project of the Food and Agriculture Organisation of the United Nations (Venema, 1990). Profile descriptions and soil analytical data were collected from Malawi's Agricultural Development Divisions by the Maize Commodity Team; a digital database was created for the advisory and extension work of the Department of Agricultural Research in Chitedze, Central Region (Benson, Nambuzi, & Ligowe, 1999). This database was cleaned and incorporated into the Africa Soil Profiles Database (Leenaars, 2012).

The soil map at scale 1:250,000 (Venema, 1990) provided the geographical basis for the SOTER map; representative soil profiles were mainly selected from the Africa Soil Profiles Database v1.0. All profiles are classified according to the World Reference Base for Soil Resources (IUSS Working Group WRB, 2007). For display purposes, all soil components are described according to the guidelines for small-scale map legends based on the World Reference Base for Soil Resources (IUSS Working Group WRB, 2010). To ensure consistency with earlier SOTER databases, the selected reference profiles are also characterised according to the Revised Legend of the Soil Map of the World (FAO, 1988).

The database contains 231 unique SOTER units, comprising 298 terrain components and 534 soil components. The SOTER units are linked to 327 polygons in the geometric database. The soil components are characterized by 379 profiles.

A total of 18 WRB Reference Soil Groups (RSG) were identified in Malawi. Lixisols are the dominant RSG, covering almost 26% of the country's land surface, followed by Luvisols with 22% and Cambisols with 18%. The remaining RSGs cover less than 10% of the Malawi territory. Among these are Gleysols, Leptosols, Fluvisols, Ferralsols and Phaeozems that together cover some 35% of the land surface.

The SOTER Malawi database can be used for broad-scale agro-environmental assessments such as estimation of soil organic carbon stocks, hydrological modelling, or crop modelling.

Keywords: Soil and terrain database, SOTER, soil map, natural resources, Malawi, World Reference Base, soil classification, WRB legend, soils, soil data, landform.

1 Introduction

Malawi is a land-locked country in south-eastern Africa bordering Mozambique, Zambia, Tanzania and Lake Malawi. It is situated between latitudes 9° and 18° S and longitudes 32° and 36° E. The country covers 118.484 km^2, of which approximately 20% is inland water of lake Malawi (Graphic Maps, 2012). The shape of the country follows roughly the Rift Valley; it is elongated in North-South direction and measures about 900 km in length with a width varying between 80 and 160 km from east to west. Shire River forms the outlet of Lake Malawi and flows about 400 km to connect the Southern end of Lake Malawi (457 m above sea level) to the Zambezi River in Mozambique. The Shire River leaves the country at the lowest point at 37 m a.s.l., while only 100 km north, Malawi's highest peak rises to 3000 m a.s.l. in the Mulanje Mountains. Most of the land is slightly rolling and plateau land with elevations between 900 m and 1250 m, alternated with hilly and mountainous land rising up to 2500 m. The country is divided into three regions (northern, central and southern) and counts 28 districts (see Appendix 1 and 2).

The dominant vegetation is Miombo woodland characterized by broadleaved *Brachystegia* species. It is relatively moist woodland that intergrades into savannah. In southern Malawi the relatively dry, broadleaved mopane woodland is more common, often intergrading into savannah vegetation.

Before the 1990's, many data on natural resources were collected in Malawi. These data, now called 'legacy-data', are typically still in paper format and are therefore not readily usable for present-day (digital) agro-environmental assessments. In the sixties, when Malawi was a British protectorate known as Nyasaland, a preliminarily national soil map at a scale of 1:2 million was developed (Young, 1960), followed by soil surveys of the Northern and Central regions at scales between 1:500,000 and 1:1,000,000 (Young & Brown, 1962), (Brown & Young, 1965). Including the additional soil surveys of the southern region (Stobbs, 1971), a Soil Map of Malawi at scale 1:1 million was published in 1983 (Lowole, 1983); the legend was based on the earlier soil surveys and related to the legend of the Soil Map of Africa at scale 1:5 million (d'Hoore, 1964). A year later, the Soil Map of Malawi at scale 1:1 million was updated, using the Legend of the Soil Map of the World (FAO-Unesco, 1974; FAO-Unesco, 1977). Some years later, the Legend of the Soil Map of the World was revised and extended (FAO, 1988) and a (draft) Soil Map of Malawi (1:1 million) based on this Revised Legend was compiled using data from FAO's Land Resources Evaluation Project (SADC, 1991). The Agricultural Development Divisions of Ministry of Agriculture published a final edition of the map in 1992 (MoA/UNDP/FAO, 1992).

The only digital source of soil information with national coverage currently available for Malawi is that held on the Harmonized World Soil Database (HWSD) (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012). For Malawi, the HWSD still relies on the FAO Digital Soil Map of the World (FAO, 1995). Currently, Malawi and Zambia are the only countries in Southern Africa for which updated information is lacking on the HWSD.

Developments in soil science made it necessary to extend and update the Revised Legend of the Soil Map of the World. The World Reference Base (WRB) for Soil Resources, a framework for soil classification, was created (IUSS Working Group WRB, 2007) which also provides guidelines for constructing small-scale map legends (IUSS Working Group WRB, 2010). The SOTER database of Malawi contains soil classifications according to the FAO Revised Legend as well as WRB.

2 Methods and materials

2.1 SOTER methodology

The SOTER Malawi database was developed in accordance with the SOTER procedures manual (van Engelen & Dijkshoorn, 2013). The SOTER mapping concept is based on relationships between physiography (landform), parent materials and soils. It identifies areas of land with a distinctive and often repetitive pattern of landform, parent material, terrain characteristics, and soils: the 'SOTER unit'. The SOTER methodology uses a stepwise approach, identifying major landforms or terrain units at its highest level. The terrain units are subdivided according to differences in parent material and terrain characteristics. These subdivisions are referred to as 'terrain components'. Terrain components can be further subdivided according to soil type. These subdivisions are referred to as 'soil components'. The map units created in such a way are called SOTER units and represent unique combinations of terrain and soil characteristics (Dijkshoorn, 2002; van Engelen & Dijkshoorn, 2013). An example of the spatial distribution of the SOTER units in their physiographic context is shown in Figure 1.

SOTER combines a geometric database with an attribute database. The geometric database stores information about the SOTER units' location, extent and topology. The attribute database stores information about the soil and terrain characteristics of each SOTER unit. A geographic information system (GIS) is used to manage the geometric database, whereas the attribute data are handled in a relational database environment (MS Access or PostGresql). A unique identifier, the SOTER-unit-ID (SUID), is used to link the attribute data to the spatial units. This enables generation of thematic soil and terrain maps from the database.

The SOTER attribute database consists of a series of relational tables that contain information about the characteristics of the terrain units, terrain components and soil components (Figure 2). The tables are linked through common identifiers. At the highest level of differentiation (i.e. terrain unit), landform and parent material characteristics are described. In each terrain unit, one or more terrain components are distinguished, based on differences in landform, topographical features or parent material. At the 1:1 million map scale, it is generally not possible to delineate the terrain components individually within the terrain units. In this case, the attributes of these non-mapable terrain components are only described in the attribute database. The final step in the differentiation of the terrain units is the identification of soil components within the terrain components. Soil components are usually also not mapable at 1:1 million scale and are, therefore, only described in the attribute database. The tabulated data of the SOTER unit, with its soil components, is comparable to a mapping unit with its soil legend.

Each soil component is characterized according to the Revised Legend of the Soil Map of the World (FAO, 1988), and, in case of SOTER Malawi, also according to the small-scale Map Legend of the WRB for Soil Resources (IUSS Working Group WRB, 2010). Further, a unique soil profile (PRID) is associated to each soil component to characterize the component. Detailed soil horizon characteristics are stored in the 'Representative horizon' table.

