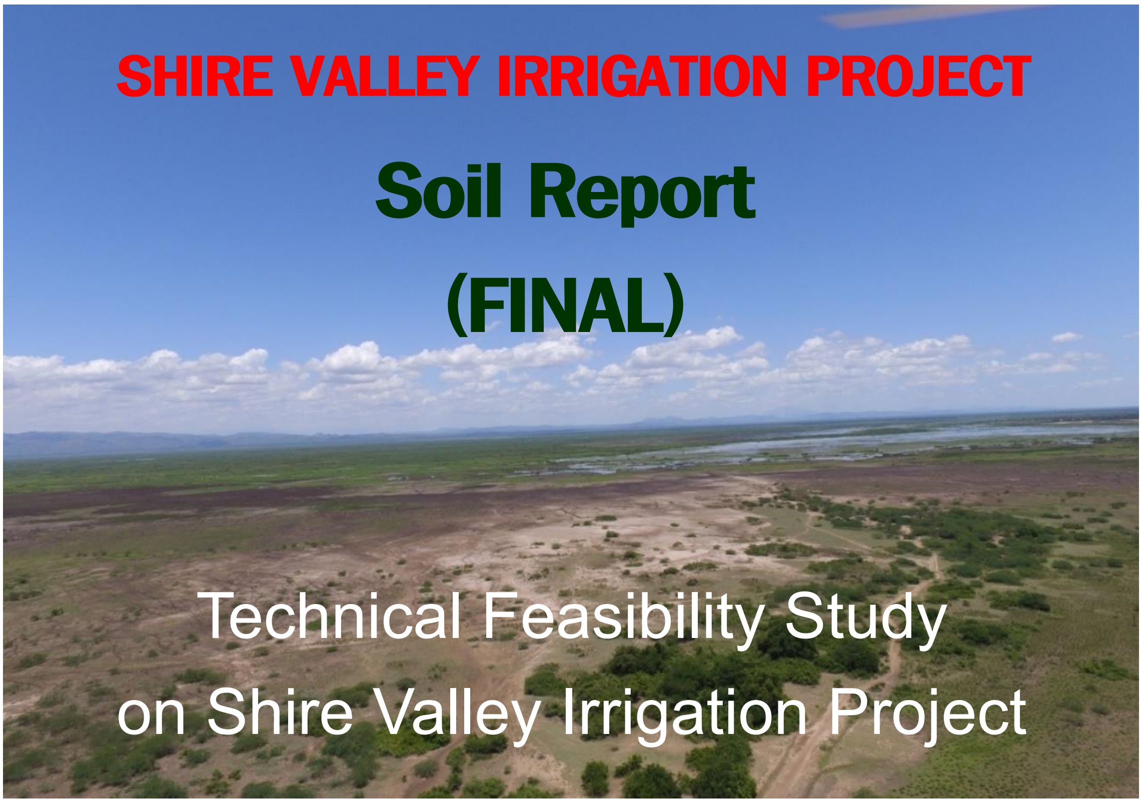
GOVERNMENT OF MALAWI

MINISTRY OF AGRICULTURE, IRRIGATION AND WATER DEVELOPMENT



SHIRE VALLEY IRRIGATION PROJECT

Soil Report

(FINAL)

Technical Feasibility Study
on Shire Valley Irrigation Project

December 2016

KOREA RURAL COMMUNITY CORPORATION

in Joint Venture with

DASAN CONSULTANTS CO., LTD.,

GK WORKS CIVIL AND STRUCTURAL ENGINEER

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SUMMARY

- ✧ Study area administratively belonging to Chikwawa and Nsanje Distiricts is approximately 55,500 ha.
- ✧ In order to determine soil characteristics and classify soil types, field surveys and soil analyses were carried out with reference to soil databases, CODA Report and commercial sugar farm data. Field soil investigations were conducted at 1,050 points and 1,003 soil samples were taken for further analysis.
- ✧ There are 11 RSGs in the Estates and 5 in the other part of SVIP Zones. Fourteen principle and 9 supplementary qualifiers are applied in the second level classification of RSGs and 218 soil types are classified.
- ✧ Soil erosion, flooding and ponding, poor drainage, heavy clayey or sandy texture, high levels of rock content on surface and/or subsoil, hard consistency, salinity and/or sodicity, low fertility could be suggested as vital soil and terrain limiting factors.
  - There are depressions (1,399 ha) and floodplains (2,601 ha) scattered in SVIP Zones.
  - Imperfectly or poorly-drained soils (16,146 ha) can lead to poor upland crop yield due to root respiration hindrance and toxic reductants.
  - Arenosols (1,711 ha) are soils too sandy to hold enough water to grow crops, whereas Vertisols (12,151 ha) and Vertic Luvisols (1,500 ha) are excessively clayey and could be disadvantageous for tillage and drainage.
  - Dominant (>80%) or abundant (40-80%) gravels and/or stones are contained through or in the layers within 100 cm from the surface in the area of approximately 1,500 ha.
  - Saline and/or sodic soils occupy approximately 10% of Phase I zones (2,400 ha). The percentage of them in the entire SVIP area increases up to around 20% (11,000 ha).
- ✧ By use of topsoil texture data and soil water deficit values by soil texture, the total readily available water within 30 cm from the surface within the soil survey area was determined to be approximately four million tonnes.
- ✧ There are 24 map codes in SVIP Zones. 1Hcs (Rain-fed Herbaceous Crops with Small Sized Fields) occupies the greatest area of 21,125 ha (38%) and followed by 1SC (Sugarcane - Irrigated Herbaceous Crop(s)) over 16,992 ha (31%), 1Hcs/2TO (Rain-fed Herbaceous Crops(s) Small (< 2ha)/Woodland Open General (15-65%)

with Herbaceous Layer) over 3,938 ha (3%), and 1Hcs+2Ts (Rain-fed Herbaceous Crops(s) - Small Field(s) (< 2ha) with a layer of Sparse Trees) over 3,659 ha (3%).

✧ Eight crops, including sugarcane in Estates, were conprehensively being cultivated in the fields during the present soil investigations. Sorghum and cotton were being grown under rain-fed traditional management at 137 out of 258 sites followed by cotton at 38 sites. Cereal crops such as sorghum, bulrush millet, maize, and rice were widely planted in single or mixed stands for subsistence production.

✧ 533 land units covering 36,771 ha in the soil survey area, except Estates, have been evaluated by use of ALES program. 67 land use types with a combination of managements, (inputs) and crops, have been selected. Nine land qualities were determined through an inventory of relevant 22 land characteristics, which are attributes that can be measured or estimated. Due to unavailability of recent cropping data collected for SVIP, crop characteristics in the 1991 FAO Report were very usefully applied and modified for setting LURs in the present evaluation.

Comparing the land suitability classes of 15 crops through five models and averaging the areas of each class, maize (long cycle varieties) and rice, paddy, are found to have the highest percentage of N against the other crops: 90% and 92%, respectively. On the other hand, the crops with over 20% of (S1+S1/S2+S2) are bulrush millet, cotton, cashew, groundnots (short cycle and long cycle varieties), sorghum and sunflower. However the areas which are not suitable for some crops could be suitable for other crops. Therefore there is no area which is not suitable for any crop.

✧ Unsuitable land units, for instance, lots of lower clayey imperfectly to very poorly-drained ones in Zone C are disadvantageous for cultivation. Therefore, some additional measures such as soil amendments to improve soil properties, and site-specific irrigation/drainage plans, are necessary for them to be cultivated better.

The Saline and/or Sodic areas are largely distributed in areas of Kasinthula, Alumenda and Kaombe both of Illovo. TFS Consultant investigated ways of managing the soil properties of these areas, and they are summarized as below:

✧ Improving drainage: Deeper drainage channel system applied including subsurface drains

✧ Applying gypsum: In the early stage of the scheme soil shall be ploughed applying with gypsum (1 ~ 2 ton/ha) (The required cost for 8,000 ha will be about 1.5 million USD.)

✧ Using acid fertilizers (Ammonium Sulphate) to improve soil property

- ✧ Plating tolerant crops such as sun hemp, velvet beans, etc.

ACKNOWLEDGEMENTS

Soil field investigations might not have been completed successfulty in the short period without ardent soil survey team members. I would like to thank especially Dr.Fandika, Mr. Nyrienda, Mr. Chisale, Mr. Kakwiwa, and Mr. Kumwenda with KARS for their devoted efforts to do good soil surveys.

Besides, Dr. Phiri and some technicians including Mr. Sonjera with BARS did their best to analyze soil samples. Mr. Lee gave me a big hand to arrange and process lots of data to make out this soil report.

Hopefully, this humble report will contribute to make a best plan of SVIP and finally to support the kind Malawian farmers in Chikawa and Nsanje to live a happy life.

Deajeon, ROK, December 2016

Myoungho Shin

Korea Rural Community Corporation

List of Acronyms and Abbreviations

AWC	Available water capacity
BARS	Bvumbwe Agricultural Research Station
BD	Bulk density
BS	Base saturation
CEC	Cation exchange capacity
EC	Electrical conductivity
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization
GIS	Geographical information system
HWSD	Harmonized World Soil Database
ICIM	Irrigated cultivation under improved traditional management
ICMM	Irrigated cultivation under modern management
ICTM	Irrigated cultivation under traditional management
KARS	Kasinthula Agricultural Research Station
KRC	Korea Rural Community Corporation
LARS	Lunyangwa Agricultural Research Station
LU	Land unit
LUR	Land use requirement
LUT	Land use types
MSO	Mzuzu Surveys Office
OC	Organic carbon
pH	Soil reaction
RAW	Readily available water
RCTM	Rain-fed cultivation under traditional management
RITM	Rain-fed cultivation under improved traditional management
RSG	Reference soil group
SAR	Sodium absorption ratio
SU	Soil unit
TRAM	Total readily available moisture
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USDA	United States Department of Agriculture
WRB	World Reference Base for Soil Resources

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I. INTRODUCTION

The pre-feasibility report on SVIP by AWFproposed to develop approximately 42,500 ha for irrigation in two phases (Phase I and II), based on taking irrigation water from the Shire River and conveying by gravity to the irrigable area mainly through open canals. Besides, the study has recommended that further studies are necessary in order to produce a comprehensive set of information required by the GoM as well as potential donor partners to produce a bankable project.

Soil survey is a vital field of the present detailed feasibility study covering two major activities of assisting the Governmental policy-making process and preparing the preliminary design to assess the feasibility of project. Practically, it intends to provide viable assistance for the whole project and related fields such as hydrology, irrigation, agronomy, and GIS as well through mutual close cooperation and interaction as illustrated in Figure 1.

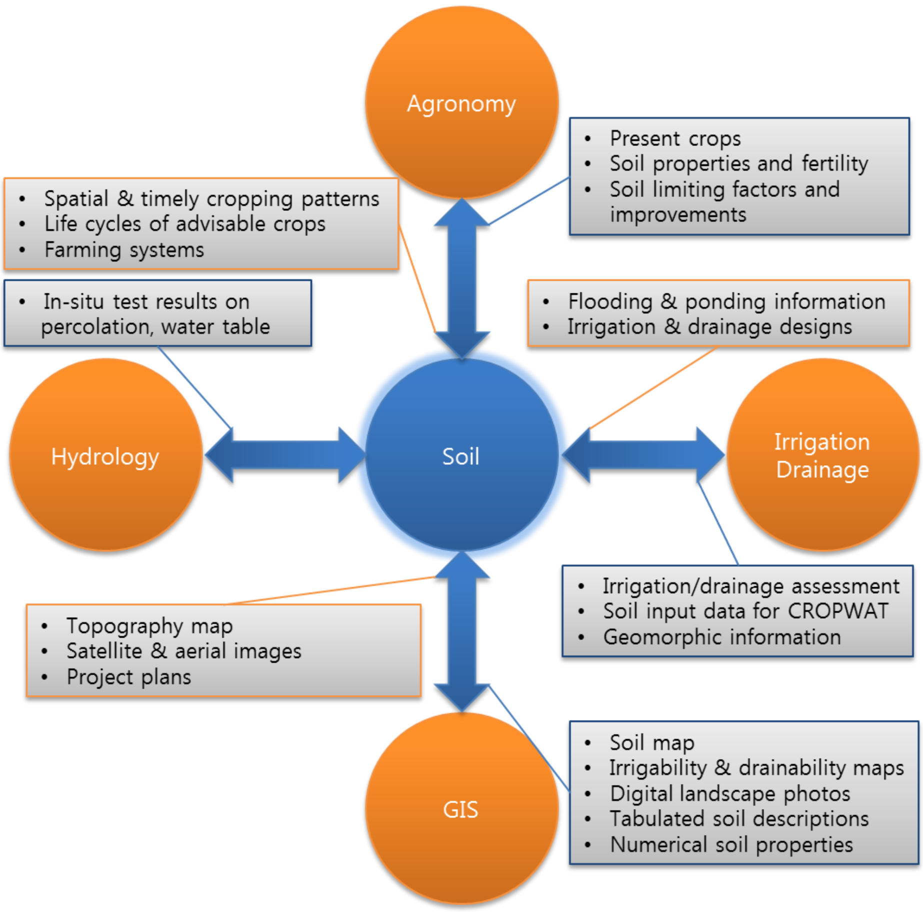

Figure 1. Schematic multi-disciplinarycollaboration for SVIP.

Soil survey has four critical goals to accomplish in the present irrigation project.

- To carry out high intensity soil surveys to update the existing ones

- To set up a standard land classification system for irrigability and drainability assessment
- To collect and analyze soil samples required for soil properties determination
- To prepare soil and land suitability maps for cropping options

Considering the four goals, soil survey in the present project is planned to be executed through four steps; preparation, field investigation, soil analysis, and land evaluation.The main steps of field investigation and soil analysis were undertaken during the period of October 2015 to February 2016 and the latest land evaluation has been carried out during the whole project period culminating in the final soil classification, land use and cropping patterns, drainability and irrigability.

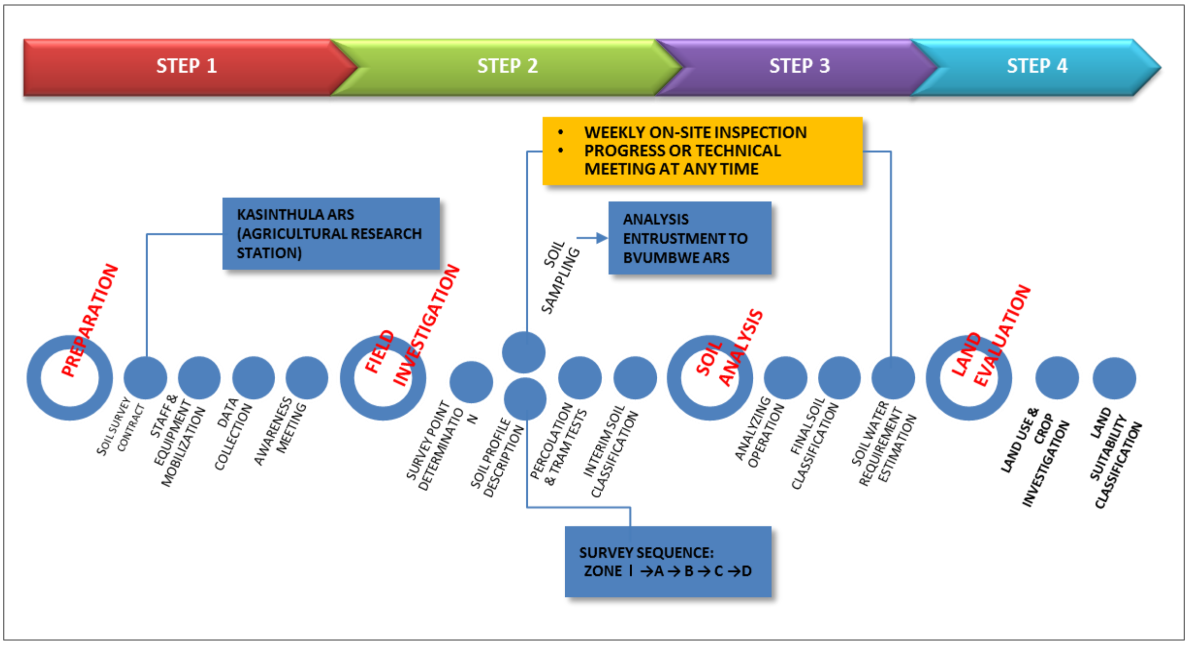

Figure 2. Diagram of the whole soil survey process.

II. SOIL

1. Methodology

1.1. Survey preparation

In order to effectively carry out soil survey in a short period, a joint-survey contract was reciprocally made between the SVIP Consultancy in Blantyre and Kasinthula Agricultural Research Station (KARS) in Chikwawa late October of 2015.

Soil surveyors specialized in soil science, agronomy, irrigation engineering, etc. were mobilized, together with technicians drivers, and organized into four survey teams; one Korean team controlling the whole process and three Malawian teams executing field investigation.

Various equipment were used for soil survey, such as GPS units,a navigation device, digital cameras, shovels, hoes, picks, tape measures, soil hardness tester, cores, core samplers, carbonate reaction reagent,the Munsell Soil Color Charts, 1:10,000 scaled aerial photographs, field books, and 4WD cars.

Before data collection commenced, Harmonized World Soil Database (HWSD) and Soil Atlas of Africa were downloaded from the FAO homepage (http://www.fao.org) to briefly go over soil types and properties. Additionally, SoilGrids1km, digital soil database of ISRIC, was explored.

Meanwhile, the FAO digital map covering the entire project area, the CODA book of drawings on soil classification and land suitability of the Phase 1 area were acquired from the Government. Illovo Group also provided soil data on soil survey points, classification and recent soil properties of Illovo Sugar Farm areas.

Prior to starting field investigation, an awareness-raising conference was held in the project area attended by representatives of farmers, chiefs, council members, and specialists for the purpose of both explaining to stakeholders the details of project, helping them to comprehend soil survey, and communicating multilaterally.

1.2. Field investigation

Closely looking at the 1:10,000-scaled aerial photo map taken in 2013 on ArcGIS, standard soil survey points, i.e., reference points were first spotted in the survey zones except for Illovo Sugar Farm. The distribution of the reference points was based on a ratio of 1 point/100 ha cell upon a 1 km×1km grid, taking into account accessibility and spatial evenness. Soil was examined at 1-3 points in a cell. In total, soil survey points amounted to 1,050. For the commercial farm areas, soil survey had already been recently carried out at 1,226 points and had enough detail so as to be used as such.

Survey area is composed of six zones which can be divided to 19 subzones in detail stretching on both sides of M1 road from the uppermost zone of I-1-a to the lowest of D-c. The total area is around 55,500 ha including commercial farms of Kasinthula, Phata, and Nchalo Estates (Figure 3).

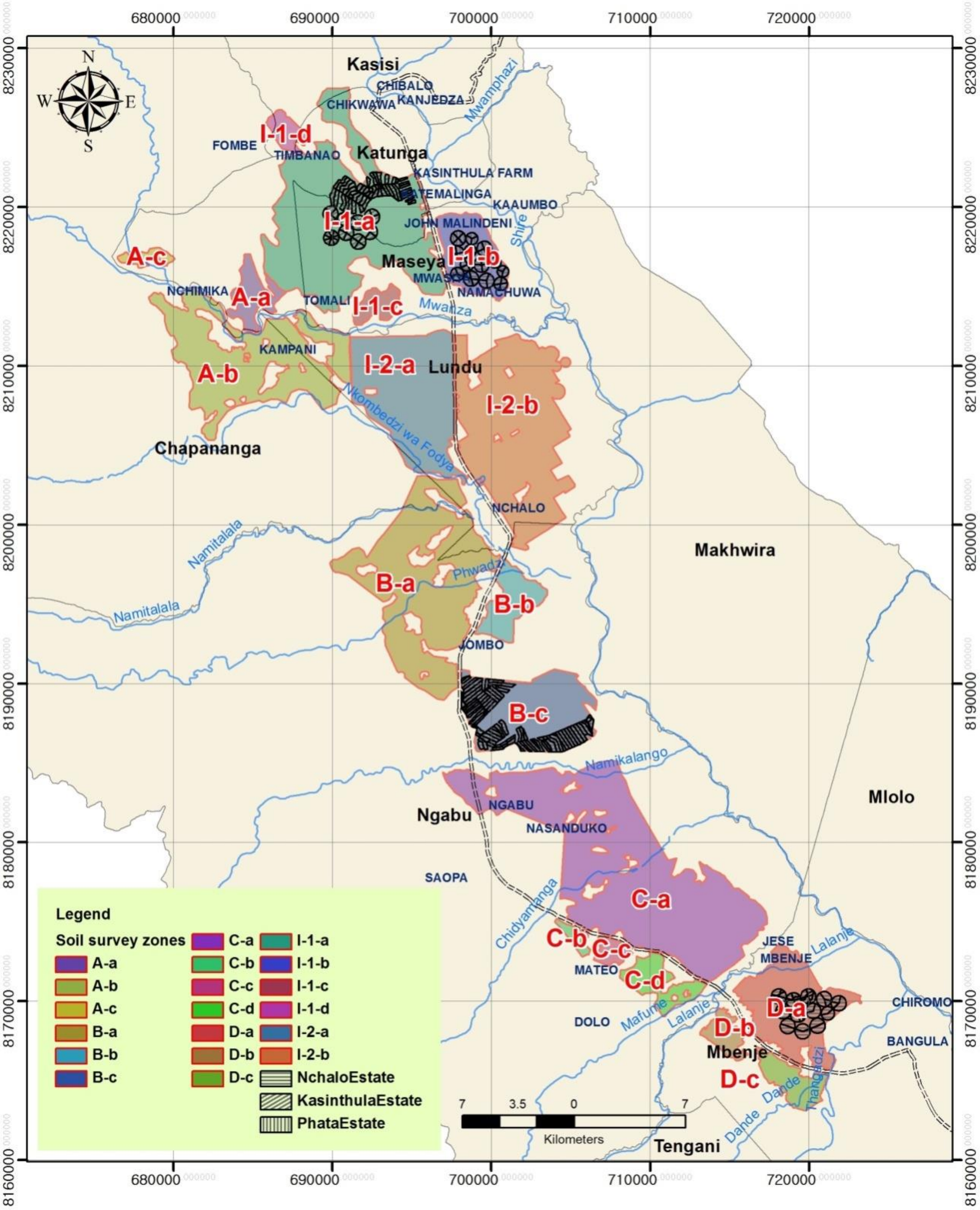

Figure 3. Location map of SVIP Zones.

Survey items,description and sampling methods were determined referring to both the Korean Field Book (KRC, 2013), the American FieldBook (USDA-NRCS, 2012)and the FAO Guidelines (FAO, 2006). On-site observations were recorded on profile description sheets at every survey point and summarized in soil information sheets.

In this survey, two main soil profile type descriptions of soil pit profile description and soil augering description as per the FAO Guidelines were adopted. As of 6th January 2016, routine profile description and soil augering had been done at 391 and 659 sites respectively.

In part of Zone C, however, field investigation was suspended until early February because of interruption by a group of farmers afraid of losing their land to SVIP. It restarted after an awareness-raising meeting where more than 300 persons comprising project-related officials, experts, chiefs, and farmers attended to receive and answer farmers' complaints in person. In the meantime, the routine profile description using an ordinary soil pit was not possible in the remaining areas due to planted crops and poor car accessibility. Thus, semi-profile description was adopted as an alternative step instead of routine, in which a 40 cm × 50 cm small pit was made. Since then, semi-profile description has been conducted at 34 sites and soil augering at 107 sites.

Percolation is a phenomenon whereby water is absorbed into soil by gravity and keeps moving downward to water table. Like permeation, it plays as an important variable in calculating the water requirement of crops, especially rice paddy. Percolation rate in the field was simply obtained by use of the Cylinder Method. At 19 sites, two open cylinderical PVC pipes (100mm in diameter) 30-50 cm long were hammered into the saturated soil with ≥ 50 cm ground water level up to a very hard layer to depths of 20-40 cm. Additional water was poured into the cylinder mounted with a Hook gauge. After a period of time, usually one day, the water level change in the cylinder was measured and the value was converted to a daily basis (mm/day).

For other crops, except rice paddy, total readily available moisture (TRAM) was also calculated from the following formula. TRAM is the maximum RAW that a soil can store within an effective depth from the surface, which is theoretically the daily maximum irrigable water.

$$\mathrm{TRAM} = (FC_{24} - ML)H\frac{1}{Cp}$$

FC_{24}: soil moiture at field capacity 24 hours after waterlogging (%), *ML*: soil moisture at wilting point, *H*: the depth (mm) of limiting layer, *Cp*: SMEP(soil moisture extract pattern) of limiting layer. The limiting layer is a layer which has the minimum TRAM value. FC was analyzed at 17 sites from the core samples taken from wet soil a day after waterlogging.