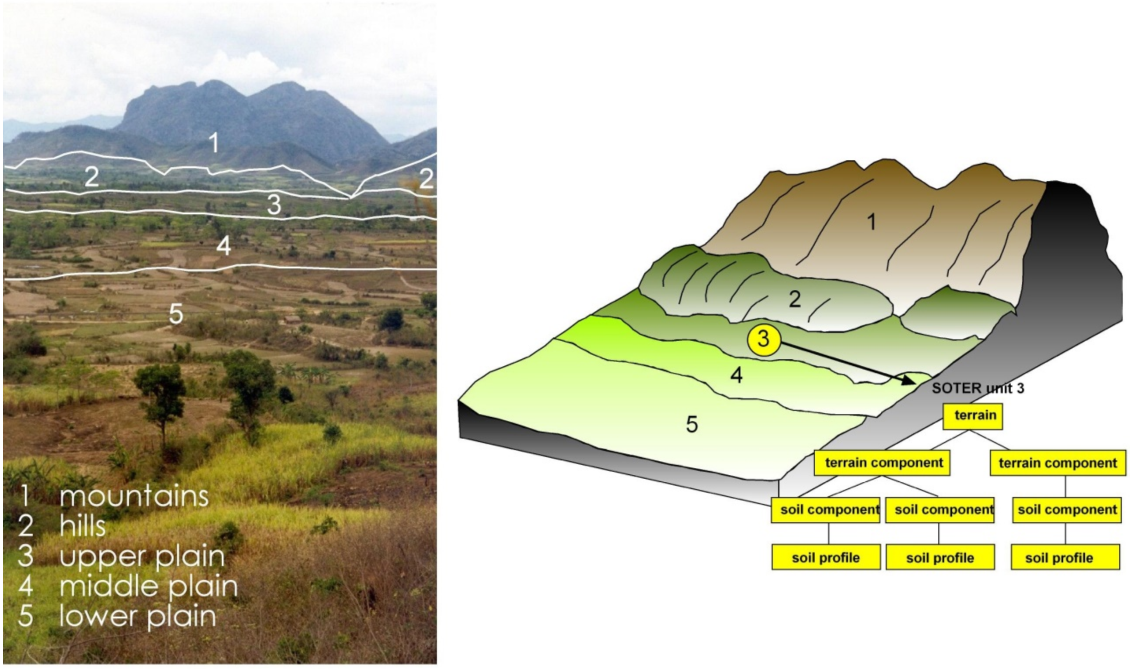


Figure 1
Representation of SOTER units and their database structure (van Engelen and Dijkshoorn, 2013).

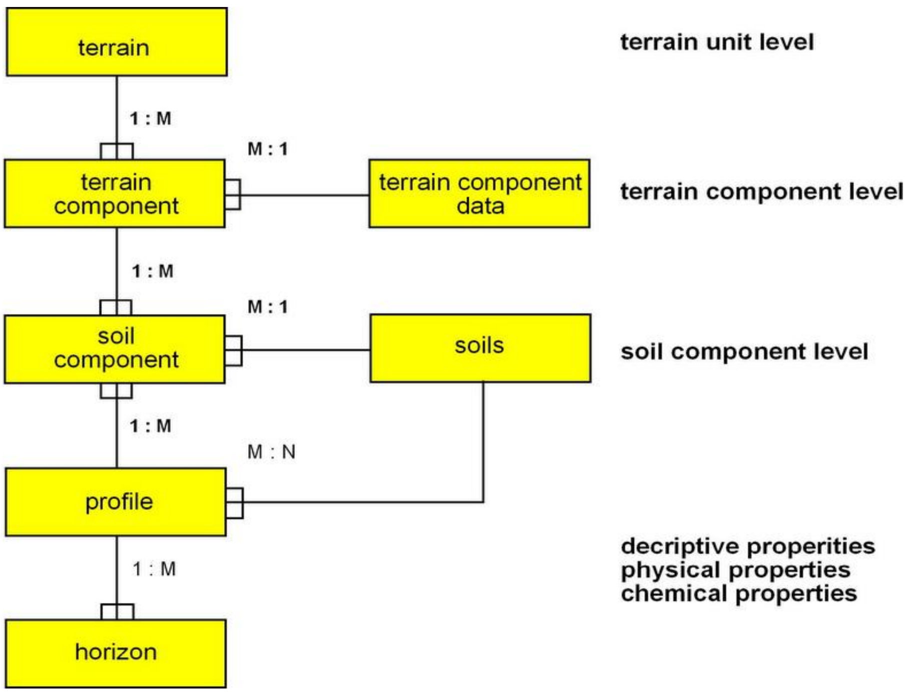


Figure 2
SOTER structure and the relation between the data storage tables (van Engelen and Dijkshoorn, 2013).

Terrain units, terrain components and soil components represent the spatial components within the database. Only the terrain units are usually represented in the geometric database and depicted on the SOTER map. This means that the terrain unit is identical to the SOTER unit. The coverage of the different terrain and soil components is accounted for as a percentage (proportion) of the SOTER unit in the database. For large scale SOTER databases (scale <1:500,000) terrain and soil components can be represented in the geometric database.

2.2 Soil and terrain data

This study draws on the soil and terrain data collected by the Land Resources Evaluation Project between 1989 and 1990 (Venema, 1990). In this project, emphasis was given to land evaluation and suitability appraisals of Malawi's potential agricultural land. Less attention was given at the time to proper data storage and archiving of all the collected soil information. The Project's field teams collected the soil profile data for each of the six Agricultural Development Divisions (ADD). In each ADD, a soil survey was executed. Information on landform and parent material was collected in the field. The profile morphology was described and soil horizons sampled for physical and chemical analysis. All selected profiles and their collected samples were properly coded with district and profile codes. The samples were send to the different laboratories for analysis, and the profile description sheets were kept in the ADD for further archiving in a soil database.

A soil map of Malawi at scale 1:250,000 was compiled by the Land Resources Evaluation Project under the aegis of Land Resources Conservation Department (MoA/UNDP/FAO, 1992), using the Revised Legend of the Soil Map of the World (FAO, 1988).

Only in later years, members of the Maize Commodity Team at Chitedze Agricultural Research Station completed the soil database (Benson, Nambuzi, & Ligowe, 1999). According to their information, data were entered directly from the original profile description sheets that were completed by the soil surveyors of the Land Resources Evaluation Project and complemented with analytical data from the laboratory sheets. Part of the field sheets and/or laboratory data could not be traced back. No profile description sheets were found for Ntcheu district and only a few for the Nkhata Bay, while 43 profiles in Ntcheu district had analytical data for more than one horizon and similarly 109 profiles for Nhkata Bay. These analytical data could not be used, because coordinates were not available as a result of missing profile descriptions sheets. Conversely, in Salima district, 88 profile descriptions were found, but without any analytical data. This makes the coverage with representative profiles somewhat unbalanced in a few districts. See also Appendix 1 and 2, for district names and the spatial distribution of the representative profiles for the SOTER database.

The Africa Soil Information Service[1] (AfSIS) project, that compiled legacy soil data for sub-Saharan Africa, has reformatted the data of the Maize Commodity Team for use in the Africa Soil Profiles (AfSP) database (Leenaars, 2012). The SOTER database is based on both: the digital data from the AfSP database, complemented with data from the original database. The latter were used to complete some descriptive field characteristics, for instance diagnostic horizons and diagnostic properties such as mottling. Five profiles were taken from other sources, principally from the National Resources Conservation Service soil profile database of Malawi (Soil Survey Division Staff, 1992).

[1] www.africasoils.net

The basis for the compilation of the SOTER map was the soil map of Malawi at scale 1:250,000 (MoA/UNDP/FAO, 1992) re-classified according to the Revised Legend. This map was complemented with soil boundary information from the provisional soil map at scale 1:1 million (SADC, 1991). The SRTM 90m Digital Elevation Database[2] was used to define the landform types of the SOTER units and to adjust their boundaries (Huting, Dijkshoorn, & van Engelen, 2008).

The standard coordinate system for all SOTER databases is the geographic system (WGS 1984). For area calculations, a projection is thus needed. For Malawi, WGS 1984 UTM 36 S(outh) was used with 0 Easting and Northing.

2.3 Quality control

As indicated, profile and horizon data were largely extracted from the AfSP database (Leenaars, 2012); additional descriptive profile and horizon data were taken from the soil profile database of Malawi (Benson, Nambuzi, & Ligowe, 1999). During processing, the inferred quality of the soil analytical data was checked. Where needed, seemingly unreliable data were discarded or corrected using expert rules. Such corrections mainly concerned CEC and exchangeable bases; details are provided in Appendix 1.

2.4 Map legends

As indicated, in accord with earlier releases of SOTER products, the soil components are classified according to the Revised Legend (FAO, 1988). However, in accord with the latest procedure manual (van Engelen and Dijkshoorn, 2013), the SOTER Malawi database also uses the small-scale Map Legend of the World Reference Base for Soil Resources (IUSS Working Group WRB, 2010). Both are given at soil component level so that these can be directly linked to the SOTER unit. The soil profiles selected as representative for the soil components of the SOTER unit should, however, first comply with the map unit characterization according to the Revised Legend (FAO, 1988), which is still used for the HWSD.

Each representative soil profile is fully classified according to the Revised Legend and the World Reference Base for Soil Resources. Both classifications are stored in the 'Profile' table.

[2] http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1

3 Results and discussion

3.1 SOTER database

The database contains 231 unique SOTER units, comprising 298 terrain components and 534 soil components. These units are linked to 327 polygons in the geometric database. The polygon map is presented at scale 1:1,000,000.

The soil components are characterized by 379 profiles of which four are virtual profiles (i.e. only the FAO and WRB classification are known). These represent Leptosols, each with a different qualifier at the soil unit level. In exploratory soil surveys, these shallow soils are usually not described and sampled. They are beforehand regarded as unsuitable for agriculture and are given little attention. Analytical data for Leptosols are, therefore, often lacking in soil databases while the associated information (of being shallow) can be highly relevant.

The 375 real profiles were selected as being regionally representative from a source databases that contained 830 profiles that had a more or less complete soil morphology description and soil analytical data. The spatial distribution of the reference profiles varies over the country and per district (Appendix 2).

Table 1 gives the content of the database in percentages of filled attributes. No or low percentages generally indicate that few or no measured data are available. However, it can also mean that the specific attribute is not very relevant for the type of soil, e.g. soluble salts in tropical highland soils.

Table 1
Overview of filled attribute proportions (%) of the SOTER database of Malawi.

Attributes of terrain table	%	Attributes of terrain table	%
1 ISO country code	100	7 median slope gradient	-
2 SOTER unit-ID	100	8 median relief intensity	-
3 year of data collection	100	9 major landform	100
4 map-ID	100	10 regional slope	100
5 minimum elevation	-	11 hypsometry	100
6 maximum elevation	-	12 general lithology	100
Attributes of terrain component table		**Attributes of terrain component table**	
13 terrain component number	100	19 texture of non-consolidated parent material	100
14 proportion of SOTER unit	100		
15 terrain component data-ID	100	20 depth to bedrock	1
16 dominant slope	100	21 surface drainage	100
17 length of slope	97	22 depth to groundwater	7
18 form of slope	45	23 frequency of flooding	98
19 surface parent material	100	24 duration of flooding	-
		25 start of flooding	-

Attributes of soil component table		Attributes of soil component table	
26 soil component number	100	34 position in terrain component	100
27 proportion of SOTER unit	100	35 surface rockiness	99
28 WRB-Legend	100	36 surface stoniness	99
29 WRB-Legend suffixes	-	37 types of erosion/deposition	80
30 Revised Legend (FAO'88)	100	38 area affected	-
31 phase FAO'88	17	39 degree of erosion	65
32 textural class topsoil	100	40 sensitivity to capping	13
33 profile-ID	100	41 rootable depth	100
Attributes of profile table		**Attributes of profile table**	
42 profile database-ID	99	51 vegetation	57
43 latitude	98	52 parent material	86
44 longitude	98	53 WRB (2006) soil group	100
45 elevation	31	54 WRB specifiers	-
46 description status	99	55 WRB version	100
47 sampling date	98	56 Revised Legend FAO'88	100
48 location status	98	57 national classification	-
49 drainage	99	58 Soil Taxonomy	1
50 land use	80	59 Soil Taxonomy version	1
Attributes of horizon table		**Attributes of horizon table**	
60 diagnostic horizon	43	89 bulk density	1
61 diagnostic property	23	90 water holding capacity	1
62 diagnostic material	11	91 pH H2O	73
63 horizon designation	99	92 electrical conductivity (1:x)	6
64 upper depth	100	93 pH KCl	1
65 lower depth	100	94 pH $CaCl_2$	1
66 distinctness of transition	59	95 electrical conductivity (sat. ext)	-
67 moist colour	88	96 soluble Na^+	-
68 dry colour	5	97 soluble Ca^{2+}	-
69 mottles –colour	8	98 soluble Mg^{2+}	-
70 mottles abundance	15	99 soluble K^+	-
71 mottles size	15	100 soluble Cl^-	-
72 grade of structure	83	101 soluble $SO4^{2-}$	-
73 size of structure elements	58	102 soluble $HCO3^-$	-
74 type of structure	83	103 soluble $CO3^{2-}$	-
75 nature mineral nodules	11	104 exchangeable Ca^{++}	60
76 abundance mineral nodules	11	105 exchangeable Mg^{++}	64
77 size concretion/mineral nodules	8	106 exchangeable Na^+	65
78 abundance coarse fragments	97	107 exchangeable K^+	65
79 size of coarse fragments	38	108 exchangeable Al^{3+}	6
80 very coarse sand	1	109 exchangeable acidity	-
81 coarse sand	1	110 CEC soil	66
82 medium sand	1	111 total carbonate equivalent	3
83 fine sand	1	112 gypsum	-
84 very fine sand	1	113 total carbon	1
85 total sand	65	114 organic carbon	60
86 silt	65	115 total nitrogen	47
87 clay	65	116 available P2O5	47
88 particle size class	90	117 phosphate retention	1
		118 Fe and Al extraction	1

For details see the SOTER Procedures manual (van Engelen and Dijkshoorn, 2013).

The minimum and maximum elevation, median slope gradient and relief intensity are not incorporated in Table 1; they were not calculated for this database, but can easily be obtained in a GIS.

The dominant landform, according to the SOTER landform criteria (van Engelen & Dijkshoorn, 2013), is shown in Table 2. A major part of Malawi (>40%) is classified as 'plain' with slopes of less than 10%, and about 10% is classified as dissected plain. Hills and ridges make up 13% of the territory, while inland water dominated by Lake Malawi covers one-fifth of the total area.

Table 2
Landform composition according to SOTER.

Landform	sq.km [3]	Proportion of area (%)
Low-gradient footslopes	2577	2.2
Plateau	2799	2.4
Plain	50050	42.4
Low gradient valley	878	0.7
Depression	1758	1.5
Hills and ridges	14869	12.6
Medium-gradient mountain	2864	2.4
Dissected plain	11566	9.8
Medium-gradient escarpment zone	740	0.6
High-gradient escarpment zone	1293	1.1
High-gradient hill	4290	3.6
High-gradient mountain	426	0.4
Lakes, inland water	23930	20.3
Total	117883	100

3.2 Soil unit distribution

A total of 18 WRB Reference Soil Groups (RSG) are identified in Malawi. Lixisols are the dominant RSG; they cover almost 26% of Malawi's land surface. Luvisols cover 22% and Cambisols 18%. The remaining RSGs each cover less than 10% each of Malawi's land surface; in combination, Gleysols, Leptosols, Fluvisols, Ferralsols and Phaeozems cover 25% of the land surface (Table 3).