At 17sites, undisturbed core samples were taken at depths of 0-10 (H1), 10-20 (H2), 20-30 (H3), and 30-40 cm (H4) from the surface in soil saturated with ground water. Then they were weighed and balanced before and after oven-dry to calculate bulk density.

Readily available water (RAW) is the soil moisture held between field capacity and a nominated refill point for unrestricted plant growth. In this range of soil moisture, plants are neither waterlogged nor water-stressed. RAW for horticultural crops is usually the amount of water between field capacity and -20 to -60kPa. RAW can be standardized by soil texture from detailed field and laboratory studies on lots of samples (Agriculture NSW Water Unit, 2014).

Rootzone RAW was determined at the same sites where TRAM was tested, regardless of SMEP, the RAW of each soil horizon (in centimeters) in the rootzone was multiplied by the thickness of that horizon and then the values for each soil horizon were summed to get the total rootzone RAW.

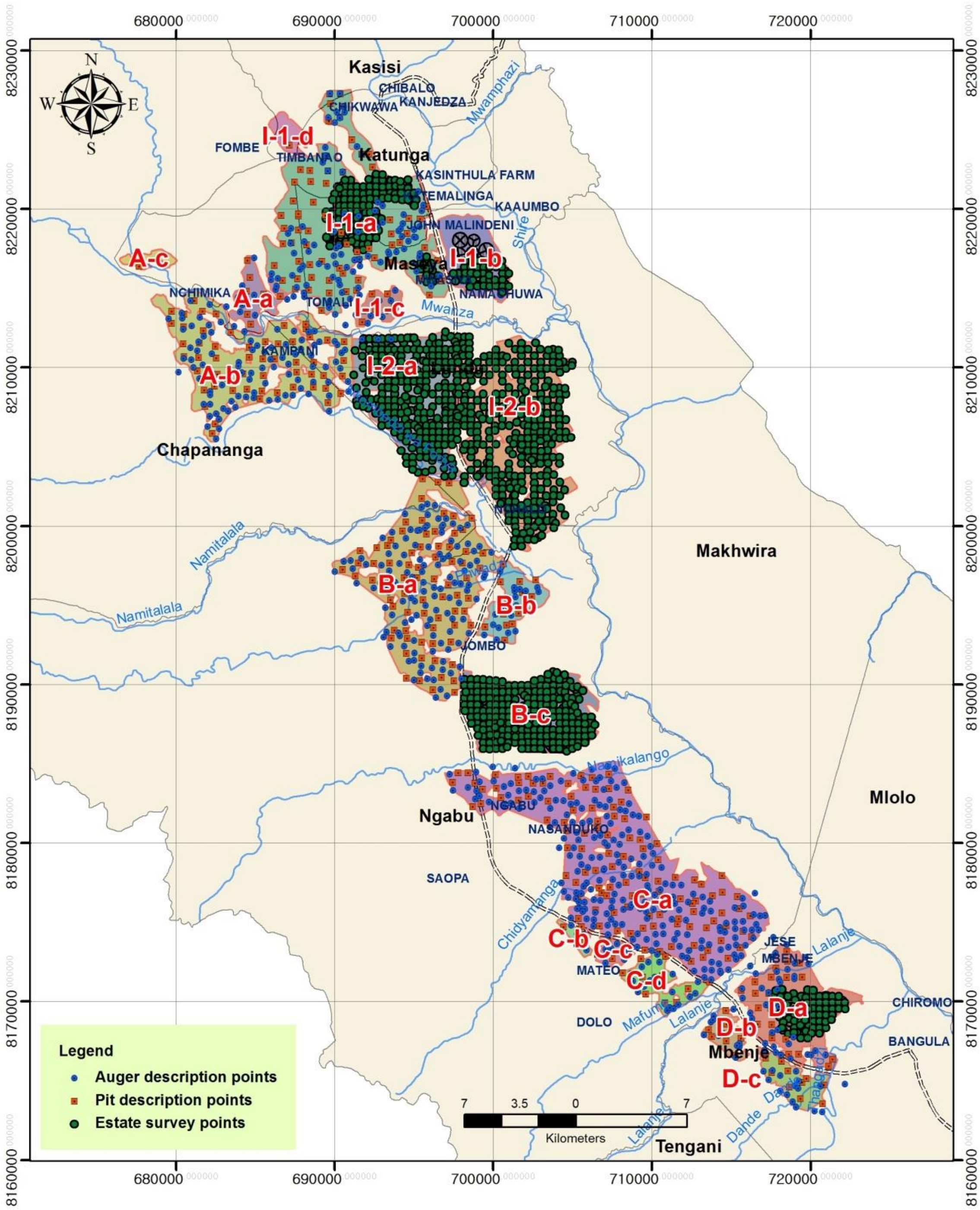

Figure 4. Location map of soil survey points.

Figure 5. Methods of field soil investigation.

A: Soil augering description, A1: Making an auger-bore hole, A2: Soil description

P: Pit profile description. P1: Making a soil pit, P2: Profile description, P3: Soil test, P4: Soil sampling.

Figure 6. Procedures of percolation and TRAM test.

1. Spotting an appropriate site, 2. Ridging, waterlogging and comparting a plot, 3. Pounding two pipes, 4. Measuring the initial water level inside them, 5. Covering the pipes, 6. Covering the whole plot, 7. Measuring water level change after one day, 8. Core sampling.

1.3. Soil analysis

One thousand and three soil samples were taken from topsoil and/or subsoil horizons. After carbonate reaction test in the laboratory of KARS, all samples from soil pits were entrusted to the Bvumbwe Agricultural Research Station (BARS) located 13 km south east of Blantyre. Soil texture, soil reaction (pH), organic carbon (OC), available phosphorus (P_2O_5), electrical conductivity (EC), cation exchange capacity (CEC), base saturation (BS), sodium absorption ratio (SAR), exchangeable sodium percentage (ESP), and bulk density (BD) were analyzed using the FAO analytical procedures for examination of chemical-physical characteristics and the final soil classification (FAO, 2014).

Soil texture was determined as percentage of sand, silt, and clay using the hydrometer method.

Soil reaction was measured with a pH-meter in a soil suspension of one part soil and five part distilled water using the dilution method.

Organic carbon was obtained using the Walkley and Black method; wet combustion of the organic matter with a potassium chromate/sulpuric acid mixture and titration of residual dichromate with ferrous sulphate.

Total nitrogen was analyzed using the Kjeldahl method. A soil sample is digested with concentrated sulphuric acid. The digest is distilled and the distillate is titrated against a weak hydrochloric acid.

Available phosphorus was quantified using the Bray (I) method. An extracting solution is used, consisting of a mixture of hydrochloric acid and ammonium fluoride. After filtering the soil suspension an aliquot is taken. Then, phosphorus in the soil extracts is determined spectrophotometrically by the use of stannous chloride indicator.

Exchangeable cations were extracted with a natural ammonium acetate solution. After filtering the suspension aliquots are taken which arempassed onto a flame photometer for determination of sodium and potassium. Another aliquot is taken to be passed through an atomic absorption spectrophotometer for magnesium and calcium determination.

Cation exchange capacity

After percolation with ammonium acetate at pH 7, the sample is percolated with sodium acetate at pH 7, washed free of excess salt and percolated with ammonium acetate. Sodium in the percolate is measured spectrophotometrically.

1.4. Soil classification

World reference base for soil resources (WRB) 2014 was mainly consulted to identify soil types at survey points. This is a revised version of the previous WRB (FAO, 2006) and a classification system for naming soils and creating soil map legends (FAO, 2014).

Field classification was carried out by professionals based on profile/landscape photos, soil description sheets and soil information sheets. At arbitrarily set soil pit description sites, comparative survey was also done by Korean soil survey team to compare and confirm the identification done by the four survey teams.

In collaboration with KARS and BARS, a WRB soil classification was assigned to soil to determine the soil type at each point, based on diagnostic horizons, properties, and materials, and this wa confirmed from field investigation and soil analysis as well.

KARS made out its soil survey report and submitted it to the Consultancy in accordance with the required format of summary, methodology, results, and annexes such as soil profile description sheets, soil information sheet, and related photos.

2. Previous studies

2.1. Soildatabase

2.1.1. HWSD

According to the Harmonized World Soil Database (HWSD) 1.2, there are roughly three Dominant Soil Groups identified in the present survey zones; Fluvisols, Vertisols, and Histosols. Soil units (FAO 74) are further divided into five; Dystric Fluvisol, Gleyic Solonchalk, Vertisols, Eutric Histosols, and Humic Gleysols.

It is found that Vertisols are the dominant Soil Group in Phase II zones while Fluvisols are dominant in Phase I zones. Outstandingly, Dystric Fluvisols are clayey and very poorly drained soil types with 150 mm AWC (Available Water Capacity) while Vertisols are very clayey (>50%) and poorly drained with 125 mm AWC.

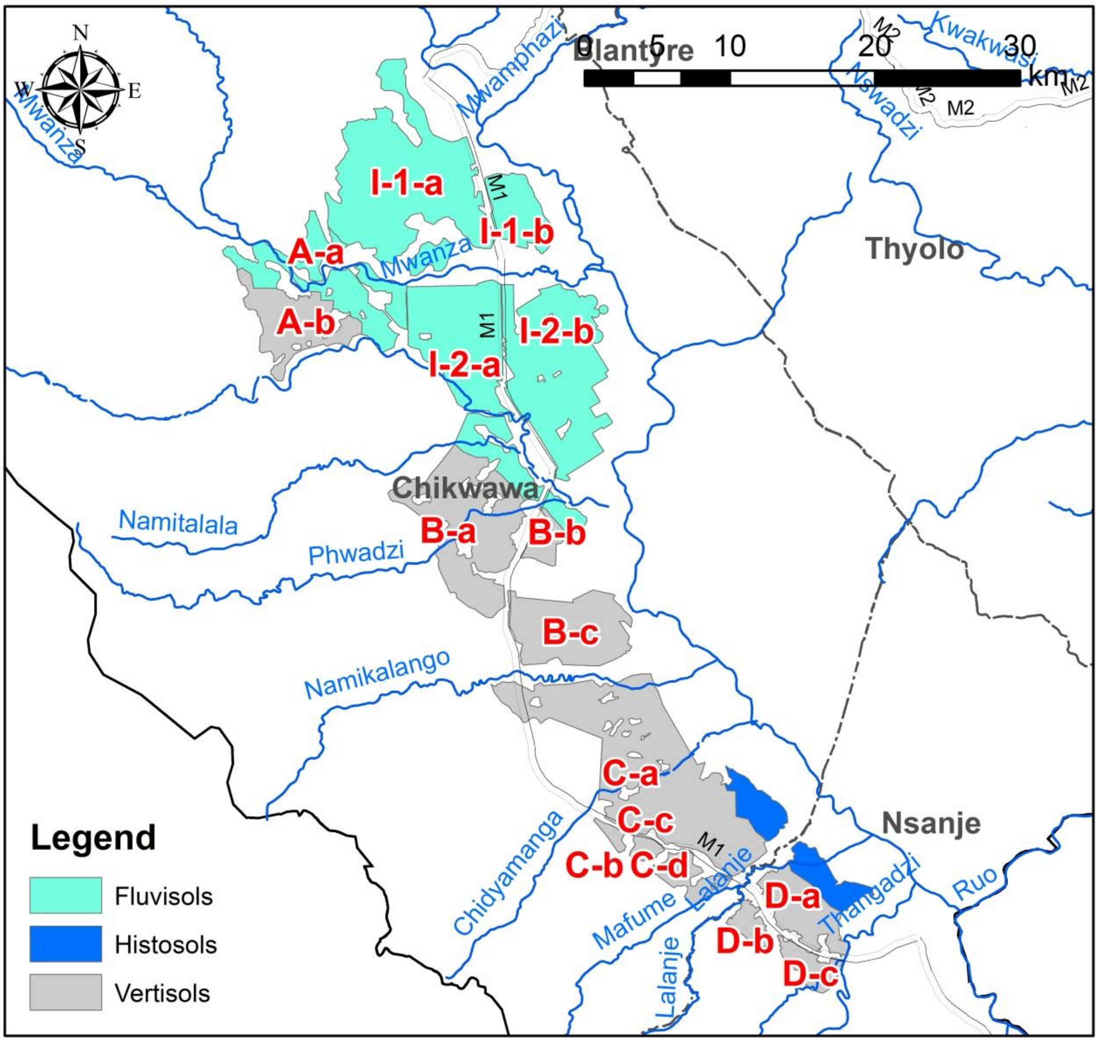

Figure 7. Soil types in SVIP Zones from HWSD.

Table 1. Characteristics of Fluvisols.

Dominant Soil Group	FL - Fluvisols	
Sequence	1	2
Share in Soil Mapping Unit (%)	70	30
Soil Unit Symbol (FAO 74)	Je	Zg
Soil Unit Name (FAO74)	Dystric Fluvisols	Gleyic Solonchaks
Topsoil Texture	Fine	Medium
Reference Soil Depth (cm)	100	100
Obstacles to Roots (ESDB) (cm)	-	-
Impermeable Layer (ESDB) (cm)	-	-
Drainage class (0-0.5% slope)	Very Poor	Poor
AWC (mm)	150	150
Gelic Properties	No	No
Vertic Properties	No	No
Petric Properties	No	No
Topsoil Sand Fraction (%)	19	36
Topsoil Silt Fraction (%)	32	43
Topsoil Clay Fraction (%)	49	21
Topsoil USDA Texture Classification	Clay (light)	Loam
Topsoil Reference Bulk Density (kg/dm^3)	1.24	1.39
Topsoil Bulk Density (kg/dm^3)	1.31	1.41
Topsoil Gravel Content (%)	4	6
Topsoil Organic Carbon (% weight)	1.26	0.42
Topsoil pH (H_2O)	6.4	8.1
Topsoil CEC (clay) (cmol/kg)	38	48
Topsoil CEC (soil) (cmol/kg)	27	11
Topsoil Base Saturation (%)	93	100
Topsoil TEB (cmol/kg)	23.7	13.9
Topsoil Calcium Carbonate (% weight)	0	9.5
Topsoil Gypsum (% weight)	0	6.5
Topsoil Sodicity (ESP) (%)	1	46
Topsoil Salinity (ECe) (dS/m)	0.1	14.5
Subsoil Sand Fraction (%)	21	37
Subsoil Silt Fraction (%)	32	39
Subsoil Clay Fraction (%)	47	24
Subsoil USDA Texture Classification	Clay (light)	Loam
Subsoil Reference Bulk Density (kg/dm^3)	1.25	1.37
Subsoil Bulk Density (kg/dm^3)	1.4	1.51
Subsoil Gravel Content (%)	3	5
Subsoil Organic Carbon (% weight)	0.55	0.3
Subsoil pH (H_2O)	7	8.1
Subsoil CEC (clay) (cmol/kg)	41	46
Subsoil CEC (soil) (cmol/kg)	22	12
Subsoil Base Saturation (%)	100	100
Subsoil TEB (cmol/kg)	18.3	18.2
Subsoil Calcium Carbonate (% weight)	0.4	12.3
Subsoil Gypsum (% weight)	0	4.1
Subsoil Sodicity (ESP) (%)	3	54
Subsoil Salinity (ECe) (dS/m)	0.1	2.8

Table 2. Characteristics of Vertisols.

Dominant Soil Group	VR - Vertisols
Sequence	1
Share in Soil Mapping Unit (%)	100
Soil Unit Symbol (FAO 74)	V
Soil Unit Name (FAO74)	Vertisols
Topsoil Texture	Fine
Reference Soil Depth (cm)	100
Obstacles to Roots (ESDB) (cm)	-
Impermeable Layer (ESDB) (cm)	-
Soil Water Regime (ESDB)	-
Drainage class (0-0.5% slope)	Poor
AWC (mm)	125
Gelic Properties	No
Vertic Properties	Yes
Petric Properties	No
Topsoil Sand Fraction (%)	18
Topsoil Silt Fraction (%)	26
Topsoil Clay Fraction (%)	56
Topsoil USDA Texture Classification	Clay (light)
Topsoil Reference Bulk Density (kg/dm^3)	1.21
Topsoil Bulk Density (kg/dm^3)	1.42
Topsoil Gravel Content (%)	3
Topsoil Organic Carbon (% weight)	0.95
Topsoil pH (H_2O)	7.3
Topsoil CEC (clay) (cmol/kg)	70
Topsoil CEC (soil) (cmol/kg)	43
Topsoil Base Saturation (%)	100
Topsoil TEB (cmol/kg)	41.6
Topsoil Calcium Carbonate (% weight)	0.8
Topsoil Gypsum (% weight)	0
Topsoil Sodicity (ESP) (%)	1
Topsoil Salinity (ECe) (dS/m)	0.1
Subsoil Sand Fraction (%)	18
Subsoil Silt Fraction (%)	24
Subsoil Clay Fraction (%)	58
Subsoil USDA Texture Classification	Clay (light)
Subsoil Reference Bulk Density (kg/dm^3)	1.21
Subsoil Bulk Density (kg/dm^3)	1.53
Subsoil Gravel Content (%)	4
Subsoil Organic Carbon (% weight)	0.55
Subsoil pH (H_2O)	7.8
Subsoil CEC (clay) (cmol/kg)	72
Subsoil CEC (soil) (cmol/kg)	43
Subsoil Base Saturation (%)	100
Subsoil TEB (cmol/kg)	45.1
Subsoil Calcium Carbonate (% weight)	3.7
Subsoil Gypsum (% weight)	0
Subsoil Sodicity (ESP) (%)	2
Subsoil Salinity (ECe) (dS/m)	0.1

Table 3. Characteristics of Histosols.

Dominant Soil Group	HS - Histosols		
Sequence	1	2	3
Share in Soil Mapping Unit (%)	60	30	10
Soil Unit Symbol (FAO 74)	Oe	Gh	Je
Soil Unit Name (FAO74)	Eutric Histosols	Humic Gleysols	Dystric Fluvisols
Topsoil Texture	Medium	Medium	Medium
Reference Soil Depth (cm)	100	100	100
Obstacles to Roots (ESDB) (cm)	-	-	-
Impermeable Layer (ESDB) (cm)	-	-	-
Drainage class (0-0.5% slope)	Very Poor	Poor	Poor
AWC (mm)	150	150	150
Gelic Properties	No	No	No
Vertic Properties	No	No	No
Petric Properties	No	No	No
Topsoil Sand Fraction (%)	25	33	39
Topsoil Silt Fraction (%)	35	45	41
Topsoil Clay Fraction (%)	40	22	20
Topsoil USDA Texture Classification	Clay (light)	Loam	Loam
Topsoil Reference Bulk Density (kg/dm^3)	1.27	1.38	1.41
Topsoil Bulk Density (kg/dm^3)	0.28	1.2	1.36
Topsoil Gravel Content (%)	28	4	4
Topsoil Organic Carbon (% weight)	38.37	3.71	0.9
Topsoil pH (H_2O)	5.9	5.5	7.3
Topsoil CEC (clay) (cmol/kg)	45	33	62
Topsoil CEC (soil) (cmol/kg)	88	18	16
Topsoil Base Saturation (%)	100	34	91
Topsoil TEB (cmol/kg)	72.9	3.1	16.4
Topsoil Calcium Carbonate (% weight)	0	0	1
Topsoil Gypsum (% weight)	0	0	0
Topsoil Sodicity (ESP) (%)	1	2	2
Topsoil Salinity (ECe) (dS/m)	0.1	0.1	0.1
Subsoil Sand Fraction (%)	46	37	41
Subsoil Silt Fraction (%)	23	35	38
Subsoil Clay Fraction (%)	31	28	21
Subsoil USDA Texture Classification	Sandy clay	Clay loam	Loam
Subsoil Reference Bulk Density (kg/dm^3)	1.35	1.35	1.4
Subsoil Bulk Density (kg/dm^3)	0.17	1.46	1.39
Subsoil Gravel Content (%)	1	5	8
Subsoil Organic Carbon (% weight)	30.5	0.69	0.4
Subsoil pH (H_2O)	5.9	5.6	7.5
Subsoil CEC (clay) (cmol/kg)	49	41	58
Subsoil CEC (soil) (cmol/kg)	79	11	14
Subsoil Base Saturation (%)	99	62	97
Subsoil TEB (cmol/kg)	91.5	9	15.1
Subsoil Calcium Carbonate (% weight)	0	0	3.9
Subsoil Gypsum (% weight)	0	0	0
Subsoil Sodicity (ESP) (%)	1	4	3
Subsoil Salinity (ECe) (dS/m)	0.1	0.1	0.1

2.1.2. Soil Atlas

Soil Atlas of Africa was published in 2013 by European Union and contains soil maps at a scale of 1:3,000,000 derived from several projects covering the African continent. They include:

- The Harmonized World Soil Database
- The Soil Geographical Database of Eurasia (scale 1:1000,000)
- The FAO-UNESCO 1:5000,000 Soil map of the World

The soil map sheet covering SVIP area presents three soil types that are Eutric Fluvisols (FLeu), Eutric Histosols (HSeu), and Vertisols (VR), similar to the HWSD map. The legend codes in parentheses describe briefly FLeu as soil in floodplains, HSeu as organic soil, and VR as soil with shrinking and swelling clays.

2.2. FAO project map

Soil maps on the whole Lower Shire Valley were made out in 1969 by Lockwood Survey Corporation Ltd. for the Kasintula Irrigation Project under the UNDP of FAO.

Mapping symbols are composed of landform, soil series, soil type, and topographic phase. Soil was classified into 52 soil series in Phase I and 156 soil series in the other area. Soil types are equal to soil textures and include coarse textured (a: Sand, b: Loamy sand, c: Loamy fine sand), moderately coarse textured (d: Sandy loam, e: Fine sandy loam), moderately fine textured (i: Clay loam, j: Sandy clay loam, k: Silty clay loam), and fine textured (l: Sandy clay, m: Silty clay, n: Clay). Topographic phases were divided into six; 0: Depressional, 1: Level (0-1%), 2: Level to gently/very gently undulating (1-2%), 3: Gently sloping/gently undulating (2-4%), 4: Sloping/undulating (4-8%), and 5: Strongly sloping/rolling (8-16%).

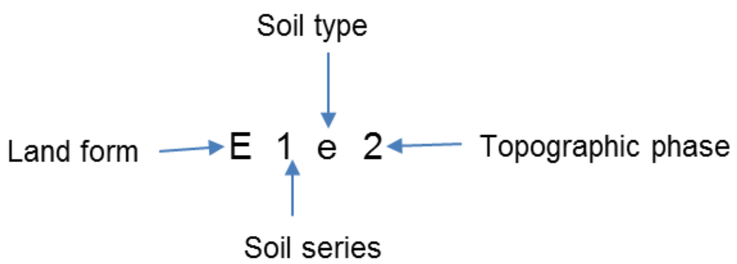

Figure 8. Mapping symbol structure in the 1969 FAO project map.