According to the Revised Legend (FAO, 1988), Haplic Lixisols, with rudic and skeletic phases, are most extensive (19%), followed by Chromic Luvisols (9%) and Ferralic Cambisols (5%) (Appendix 3). In addition to the Ferralic Cambisols, seven other lower level units of the Cambisol soil group are distinguished; these include skeletic, lithic, phreatic, petroferric or salic members; for details see FAO (1988)

Appendix 4 gives the subdivision according to the small-scale Map Legend of the RSGs that uses the World Reference Base for Soil Resources up to the second map unit qualifier. Dominant soil units are Chromic (9%) and Rhodic (6%) Lixisols, Chromic Luvisols (8%), Chromic Paraleptic Luvisols (4 %), Eutric Gleysols (4%) and Eutric Leptosols (3.5%). Applying this small-scale Map Legend at second level qualifier (soil subunit level)

3 Digitizing errors and rounding have caused lower land and lake surface, and so a lower total of the national territory.

results in a much larger scatter of map units; most of these are smaller than 1%. For example, Cambisols are divided over 29 subunits, with only 3 units larger than 1%.

The small-scale Map Legend distinguishes several new WRB-RSGs that do not occur explicitly on the FAO Revised Legend. WRB-RSG 'Umbrisols', for example, were mostly considered to be Humic Cambisols (CMu) (Appendix 3). Similalry, Hydragic Anthrosols, soils developed under wet cultivation and found along the Malawi lakeshore in Karonga district (northern region), were grouped under Eutric Fluvisols in the Revised Legend.

Table 3
Estimated area and proportion of WRB Reference Soil Groups (RSG) in Malawi.

Reference Soil Groups	Area (km^2)	Percentage of the National Territory	Percentage of the Land Area
Acrisols	2449	2.1	2.6
Alisols	386	0.33	0.4
Arenosols	2135	1.8	2.3
Anthrosols	11	0.01	0.01
Cambisols	16633	14.1	17.7
Ferralsols	4024	3.4	4.3
Fluvisols	4767	4.0	5.1
Gleysols	5765	4.9	6.2
Leptosols	5163	4.4	5.5
Luvisols	20115	17.0	21.5
Lixisols	24169	20.5	25.8
Phaeozems	3876	3.3	4.1
Planosols	830	0.7	0.9
Plinthosols	111	0.1	0.1
Regosols	960	0.8	1.0
Solonetz	709	0.6	0.8
Umbrisols	307	0.3	0.3
Vertisols	1387	1.2	1.5
Lakes, inland water	23930	20.3	-
Total	117727	99.8	100

Lixisols, the largest RSG, is rather well distributed from north to south over the country and is not particularly concentrated in a certain region. The second largest RSG, Luvisols, occurs more frequently in the central region, while Cambisols are found frequently in the northern and southern regions (Figure 3).

Strongly weathered and leached soils, such as the Ferralsols and Acrisols are found on stable, old and often strongly undulating lands, such as the Nyaki and Viphya plateaus in the northern region. These soils also occur on the south slopes of the Mulanje Mountain massive in the southern region.

A relatively high percentage of Fluvisols, Gleysols, Vertisols, Planosols and Solonetz are found in the southern region. Their occurrence is related to present and former levels of Rift Valley lakes, such as Lake Malawi and Lake Chilwa, and to the sediments of the Shire River before joining the Zambezi River in Mozambique.

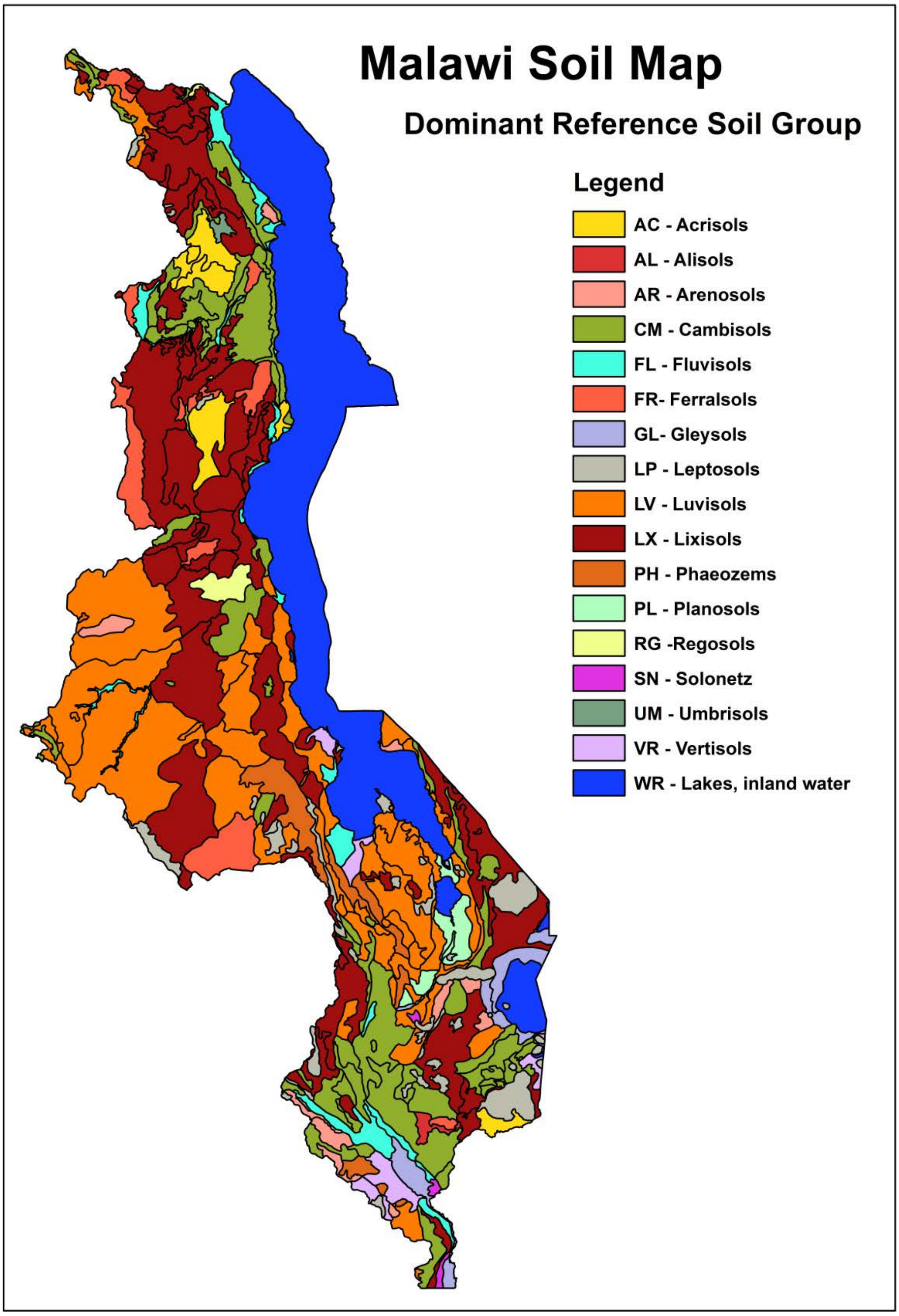


Figure 3
Soil map showing the dominant Reference Soil Groups according to SOTER.

3.3 Applications of the database

The SOTER Malawi database is meant for broad-scale (national level) agro-environmental applications. Examples include assessments of soil organic carbon stocks (Batjes, 2008; Batjes, 2014), hydrological modelling (Bossa *et al.*, 2012; Wösten *et al.*, 2013), land suitability evaluation (Zhang *et al.*, 2010), or crop modelling (Dobor *et al.*, 2016). The database may be considered in a future update of the HWSD product in the framework of the Global Soil Partnership. Malawi is one of the two countries in Southern Africa for which the HWSD still relies on the FAO Digital Soil Map of the World.

Table 1 shows that there are numerous gaps in the soil analytical data. Prior to any modelling, such gaps will have to be filled using consistent procedures, see for instance Batjes (2007) and Batjes *et al.* (2007).

SOTER is based on conventional soil mapping, implemented at a broad scale. In the future, digital soil mapping approaches may be used to refine this information to make the soil information suitable for use at sub-regional or local level. An example is the recently produced SoilGrids product for Africa (Hengl *et al.*, 2015), which consists of a set of gridded maps of key soil properties at 250-m spatial resolution.

4 Conclusions

The SOTER database for Malawi provides an updated GIS-based soil resource inventory with national coverage; in view of its 1:1 million scale, it is considered appropriate for broad scale agro-environmental applications. SOTER Malawi can be used to update the corresponding information on the HWSD, subject to gap filling.

The SOTER database of Malawi is the first SOTER database that contains soils classified according to the WRB for soil classification. For consistency with previous compiled SOTER databases, it also contains classification according to the Revised Legend of the Soil Map of the World (FAO, 1988). Use of the small-scale WRB Map Legend (IUSS Working Group WRB, 2010) for characterizing the SOTER units, applied to the first two prefix qualifiers as recommended for this scale, led to a high dispersion of soil (sub-)units within the RSGs. In our view, this is not very practical for application at the standard scale (1:1 million) adopted for most SOTER products.

Acknowledgement
The authors thank Jan Venema for his advice during compilation of the database.

References

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

Batjes, N.H., Al-Adamat,R., Bhattacharyya, T., Bernoux, M.M., Cerri, C.E.P., Gicheru, P., Kamoni, P., Milne, E.P., Pak, D.K., Rawajfih, Z. 2007. Preparation of consistent soil data sets for modelling purposes: Secondary SOTER data for four case study areas. Agriculture, Ecosystems and Environment 122(1), 26-34.

Batjes, N.H., 2008. Mapping soil carbon stocks of Central Africa using SOTER. Geoderma 146(1-2), 58-65.

Batjes, N.H., 2014. Projected changes in soil organic carbon stocks upon adoption of recommended soil and water conservation practices in the Upper Tana river catchment, Kenya. Land Degradation and Development 25(3), 278-287.

Benson, T., Nambuzi, S., & Ligowe, I.A. 1999. Malawi Soil Database. Chitedze, Central Region, Malawi.

Bossa, A.Y., Diekkrüger, B., Igué, A.M., Gaiser, T., 2012. Analyzing the effects of different soil databases on modeling of hydrological processes and sediment yield in Benin (West Africa). Geoderma 173-174, 61-74.

Brown, P., & Young, A. 1965. The physical environment off Central Malawi with special reference to soils and agriculture. Zomba: Government Printer.

Department of Surveys 1979. Malawi Vegetation and Biotic Communities (scale 1:1,000,000). Blantyre: Department of Surveys, Malawi Government.

Dobor, L., Barcza, Z., Hlásny, T., Árendás, T. Sptikó, T., Fodor, N. 2016. Crop planting data matters: Estimation methods and effects on future yields. Agricultural and Forest Meteorology 223, 103-115.

d'Hoore, J. 1964. Soil Map of Africa (scale 1:5,000,000). Lagos: Commission for Technical Cooperation in Africa.

Dijkshoorn, J. 2002. From soil map to digital land resources database; land resources inventories, SOTER and its applications. Revista de Ciencias Agrarias, XXV.

Eschweiler, J., Paris, S., Venema, J., Lorkeers, A., & Green, R. 1991. Methodology for land resouces survey and suitability appraisal. Malawi Government Ministry of Agriculture, Land Husbandry Branch/ United Nations Development Programme, Food and Agriculture Organisation of the United Nations. Lilongwe: UNDP/FAO.

FAO 1988. FAO/Unesco Soil Map of the World, Revised Legend, with corrections and updates. World soil Resources Report 60, FAO, Rome. Reprinted with updates as Technical Paper 20, ISRIC, wageningen, 1997.

FAO-Unesco 1974. Soil Map of the World, 1:5,000,000, Legend (Vol. Volume 1). Rome/Paris: Food and Agricultural Organisation of the United Nations and United Nations Educational, Scientific and Cultural Organisation.

FAO-Unesco 1977. Soil map of the world, 1: 5,000,000, Africa (Vol. Volume 6). Rome/Paris, Italy: Food and Agriculture Organisation of the United Nations and the United nations Educational, Scientific and Cultural Organisation.

FAO 1995. Digital Soil Map of the World and Derived Soil Properties (Version 3.5). FAO, Rome, Italy.

FAO/IIASA/ISRIC/ISS-CAS/JRC 2012. Harmonized World Soil Database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Graphic Maps 2012. Worldatlas, explore your world. (G. M.-M. Group, Producer) Retrieved 01 2014, from World Atlas: http://www.worldatlas.com

Hengl, T. Heuvelink, G.B.M., Kempen, B., Leenaars, J.G.B., Walsh, M.G., Shepherd, K.D., *et al.*, (2015). Mapping soil properties of Africa at 250 m resolution: Random forests significantly improve current predictions. PloS ONE 10(6): e0125814. doi:10.1371/journal.pone.0125814

Huting, J., Dijkshoorn, J., & van Engelen, V. 2008. GIS-procedures for mapping SOTER landform for LADA Partner countries. ISRIC - World soil Information. Wageningen: ISRIC-World Soil Information.

IUSS Working Group WRB 2010. Addendum to the World Reference Base for Soil Resources: Guidelines for constructing small-scale map legends using the World Reference Base for Soil Resources. FAO, Rome.

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

Leenaars, J.G.B. 2012. Africa Soil Profiles Database, Version 1.0. A compilation of georeferenced and standardized soil profile data for Sub-Sahara Africa (with dataset). ISRIC Report 2012/03. Africa Soil Information Service (AfSIS) project and ISRIC-World Soil Information, Wageningen, The Netherlands.

Lowole, M. 1983. Soil Map of Malawi (at a scale of 1:1:000,000). Lilongwe, Malawi: Soil Survey Section Kasungu, Dept. of Agtricultural Research.

MoA/UNDP/FAO 1992. Soils Map of Malawi (scale 1:250,000). (R. Green, Ed.) Lilongwe: Land Resources Conservation Department.

SADC 1991. Soil Map of Malawi (draft) with FAO-Unesco 1988 Revised Legend. Harare: Regional Inventory of Agricultural Resource Base.

Soil Survey Division Staff 1992. Profile database Malawi. National Resources Conservation Service. Lincoln, United States.

Stobbs, A. 1971. Malawi Natural Regions and Areas. Southern Malawi, (scale 1:1,000,000). Nyasaland Department of agriculture. Directorate of Overseas Surveys, British Government.

van Engelen, V.W.P., Dijkshoorn, J.A. 2013. Global and National Soils an Terrain Digital Database (SOTER). Procedures Manual Version 2.0, ISRIC - World Soil Information, Wageningen. van Engelen, V.W.P., Wen, T. (1995). Global and National Soil and Terrain Digital Database (SOTER) Procedures Manual,. ISRIC - World Soil Information. Wageningen: ISRIC.

Venema, J. 1990. Methods of description, classification and mapping of the physiography and soils of Malawi. Malawi Government, Ministry of Agriculture, Land Husbandry Branch/ United Nations Development Programme and Food and Agriculture Organisation of the United Nations. Lilongwe: UNDP/FAO.

Wösten, J.H.M., Verzandvoort, S.J.E., Leenaars, J.G.B., Hoogland, T., Wesseling, J.G., 2013. Soil hydraulic information for river basin studies in semi-arid regions. Geoderma 195–196, 79-86.

Young, A. 1960. A Preliminarily Soil Map of Nyasaland (at scale 1:2 million). Zomba, Malawi: The Government Printer.