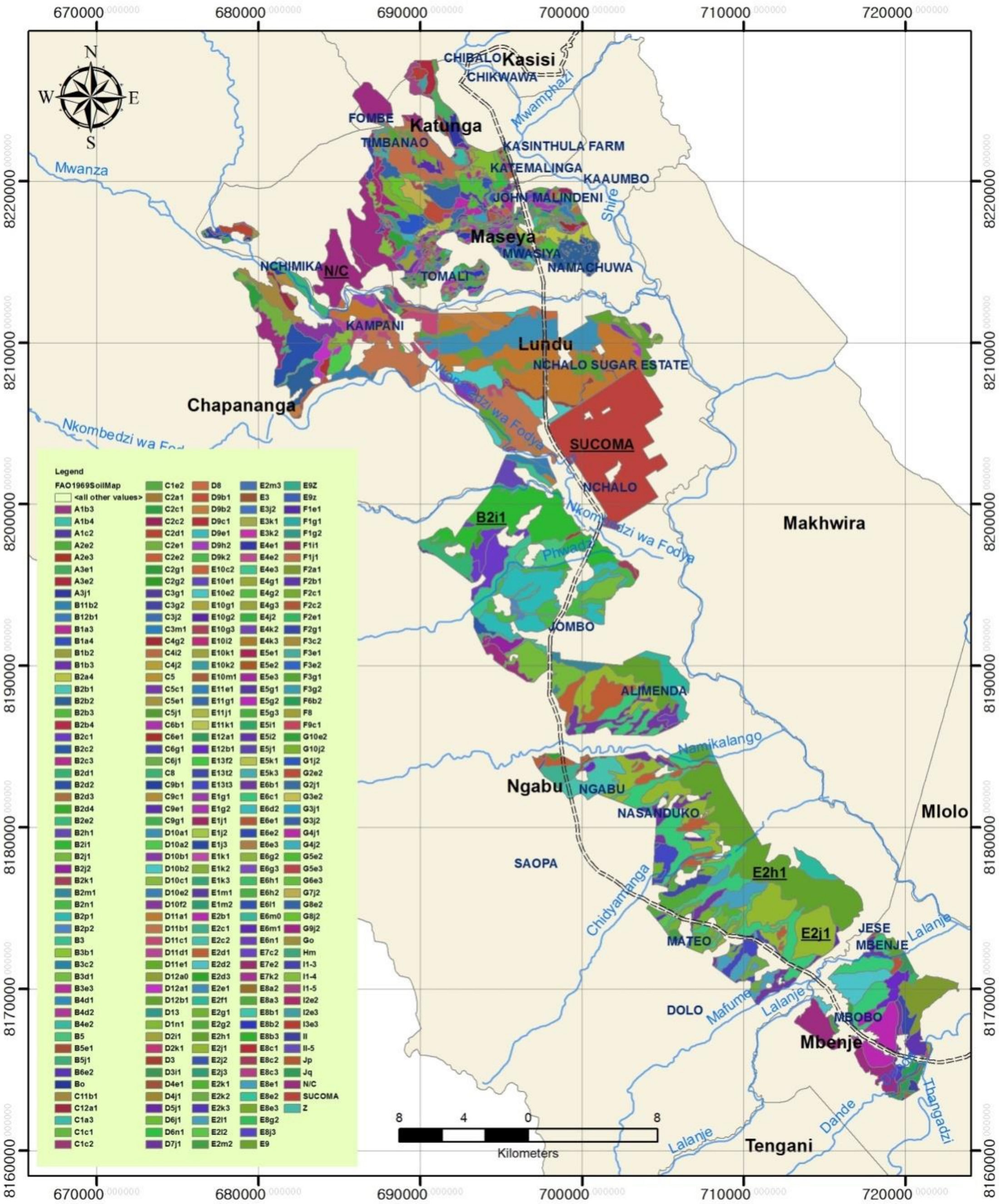

Figure 9. 1969 FAO Soil Map.

2.3. FAO digital map

From the FAO digital soil map of the Lower Shire Valley Area, nine soil types (RSGs+the second-level prefixes) were extracted in the area of approximately 55,000 ha by comparing it with the present soil survey zones. Almost all soil types are distributed in the plain of a gradient of flat to very gently sloping.

Eutric Fluvisols (FLeu) are the dominant soil type occupying around 26,000 ha, 46.9% of the whole area, which are spread widely in Phase I area, Zone A, and Zone C. These soils in the lowland have various textures and can be readily flooded and ponded by the Shire River and several tributaries that have poor drainage.

Eutric Vertisols (VReu) are the second largest soil type covering about 11,000 ha (19.4%). They are very clayey (sandy clay), eroded, and imperfectly to poorly drained but might require lots of irrigation water for its texture and severe cracks.

Haplic Luvisols (LVha) are very deep well drained brown soils with distinctive surface soil texture (sandy loam) from subsoil (sandy clay loam) whose area reach 9,500 ha, mostly existing between hills and plains in survey zones.

Calcaric Cambisols (CMca) are very deep, well drained, and brown soils with sandy loam texture. They can be eroded and contain a significant amount of calcium carbonate to react with HCl solution.

Table 4. Soil types of survey zones in FAO digital soil map.

Soil type	Area (ha)	Description	Soil texture	pH	EC (dS/m)
Calcaric Cambisols	5,022 (9.1 %)	Very deep or deep, moderately well or well drained, brown, medium textured partly calcareous soils of medium or high chemical fertility	SL/SL SCL/SCL	7.0	0-2
Calcic Luvisols	1,121 (2.0 %)	Moderately deep, well drained, dark brown, medium textured gravelly calcareous soils of moderate chemical fertility	L/L	7.0	0-2
Eutric Cambisols	1,524 (2.7 %)	Moderately deep, well drained, yellowish brown or brown, coarse and/or medium texture, frequently skeletal subsoil of moderate chemical fertility	LS,SL /SCL	5.5-6.0	0-2
Eutric Fluvisols	26,048 (46.9 %)	Very deep, poorly to well drained, dark brown, variable textured soils of moderate or high chemical fertility	Variable	5.0-6.0	0-2
Eutric Gleysols	1	Very deep, poorly to imperfectly drained, dark grey, medium to fine textured soils of moderate chemical fertility	SCL/SCL	5.5	0-2
Eutric Regosols	13	Shallow, moderately well drained, dark brown, medium textured gravelly soil of moderate chemical fertility	L/L	6.0	0-2
Eutric Vertisol	10,755 (19.4 %)	Very deep, imperfectly to poorly drained, dark grey, fine textured soils of moderate chemical fertility	SC/SC	7.0	0-2
Gleyic Cambisols	1,501 (2.7 %)	Very deep, imperfectly to poorly drained, dark brown to grey, medium to fine textured soils	SCL/SCL	7.0	2-4
Haplic Luvisols	9,490 (17.1 %)	Very deep, well drained, brown, medium textured soils of medium chemical fertility	SL/SCL	5.5	0-2
n/a	14				
Sum	55,488				

Description about soil characteristics is summarized as in the attribute table of FAO digital map.
LS: loamy sand, SL: sandy loam, SCL: sandy clay loam, SC: sandy clay, L: loam

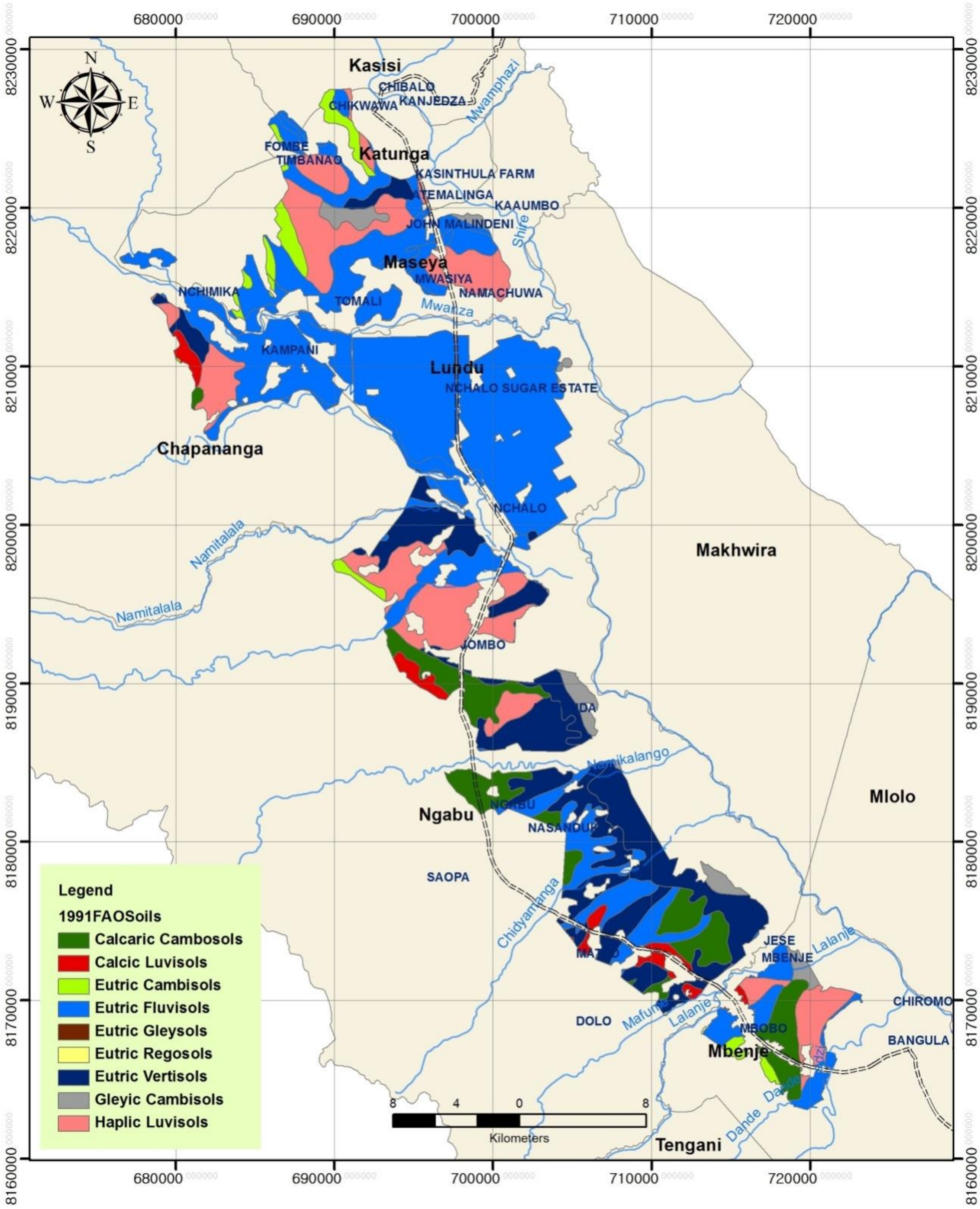

Figure 10. 1991 FAO Soil Map.

2.3. CODA Report

Nine soil map sheets pertaining to I-1-a, I-1-b, I-1-c zones (9,388 ha) were digitized from the CODA Books of Drawing made in 2008, where soil is classified into 12 soil units according to FAO guidelines and USDA Soil Taxonomy.

Five of them occupy 73.1 % of three zones (1.055 ha), which are Ft, St, Et, Ef, and At. Because the main elaborate report was not acquired, the general characteristics of soil units were inferred from Soil Taxonomy (USDA, 1983) as follows.

- **Ustifluvents:** other Fluvents that have an ustic soil moisture regime.

Typic Ustifluvents

a. Do not have mottles within 50 cm of the surface that have chroma of 2 or less and do not have, at a depth within 1.5 m of the surface, a horizon that is saturated with water at some period or is artificially drained and that has chroma less than 1 or a hue bluer than 10Y; and

b. Do not have the following combination of characteristics;

① Cracks at some period in most years, when the soil is not irrigated, that are 1 cm or more wide at a depth of 50 cm, that are at least 30 cm long in some part, and that expend upward to the soil surface or to the base of an Ap horizon;

② A coefficient of linear extensibility (COLE) of 0.07 or more in a horizon or horizons at least 50 cm thick and a potential linear extensibility of 6 cm or more in the upper 1.25 m of the soil or in the whole soil if a lithic or paralithic contact is deeper than 50 cm but shallower than 1.25 m; and

③ More than 35 percent clay in horizons that total >50 cm in thickness.

c. Have an Ap horizon that has a moist color value of 4 or more or has a dry color value of 6 or more when crusted and smoothed, or the A1 horizon is <15 cm thick if its moist color value is less than 3.5.

- **Ustipsamments:** other Psamments that have an ustic soil moisture regime.

Psamments are other Entisols that have less than 35 percent (by volume) rock fragments and a texture class of loamy fine sand or coarser in all layers (sandy loam lamellae are permitted) within the particle-size control section.

Typic Ustipsamments

a. Do not have lamellae within 1.5 m of the soil surface that meet all requirements for an argillic horizon except thickness;

b. Do not have distinct or prominent mottles above a depth of 1 m and are not saturated with water within 1 m of the surface during any time of year in most years; and

c. Do not have a lithic contact within 50 cm of the surface.

- **Ustochrepts:** other Ochrepts that have an ustic soil moisture regime.

Ochrepts are other Inceptisols that have an ochric epipedon; or that have an umbric or mollic epipedon that is < 25 cm thick and have also a mesic or warmer soil temperature regime. Vertic ustochrepts have cracks at some period to the base of an Ap horizon and more than 35% clay in horizons that total >50 cm in thickness.

- **Halpustalfs:** other Ustalfs.

  Ustalfs are other Alfisols that have an ustic soil moisture regime. Vertic haplustalfs have cracks at some period to the base of an Ap horizon and more than 35% clay in horizons that total >50 cm in thickness.

- **Natrustalfs:** other Ustalfs that have a natric horizon.

  Salorthidic Natrustalfs have a salic horizon that has its upper boundary within 75 cm of the soil surface

- **Chromusterts**: other vertisols that have an ustic moisture regime.

Usterts are other Vertisols that, if not irrigated during the year, have cracks in normal years that are 5 mm or more wide, through a thickness of 25 cm or more within 50 cm of the mineral soil surface, for 90 or more cumulative days per year.

They are Usterts that have a moist chroma of 1.5 or more in some part of the matrix of the upper 30 cmm in more than half of each pedon.

Typic Chromusterts

a. Have a moist color value of less than 3.5 and a dry value of less than 5.5 throughout the upper 30 cm or more in more than half of each pedon;
b. Do not have, within 1 m of the soil surface, prismatic or blocky structure accompanied by clay skins on ped faces that have a color value lower than that in the matrix; and
c. Have cracks that remain open more than 150 cumulative days in most years and

   have a mean annual soil temperature that is 15 ℃ or higher.

- **Pellusterts**: other Usterts

Typic Pellusterts

Have a moist color value of less than 3.5 and a dry value of less than 5.5 throughout the upper 30 cm in more than half of each pedon;

a. Have cracks that remain open for more than 150 cumulative days during each year and have a mean annual soil temperature that is 15 ℃ or higher; and
b. Do not have, within 1 m of the soil surface, prismatic or blocky structure accompanied by clay skins on ped faces that have a color value lower than that in the matrix.

Table 5. Soil units in the 2008 CODA Book of Drawing.

Symbols	Order	Suborder	Great group	Subgroup	Area(ha)
Ft	Entisols	Fluvents	Ustifluvents	Typic	977
St	Entisols	Psamments	Ustipsamments	Typic	1,055
Et	Inceptisols	Ochrepts	Ustochrepts	Typic	1,046
Ef	Inceptisols	Ochrepts	Ustochrepts	Fluventic	1,463
Ev	Inceptisols	Ochrepts	Ustochrepts	Vertic	445
At	Alfisols	Ustalfs	Haplustalfs	Typic	2,330
Av	Alfisols	Ustalfs	Haplustalfs	Vertic	421
Nt	Alfisols	Ustalfs	Natrustalfs	Typic	53
Ns	Alfisols	Ustalfs	Natrustalfs	Salorthidic	620
Ct	Vertisols	Usterts	Chromusterts	Typic	90
Pt	Vertisols	Usterts	Pellusterts	Typic	355
nc					462
					9,388

Then additional information such as landform, soil texture, and phases areassigned to soil unitsformapping. Mapping symbols come from the combination of landform, soil unit, texture, and phase in order and reaches approximately 100.

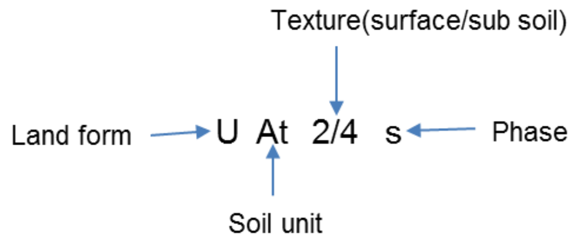

Figure 11. Mapping symbol structure in the CODA soil map.

Land form has 8 categories that are upper Shire terrace, middle Shire terrace, lower Shire terrace, Mwanza alluvium, Nthumba alluvium, western pediment, and upland basement complex. Four soil family textures (sandy, coarse loamy, fine loamy, fine) are added to soil units divided by surface soil and subsoil using a slash mark. Furthermore, six phases related to soil chemical properties (sodic: ESP > 10 %, saline: ECe > 2 dS/m, calcic: $CaCO_3$> 15%) and effective depth (moderately deep: 60-90 cm, shallow: 40-60 cm, very shallow: < 40 cm) areconsidered for mapping.

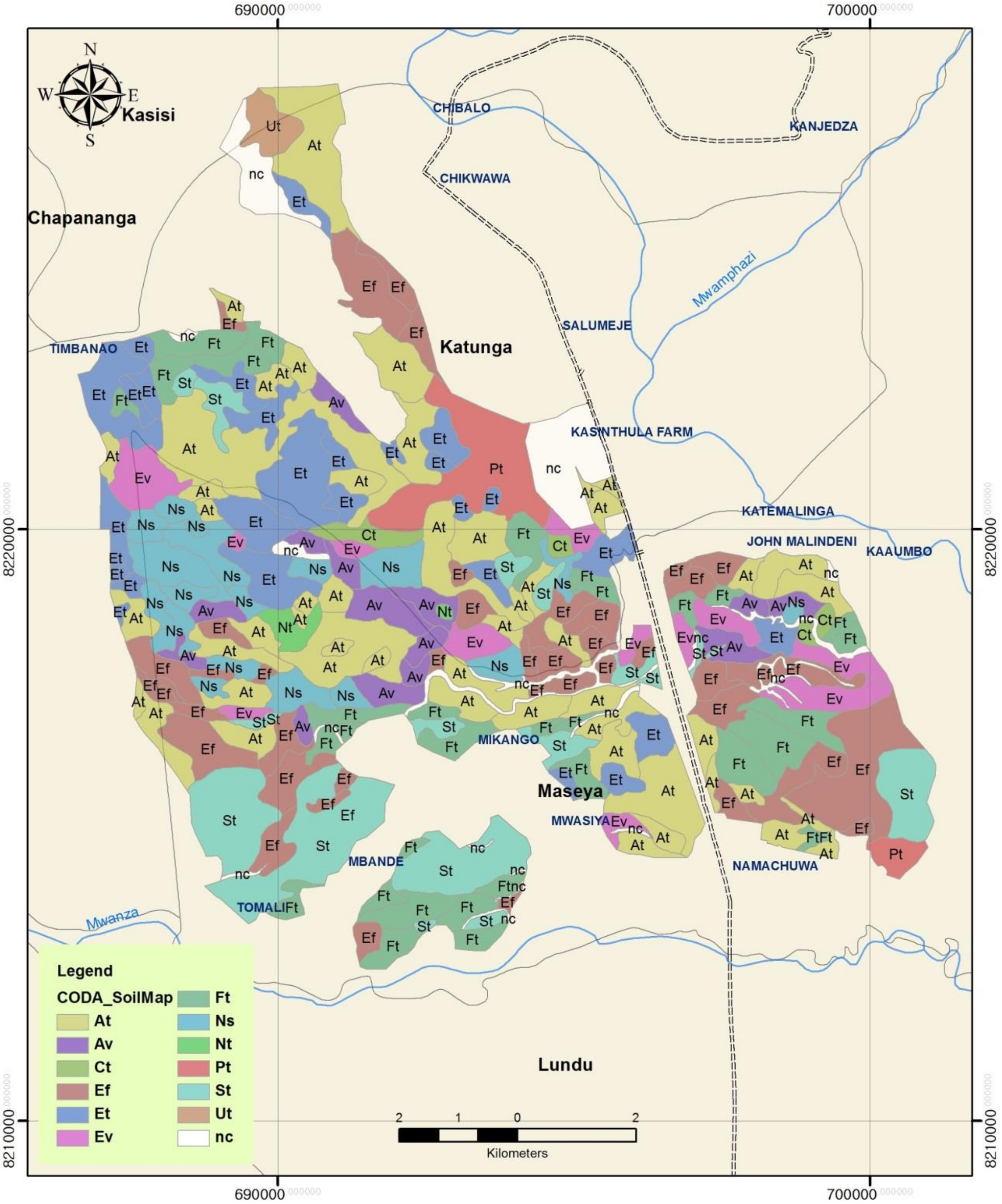

Figure 12. CODA Soil Map.

2.4. Commercialfarm data

Commercial farms spread over six zones of I-1-a, I-1-b, I-2-a, I-2-b, B-c, and D-a and consists of Nchalo, Alumenda, Sande Ranch, Phata, Kasinthula, Kaombe-mcp, and Kaombe Trustwhere sugarcane was cultivated in a total of 15,757 ha in 2015.

Table 6. 2015 Land use of Estates

Estate	Cane-plantedarea (ha)	Otherarea[1] (ha)
Nchalo	9,995	5,004
Alumenda	2,764	982
Sande Ranch	454	217
Phata	296	
Kasinthula	1,429	
Kaombe-mcp	484	1,182
Kaombe Trust	335	
Sum	15,757	7,385

Five soil types are distributed within the commercial sugarcane farm fields, except for roads, according to the FAO digital map depicting Illovo Estates' boundaries; Calcaric Cambisols, Eutric Cambisols, Eutric Fluvisols, Eutric Vertisols, Gleyic Cambisols, and Haplic Luvisols. The total farm area estimated from the map (Table 7 and Figure 13) is quite different from the value in Table 6.

Eutric Fluvisolsare the dominant very deep soils with poorly, moderately well or well drainage and variable texture and are lying on all I-2-a, I-2-b zones. At the lower eastern edge of Nchalo and Kaombe, Gleyic Cambisols have the EC of 2-4 ds/m at which sugarcane can be a little damaged without appropriate water supply. Additionally, part of Eutric Fluvisols near several rivers can be exceptionally or frequently flooded and is poorly drained.

[1]Roads, drains, canals, dams, villages, and wasteland.

Table 7. Soil types inEstatesfrom FAO digital soil map.

Soil type	Area (ha)	Description	Soil texture	pH	EC (dS/m)
CMca	1,765 (6.3 %)	Very deep or deep, moderately well or well drained, brown, medium textured partly calcareous soils of medium or high chemical fertility. Slightly and moderately eroded.	SL/SL SCL/SCL	6.5-7.0	0-2
FLeu	19,928 (70.9 %)	Very deep, poorly towell drained, dark brown, variable textured soils of moderate or high chemical fertility. Slightly eroded.Exceptionally or frequently flooded.	LS,SL/LS,SL Variable	5.0-6.0	0-2
VReu	3,168(11.3 %)	Very deep, imperfectly to poorly drained, dark grey, fine textured soil of moderate chemical fertility. Moderately or severely ponded.	SC/SC	7.0	0-2
CMgl	477(1.7 %)	Very deep, imperfectly to poorly drained, dark brown to grey, medium to fine textured. Exceptionally flooded and severely eroded.	SCL/SCL	7.0	2-4
LVha	2,774(9.9 %)	Very deep, well drained, brown, medium textured soils of medium chemical fertility. Slightly eroded.	SL/SCL	5.5	0-2
Sum	28,112 (100 %)				

1) Description is summarized about soil characteristics in the attribute table of FAO digital map.
2) LS: loamy sand, SL: sandy loam, SCL: sandy clay loam, SC: sandy clay, L: loam
3) FLeu: Eutric Fluvisols, LVha: Haplic Luvisols, VReu: Eutric Vertisols, CMca: Calcaric Cambisols, CMgl: Gleyic Cambisols

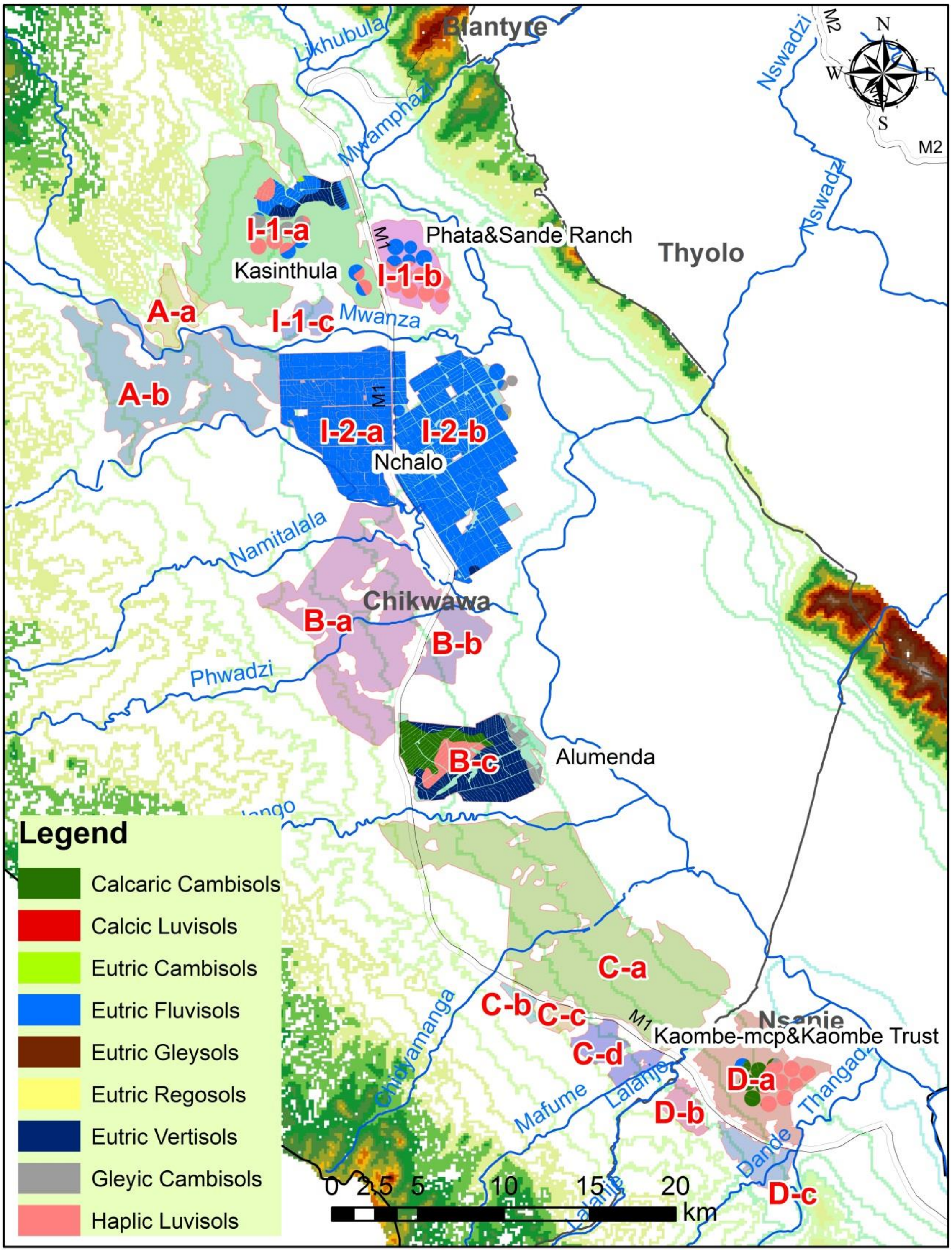

Figure 13. Soil types in commercial sugarcane farms.