Young, A., & Brown, P. 1962. The physical environment of Northern Nyasaland with special reference to soils and agriculture. Zomba: Government Printer, Malawi.

Zhang, G., Wu, Y., Zhao, Y., 2010. Physical suitability evaluation of reserve resources of cultivated land in China based on SOTER. Transactions of the Chinese Society of Agricultural Engineering 26(4), 1-8.

Appendix 1 Overview of Malawi districts, codes and number of soil profiles

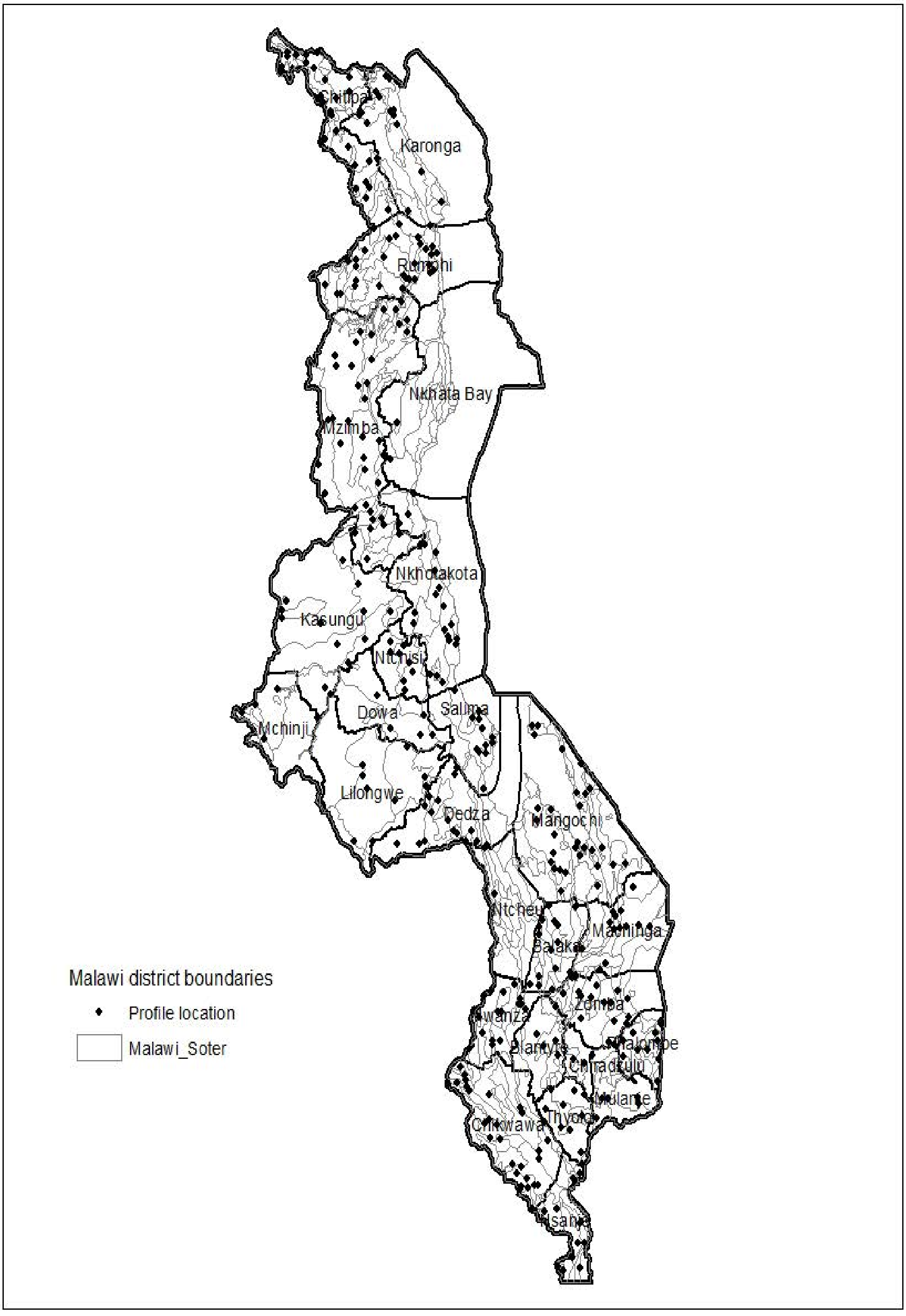
District	Old code	New code	Number of Profiles	CEC Exch. bases	Remarks
Balaka		BK	14	10[4]	Coded as Machinga (MHG)
Blantyre	Bt	BL	5	10	
Chikwawa	Ck	CK	26	10	Exchangeable Calcium discarded
Chiradzulu	Cr	CZ	2	10	
Chitipa	Ch/Ct	CP	29	original	
Dedza	De	DZ	18	original	
Dowa	Do	DA	5	original	
Karonga	Kr	KA	13	10	Some data of exchangeable cations unreliable, discarded
Kasungu	Kas/Ks	KU	13	original	
Lilongwe	Li	LL	7	original	
Machinga	Mc/Mch	MHG	14	10	
Mangochi	Ma	MH	29	10	Some data of exchangeable cations unreliable, discarded
Mchinji	Mj	MC	7	original	
Mulanje	Mu	MJ	6	10	
Mwanza	Mw	MW	16	10	Some data of exchangeable cations unreliable, discarded
Mzimba	Mz	MZ	40	original	
Nkhata Bay	Nk	NB	6	original	Only a few profile descriptions
Nkhotakota	Kk	KK	19		No chemical soil analyses
Nsanje	Ns	NE	12	10	
Ntcheu		NU	1	original	No profile descriptions found
Ntchisi	Ni	NS	8	original	
Phalombe		PE	11	10	Coded as Mulanje (MJ)
Rumphi	Ru	RU	32	original	
Salima	Sa	SA	12		No chemical soil analyses
Thyolo	Th	TO	11	10	
Zomba	Zo	ZA	16	10	

During the compilation of the AfSP database it was noted that the values for CEC and exchangeable cations were unrealistic high for many profiles, while other profiles showed values for these attributes in more realistic ranges. After closer examination, it appeared that the differences were linked to the different laboratories that analysed the soil samples. The CEC and exchangeable cations as reported by the laboratory of Chitedze Agricultural Research Station (Lilongwe) showed realistic values and these were considered adequate for

[4] The original laboratory data for cation exchange capacity (CEC) and the exchangeable cations were divided by a factor 10, when indicated.

inclusion in the AfSP and later the SOTER database. The data for CEC and exchangeable bases originating from the laboratory of Blantyre Agricultural Research Station were far too high. All values for CEC were assumed too high by a factor 10, and were therefore divided by a factor 10 before incorporation in the database. The values for the exchangeable bases have been entirely excluded from the AfSP database (because of inconsistencies with pH values), while these values were also assumed too high by a factor 10 and included in the SOTER database. This made almost all these values in line with expected values for these soils and so, acceptable in the database. However, a few profiles remained that still showed unrealistic high values for CEC and/or exchangeable cations; these attributes were discarded from these profiles. Also, unrealistic high exchangeable calcium values occurred in a number of profiles for a few districts (e.g. Chikwawa) that had normal values for the CEC; these deviating exchangeable calcium values were not entered in the database.

Appendix 2 Distribution of soil profiles



Appendix 3 Area of main soil units for Malawi (FAO 1988)

Revised Legend soil units	Revised Legend code	Area km^2	Area %[5]
Haplic Alisols	ALh	385.5	0.33
Ferric Acrisols	ACf	79.3	0.07
Haplic Acrisols	ACh	2369.3	2.01
Cambic Arenosols	ARb	399.9	0.34
Ferralic Arenosols	ARo	870.3	0.74
Luvic Arenosols	ARl	646.6	0.55
Gleyic Arenosols	ARg	99.0	0.08
Haplic Arenosols, incl. petroferric phase	ARh	119.2	0.10
Chromic Cambisols, incl. skeletic phase	CMx	4819.2	4.08
Calcaric Cambisols	CMc	682.8	0.58
Dystric Cambisols	CMd	298.8	0.25
Eutric Cambisols, incl. lithic, phreatic and skeletic phases	CMe	3493.5	2.96
Ferralic Cambisols, incl. skeletic and lithic phases	CMo	6170.5	5.23
Gleyic Cambisols, incl. petroferric ph.	CMg	570.9	0.48
Humic Cambisols, incl. lithic phase	CMu	306.5	0.26
Vertic Cambisols, incl. salic phase	CMv	596.8	0.51
Calcaric Fluvisols	FLc	175.5	0.15
Dystric Fluvisols	FLd	51.7	0.04
Eutric Fluvisols, incl. inundic, phreatic and sodic phases	Fle	4246.3	3.60
Mollic Fluvisols, incl. inundic phase	FLm	147.5	0.13
Salic Fluvisols, incl. sodic phase	Fls	156.7	0.13
Rhodic Ferralsols	FRr	1528.3	1.29
Xanthic Ferralsols	FRx	479.3	0.41
Humic Ferralsols	FRu	183.6	0.16
Haplic Ferralsols	FRh	1833.1	1.55
Eutric Gleysols, incl. inundic phase	GLe	5282.2	4.47
Mollic Gleysols	GLm	482.6	0.41
Dystric Leptosols	LPd	248.2	0.21
Eutric Leptosols	LPe	4213.4	3.57
Mollic Leptosols	LPm	95.8	0.08
Lithic Leptosols	LPq	605.7	0.51

5 % of total area

Revised Legend soil units	Revised Legend code	Area km^2	Area %[5]
Ferric Luvisols	LVf	1537.7	1.30
Gleyic Luvisols, incl. sodic and phreatic phases	LVg	1385.5	1.17
Stagnic Luvisols	LVj	251.3	0.21
Calcic Luvisols, incl. sodic phase	LVk	136.5	0.12
Vertic Luvisols	LVv	17.0	0.01
Chromic Luvisols	LVx	10717.0	9.08
Haplic Luvisols, incl. sodic phase	LVh	6069.5	5.14
Ferric Lixisols, incl. skeletic phase	LXf	674.1	0.57
Plintic Lixisols	LXp	154.3	0.13
Gleyic Lixisols	LXg	514.4	0.44
Haplic Lixisols, incl. rudic and skeletic phases	LXh	22826.1	19.34
Calcaric Phaeozems, incl. rudic phase	PHc	158.2	0.13
Luvic Phaeozems, incl. rudic, sodic and petroferric phases	PHl	2236.1	1.89
Gleyic Phaeozems	PHg	73.4	0.06
Stagnic Phaeozems	PHj	252.0	0.21
Haplic Phaeozems, incl. rudic, lithic and skeletic phases	PHh	1156.6	0.98
Eutric Planosols, incl. sodic phase	PLe	830.1	0.70
Eutric Plinthosols, incl. petroferric phase	PTe	111.2	0.09
Calcaric Regosols	RGc	134.2	0.11
Eutric Regosols, incl. lithic phase	RGe	825.3	0.70
Calcic Solonetz	SNk	368.7	0.31
Stagnic Solonetz	SNj	43.3	0.04
Haplic Solonetz	SNh	297.4	0.25
Eutric Vertisols	VRe	809.9	0.69
Calcic Vertisols	VRk	576.6	0.49
Lakes, inland water		23929.8	20.27
Total		117724	99.7

Appendix 4 Area of soil units for Malawi according to the small-scale Map Legend of the WRB for Soil Resources

Legend units for soils (WRB)	WRB map Legend code	Area km^2	Area %
Chromic Alisols	ALcr	139.4	0.12
Chromic Humic Alisols	ALhu.cr	246.1	0.21
Alisols		**385.5**	**0.33**
Chromic Acrisols	ACcr	208.0	0.18
Chromic Humic Acrisols	AChu.cr	1300.0	1.10
Rhodic Humic Acrisols	AChu.ro	418.5	0.35
Rhodic Acrisol,	ACro	302.7	0.26
Rhodic Ferric Acrisols	ACfr.ro	79.3	0.07
Haplic Acrisols	ACha	140.1	0.12
Acrisols		**2448.6**	**2.08**
Brunic Arenosols	ARbr	25.6	0.02
Brunic Hypoluvic Arenosols	ARwl.br	140.5	0.12
Brunic Ferralic Arenosols	ARfl.br	102.4	0.09
Endogleyic Hypoluvic Arenosols	ARwl.ng	23.9	0.02
Gleyic Arenosols	ARgl	75.1	0.06
Hypoluvic Ferralic Arenosols	ARfl.wl	654.8	0.55
Hypoluvic Arenosols	ARwl	309.2	0.26
Rubic Ferralic Arenosols	ARfl.ru	90.2	0.08
Eutric Ferralic Arenosols	ARfl.eu	301.2	0.26
Eutric Arenosols	AReu	118.1	0.10
Dystric Pisoplinthic Arenosols	ARpx.dy	105.8	0.09
Dystric Ferralic Arenosols	ARfl.dy	105.8	0.09
Dystric Arenosol	ARdy	82.3	0.07
Arenosols		**2134.9**	**1.81**
Eutric Hydragic Anthrosols	AThg.eu	10.9	0.01
Anthrosols		**10.9**	**0.01**
Calcaric Cambisols	CMca	255.0	0.22
Calcaric Paraleptic Cambisols	CMler.ca	326.6	0.28
Calcaric Sodic Cambisols	CMso.ca	101.2	0.09
Chromic Cambisols,	CMcr	202.9	0.17
Chromic (Endo)Skeletic Cambisols	CMsk(n).cr	766.9	0.65
Chromic Paraleptic Cambisols	CMler.cr	4454.7	3.77
Chromic Leptic Cambisols	CMle.cr	165.6	0.14
Chromic Ferralic Cambisols	CMfl.cr	1864.2	1.58
Dystric Cambisols	CMdy	134.3	0.11
Dystric Rhodic Cambisols	CMro.dy	164.5	0.14
Epidystric Ferralic Cambisols	CMdyp.fl	97.3	0.08
Eutric Cambisols	CMeu	1017.1	0.86