However, Illovo Farm's soil survey shows that there are 42 soil types classified by a WRB Soil Classification. Some of them are named by combining two RSGs. Vertisols are observed in the most fields of 283 (23.1%) and followed by Luvisols, Calcisols, Nitisols, Arenosols, and several combined RSGs.

Like the above FAO digital map, Vertisols are one of dominant soils. However, most fields are classified as Cambisols and Arenosols, Calcisols, Gleysols, Nitisoils and are distributed in more fields than Fluvisols.

Effective rooting depth is more than 100 cm and clay in top soil is 39 %, soil structure is blocky or apedal (structureless) at a depth of 0-30 cm. Available water capacity (AWC) is 148 mm but, on the other hand, total available moisture (TAM) is 163.8 mmm. AWC and TAM data could be also very helpful to calculate water requirement in the present survey zones (Table 8).

Generally, Ilovo Estates contain significant sodium and salts accumulated naturally or by irrigation in the soils that can adversely affect sugarcane growth in the future. Ten out of 42 soils (Calcisols/Vertisols, Cambisols/Albeluvisols, Cambisols/Ferralsols, Cambisols/Fluvisols, Gleysols/Plinthosols, Nitisols/Gleysols, Plinthosols, Vertisols, Vertisols/Cambisols, and Vertisols/Gleysols) have a higher level of exchangeable sodium percentage than the mean value (6.89%). It is outstanding that Gleysols/Plinthosolsare sodic (ESP > 10%) and Nitisols/Vertisols are saline (ECe >2 dS/m) while Vertisols/Cambisolsare saline-sodic soils (ESP > 10%, ECe >2 dS/m).

The soil map in Figure 14 was delineated by the use of soil data from Ilovo Group Office in Blantyre so it can be different from an official opinion of Ilovo Group. Moreover, the number of RSGs is reduced to 11 by merging similar soils for simplifying soil classification.

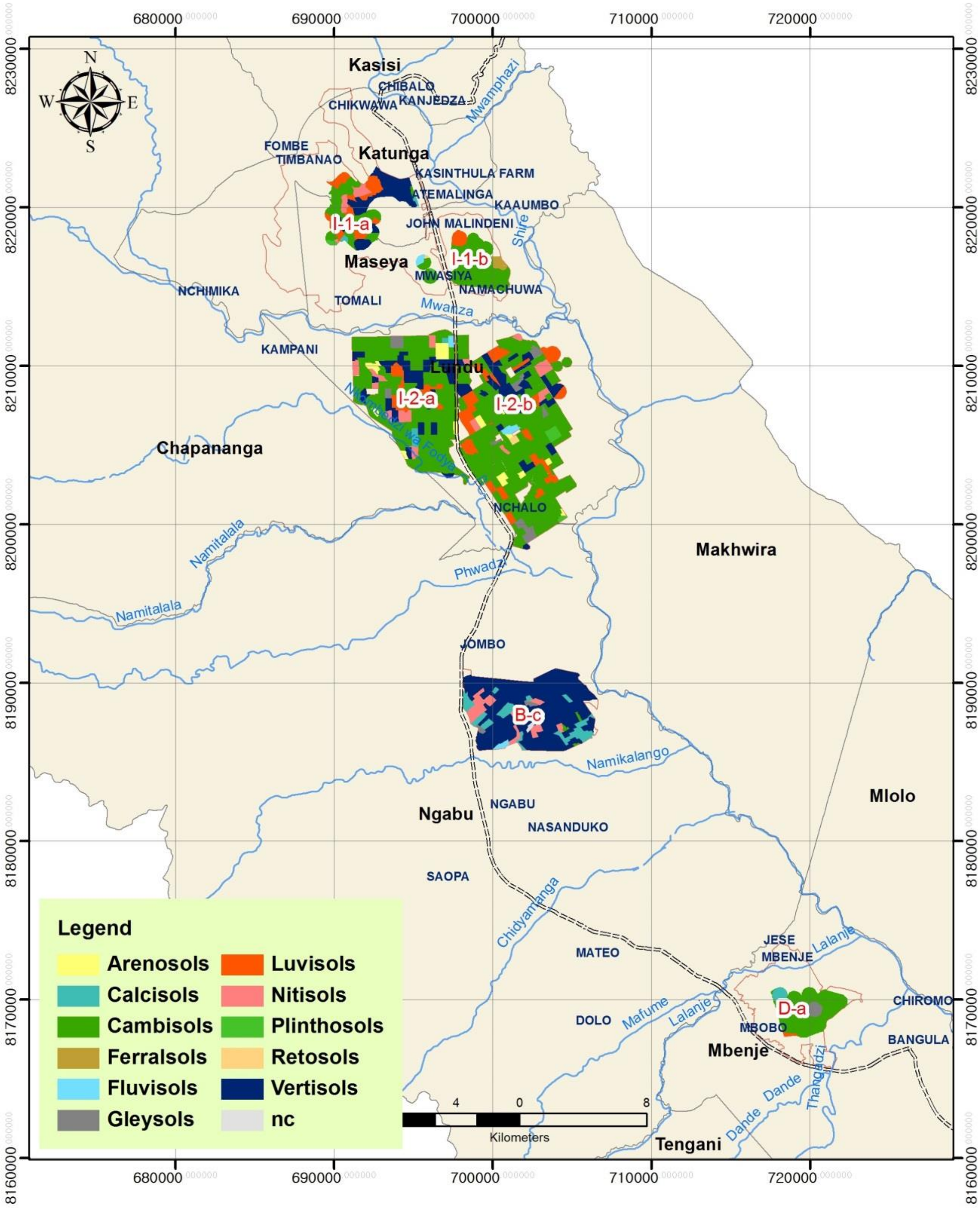

Figure 14. Soil map of Estates.

Table 8. RSGs and physical propertiesinEstates.

RSGs	Area (ha)	No. field	Rooting depth(cm)	Clay (topsoil)	Structure[2]	AWC(mm)	TAM(mm)
Albeluvisols		1	135	15	Apedal	90	121.5
Albeluvisols/Cambisols		1	145	35	Apedal	120	174.0
Albeluvisols/Fluvisols		1	100	15	Apedal	90	90.0
Arenosols		18	93	20	Apedal,structureless	105	98.6
Arenosols/Cambisols		3	92	18	Apedal	100	91.5
Arenosols/Fluvisols		1	85	8	Structureless	90	76.5
Calcisols		39	74	40	Apedal, blocky	149	110.7
Calcisols/Vertisols		1	75	60	Blocky	160	120.0
Cambisols		617	142	30	Apedal, blocky	135	192.5
Cambisols/Albeluvisols		1	55	35	Apedal	160	88.0
Cambisols/Arenosols		10	137	18	Apedal	108	147.3
Cambisols/Calcisols		4	114	43	Apedal, blocky	155	178.0
Cambisols/Ferralsols		2	151	14	Apedal,structureless	90	135.9
Cambisols/Fluvisols		1	105	35	Apedal	120	126.0
Cambisols/Gleysols		1	50	35	Apedal	160	80.0
Cambisols/Luvisols		16	137	42	Apedal, blocky	153	208.1
Cambisols/Nitisols		6	136	49	Blocky, apedal	160	218.1
Cambisols/Vertisols		3	144	44	Blocky, apedal	160	230.4
Ferralsols/Cambisols		4	145	11	Structureless	90	130.1
Fluvisols		8	120	26	Apedal, blocky	126	151.8
Fluvisols/Calcisols		1	75	10	Blocky	90	67.5
Gleysols		19	33	43	Blocky, apedal	163	53.2
Gleysols/Cambisols		2	30	33	Apedal	160	48.0
Gleysols/Plinthosols		1	75	60	Apedal	180	135.0
Luvisols		53	103	33	Blocky, apedal	146	149.3
Luvisols/Albeluvisols		1	95	30	Blocky	120	114.0
Luvisols/Cambisols		18	111	34	Blocky, apedal	160	159.2
Luvisols/Nitisols		4	91	46	Blocky	165	152.3
Luvisols/Vertisols		2	88	45	Blocky, apedal	170	149.0
Nitisols		33	103	52	Blocky, apedal	163	166.7
Nitisols/Calcisols		8	63	56	Blocky	165	101.3
Nitisols/Cambisols		4	130	40	Blocky	150	208
Nitisols/Gleysols		5	26	56	Blocky	168	44.4
Nitisols/Luvisols		5	84	53	Blocky	168	141.6
Nitisols/Vertisols		7	94	60	Blocky	171	159.4
Plinthosols		8	105	31	Blocky, apedal	140	144.3
Plinthosols/Cambisols		1	90	35	Apedal	160	144.0
Vertisols		283	76	59	Blocky, apedal	175	132.1
Vertisols/Cambisols		3	75	57	Blocky	173	130.0
Vertisols/Gleysols		5	45	57	Blocky, apedal	176	77.6
Vertisols/Luvisols		4	75	56	Blocky	150	112.5
Vertisols/Nitisols		17	80	58	Blocky	171	136.8
Sum		1,226	114	39		148	163.8

[2] Major two structures at a depth of 0-30 cm

Table 9. Soil texture and chemical propertiesof Estates.

Soil type	Soil texture[3]	**Ex.Na**(%)	**EC**(dS/m)	**SAR**(%)	**pH**
		0 - 90 cm			
Albeluvisols	MLS/MLS/FSC	0.98	0.14	0.75	6.81
Albeluvisols/Cambisols	FSCL/FSL/FSC	2.00	ND	ND	ND
Albeluvisols/Fluvisols	MLS/MLS/MLS	1.00	ND	ND	ND
Arenosols	MLS/CS	3.78	0.62	2.67	7.56
Arenosols/Cambisols	MLS/MLS	2.30	0.39	1.57	7.37
Arenosols/Fluvisols	MS/MS/MS	1.00	ND	ND	ND
Calcisols	MSCL/MSCL	6.63	1.21	3.67	8.50
Calcisols/Vertisols	CL/FSC	7.64	1.21	5.02	8.62
Cambisols	FSCL/FSC/FSC	5.88	0.70	3.55	7.44
Cambisols/Albeluvisols	FSCL/FSC/MS	8.96	1.95	4.71	8.00
Cambisols/Arenosols	MLS/MSL	2.40	0.30	1.73	7.23
Cambisols/Calcisols	FSCL/C/FSC	5.07	0.75	3.09	8.08
Cambisols/Ferralsols	CLS/CLS/CSCL	11.6	0.75	4.46	6.12
Cambisols/Fluvisols	FSCL/FSCL/FLS	9.50	0.97	9.82	8.22
Cambisols/Gleysols	FSCL/FSC	2.00	ND	ND	ND
Cambisols/Luvisols	FSCL/C/C	6.56	0.78	3.54	7.11
Cambisols/Nitisols	C/MSC/CLS	3.77	0.43	2.44	7.33
Cambisols/Vertisols	FSC/FSC/FSC	4.40	0.45	3.18	7.86
Ferralsols/Cambisols	CLS/CLS/CSL	5.34	0.61	2.51	6.40
Fluvisols	MSL/MLS/MSC	3.10	0.53	1.78	7.97
Fluvisols/Calcisols	C/CS/CSC	1.61	0.37	1.26	8.30
Gleysols	MSC/C/CSC	6.48	0.83	4.39	7.74
Gleysols/Cambisols	FSC/C	7.45	0.63	4.90	8.08
Gleysols/Plinthosols	C/C/C	10.2	1.00	7.87	8.23
Luvisols	MSCL/FSC/MLS	5.76	0.67	3.05	7.32
Luvisols/Albeluvisols	FSCL/MS/FSC	0.60	0.15	0.50	6.86
Luvisols/Cambisols	FSCL/FSC	5.39	0.64	3.31	7.54
Luvisols/Nitisols	FSC/MSC/C	4.55	0.84	2.78	7.66
Luvisols/Vertisols	FSCL/C	4.08	0.66	2.44	7.92
Nitisols	C/FSC/MSC	5.32	0.53	2.80	7.63
Nitisols/Calcisols	C/C/CS	6.08	0.68	2.92	8.22
Nitisols/Cambisols	FSC/FSC/FSC	12.1	0.93	7.50	7.90
Nitisols/Gleysols	C/MSC/CS	7.92	0.67	3.79	8.14
Nitisols/Luvisols	FSC/MSC/C	2.61	0.31	1.65	7.48
Nitisols/Vertisols	C/FSC/FSC	6.54	3.21	3.19	8.10
Plinthosols	MSCL/MSC/MLS	8.93	1.72	4.97	7.56
Plinthosols/Cambisols	FSCL/FSC	4.77	0.34	2.96	7.87
Vertisols	C/C/C	8.98	0.92	4.72	8.25
Vertisols/Cambisols	C	16.9	2.87	14.0	8.08
Vertisols/Gleysols	C/C/C	10.9	0.66	5.22	8.34
Vertisols/Luvisols	C/FSC	3.98	1.84	2.53	7.24
Vertisols/Nitisols	C/C/C	6.59	0.68	3.77	8.06
Sum		6.89	0.79	3.89	7.78

M/CS:medium/coarse sand, F/M/CLS: fine/medium/coarse loamy sand, F/CSL: fine/coarse sandy loam, FSCL: fine sandy clay loam, F/M/CSC: fine/medium/coarse sandy clay, C: clay

[3] Major textures from between the first horizon and the third.

3. Updatedsoil classification

3.1. Geography

Survey zones administratively belong to Chikwawa and Nsanje Distircts and almost located in the vast plains surrounded by mountains lying west and east.

The elevation ranges from 61 to 135 m. The main river is the Shire which has many tributaries including the Mwanza and Thangadzi rivers. The survey zones seem to have developed as fine earth formed by weathering and erosion carried away and deposited for ages.

3.2. Climate

The climate is hot and dry relative to the rest of the regions of Malawi. The rainy season starts on November and lasts until April with a mean annual rainfall below 1,000 mm. Dry spells of several weeks within the rainy season are common. During the period between October and December when the soil survey was conducted, the temperature often recorded over 40°C in the afternoon and the rainfall was nearly zero.

3.3. Landform and slope

The landforms in SVIP Zones are divided into uplands (925 ha), dissected uplands (157 ha), dissected footslopes (1,105 ha), ridges in footslopes (1,097 ha), footslopes (5,424 ha), outwash plains (42,792 ha), depressions (1,399 ha), and floodplains (2,601 ha). Almost all the soil survey zones are flat or level plains with an elevation of 101 to 106 meters. In general, slope is very gentle with a slope direction of east toward the Shire River (Table 10).

Partially depressed areas as well as the eastern lower parts of survey zones were flooded on the January of 2016. It was observed that small depressions and the lowlands near M1 road can be easily ponded. Large tributaries and streams frequently flooded after a rainstorm.This is not so with the uplands and footslopes with a slope between 2-8% located in the western parts of survey zones.

Table 10. Slope distribution in SVIP Zones.

Slope	0-2%	2-4%	4-8%	nc	Sum
Hacterage (ha, %)	53,491 (96.3)	1,457 (2.6)	455 (0.8)	140 (0.3)	55,543 (100.0)

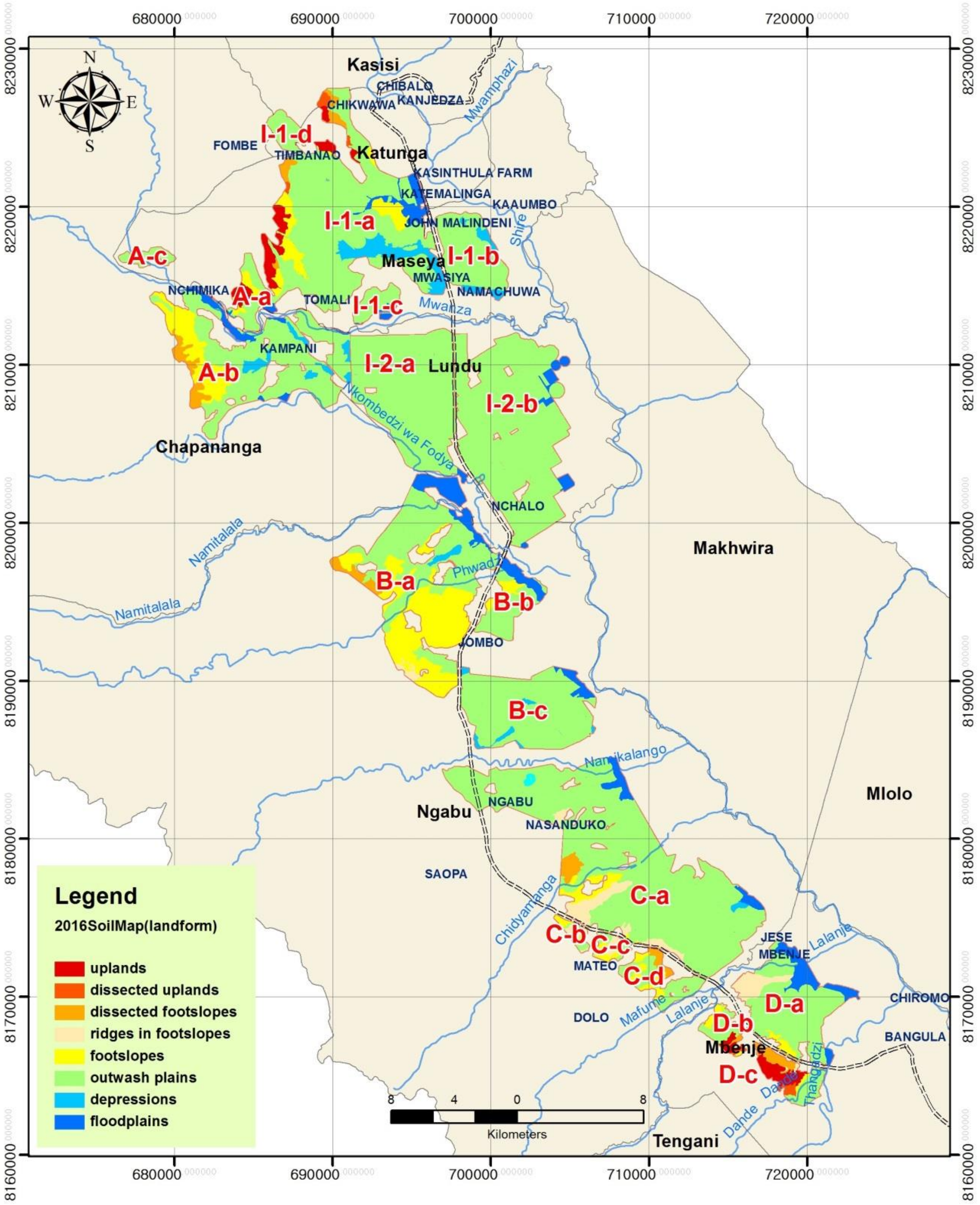

Figure 15. Landforms in SVIP Zones.

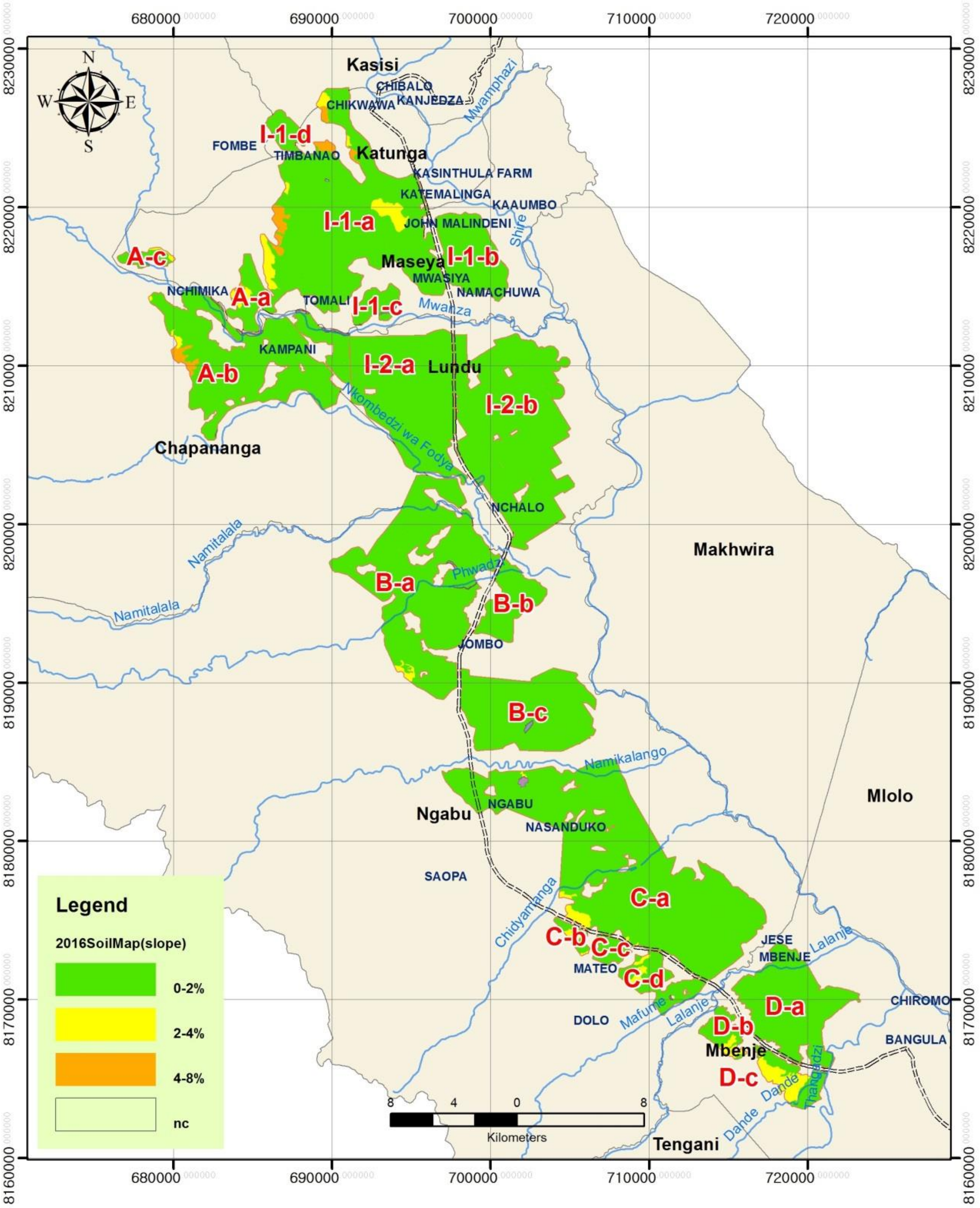

Figure 16. Slope gradient inSVIP Zones.