Legend units for soils (WRB)	WRB map Legend code	Area km^2	Area %
Eutric Chromic Cambisols	CMcr.eu	138.8	0.12
Eutric Ferralic Cambisols	CMfl.eu	1025.6	0.87
Eutric Paraleptic Cambisols	CMler.eu	542.8	0.46
Eutric Ferric Cambisols	CMfr.eu	94.7	0.08
Eutric Skeletic Cambisols	CMsk.eu	449.2	0.38
Eutric Stagnic Cambisols	CMst.eu	56.0	0.05
Paraleptic Cambisols	CMler	209.2	0.18
Ferralic Cambisols	CMfl	147.6	0.13
Ferralic Skeletic Cambisols	CMsk.fl	350.9	0.30
Ferralic Paraleptic Cambisols	CMler.fl	1576.6	1.34
Ferralic Leptic Cambisols	CMle.fl	794.8	0.67
Rhodic Ferralic Cambisols	CMfl.ro	528.3	0.45
Gleyic Cambisols	CMgl	309.7	0.26
Ferric Endogleyic Cambisols	CMgln.fr	227.5	0.19
Ferralic Endogleyic Cambisols	CMgln.fl	33.7	0.03
Salic Vertic Cambisols	CMvr.sz	301.2	0.26
Fluvic Vertic Cambisols	CMvr.fv	200.9	0.17
Vertic Paraleptic Cambisols	CMler.vr	94.6	0.08
Cambisols		**16632.5**	**14.11**
Calcaric Fluvisols	FLca	55.5	0.05
Calcaric Gleyic Fluvisols	FLgl.ca	72.9	0.06
Calcaric Vertic Fluvisols	FLvr.ca	47.1	0.04
Eutric Fluvisols	FLeu	1945.1	1.65
Eutric Gleyic Fluvisols	FLgl.eu	1437.3	1.22
Vertic Gleyic Fluvisols	Flgl.vr	56.7	0.05
Gleyic Fluvisols	FLgl	492.3	0.42
(Eutric) Vertic Fluvisols	FLvr.eu	119.5	0.10
Hyposodic Fluvisols	FLwn	184.5	0.16
Mollic Fluvisols	FLmo	63.1	0.05
Mollic Gleyic Fluvisols	FLgl.mo	84.5	0.07
Gleyic Salic Fluvisols	FLsa.gl	156.7	0.13
Dystric Fluvisols	FLdy	51.7	0.04
Fluvisols		**4766.9**	**4.04**
Rhodic Ferralsols	FRro	44.8	0.04
Rhodic Umbric Ferralsols	FRum.ro	84.1	0.07
Rhodic Acric Ferralsols	FRac.ro	107.8	0.09
Rhodic Acric Umbric Ferralsols	FRum.ac.ro	234.9	0.20
Rhodic Lixic Ferralsols	FRlx.ro	120.1	0.10
Rhodic Lixic Umbric Ferralsols	FRum.lx.ro	234.1	0.20
Lixic Ferralsols	FRlx	755.0	0.64
Humic Lixic Ferralsols	FRlx.hu	43.9	0.04
Humic Acric Ferralsols	FRac	252.4	0.21
Humic Umbric Ferralsols	FRum.hu	118.4	0.10
Acric Umbric Ferralsols	FRum.ac	65.1	0.06
Mollic Ferralsols	FRmo	1382.4	1.17
Xanthic Ferralsols	FRxa	154.0	0.13
Xanthic Lixic Ferralsols	FRlx.xa	325.3	0.28
Haplic Ferralsols	FRha	101.9	0.09
Ferralsols		**4024.2**	**3.42**

Legend units for soils (WRB)	WRB map Legend code	Area km^2	Area %
Eutric Gleysols	GLeu	4643.4	3.93
Eutric (Epi)Arenic Gleysols	GLar.eu	278.7	0.24
Molic Gleysols	GLmo	482.6	0.41
Hyposodic Gleysols	GLwn	360.1	0.31
Gleysols		**5764.8**	**4.89**
Dystric Leptosols	LPdy	248.2	0.21
Eutric Leptosols	LPeu	4161.5	3.53
Eutric Skeletic Leptosols	LPsk.eu	28.5	0.02
Umbric Leptosols	LPum	23.4	0.02
Mollic Leptosols	LPmo	83.7	0.07
Calcaric Mollic Leptosols	LPmo.ca	12.1	0.01
Lithic Leptosols	LPli	605.7	0.51
Leptosols		**5163.1**	**4.37**
Ferric Luvisols	LVfr	296.1	0.25
Manganiferric Luvisols	LVmf	827.2	0.70
Chromic Ferric Luvisols	LVfr.cr	553.9	0.47
Ferric (Endo)Gleyic Luvisols	LVng.fr	358.6	0.30
Gleyic Luvisols	LVgl	51.3	0.04
Vertic Gleyic Luvisols (Hyposodic))	LVgl.vr(wn)	1271.4	1.08
Stagnic Luvisols	LVst	251.3	0.21
Arenic Luvisols	LVar	1311.2	1.11
Endoskeletic Luvisols	LVskn	174.4	0.15
Chromic Endoskeletic Luvisols	LVskn.cr	530.9	0.45
Chromic Luvisols	LVcr	9168.0	7.77
Chromic Vertic Luvisols	LVvr.cr	17.0	0.01
Chromic Paraleptic Luvisols	LVler.cr	619.5	0.52
Chromic Leptic Luvisols	LVle.cr	30.5	0.03
Rhodic Luvisols	LVro	2712.0	2.30
Rhodic Paraleptic Luvisols	LVler.ro	246.1	0.21
Calcic Hyposodic Luvisols	LVwn.cc	136.5	0.12
Haplic Luvisols	LVha	1558.7	1.32
Luvisols		**20114.6**	**17.04**
Arenic Lixisols	LXar	39.1	0.03
Chromic Lixisols	LXcr	10406.2	8.82
Chromic Ferric Lixisols	LXfr.cr	398.5	0.34
Chromic Endoskeletic Lixisols	LXskn.cr	576.9	0.49
Chromic Paraleptic Lixisols	LXler.cr	1476.2	1.25
Chromic Plinthic Lixisols	LXpl.cr	154.3	0.13
Gleyic Lixisols	LXgl	514.4	0.44
Manganiferric Lixisols	LXmf	81.7	0.07
Manganiferric Skeletic Lixisols	LXsk.mf	193.8	0.16
Rhodic Lixisols	LXro	7350.5	6.23
Rhodic Endoskeleitic Lixisols	LXskn.ro	669.4	0.57
Rhodic Endoleptic Lixisols	LXnl.ro	448.0	0.38
Rhodic Paraleptic Lixisols	LXler.ro	899.5	0.76
Haplic Lixisols	LXha	960.4	0.81
Lixisols		**24168.9**	**20.48**

Legend units for soils (WRB)	WRB map Legend code	Area km^2	Area %
Calcaric Paraleptic Phaeozems	PHler.ca	158.2	0.13
Calcaric Luvic Phaeozems	PHlv.ca	176.7	0.15
Chromic Luvic Phaeozems	PHlv.cr	18.6	0.02
Luvic Phaeozems	PHlv	1419.2	1.20
Luvic Paraleptic Phaeozems	PHler.lv	621.6	0.53
Luvic Stagnic Phaeozems	PHst.lv	252.0	0.21
Gleyic Phaeozems	PHgl	73.4	0.06
Leptic Phaeozems	PHle	130.3	0.11
Paraleptic Phaeozems	PHler	44.8	0.04
Skeletic Paraleptic Phaeozems	PHler.sk	59.4	0.05
Skeletic Phaeozems	PHsk	868.7	0.74
Haplic Phaeozems	PHha	53.4	0.05
Phaeozems		**3876.3**	**3.29**
Luvic Solodic Planosols	PLsc.lv	670.6	0.57
Vertic Luvic Planosols	PLlv.vr	159.5	0.14
Planosols		830.1	0.71
Eutric Petric Plinthosols	PTpt.eu	111.2	0.09
Plinthosols		**111.2**	**0.09**
Calcaric Paraleptic Regosols	RGler.ca	134.2	0.11
Eutric Paraleptic Regosols	RGler.eu	65.7	0.06
Eutric Leptic Regosols	RGle.eu	346.2	0.29
Epileptic Regosols	RGel	413.3	0.35
Regosols		**959.4**	**0.81**
Calcic Solonetz	SNcc	105.3	0.09
Calcic Vertic Solonetz	SNvr.cc	263.4	0.22
Stagnic Solonetz	SNst	43.3	0.04
Salic Gleyic Solonetz	SNgl.sz	231.5	0.20
Haplic Solonetz	SNha	65.8	0.06
Solonetz		**709.3**	**0.61**
Calcic Sodic Vertisols	VRso.cc	286.8	0.24
Calcic Hyposodic Vertisols	VRwn.cc	123.0	0.10
Hyposodic Vertisols	VRwn	281.3	0.24
Pellic Hyposodic Vertisols	Vrwn.pe	182.9	0.15
Pellic Sodic Vertisols	VRso.pe	110.1	0.09
Pellic Vertisols	VRpe	366.0	0.31
Mazic Vertisols	VRmz	36.4	0.03
Vertisols		**1386.5**	**1.16**
Mollic Umbrisols	UMmo	71.5	0.06
Paraleptic Umbrisols	UMler	125.5	0.11
Cambic Ferralic Umbrisols	UMfl.cm	109.4	0.09
Umbrisols		**306.4**	**0.26**
Lakes, inland water		23929.8	20.27
Total		117723	99.8

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