3.4. Soils

From the present on-site observation and soil analysis, 11 RSGs and 17qualifiers were used in order to classify soils, asshown in Table 11, considering soil texture, rock fragments, drainage, flooding and ponding, carbonate content, erosion, crack development, etc.

Table 11. RSGs and qualifiers applied in soil classification.

RSG	Hectarage	Principal qualifiers	Supplemented qualifiers
Arenosols[4]	1,711	Rubic, Fluvic Salic, Dystric	
Calcisols[5]	540	-	-
Cambisols[6]	15,541	Gleyic, Stagnic Fluvic, Vertic Skeletic, Salic Sodic, Calcaric Dysric/Eutric	Arenic/Clayic/Loamic
Ferralsols[7]	57	-	-
Fluvisols[8]	10,993	Gleyic, Stagnic Skeletic, Sodic Calcaric, Dystric/Eutric	Arenic/Clayic/Loamic Salic
Gleysols[9]	412		
Luvisols[10]	12,912	Abruptic, Gleyic Stagnic, Vertic Calcic, Skeletic Endocalcaric	Clayic/Loamic Salic Sodic
Nitisols[11]	817	-	-
Plinthosols[12]	107	-	-
Retisols[13]	28	-	-
Vertisols[14]	12,151	Salic, Sodic Calcic, Skeletic Haplic	Calcaric Gleyic Stagnic
Not classified (nc)	259		
Sum	55,528		

[4] Arenosols in Esatates = Arenosols +Arenosols/Cambisols + Arenosols/Fluvisols
[5] Calcisols in Esatates = Calcisols +Calcisols/Vertisols
[6] Cambisols in Estates = Cambisols + Cambisols/Albeluvisols or Arenosols or Calcisols or Ferralsols or Fluvisols or Gleysols or Luvisols or Nitisols or Vertisols
[7] Ferralsols in Estates = Ferrasols/Cambisols
[8]Fluvisols in Estates = Fluvisols + Fluvisols/Calcisols
[9]Gleysols in Estates = Gleysols + Gleysols/Cambisols or Plinthosols
[10]Luvisols in Estates = Luvisols + Luvisols/Cambisols or Plinthosols
[11]Nitisols in Estates = Nitisols + Nitisols/Calcisols or Cambisols or Vertisols
[12]Plinthosols in Estates = Plinthosols + Plinthosols/Cambisols
[13]Retisols in Estates = Albeluvisols + Albuluvisols/Cambisols or Fluvisols
[14]Vertisols in Estates = Vertisols + Vertisols/Cambisols or Gleysols or Nitisols or Luvisols

3.5.1. Reference soil groups

There are 11RSGs in the Estates and 5 in the other part of SVIP Zones. The soil map in the first level, i.e., RSGs are delineated as per Figure 17.

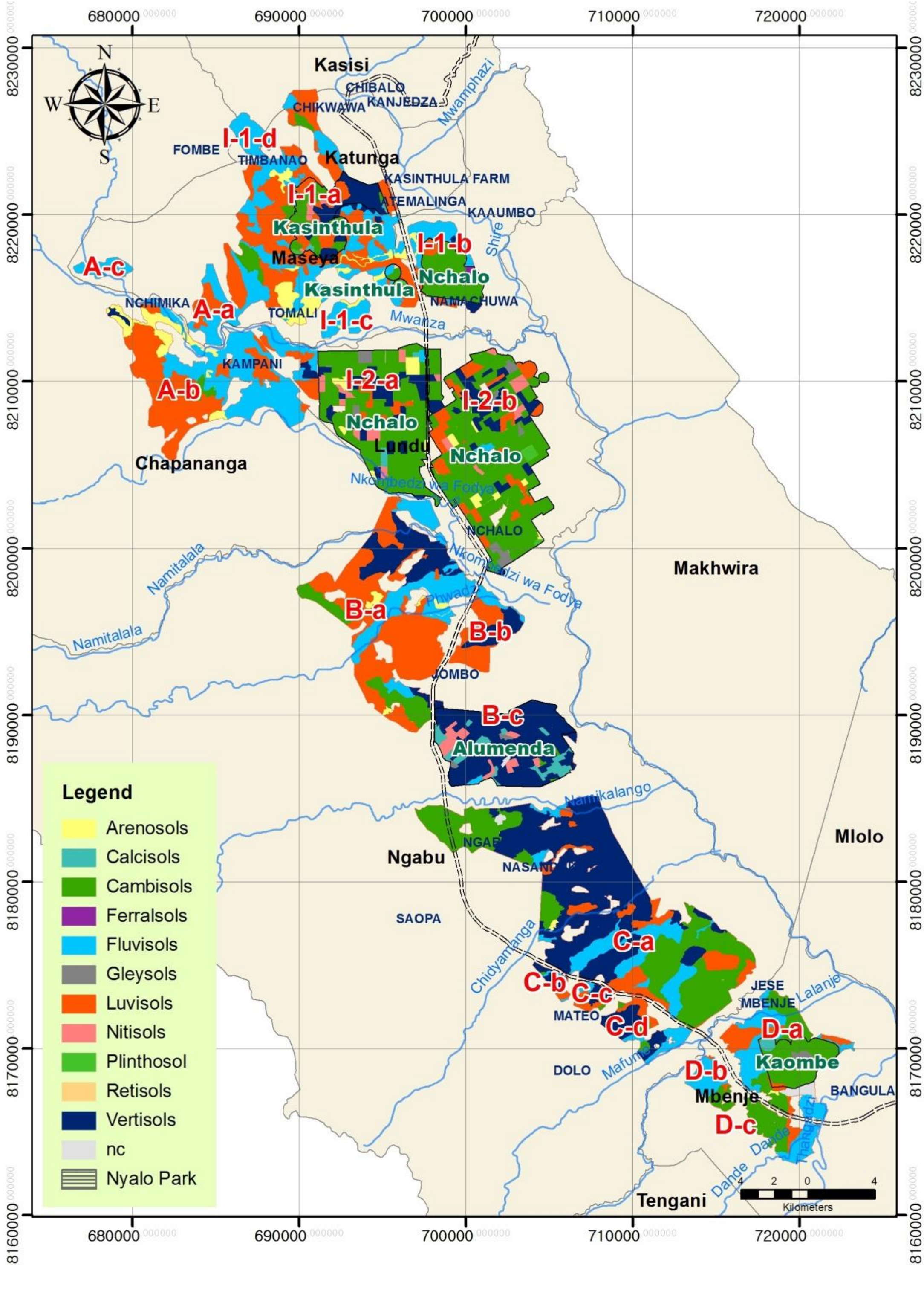

Figure 17. 2016 soil map classified in the first level.

The definitions and characteristics of 11 RSGs are summmarized as follows.

1) Arenosols (AR)

Arenosols comprise deep sandy soils. These include soils in residual sands after in-situ weathering of usually quartz-rich sediments or rock, and soils in recentlydeposited sands. Parent materials are unconsolidated, in places calcareous, translocated materials of sandy texture. In the dry zone, there is little or no soil development.

The characteristic that all Arenosols have in common is their coarse texture, accounting for their generally high permeability and low water and nutrient storage capacity. On the other hand, Arenosols offer ease of cultivation,rooting and harvesting of root and tuber crops.

Table 12. Characteristics of Arenosols in SVIP Zones.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture[15] (top/sub)
Soil survey area	1,407	U, AA4T	0-2	Well	Slight	LS/LS
Estates	304	AA4C	0-2	-	Slight	Si/Si
Location	**pH[16]**	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (%)**	**P (ppm)**
Soil survey area	6.9/6.9	4.8/6.2	0.6/1.0	1.64/1.65	0.05/0.05	35.7/27.7
Estates	7.6/7.5	0.7/0.5	3.6/3.8	1.89/-	-	494.5/-

2) Calcisols (CL)

Calcisols accommodate soils with substantial accumulation of secondary carbonates.Calcisols are widespread in arid and semi-arid environments, often associated with highly calcareous parent materials.Parent materials are mostly alluvial, colluvial and aeolian deposits of base-richweathering material.Typical Calcisols have a pale brown surface horizon; substantial accumulation of secondary carbonates occurs within 100 cm of the soil surface.

[15]For OM and P in Estates, topsoil : 0-30cm

[16] For texture, pH, EC, and ESP in Estates, topsoil : 0-50cm and subsoil : 50-90 cm

Table 13. Characteristics of Calcisols in Estates.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture (top/sub)
Estates	540	AA4C	0-2	-	Slight	SiCL/CL
	pH	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (%)**	**P (ppm)**
	8.5/8.6	1.1/1.2	6.6/6.6	1.34/-	-	110.4/-

3) Cambisols (CM)

Cambisols combine soils with at least an incipient subsurface soil formation.Transformation of parent material is evident from structure formation and mostly brownish discoloration, increasing clay percentage, and/or carbonate removal. Parent materials are medium and fine textured materials derived from a wide range of rocks. Cambisols are characterized by slight or moderate weathering of parent material and by absence of appreciable quantities of illuviated clay, organic matter, Al and/or Fe compounds.

Cambisols also encompass soils that fail one or more characteristics diagnostic for other RSGs, including highly weathered ones. Cambisols generally make good agricultural land and are used intensively.

Table 14. Characteristics of Cambisols in SVIP Zones.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture (top/sub)
Soil survey area	5,724	U, AA4T	0-8	Poor-well	Slight-moderate	SCL/SCL
Estates	9,817	AA4C	0-2	-	Slight	SiL/CL
Location	**pH**	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (ppm)**	**P (ppm)**
Soil survey area	7.7/7.9	1.3/1.0	3.0/5.6	1.80/1.61	0.06/0.05	29.4/33.3
Estates	7.4/7.5	0.7/0.7	5.7/6.0	2.18/-	-	225.3/-

4) Ferralsols (FR)

Ferralsols represent the classical, deeply weathered, red or yellow soils of the humid tropics. These soils have diffuse horizon boundaries, a clay assemblage dominated by low-activity clays (mainly kaolinite) and a high content of sesquioxides. Parent materials are strongly weathered material on old, stable geomorphic surfaces.Deep and intensive weathering has resulted in a residual concentration of resistant primary minerals (e.g. quartz) along with sesquioxides and kaolinite. This mineralogy and the relatively low pH explain the stable microstructure and yellowish (goethite) or reddish (hematite) soil colors.

Most Ferralsols have good physical properties. Great soil depth, good permeability and stable microstructure make Ferralsols less susceptible to erosion than most other intensely weathered tropical soils. Moist Ferralsols are friable and easy to work. They are well drained but may at times be droughty because of their low available water storage capacity.

Table 15. Characteristics of Ferralsols in Estates.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture (top/sub)
Estates	57	AA4C	0-2	-	Slight	LS/SL
	pH	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (ppm)**	**P (ppm)**
	6.4/6.4	0.6/0.6	4.5/6.4	1.94/-	-	294.0/-

5) Fluvisols (FL)

Fluvisols accommodate genetically young soils in fluvial, lacustrine or marine deposits. Parent materials are predominantly recent fluvial deposits. Profiles with evidence of stratification; weak horizon differentiation but a distinct topsoil horizon may be present.The good natural fertility of most Fluvisols and attractive dwelling sites on river levees were recognized in prehistoric times.

Paddy rice cultivation is widespread on tropical Fluvisols with satisfactory irrigation. Many dryland crops are grown on Fluvisols as well, normally with some form of water control.

6) Gleysols (GL)

Gleysols comprise soils saturated with groundwater for long enough periods to develop reducing conditions resulting in gleyic properties, including underwater soils. Parent material consists of a wide range of unconsolidated materials, mainly fluvial sediments. Evidence of reduction processes with segregation of Fe compounds starts within 40 cm of the soil surface.

For many Gleysols, the main obstacle to utilization is the necessity to install a drainage system to lower the groundwater table. Adequately drained Gleysols can be used for arable cropping, dairy farming and horticulture. Soil structure will be destroyed for along time if soils are cultivated when too wet.

Table 16. Characteristics of Fluvisols in SVIP Zones.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture (top/sub)
Soil survey area	10,861	U, AA4T	0-2	Poor-very well	Slight	SCL/SCL
Estates	132	AA4C	0-2	-	Slight	SiL/SL
Location	**pH**	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (ppm)**	**P (ppm)**
Soil survey area	7.1/7.2.	0.01/0.01	1.1/2.0	1.77/1.26	0.06/0.04	38.6/29.8
Estates	8.0/8.1	0.5/0.6	2.2/3.7	1.82/-	-	224.4/-

Table 17. Characteristics of Gleysols in Estates.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture (top/sub)
Estates	412	AA4C	0-2	Poorly	None	SiCL/SiCL
	pH	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (ppm)**	**P (ppm)**
	7.6/7.7	0.8/0.8	6.1/7.5	2.29	-	318.9

7) Luvisols (LV)

Luvisols have a higher clay content in the subsoil than in the topsoil, as a result of pedogenetic processes (especially clay migration) leading to an argic subsoil horizon.They have high-activity clays throughout the argic horizon and a high base saturation in the 50-100 cm depth. Parent materials are a wide variety of unconsolidated materials including aeolian, alluvial and colluvial deposits. Luvisols have pedogenetic differentiation of clay content, with a lower content in the topsoil and a higher content in the subsoil, without marked leaching of base cations or advanced weathering of high-activity clays.

Most of them are fertile soils and suitable for a wide range of agricultural uses. Luvisols with a high silt content are susceptible to structure deterioration where tilled when wet or with heavy machinery. Luvisols on steep slopes require erosion control measures. In places, the dense subsoil causes temporarily reducing conditions with stagnic properties.

Table 18. Characteristics of Luvisols in SVIP Zones.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture (top/sub)
Soil survey area	11,293	U, AA4T	0-8	Imperfect-somewhat excessive	None-severe	SCL/SCL
Estates	1,619	AA4C	0-2	-	Slight	SCL/CL
	pH	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (ppm)**	**P (ppm)**
Soil survey area	7.0/7.2	1.5/1.6	2.3/3.5	1.46/1.19	0.05/0.04	32.3/25.5
Estates	7.2/7.5	0.7/0.7	4.6/6.6	2.24/-	-	159.8/-

8) Nitisols (NT)

Nitisols are deep, well-drained, red tropical soils with diffuse horizon boundaries and a subsurface horizon with at least 30 percent clay and moderate to strong angular blocky structure breaking into polyhedral or flat-edged or nut-shaped elements with, in moist state, shiny aggregate faces. Weathering is relatively advanced but they are far more productive than most other red tropical soils. Parent materials are finely textured weathering products of intermediate to basic parent rock.

Nitisols are red or reddish-brown clayey soils with a nitic subsurface horizonof high aggregate stability. The clay assemblage of them is dominated by kaolinite/(meta) halloysite. Nitisols are rich in Fe and have little water-dispersible clay. The deep and porous solum and the stable soil structure of them permit deep rooting and make these soils quite resistant to erosion. The good workability of Nitisols, their good internal drainage and fair water holding properties are complemented by chemical (fertility) properties that compare favorably with those of most other tropical soils.

9) Plinthosols (PT)

Plinthosols are soils with plinthite, petroplinthite or pisoliths. Plinthite is a Fe-rich (in some cases also Mn-rich), humus-poor mixture of kaolinitic clay (and other products of strong weathering such as gibbsite) with quartz and other constituents. It usually changes irreversibly to a layer with hard concretions or nodules or to a hardpan on exposure to repeated wetting and drying. They are a continuous or fractured sheet of connected, strongly cemented to indurated concretions or nodules or concentrations in platy, polygonal or reticulate patterns. Pisoliths are discrete, strongly cemented to indurated concretions or nodules. Both petroplinthite and pisoliths develop from plinthite by hardening. Parent material is plinthite more common in weathering material from basic rock than in acidic rock weathering.

Plinthosols present considerable management problems. Poor natural soil fertility caused by strong weathering, waterlogging in bottomlands and drought on Plinthosols with petroplinthite or pisoliths are serious limitations.

Table 19. Characteristics of Nitisols in Estates.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture (top/sub)
Estates	817	AA4C	0-2	-	Slight	SiC/CL
	pH	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (ppm)**	**P (ppm)**
	7.8/7.8	0.6/0.6	5.5/6.7	2.45/-	-	154.1

Table 20. Characteristics of Plinthosols in Estates.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture (top/sub)
Estates	107	AA4C	0-2	-	Slight	SCL/SC
	pH	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (ppm)**	**P (ppm)**
	7.1/7.4	1.4/0.7	8.8/9.2	2.1	-	198.3

10) Retisols (RT)

Retisols have a clay illuviation horizon with an inter-fingering of bleached coarser textured soil material into the illuviation horizon forming a net-like pattern. The inter-fingering bleached coarser-textured material is characterized by a partial removal of clay and free iron oxides. There may be also bleached coarser-textured material falling from the overlying horizon into cracks in the illuvial horizon. Parent materials are materials of fluvial origin and aeolian deposits. A thin, dark surface horizon over a layer with coarser-texture dalbic material inter-fingers as a net into an underlying brown argic or natric horizon.The agricultural suitability of Retisols is limited because of their acidity, low nutrient levels, tillage and drainage problems.

11) Vertisols (VR)

Vertisols are heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. Parent materials are sediments that contain a high proportion of swelling clays. Alternate swelling and shrinking of expanding clays results in deep cracks in the dry season, and formation of slickensides and wedge-shaped structural elements in the subsurface soil.

Large areas of Vertisols in the semi-arid tropics are still unused or are used only for extensive grazing, wood chopping, charcoal burning and the like. These soils have considerable agricultural potential, but adapted management is a precondition for sustained production. The comparatively good chemical fertility and their occurrence on extensive level plains where reclamation and mechanical cultivation can be envisaged are assets of Vertisols. Their physical soil characteristics, and notably their difficult water relations, cause management problems. Buildings and other structures on Vertisols are at risk and engineers have to take special precautions to avoid damage.

Table 21. Characteristics of Retisols in Estates.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture (top/sub)
Estates	28	AA4C	0-2	-	Slight	SCL/SCL
	pH	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (ppm)**	**P (ppm)**
	6.9/6.8	0.2/0.1	1.1/0.8	1.36	-	226.3

Table 22. Characteristics of Vertisols in SVIP Zones.

Location	Area (ha)	Land use	Slope (%)	Drainage	Erosion	Texture (top/sub)
Soil survey area	7,426	U, AA4T	0-4	Imperfect-well	None-severe	C/C
Estates	4,725	AA4C	0-2	-	Slight	C/C
	pH	**EC (dS/m)**	**ESP (%)**	**OM (%)**	**N (ppm)**	**P (ppm)**
Soil survey area	7.8/8.0	2.6/3.8	2.1/3.5	1.88/1.71	0.07/0.06	32.0/32.4
Estates	8.1/8.3	0.9/0.9	7.8/10.0	2.43/-	-	137.7/-

3.5.2. Principle qualifiers

The definitions of the qualifiers for the second-level units relate to RSGs, diagnostic horizons, properties and materials, attributes such as colour, chemical conditions, texture, etc.

Subqualifiers may be used in the soil name instead of the qualifier listed in the Key. Subqualifiers that cannot replace a listed qualifier are found in alphabetical order. Qualifiers that have depth requirements can be combined with the specifiers Epi-,Endo-, Amphi- and Panto- to create subqualifiers (e.g. Epicalcic, Endocalcic) further expressing the depth of occurrence.

① If a qualifier refers to a horizon or layer (e.g. Calcic, Arenic):

- Epi-: the horizon or layer has its lower limit ≤ 50 cm of the (mineral) soil surface.
- Endo-: the horizon or layer starts between > 50 and ≤ 100 cm of the (mineral) soil surface.
- Amphi-: the horizon or layer starts < 50 cm of the (mineral) soil surface and has its lower limit > 50 cm of the (mineral) soil surface.
- Panto-: the horizon or layer starts at the (mineral) soil surface and has its lower limit ≥ 100 cm of the (mineral) soil surface.

② If a qualifier refers to the major part of a certain depth range (Dystric and Eutric):

- Epi-: the characteristic is present in the major part between the (mineral) soil surface (or the specified upper limit) and 50 cm from the (mineral) soil surface and is absent in the major part between 50 and 100 cm from the (mineral) soil surface or between 50 cm from the (mineral) soil surface and continuous rock, technic hard material or a cemented or indurated layer, whichever is shallower.
- Endo-: the characteristic is present in the major part between 50 and 100 cm from the (mineral) soil surface or between 50 cm from the (mineral) soil surface and continuous rock, technic hard material or a cemented or indurated layer, whichever is shallower, and absent in the major part between the (mineral) soil surface (or the specified upper limit) and 50 cm from the (mineral) soil surface.
- Panto-: the characteristic is present from the (mineral) soil surface to a depth of 100 cm from the (mineral) soil surface throughout.

③ If a qualifier refers to a specified depth range throughout (e.g. Sodic, Calcaric):

- Epi-: the characteristic is present throughout between the (mineral) soil surface (or the specified upper limit) and 50 cm from the (mineral) soil surface and is absent in some layer between 50 and 100 cm from the (mineral) soil surface.
- Endo-: the characteristic is present throughout between 50 and 100 cm from the

(mineral) soil surface or between 50 cm from the (mineral) soil surface and continuous rock, technic hard material or a cemented or indurated layer, whichever is shallower, and is absent in some layer ≤ 50 cm from the (mineral) soil surface.

Fourteen principle qualifiers applied in the second level classification of RSGs are defined as follows.

1) Abruptic (ap): having an abrupt textural difference within ≤ 100 cm of the mineral soil surface.

2) Calcaric (ca): having calcaric material throughout between 20 and 100 cm from the soil surface, or between 20 cm and continuous rock, or a cemented or indurated layer, whichever is shallower.

3) Calcic (cc): having a calcic horizon starting ≤ 100 cm from the soil surface.

Hypercalcic (jc): having a calcic horizon with a calcium carbonate equivalent in the fine earth fraction of ≥ 50% (by mass) and starting ≤ 100 cm from the soil surface.

Hypocalcic (wc): having a calcic horizon with a calcium carbonate equivalent in the fine earth fraction of < 25% (by mass) and starting ≤ 100 cm from the soil surface.

Protocalcic (qc): having a layer with protocalcic properties starting ≤ 100 cm from the soil surface and not having a calcic or petrocalcic horizon starting ≤ 100 cm from the soil surface.

4) Dystric (dy): having a base saturation of < 50% in the major part between 20 and 100 cm from the mineral soil surface or between 20 cm and a cemented or indurated layer, whichever is shallower, or in a layer ≥ 5 cm thick, directly above a cemented or indurated layer, if the cemented or indurated layer starts ≤ 25 cm from the mineral soil surface.

5) Eutric (eu): having a base saturation of ≥ 50% in the major part between 20 and 100 cm from the mineral soil surface or between 20 cm and a cemented or indurated layer, whichever is shallower, or in a layer ≥ 5 cm thick, directly above a cemented or indurated layer, if the cemented or indurated layer starts ≤ 25 cm from the mineral soil surface.

6) Fluvic (fv): having fluvic material ≥ 25 cm thick, and starting ≤ 75 cm from the mineral soil surface.

7) Gleyic (gl): having a layer ≥ 25 cm thick, and starting ≤ 75 cm from the mineral soil surface, that has gleyic properties throughout and reducing conditions in in some parts of every sublayer.

8) Haplic (ha): having a typical expression of certain features (typical in the sense that there is no further or meaningful characterization) and only used if none of the preceding qualifiers applies.

9) Rubic (ru): having within ≤ 100 cm of the soil surface, a subsurface layer ≥ 30 cm thick, with a Munsell colour hue redder than 10YR and/or a chroma of ≥ 5, both moist (in Arenosols only).

10) Salic (sz): having a salic horizon starting ≤ 100 cm from the soil surface.

Hypersalic (jz): having an ECe of ≥ 30 dS m^{-1} at 25 °C in some layer within ≤ 100 cm of the soil surface.

Protosalic (qz): having an ECe of ≥ 4 dS m^{-1} at 25 °C in some layer within ≤ 100 cm of the soil surface and not having a salic horizon starting ≤ 100 cm from the soil surface.

11) Skeletic (sk): having ≥ 40% (by volume) coarse fragments averaged over a depth of 100 cm from the soil surface or to continuous rock, technic hard material or a cemented or indurated layer, whichever is shallower.

12) Sodic (so): having ≥ 15% exchangeable Na plus Mg and ≥ 6% exchangeable Na on the exchange complex, in a layer ≥ 20 cm thick, starting ≤ 100 cm from the soil surface and not having a natric horizon starting ≤ 100 cm from the soil surface.

13) Stagnic (st): having a layer ≥ 25 cm thick, and starting ≤ 75 cm from the mineral soil surface, that does not form part of a hydragric horizon and that has:

• stagnic properties in which the area of reductimorphic colours plus the area of oximorphic colors is ≥ 25% of the total area, and

• reducing conditions for some time during the year in the major part of the soil volume that has the reductimorphic colors.

14) Vertic (vr): having a vertic horizon starting ≤ 100 cm from the soil surface.

Protovertic (qv): having a protovertic horizon starting ≤ 100 cm from the soil surface and not having a vertic horizon starting ≤ 100 cm from the soil surface.

3.5.3. Supplementary qualifiers

Nine supplementary qualifiers are introduced in order to complement principle qualifiers.

1) Arenic (ar): having a texture class of sand or loamy sand in a layer ≥ 30 cm thick, within ≤ 100 cm of the mineral soil surface or between the mineral soil surface and a cemented or indurated layer, whichever is shallower.

2) Calcaric (ca): having calcaric material throughout between 20 and 100 cm from the soil surface, or between 20 cm and continuous rock, or a cemented or indurated layer, whichever is shallower.

3) Clayic (ce): having a texture class of clay, sandy clay or silty clay, in a layer ≥ 30 cm thick, within ≤ 100 cm of the mineral soil surface or between the mineral soil surface and a cemented or indurated layer, whichever is shallower.

15) Fluvic (fv): having fluvic material ≥ 25 cm thick, and starting ≤ 75 cm from the mineral soil surface.

4) Gleyic (gl): having a layer ≥ 25 cm thick, and starting ≤ 75 cm from the mineral soil surface, that has gleyic properties throughout and reducing conditions in in some parts of every sublayer.

5) Loamic (lo): having a texture class of loam, sandy loam, sandy clay loam, clay loam or silty clay loam in a layer ≥ 30 cm thick, within ≤ 100 cm of the mineral soil surface or between the mineral soil surface and a cemented or indurated layer, whichever is shallower.

6) Salic (sz): having a salic horizon starting ≤ 100 cm from the soil surface.

Hypersalic (jz): having an ECe of ≥ 30 dS m-1 at 25 °C in some layer within ≤ 100 cm of the soil surface.

Protosalic (qz): having an ECe of ≥ 4 dS m^{-1} at 25 °C in some layer within ≤ 100 cm of the soil surface and not having a salic horizon starting ≤ 100 cm from the soil surface.

7) Sodic (so): having ≥ 15% exchangeable Na plus Mg and ≥ 6% exchangeable Na on the exchange complex, in a layer ≥ 20 cm thick, starting ≤ 100 cm from the soil surface and not having a natric horizon starting ≤ 100 cm from the soil surface.

8) Stagnic (st): having a layer ≥ 25 cm thick, and starting ≤ 75 cm from the mineral soil surface, that does not form part of a hydragric horizon and that has:

• stagnic properties in which the area of reductimorphic colours plus the area of oximorphic colors is ≥ 25% of the total area, and

• reducing conditions for some time during the year in the major part of the soil volume that has the reductimorphic colors.

3.5.4. Soil types and soil units

Soils distributed in SVIP Zones are classified into 218 soil types composed of 960 soil unit polygons according to the RSGs, qualifiers, and specifiers in Table 11.

The new soil map is delineated in Figure 18 and the legend is presented in more detail in Table 23. The characteristics of each soil unit can be referred to in Annex 3 (Soil Unit and Land Unit Inventory).

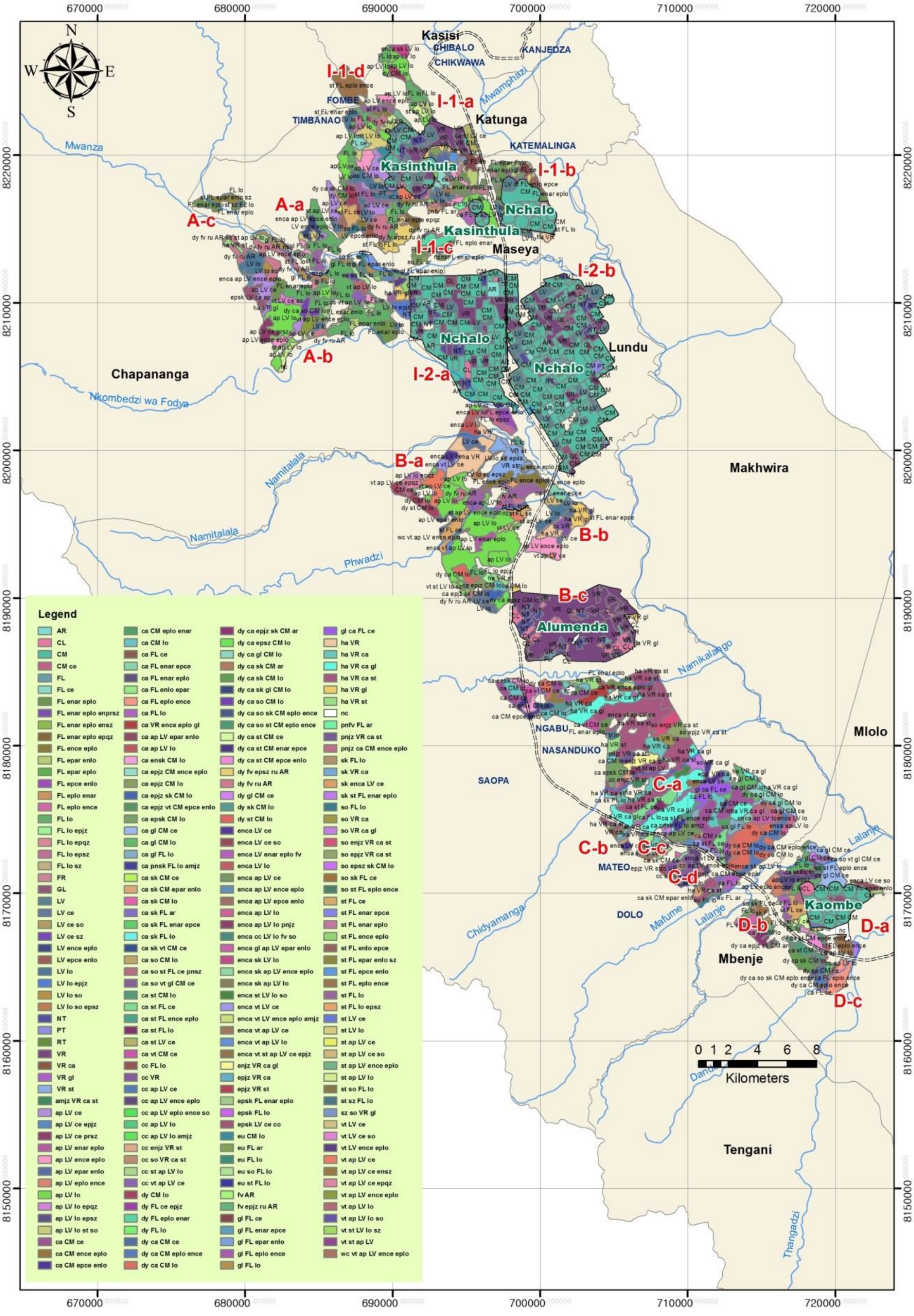

Figure 18. 2016 Soil Map of SVIP Zones.

Table 23. List of soil types in legend.

Legend	Soil type (RSG +Qualifiers)	Ha
AR	Arenosols	304
CL	Calcisols	540
CM	Cambisols	9,817
CM ce	Cambisols Clayic	40
FL	Fluvisols	132
FL ce	Fluvisols Clayic	204
FL enar eplo	Fluvisols Endoarenic Epiloamic	1,015
FL enar eplo enprsz	Fluvisols Endoarenic Epiloamic Endoprotosalic	8
FL enar eplo ensz	Fluvisols Endoarenic Epiloamic Endosalic	3
FL enar eplo epqz	Fluvisols Endoarenic Epiloamic Epiprotosalic	67
FL ence eplo	Fluvisols Endoclayic Epiloamic	422
FL epar enlo	Fluvisols Epiarenic Endoloamic	375
FL epar eplo	Fluvisols Epiarenic Epiloamic	12
FL epce enlo	Fluvisols Epiclayic Endoloamic	106
FL eplo enar	Fluvisols Epiloamic Endoarenic	30
FL eplo ence	Fluvisols Epiloamic Endoclayic	144
FL lo	Fluvisols Loamic	2,674
FL lo epjz	Fluvisols Loamic Epihypersalic	37
FL lo epqz	Fluvisols Loamic Epiprotosalic	24
FL lo epsz	Fluvisols Loamic Episalic	157
FL lo sz	Fluvisols Loamic Salic	22
FR	Ferralsols	57
GL	Gleysols	412
LV	Luvisols	1,599
LV ce	Luvisols Clayic	299
LV ce so	Luvisols Clayic Sodic	23
LV ce sz	Luvisols Clayic Salic	26
LV ence eplo	Luvisols Endoclayic Epiloamic	109
LV epce enlo	Luvisols Epiclayic Endoloamic	57
LV lo	Luvisols Loamic	1,253
LV lo epjz	Luvisols Loamic Epihypersalic	111
LV lo so	Luvisols Loamic Sodic	39
LV lo so epsz	Luvisols Loamic Sodic Episalic	66
NT	Nitisols	817

Legend	Soil type (RSG +Qualifiers)	Ha
PT	Plinthosols	107
RT	Retisols	28
VR	Vertisols	4,709
VR ca	Vertisols Calcaric	22
VR gl	Vertisols Gleyic	16
VR st	Vertisols Stagnic	493
amjz VR ca st	Amphihypersalic Vertisols Calcaric Stagnic	41
ap LV ce	Abruptic Luvisols Clayic	731
ap LV ce epjz	Abruptic Luvisols Clayic Epihypersalic	28
ap LV ce prsz	Abruptic Luvisols Clayic Protosalic	130
ap LV enar eplo	Abruptic Luvisols Endoarenic Epiloamic	78
ap LV ence eplo	Abruptic Luvisols Endoclayic Epiloamic	698
ap LV epar enlo	Abruptic Luvisols Epiarenic Endoloamic	123
ap LV eplo ence	Abruptic Luvisols Epiloamic Endoclayic	126
ap LV lo	Abruptic Luvisols Loamic	3,199
ap LV lo epqz	Abruptic Luvisols Loamic Epiprotosalic	38
ap LV lo epsz	Abruptic Luvisols Loamic Episalic	172
ap LV lo st so	Abruptic Luvisols Loamic Stagnic Sodic	24
ca ap LV epar enlo	Calcaric Abruptic Luvisols Epiarenic Endoloamic	28
ca ap LV lo	Calcaric Abruptic Luvisols Loamic	38
ca CM ce	Calcaric Cambisols Clayic	742
ca CM ence eplo	Calcaric Cambisols Endoclayic Epiloamic	51
ca CM epce enlo	Calcaric Cambisols Epiclayic Endoloamic	90
ca CM eplo enar	Calcaric Cambisols Epiloamic Endoarenic	40
ca CM lo	Calcaric Cambisols Loamic	436
ca ensk CM lo	Calcaric Endoskeletic Cambisols Loamic	111
ca epjz CM ence eplo	Calcaric Epihypersalic Cambisols Endoclayic Epiloamic	14
ca epjz CM lo	Calcaric Epihypersalic Cambisols Loamic	82
ca epjz sk CM lo	Calcaric Epihypersalic Skeletic Cambisols Loamic	73
ca epjz vt CM epce enlo	Calcaric Epihypersalic Vertic Cambisols Epiclayic Endoloamic	18
ca epsk CM lo	Calcaric Episkeletic Cambisols Loamic	172
ca FL ce	Calcaric Fluvisols Clayic	17
ca FL enar epce	Calcaric Fluvisols Endoarenic Epiclayic	86
ca FL enar eplo	Calcaric Fluvisols Endoarenic Epiloamic	44
ca FL enlo epar	Calcaric Fluvisols Endoloamic Epiarenic	39

Legend	Soil type (RSG +Qualifiers)	Ha
ca FL eplo ence	Calcaric Fluvisols Epiloamic Endoclayic	290
ca FL lo	Calcaric Fluvisols Loamic	376
ca gl CM ce	Calcaric Gleyic Cambisols Clayic	361
ca gl CM lo	Calcaric Gleyic Cambisols Loamic	166
ca gl FL lo	Calcaric Gleyic Fluvisols Loamic	110
ca pnsk FL lo amjz	Calcaric Pantoskeletic Fluvisols Loamic Amphihypersalic	57
ca sk CM ce	Calcaric Skeletic Cambisols Clayic	25
ca sk CM epar enlo	Calcaric Skeletic Cambisols Epiarenic Endoloamic	36
ca sk CM lo	Calcaric Skeletic Cambisols Loamic	12
ca sk FL ar	Calcaric Skeletic Fluvisols Arenic	30
ca sk FL enar epce	Calcaric Skeletic Fluvisols Endoarenic Epiclayic	25
ca sk FL lo	Calcaric Skeletic Fluvisols Loamic	32
ca sk vt CM ce	Calcaric Skeletic Vertic Cambisols Clayic	43
ca so CM lo	Calcaric Sodic Cambisols Loamic	8
ca so st FL ce pnsz	Calcaric Sodic Stagnic Fluvisols Clayic Pantosalic	35
ca so vt gl CM ce	Calcaric Sodic Vertic Gleyic Cambisols Clayic	29
ca st CM lo	Calcaric Stagnic Cambisols Loamic	167
ca st FL ce	Calcaric Stagnic Fluvisols Clayic	328
ca st FL ence eplo	Calcaric Stagnic Fluvisols Endoclayic Epiloamic	67
ca st FL lo	Calcaric Stagnic Fluvisols Loamic	102
ca st LV ce	Calcaric Stagnic Luvisols Clayic	113
ca VR ence eplo gl	Calcaric Vertisols Endoclayic Epiloamic Gleyic	214
ca vt CM ce	Calcaric Vertic Cambisols Clayic	146
cc ap LV ce	Calcic Abruptic Luvisols Clayic	9
cc ap LV ence eplo	Calcic Abruptic Luvisols Endoclayic Epiloamic	90
cc ap LV eplo ence so	Calcic Abruptic Luvisols Epiloamic Endoclayic Sodic	11
cc ap LV lo	Calcic Abruptic Luvisols Loamic	26
cc ap LV lo amjz	Calcic Abruptic Luvisols Loamic Amphihypersalic	5
cc enjz VR st	Calcic Endohypersalic Vertisols Stagnic	43
cc FL lo	Calcic Fluvisols Loamic	19
cc so VR ca st	Calcic Sodic Vertisols Calcaric Stagnic	71
cc st ap LV lo	Calcic Stagnic Abruptic Luvisols Loamic	50
cc VR	Calcic Vertisols	327
cc vt ap LV ce	Calcic Vertic Abruptic Luvisols Clayic	60
dy ca CM ce	Dystric Calcaric Cambisols Clayic	32

Legend	Soil type (RSG +Qualifiers)	Ha
dy ca CM eplo ence	Dystric Calcaric Cambisols Epiloamic Endoclayic	376
dy ca CM lo	Dystric Calcaric Cambisols Loamic	834
dy ca epjz sk CM ar	Dystric Calcaric Epihypersalic Skeletic Cambisols Arenic	83
dy ca epsz CM lo	Dystric Calcaric Episalic Cambisols Loamic	76
dy ca gl CM lo	Dystric Calcaric Gleyic Cambisols Loamic	234
dy ca sk CM ar	Dystric Calcaric Skeletic Cambisols Arenic	9
dy ca sk CM lo	Dystric Calcaric Skeletic Cambisols Loamic	232
dy ca sk gl CM lo	Dystric Calcaric Skeletic Gleyic Cambisols Loamic	21
dy ca so CM lo	Dystric Calcaric Sodic Cambisols Loamic	92
dy ca so sk CM eplo ence	Dystric Calcaric Sodic Skeletic Cambisols Epiloamic Endoclayic	29
dy ca so st CM eplo ence	Dystric Calcaric Sodic Stagnic Cambisols Epiloamic Endoclayic	27
dy ca st CM ce	Dystric Calcaric Stagnic Cambisols Clayic	68
dy ca st CM enar epce	Dystric Calcaric Stagnic Cambisols Endoarenic Epiclayic	26
dy ca st CM epce enlo	Dystric Calcaric Stagnic Cambisols Epiclayic Endoloamic	100
dy CM lo	Dystric Cambisols Loamic	366
dy FL ce epjz	Dystric Fluvisols Clayic Epihypersalic	21
dy FL eplo enar	Dystric Fluvisols Epiloamic Endoarenic	155
dy FL lo	Dystric Fluvisols Loamic	13
dy fv epsz ru AR	Dystric Fluvic Episalic Rubic Arenosols	250
dy fv ru AR	Dystric Fluvic Rubic Arenosols	1,121
dy gl CM ce	Dystric Gleyic Cambisols Clayic	43
dy sk CM lo	Dystric Skeletic Cambisols Loamic	52
dy st CM lo	Dystric Stagnic Cambisols Loamic	14
enca ap LV ce	Endocalcaric Abruptic Luvisols Clayic	214
enca ap LV ence eplo	Endocalcaric Abruptic Luvisols Endoclayic Epiloamic	70
enca ap LV epce enlo	Endocalcaric Abruptic Luvisols Epiclayic Endoloamic	49
enca ap LV lo	Endocalcaric Abruptic Luvisols Loamic	223
enca ap LV lo pnjz	Endocalcaric Abruptic Luvisols Loamic Pantohypersalic	50
enca cc LV lo fv so	Endocalcaric Calcic Luvisols Loamic Fluvic Sodic	56
enca gl ap LV epar enlo	Endocalcaric Gleyic Abruptic Luvisols Epiarenic Endoloamic	73
enca LV ce	Endocalcaric Luvisols Clayic	204
enca LV ce so	Endocalcaric Luvisols Clayic Sodic	50
enca LV enar eplo fv	Endocalcaric Luvisols Endoarenic Epiloamic Fluvic	14
enca LV lo	Endocalcaric Luvisols Loamic	168
enca sk ap LV ence eplo	Endocalcaric Skeletic Abruptic Luvisols Endoclayic Epiloamic	24

Legend	Soil type (RSG +Qualifiers)	Ha
enca sk ap LV lo	Endocalcaric Skeletic Abruptic Luvisols Loamic	5
enca sk LV lo	Endocalcaric Skeletic Luvisols Loamic	80
enca st LV lo so	Endocalcaric Stagnic Luvisols Loamic Sodic	51
enca vt ap LV ce	Endocalcaric Vertic Abruptic Luvisols Clayic	127
enca vt ap LV lo	Endocalcaric Vertic Abruptic Luvisols Loamic	34
enca vt LV ce	Endocalcaric Vertic Luvisols Clayic	144
enca vt LV ence eplo amjz	Endocalcaric Vertic Luvisols Endoclayic Epiloamic Amphihypersalic	38
enca vt st ap LV ce epjz	Endocalcaric Vertic Stagnic Abruptic Luvisols Clayic Epihypersalic	38
enjz VR ca gl	Endohypersalic Vertisols Calcaric Gleyic	138
epjz VR ca	Epihypersalic Vertisols Calcaric	49
epjz VR st	Epihypersalic Vertisols Stagnic	22
epsk FL enar eplo	Episkeletic Fluvisols Endoarenic Epiloamic	47
epsk FL lo	Episkeletic Fluvisols Loamic	15
epsk LV ce co	Episkeletic Luvisols Clayic Colluvic	121
eu CM lo	Eutric Cambisols Loamic	70
eu FL ar	Eutric Fluvisols Arenic	94
eu FL lo	Eutric Fluvisols Loamic	29
eu so FL lo	Eutric Sodic Fluvisols Loamic	94
eu st FL lo	Eutric Stagnic Fluvisols Loamic	34
fv AR	Fluvic Arenosols	23
fv epjz ru AR	Fluvic Epihypersalic Rubic Arenosols	13
gl ca FL ce	Gleyic Calcaric Fluvisols Clayic	224
gl FL ce	Gleyic Fluvisols Clayic	157
gl FL enar epce	Gleyic Fluvisols Endoarenic Epiclayic	20
gl FL epar enlo	Gleyic Fluvisols Epiarenic Endoloamic	85
gl FL eplo ence	Gleyic Fluvisols Epiloamic Endoclayic	17
gl FL lo	Gleyic Fluvisols Loamic	278
ha VR	Haplic Vertisols	726
ha VR ca	Haplic Vertisols Calcaric	528
ha VR ca gl	Haplic Vertisols Calcaric Gleyic	1,342
ha VR ca st	Haplic Vertisols Calcaric Stagnic	2,245
ha VR gl	Haplic Vertisols Gleyic	342
ha VR st	Haplic Vertisols Stagnic	255
nc	not classified	259
pnfv FL ar	Pantofluvic Fluvisols Arenic	38

Legend	Soil type (RSG +Qualifiers)	Ha
pnjz ca CM ence eplo	Pantohypersalic Calcaric Cambisols Endoclayic Epiloamic	55
pnjz VR ca st	Pantohypersalic Vertisols Calcaric Stagnic	56
sk enca LV ce	Skeletic Endocalcaric Luvisols Clayic	20
sk FL lo	Skeletic Fluvisols Loamic	48
sk st FL enar eplo	Skeletic Stagnic Fluvisols Endoarenic Epilomic	38
sk VR ca	Skeletic Vertisols Calcaric	21
so enjz VR ca st	Sodic Endohypersalic Vertisols Calcaric Stagnic	167
so epjz VR ca st	Sodic Epihypersalic Vertisols Calcaric Stagnic	108
so epsz sk CM lo	Sodic Episalic Skeletic Cambisols Loamic	23
so FL lo	Sodic Fluvisols Loamic	78
so sk FL ce	Sodic Skeletic Fluvisols Clayic	43
so st FL eplo ence	Sodic Stagnic Fluvisols Epiloamic Endoclayic	36
so VR ca	Sodic Vertisols Calcaric	68
so VR ca gl	Sodic Vertisols Calcaric Gleyic	133
st ap LV ce	Stagnic Abruptic Luvisols Clayic	17
st ap LV ce so	Stagnic Abruptic Luvisols Clayic Sodic	15
st ap LV ence eplo	Stagnic Abruptic Luvisols Endoclayic Epiloamic	98
st ap LV lo	Stagnic Abruptic Luvisols Loamic	189
st FL ce	Stagnic Fluvisols Clayic	602
st FL enar epce	Stagnic Fluvisols Endoarenic Epiclayic	15
st FL enar eplo	Stagnic Fluvisols Endoarenic Epiloamic	58
st FL ence eplo	Stagnic Fluvisols Endoclayic Epiloamic	77
st FL enlo epce	Stagnic Fluvisols Endoloamic Epiclayic	54
st FL epar enlo sz	Stagnic Fluvisols Epiarenic Endoloamic Salic	91
st FL epce enlo	Stagnic Fluvisols Epiclayic Endoloamic	46
st FL eplo ence	Stagnic Fluvisols Epiloamic Endoclayic	505
st FL lo	Stagnic Fluvisols Loamic	845
st FL lo epsz	Stagnic Fluvisols Loamic Episalic	28
st LV ce	Stagnic Luvisols Clayic	20
st LV lo	Stagnic Luvisols Loamic	302
st so FL lo	Stagnic Sodic Fluvisols Loamic	5
st sz FL lo	Stagnic Salic Fluvisols Loamic	14
sz so VR gl	Salic Sodic Vertisols Gleyic	15
vt ap LV ce	Vertic Abruptic Luvisols Clayic	391
vt ap LV ce ensz	Vertic Abruptic Luvisols Clayic Endosalic	27

Legend	Soil type (RSG +Qualifiers)	Ha
vt ap LV ce epqz	Vertic Abruptic Luvisols Clayic Epiprotosalic	75
vt ap LV ence eplo	Vertic Abruptic Luvisols Endoclayic Epiloamic	117
vt ap LV lo	Vertic Abruptic Luvisols Loamic	76
vt ap LV lo so	Vertic Abruptic Luvisols Loamic Sodic	35
vt LV ce	Vertic Luvisols Clayic	118
vt LV ce so	Vertic Luvisols Clayic Sodic	72
vt LV ence eplo	Vertic Luvisols Endoclayic Epiloamic	42
vt st ap LV	Vertic Stagnic Abruptic Luvisols	37
vt st LV lo sz	Vertic Stagnic Luvisols Loamic Salic	50
wc vt ap LV ence eplo	Hypercalcic Vertic Abruptic Luvisols Endoclayic Epiloamic	19
218 soil types		**55,528**

3.5.5. Soil and terrain limitations

In the 2008 CODA Report, soil limiting factors for cropping were investigated as soil texture, effective depth, water holding capacity, topography, fertility potential, alkalinity, and salinity. Meanwhile, the 1991 FAO map considered soil depth, occurrence of flooding, salinity, drainage, texture, topsoil consistence, presence of free lime, and inherent chemical fertility of the upper 50 cm of the soil.

On the present soil survey, similiarily, soil erosion, flooding and ponding, poor drainage, heavy clayey or sandy texture, high levels of rock content on surface and/or subsoil, hard consistency, salinity and/or sodicity, low fertility could be suggested as vital soil and terrain limiting factors.

1) Soil erosion

Except for part of the western uplands and footslopes, which has soil erosion class of severe unsuitable for cultivation, almost the entire project area (98.4%) has slight erosion hazard due to gentle slope and flat landform. However, a shower of rainstorm can frequently result in severe soil erosion particularly alongside creeks and ditches (Table 24 and Figure 19).

Table 24. Soil erosion classinSVIP Zones.

Erosion class	None	Slight	Moderate	Severe	nc	Sum
Hectarage (%)	522 (0.94)	54,654 (98.4)	249 (0.45)	101 (0.18)	17 (0.03)	55,543 (100.00)

2) Flooding and ponding

There are depressions (1,399 ha) and floodplains (2,601 ha) scattered in SVIP Zones. Partially depressed areas as well as the eastern lower parts of survey zones were flooded on the January of 2016 (Figure 15).

It was observed that small depressions and the lowlands near M1 road can be easily ponded. Large tributaries and streams frequently flooded after a rainstorm. Appropriate embankments along the banks of the Shire and tributaries, draining networks in the fields are long-term pre-requisites for safe and stable cultivation.

3) Soil drainage

Approximately 35 % of the survey zones, including nearly classified Estate fields, consists of well-drained soils that has good qualities for upland crop cultivation (Table

25 and Figure 20). However, imperfectly or poorly-drained soils (16,146 ha) can lead to poor upland crop yield by root respiration hindrance and toxic reductants.

Due to bad soil drainage, the project area, espcially in Zone C, could have a large area of depressed fields inundated in the rainy season. Measures such as canal amendment, land reclamation, and agricultural draining management are indispensable for reducing the damage.

Table 25. Soil drainage of SVIP Zones.

Drainage class	Somewhat excessively	Very well	Well	Modrately well	Imperfect	Poor	nc	Sum
Hectarage (%)	185 (0.3)	59 (0.1)	19,378 (34.9)	1,406 (2.5)	13,071 (23.5)	3,075 (5.5)	18,369 (33.1)	55,543 (100.0)

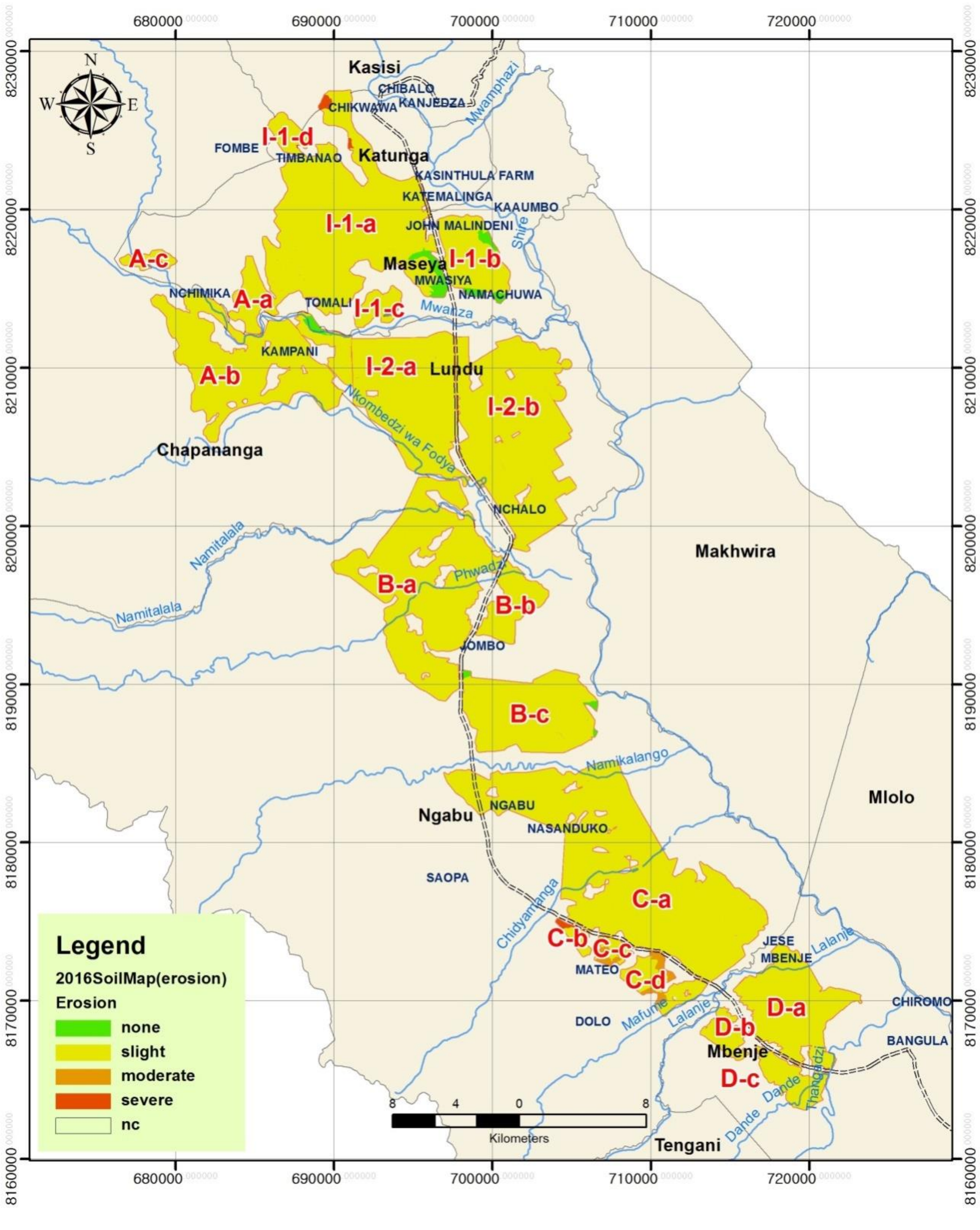

Figure 19. Soil erosion in SVIP Zones.

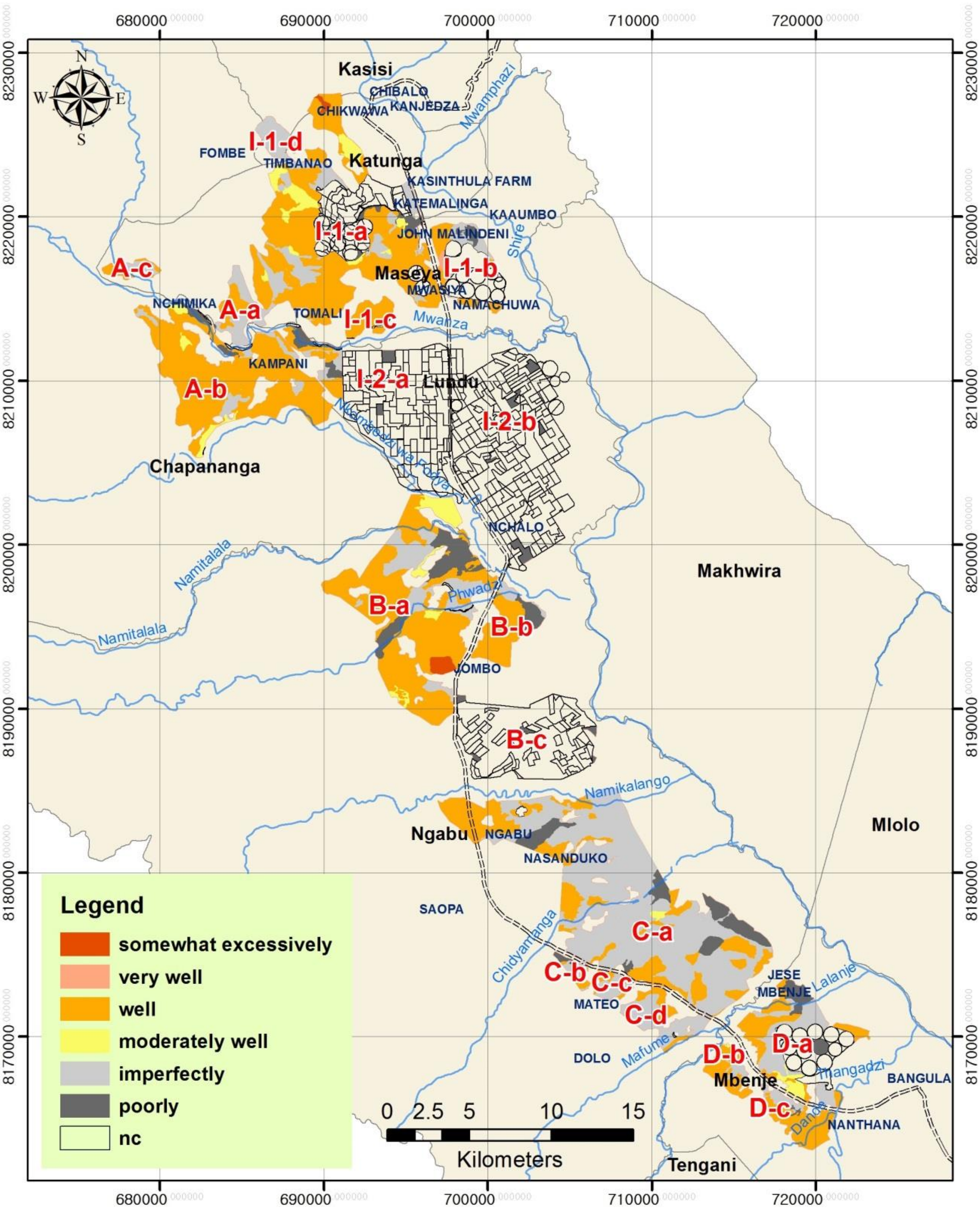

Figure 20. Drainage classes inSVIP Zones.

4) Soil texture

The averaged ratio of sand, silt and clay at all soil survey points is 52.4%-17.7%-29.9 %, the texture of which belongs to sandy clay loam (SCL).The particle ratio in the topsoil is 53.0%-19.8%-27.2%(SCL) and 52.1%-16.4%-31.5% in the subsoil (SCL). Across every zone, the dominant texture is SCL ranged from sandy loam (SL) to clay. I-1-c has the least clay content of SL, while Zone C has a higher clay content from clay (C) to clay loam (CL).

The clay content plays an important role on feeding of crop, water retention and permeability of the soil. Arenosols (1,711 ha) are soils too sandy to hold enough water to grow crops, whereas Vertisols (12,151 ha) and Vertic Luvisols (1,500 ha) are excessively clayey and could be disadvantageous for tillage and drainage.

In the area of soils with heavy clay content in topsoil, it would be desirable to cover and mix original soils with a sandy soil and to steadily introduce machinery such as tillers and tractors in order to facilitate farmers' agricultural activities and to help crops with efficient uptake of essential nutrients from soil. If there is a concreted or indurated or clayey horizon at a depth that restricts root-growth, that horizon should be softened enough for roots to extend well into the soil by plowing that horizon up to 40cm deep with a subsoiler, special equipment mounted on a tractor or a bulldozer, for breaking soil structure physically.

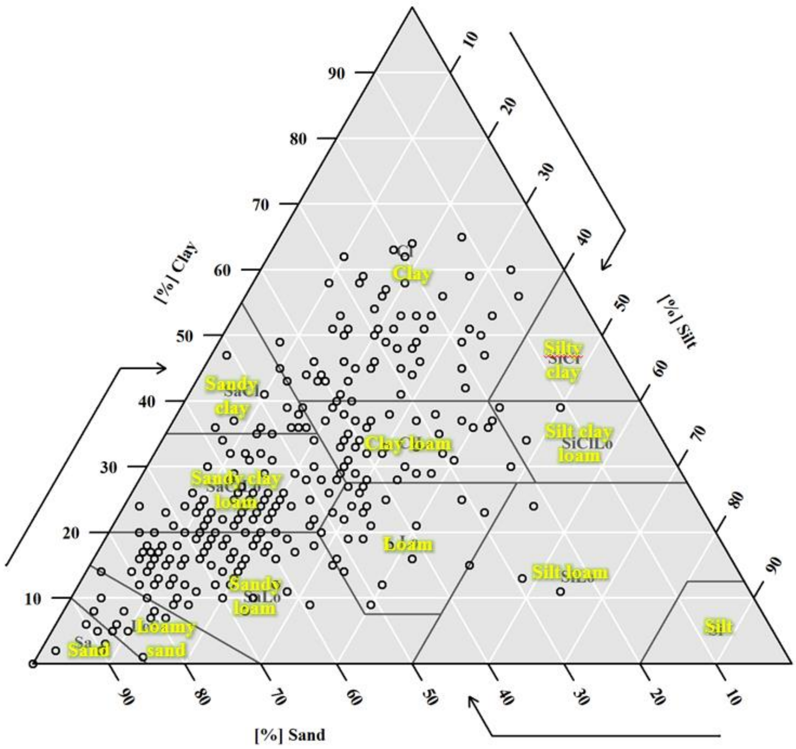

Figure 21.Topsoil texture triangle.

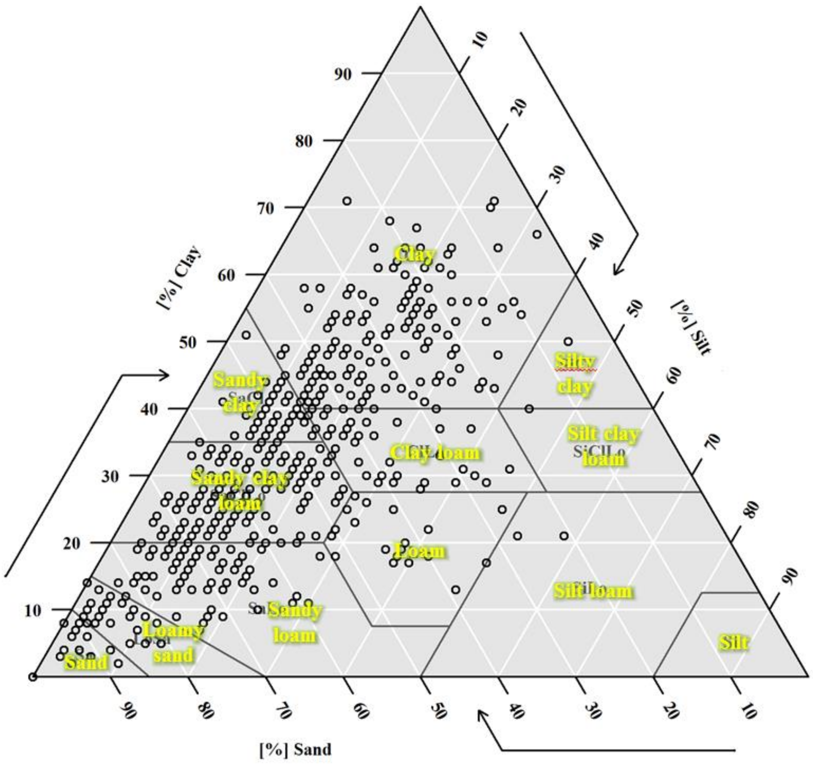

Figure 22. Subsoil texture triangle.

5) Rock fragments

Dominant (>80%) or abundant (40-80%) gravels and/or stones are contained through or in the layers within 100 cm from the surface of skeletic soils in the area of approximately 1,500 ha (Figure 23). These rock fragments reduce the effective rooting depth of crops resulting in low water holding capacity, loss of nutrients, and finally worse crop yields.

In case stone fragments are exposed on soil surface, agricultural practices such as seeding, tillage, harvesting, and so on are not easy and plants cannot settle on the site. Stone removal is to remove stones off the site and to diminish its content below 20% by volume. However, as it is impossible to remove 100% of stones in practice, soil dressing is more efficient and cost-saving at times.

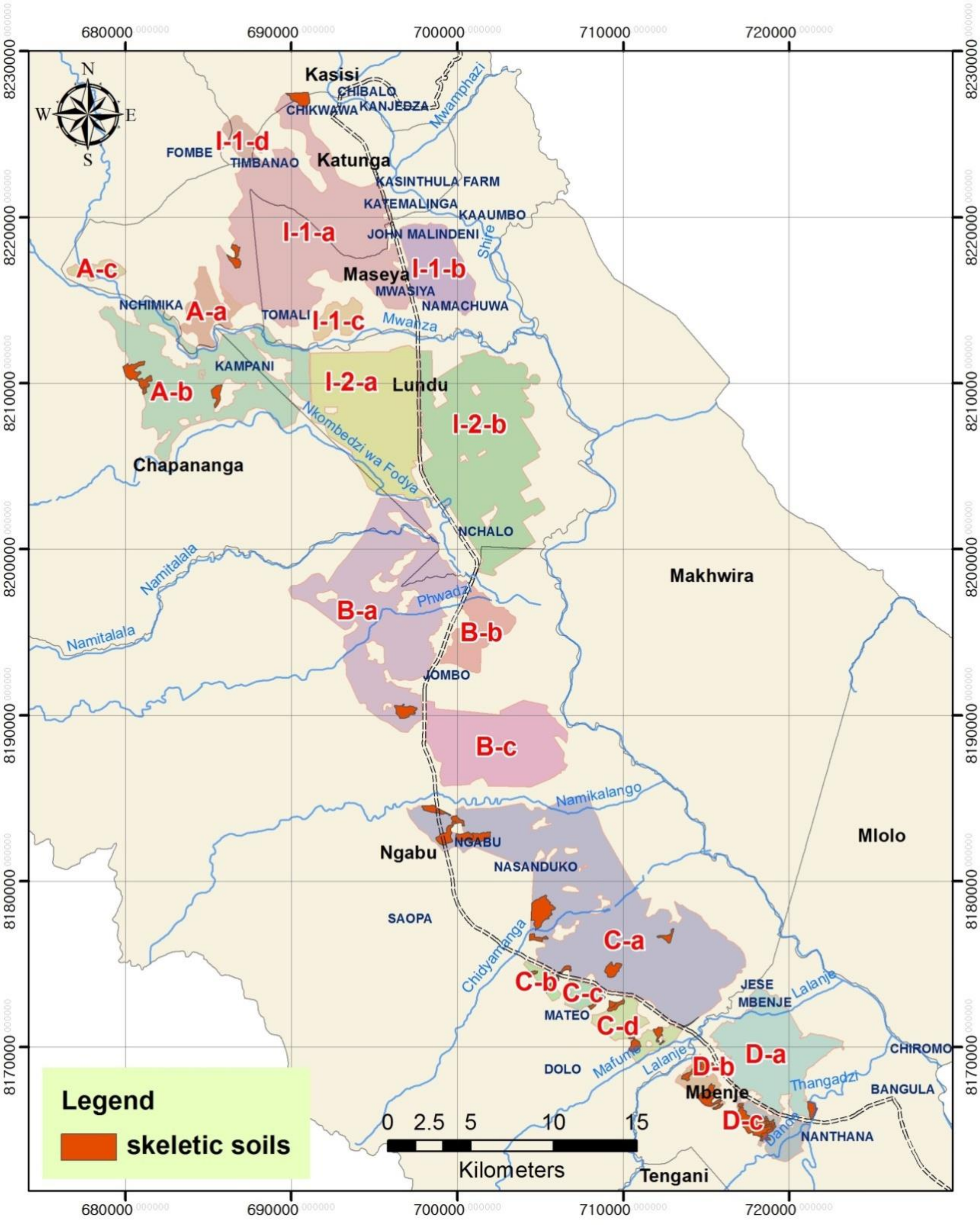

Figure 23. Skeletic soils in SVIP Zones.

6) Salinity and sodicity

According to the1969 FAO Soil Map,salt-affected zones were A-b, A-e, I-2-a, I-2-b, B-b, and D-a, the hectarage of which was 1,480 ha. They changed to I-1-a, I-1-b, I-2-b, B-b, B-c, C-a, and D-a of 1,803 ha in total in 1991. The 2008 CODA Mappresents that salt-affected zones was I-1-a and I-1-b in Phase I Area and covered only 754 ha.

The findings from the present study is that salt-affected zones expand to I-1-a, I-1-c, A-a, A-b, B-a, C-a, C-d, D-a, and D-b not including Estates. Actually, saline and/or sodic soils occupy approximately 10% of Phase I Zones (2,400 ha). The percentage increases up to around 20% (11,000 ha) for the entire (Figure 24).

Rain or irrigation, in the absence of leaching, can bring salts to the surface by capillary action. Salinity from irrigation can increase in soil over time wherever irrigation is implemented, since almost all water (even natural rainfall) contains some dissolved salts. When the plants use the water, the salts are left behind in the soil and eventually begin to accumulate.

Since soil salinity makes it more difficult for plants to absorb soil moisture, these salts must be leached out of the plant root zone by applying additional water (soil flushing). This water in excess of plant needs is called the leaching fraction. Salination from irrigation water is also greatly increased by poor drainage and use of saline water for irrigating agricultural crops, therefore drainage channels and water purity systems need to be developed.

Causes and Measures

Rain or irrigation, in the absence of leaching, can bring salts to the surface by capillary action. Salinity from irrigation can increase in soil over time wherever irrigation is implemented, since almost all water (even natural rainfall) contains some dissolved salts. When the plants use the water, the salts are left behind in the soil and eventually begin to accumulate.

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The Saline and/or Sodic areas are largely distributed in Kasinthula, Alumenda and Kaombe of Illovo. TFS Consultant (with Kasinthula Research Station; Dr. I.R. Fandika) investigated ways of managing the soil properties of these areas, and they are summarized as below:

- Improving drainage: Deeper drainage canals system applied including subsurface drains

- Applying gypsum: In the early stage of the scheme soil shall be ploughed applying with gypsum (1 ~ 2 ton/ha)
- Using acid fertilizers (Ammonium Sulphate) to improve soil property
- Plating tolerant crops such as sun hemp, velvet beans, etc.

The following recommendation was provide by Dr. I.R. Fandika (Kasinthula Research Station) for a sustainable salinity management:

(1) Land reclamation by adding soil amendments

The sodic soil conditions will require two management steps: (1) replacing the exchangeable Na with a more favorable ion such as calcium and magnesium and (2) leaching the soluble Na that has been replaced on the soil colloid, by applying excessive irrigation water during irrigation. Therefore, it is advisable that all the area identified as sodic be ploughed and be applied with gypsum at the early stage of the scheme establishment. Usually no more than 1 to 2 tons of gypsum per ha should be applied at one time. Lighter, more frequent application of gypsum tends be more effective than a single heavy application.

(2) Use of Tolerant Crops

Cotton has been identified as the highest salt tolerant crop which has the highest percent yield potential in some irrigation scheme. Rice, wheat, sorghum, millet, and soybeans were identified as medium tolerant crops to the salinity levels. It is a practical option, therefore, during the recovery or reclamation process of the proposed irrigation scheme saline or sodic land to use either the high or medium salt tolerant crops. It should be noted that maize will not be an economic crop during the reclamation period of the irrigation scheme as is sensitive to the salinity levels.

(3) Good Drainage Infrastructure

An increase in the salinity for the irrigation scheme is often associated with water logging (Dougherty and Hall, 1995) and with soils that have low hydraulic conductivity and low porosity. Therefore, an appropriate and well maintained drainage network will effectively mitigate the problem by removing salts from the field.

(4) Use of Raised Beds

It is also recommended that upland crops around this part of the scheme be grown on raised beds to ensure favorable condition for plant roots.

(5) Application of Organic Manure

An addition of organic manure to soils at the scheme will serve as a binding agent for soil colloids and buffer for soil pH and salinity thereby creating favorable condition for crop growth. Application of organic manure sourced from compost and farmyard need to be encouraged during the reclamation of the irrigation scheme.

(6) Annual Saline Monitoring

Following the soil verification survey of the irrigation scheme, soil changes for the scheme will need to be monitored (Dougherty and Hall, 1995) annually so that potential problems can be managed. Annual monitoring of the scheme can involve annual soil analysis to be complemented by field research of the potential tolerant crops to determine the actual yield potential with different management systems that will be applied.

(7) Conclusion

It can be concluded that saline and sodic soils are spatially distributed at the far end (South east and west) of the irrigation scheme. The land is easily reclaimable by applying gypsum before irrigation farming starts and through initial use of tolerant crops such as cotton, rice, sorghum, millet, soybeans and wheat. Rice is highly recommendable as is already being grown around the area by smallholder farmers.

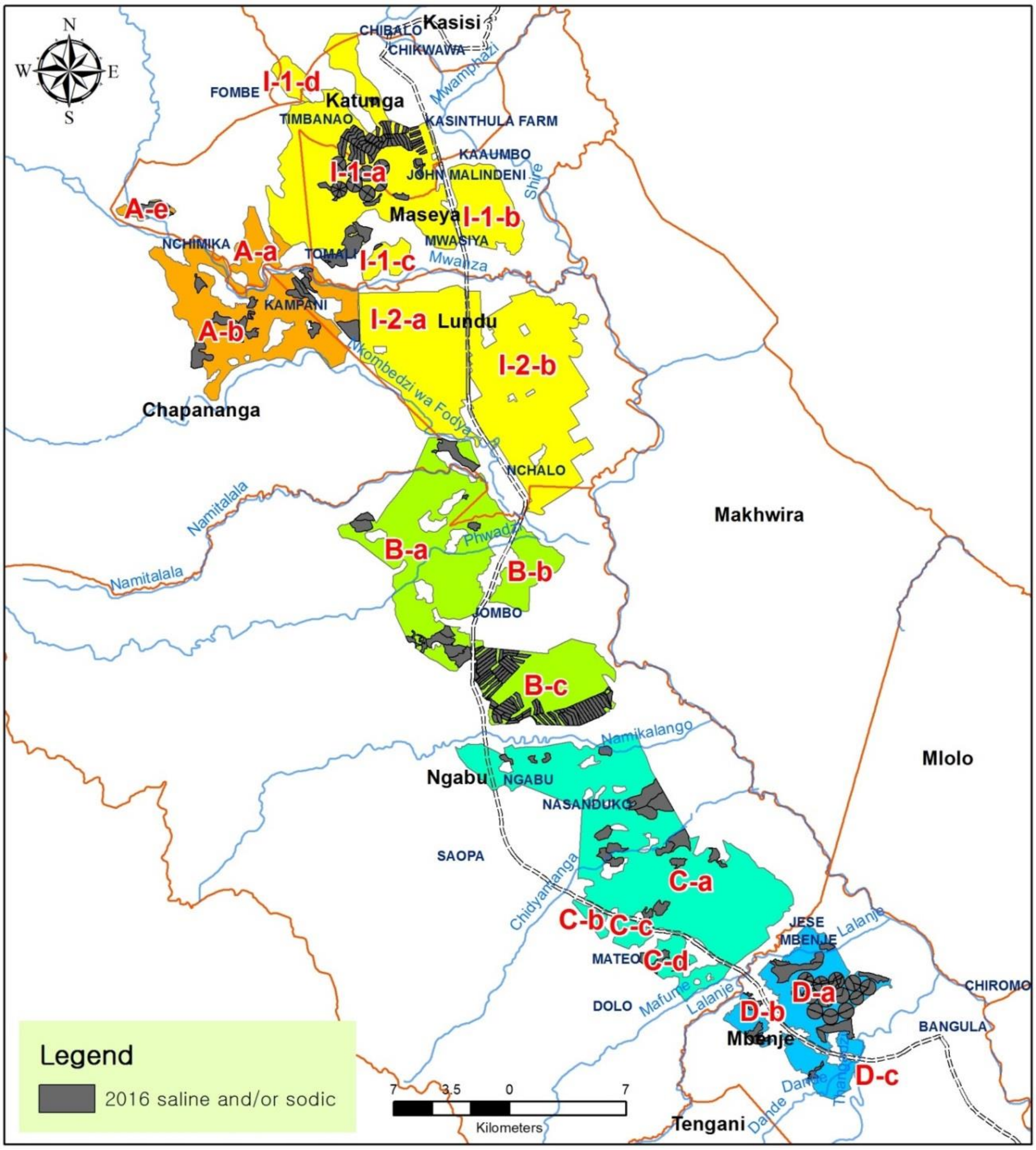


Figure 24. 2016 Saline and/or sodic soils in SVIP Zones.

III. SOIL WATER REQUIREMENT

1. Percolation

The percolation rate at 18 sites ranged from 5.7 to 169.24 mm/day, considerably different depending on cracks, soil texture, and soil drainage. It was impossible to do percolation test at E32N17Pc on the severely cracked vertisols area of Zone C-a as the water poured into soil flowed down too rapidly through very wide and deep cracks sunken by rain.

Percolation rate by soil type was 32.9 mm/day for Eutric Fluvisols, 56.4 mm/day for Eutric Vertisols, 56.9 mm/day for Eutric Cambisols, 22.8 mm/day for Calcaric Cambisols, 47.0 mm/day for Gleyic Cambisols, 24.8 mm/day for Calcic Luvisols, and 57.1 mm/day for Haplic Luvisols, respectively. Thus, almost all survey zones, except for part of Eutric Fluvisols and Eutric Vertisols, seemingly have high percolation rate, i.e., require excessive water supply for rice paddy field.

Besides, the weighted average percolation rates of soil types and the entire survey area could be estimated if soil classification is completed on the basis of soil analysis.

2. TRAM

Soil moisture at wilting point was inferred from soil texture using the table suggested by James (James, 1988). Soil texture at each point was determined by feeling method or from the attribute table of FAO digital map.

TRAM ranged from 0.1 to 12.6 mm, which seems to be excessively underestimated from clayey textures and experiences. Furthermore, TRAM in many clayey horizons was unmeasurable because FC_{24} was smaller than WP quoted from James' table (James, 1988).

The values in Table 27 are very rough or be even erroneous and should be updated considering actual soil analysis results such as soil texture, soil moisture at wilting point in the field. Besides, TRAM could be more acurately calculated from double bulk density test that is designed to replace the time-consuming field TRAM test.

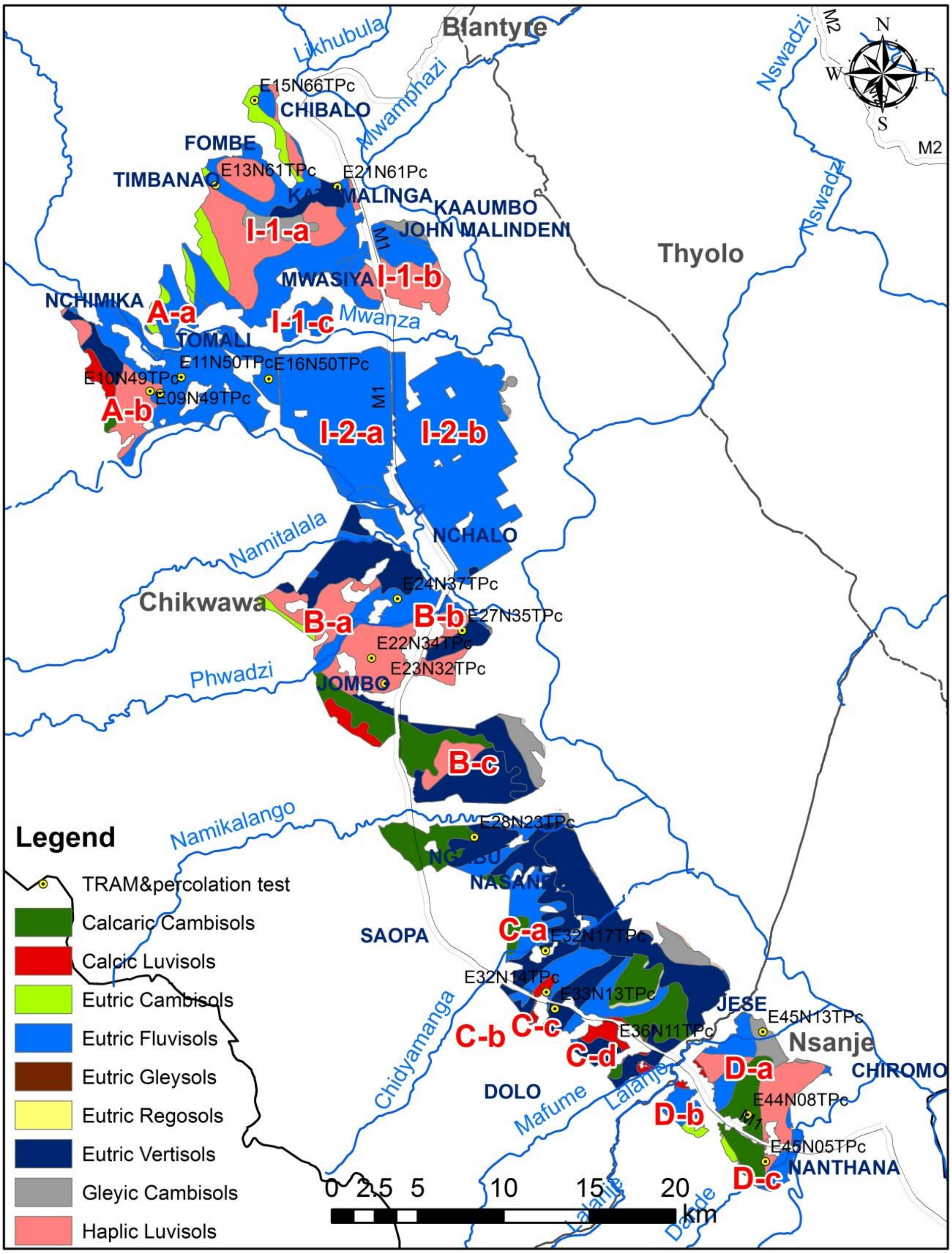


Figure 25. Test points of TRAM and percolation.

TPc: TRAM + Percolation, T: Only TRAM.

Table 26. Results of percolation test.

Survey point	Soil type	Level decrease (mm)	Elapsed time (min)	Percolation (mm/day)
E16N50TPc	FLeu	37.68	1,396	38.87
E15N66TPc	CMeu	53.58	1,355	56.94
E13N61TPc	FLeu	71.55	1,352	76.21
E24N37TPc	FLeu	27.26	1,515	25.92
E22N34TPc	LVha	32.42	1,359	34.37
E23N32TPc	LVha	31.63	1,140	39.95
E27N35TPc	VReu	10.08	1,140	12.74
E11N50TPc	FLeu	40.68	1,368	42.85
E09N49TPc	LVha	92.51	1,372	97.09
E10N49TPc	FLeu	5.27	1,331	5.70
E32N14TPc	LVca	22.95	1,334	24.77
E44N08TPc	CMca	21.04	1,327	22.83
E21N61Pc	FLeu	7.37	1,333	7.96
E45N13TPc	CMgl	54.14	1,212	46.95
E36N11TPc	VReu	33.47	1,228	39.24
E33N13TPc	VReu	3.60	1,177	4.40
E28N23TPc	VReu	130.17	1,118	169.24
E32N17Pc	VReu	-	-	UM
Mean				45.27

Table 27. Results of TRAM test.

Survey point (Soil type)	Layer	Texture	SMEP (%)	Bulk density (g/ml)	FC_{24} (%, w/w)	WP (%, w/w)	RAW_w (%, w/w)	RAW_v (%, v/v)	WR[17] (mm)	TRAM (mm)
E16N50TPc	L1	C	60	1.48	21.2	17	4.2	6.2	3.72	3.04
(FLeu)	L2	C	40	1.52	22.0	17	5.0	7.6	3.04	
	L3	C	-	1.55	13.7	17	UM	-	-	
	L4	C	-	1.55	15.7	17	UM	-	-	
E15N66TPc	L1	LS	50	1.54	12.5	5	7.5	11.6	5.8	0.1
(CMeu)	L2	LS	30	1.53	10.6	5	5.6	8.6	2.58	
	L3	SCL	20	1.62	11.3	11	0.3	0.5	0.1	
E13N61TPc	L1	LS	40	1.15	25.7	5	20.7	23.8	9.52	0.68
(Fleu)	L2	LS	30	1.21	26.1	5	21.1	25.5	7.65	
	L3	LS	20	1.32	16.9	5	11.9	15.7	3.14	
	L4	LS	10	1.50	9.50	5	4.5	6.8	0.68	
E24N37TPc	L1	S	40	1.63	19.3	3	16.3	26.6	10.64	2.04
(FLeu)	L2	S	30	1.68	21.2	3	18.2	30.6	9.18	
	L3	S	20	1.67	18.3	3	15.3	25.6	5.12	
	L4	S	10	1.61	15.7	3	12.7	20.4	2.04	
E22N34TPc	L1	LS	40	1.52	20.0	5	14.5	22.0	8.8	0.22
(LVha)	L2	LS	30	1.54	15.8	5	10.8	16.6	4.98	
	L3	SCL	20	1.66	14.1	11	3.1	5.1	1.02	
	L4	SCL	10	1.83	12.2	11	1.2	2.2	0.22	
E23N32TPc	L1	LS	40	1.66	19.0	5	14.0	23.2	9.28	0.42
(LVha)	L2	LS	30	1.70	14.4	5	9.4	16.0	4.8	
	L3	SCL	20	1.79	14.8	11	3.8	6.8	1.36	
	L4	SCL	10	1.83	13.3	11	2.3	4.2	0.42	
E27N35TPc	L1	SCL	60	1.63	17.4	11	6.4	10.4	6.24	1.48
(VReu)	L2	SCL	40	1.87	13.0	11	2.0	3.7	1.48	
	L3	C	-	1.92	5.80	17	UM	-	-	
E11N50TPc	L1	LS	60	1.17	33.0	5	28.0	32.8	19.7	11.8
(FLeu)	L2	LS	40	1.44	25.4	5	20.4	29.4	11.8	
	L3	C	-	1.56	13.6	17	UM	-	-	
	L4	C	-	1.47	13.1	17	UM	-	-	
E09N49TPc	L1	LS	50	1.55	13.1	5	8.1	12.6	6.3	1.34
(LVha)	L2	LS	30	1.47	10.3	5	5.3	7.8	2.34	
	L3	LS	20	1.49	9.50	5	4.5	6.7	1.34	
	L4	C	-	1.38	6.60	17	UM	-	-	
E10N49TPc	L1	SCL	100	1.72	18.3	11	7.3	12.6	12.6	12.6
(FLeu)	L2	SCL	-	1.83	7.80	11	UM	-	-	
	L3	SCL	-	1.98	5.60	11	UM	-	-	

[17] WR(Water Requirement) = RAW_w×100/SMEP

Survey point (Soil type)	Layer	Texture	SMEP (%)	Bulk density (g/ml)	FC_{24} (%, w/w)	WP (%, w/w)	RAW_w (%, w/w)	RAW_v (%, v/v)	WR[17] (mm)	TRAM (mm)
E32N14TPc	L1	CL	40	1.13	27.9	13	14.9	16.8	6.72	0.83
(LVca)	L2	CL	30	1.38	26.5	13	13.5	18.6	5.58	
	L3	SCL	20	1.35	24.8	11	13.8	18.6	3.72	
	L4	SCL	10	1.08	18.7	11	7.7	8.3	0.83	
E44N08TPc	L1	SL	50	1.75	17.4	6	11.4	20.0	10.0	2.08
(CMca)	L2	SL	30	1.74	17.0	6	11.0	19.1	5.73	
	L3	SL	20	1.65	12.3	6	6.3	10.4	2.08	
	L4	SCL	-	1.66	9.80	11	UM	-	-	
E45N05TPc	L1	SCL	40	1.65	15.4	11	4.4	7.3	2.92	0.65
(LVha)	L2	SCL	30	1.58	14.1	11	3.1	4.9	1.47	
	L3	SCL	20	1.60	15.2	11	4.2	6.7	1.34	
	L4	SCL	10	1.72	14.8	11	3.8	6.5	0.65	
E45N13TPc	L1	C	40	1.41	23.0	17	6.0	8.5	3.40	0.56
(CMgl)	L2	C	30	1.28	31.0	17	24.0	30.7	9.21	
	L3	C	20	1.41	26.6	17	9.6	13.5	2.70	
	L4	C	10	1.11	22.0	17	5.0	5.6	0.56	
E36N11TPc	L1	SCL	40	1.28	28.6	11	17.6	22.5	9.00	1.75
(VReu)	L2	SCL	30	1.19	24.8	11	13.8	16.4	4.92	
	L3	SCL	20	1.24	25.4	11	14.4	17.9	3.58	
	L4	SCL	10	1.27	24.8	11	13.8	17.5	1.75	
E33N13TPc	L1	LS	40	1.25	32.5	5	27.5	34.4	13.8	2.28
(VReu)	L2	LS	30	1.33	29.0	5	24.0	31.9	9.57	
	L3	CL	20	1.27	22.4	13	9.4	11.9	2.38	
	L4	CL	10	1.22	31.7	13	18.7	22.8	2.28	
E28N23TPc	L1	C	40	1.41	20.1	17	3.1	4.4	1.76	0.81
(VReu)	L2	C	30	1.32	22.3	17	5.3	7.0	2.10	
	L3	C	20	1.44	23.2	17	6.2	8.9	1.78	
	L4	C	10	1.55	22.2	17	5.2	8.1	0.81	

3. RAW

Regardless of SMEP, RAW at tha same 14sites where TRAM was tested can be calculated in consideration of soil water deficit (SWD) by soil texture of each horizon in the rootzone.

For instance, total RAW at E16N50 where very clayey soils (FLeu) exisit is 18.75 mm by summing up RAWs of two horizons which came from multiplying each SWD by each horizon depth. This means that when irrigating with a full cover sprinkler system farmers should apply approximately 19 mm to refill the rootzone once tensiometers have reached -40 kPa.

Total RAW ranged from 18.75 to 54.9 mm (on average 43.92 mm) for 14 sites, which is greatly different from TRAM, and the RAW of some soil types, assigning all sites to RSGs,wasestimated 36.86 mm for FLeu, 49.82 mm for LVha, 47.1 mm for VReu, 31.55 mm for LVca, 48.2 mm for CMca, respectively.

Table 28. RAW stored between -8 and -1500 kPa.

Texturegrade	Soil water deficit (mm/cm)				
	-8 to -20 kPa	-8 to -40 kPa	-8 to -60 kPa	-8 to -200 kPa	-8 to -1500 kPa
Sand (S)	0.33	0.36	0.38	0.40	0.62
Loamy sand (LS)	0.45	0.52	0.55	0.58	0.87
Clayey sand (CS)*	-	0.55	0.60	0.64	1.00
Sandy loam (SL)	0.46	0.59	0.65	0.70	1.15
Light sandy clay loam (LSCL)	0.45	0.65	0.74	1.03	1.37
Loam (L)	-	0.69	0.84	1.00	1.43
Sandy clay loam (SCL)	0.39	0.61	0.71	1.01	1.44
Clay loam (CL)	0.30	0.53	0.65	0.73	1.48
Clays (SC, LC, LMC, MC)	0.27	0.46	0.57	0.66	1.49
Heavy clay (HC)**	-	0.25	0.41	0.49	1.20

*Interpolated value **Samples from Kununurra, WA
(Source: K.G. Wetherby, soil survey and land use specialist.)

Table 29. RAW at TRAM test sites.

Survey point (Soil type)	horizon	Depth	Texture	SWD (mm/cm)	RAW (mm)
E16N50TPc	A	25	HC	0.25	6.25
(FLeu)	B	50	HC	0.25	12.5
					18.75
E24N37TPc	A	17	S	0.36	6.12
(Fleu)	B	33	S	0.36	11.88
	C	35	S	0.36	12.6
					30.6
E22N34TPc	A	18	LS	0.52	9.36
(LVha)	B	34	SCL	0.61	20.74
	C	23	SCL	0.61	14.03
	D	10	S	0.36	3.6
					47.73
E23N32TPc	A	25	LS	0.52	13
(LVha)	B	25	SCL	0.61	15.25
	C	35	FSCL	0.61	21.35
					49.6
E27N35TPc	A	19	SC	0.46	8.74
(VReu)	B	48	C	0.46	22.08
	C	28	CSCL	0.61	17.08
					47.9
E11N50TPc	A	20	LS	0.52	10.4
(FLeu)	B	40	SC	0.46	18.4
	C	40	SC	0.46	18.4
					47.2
E09N49TPc	A	15	LS	0.52	7.8
(LVha)	B	20	SL	0.59	11.8
	C	45	SCL	0.61	27.45
					47.05
E10N49TPc	A	40	FSCL	0.61	24.4
(FLeu)	B	50	CL	0.53	26.5
					50.9
E32N14TPc	A	25	CL	0.53	13.25
(LVca)	B	30	CSCL	0.61	18.3
					31.55
E44N08TPc	A	30	SL	0.59	17.7
(CMca)	B	20	SCL	0.61	12.2
	C	30	SCL	0.61	18.3
					48.2
E45N05TPc	A	30	SCL	0.61	18.3

Survey point (Soil type)	horizon	Depth	Texture	SWD (mm/cm)	RAW (mm)
(LVha)	B	20	SCL	0.61	12.2
	C	40	CSCL	0.61	24.4
					54.9
E36N11TPc	A	25	SCL	0.61	15.25
(VReu)	B	25	CSCL	0.61	15.25
	C	30	CSCL	0.61	18.3
					48.8
E33N13TPc	A	20	LS	0.52	10.4
(VReu)	B	35	CL	0.53	18.55
	C	35	CSCL	0.61	21.35
					50.3
E28N23TPc	A	30	C	0.46	13.8
(VReu)	B	35	C	0.46	16.1
	C	25	CSC	0.46	11.5
					41.4

The weighted average RAWs of soil types and soil survey area can be more accurately estimated based on soil profile descriptions and soil classification after soil analysis.By use of topsoil texture data (Table 52) and soil water deficit values by soil texture (Table 28), the total RAWwithin 30 cm from the surface of soil survey area can be calculated approximately four million tonnes (Table 30).

Table 30. RAW calculation in soil survey area.

	Fine				Medium			Coarse			Sum
	HC	C	SC	CL	SCL	L	SLm	SLc	LS	S	
Soil water deficit (mm/cm)	0.25	0.46	0.46	0.53	0.61	0.69	0.59	0.59	0.52	0.36	-
Irrigated depth (m)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	-
Area (ha)	441	9,992	3,602	2,219	11,976	1,988	1,993	2,216	2,132	152	36,711
RAW (10^3 m^3)	33	1,379	497	353	2,191	412	353	392	333	16	3,959

IV. Land and Crop

1. Land cover and land use

1.1. Land cover

The Atlas of Malawi, land cover and land cover change (1990s-2010s) published in 2013 provides information on the land cover resources, their distribution and changes over time.

The land cover change database was prepared according to the FAO, Land and Water Divisionand Global Land Cover Network(GLCN) land cover change mapping methodology; underpinned by the use of FAO/ISO standards and the Land Cover Mapping Toolbox (FAO, 2012).The national land cover legend was prepared using the Land Cover Classification System (LCCS).The final land cover change database is composed of more than 200,000 land cover units (polygons), classified into 23 land cover classes and aggregated into 8 major land cover classes (Figure 27).

There are 24 map codes in SVIPZones. 1Hcs (Rain-fed Herbaceous Crops with Small Sized Fields) occupies the greatest area of 21,125 ha (38%) and followed by 16,992 ha (31%) of 1SC (Sugarcane - Irrigated Herbaceous Crop(s)), 3,938 ha (3%) of 1Hcs/2TO (Rain-fed Herbaceous Crops(s) Small (< 2ha)/Woodland Open General (15-65%) with Herbaceous Layer), and 3,659 ha (3%) of 1Hcs+2Ts (Rain-fed Herbaceous Crops(s) - Small Field(s) (< 2ha) with a layer of Sparse Trees) in turn (Figure 26).

1.2. Land use

Most of the zone is intensively cultivated. Irrigated sugarcane is grown on large-scale pumping irrigation water out of the Shire River.On the other hand, patches of mixed low altitude savanna and severely degraded grassland are used for grazing. Lengwe National Park covers 2,860 ha. If fallow land approaching 8% is to be gradually developed, arable land would keep increasing in the future.

Eight crops, as well as sugarcane in Estates, were observed to be comprehensively cultivated in the field during the present soil investigation. Sorghum and cotton were being grown under rain-fed traditional management at 137 out of 258 sites followed by cotton at 38 sites. Cereal crops such as sorghum, bulrush millet, maize, and rice were widely planted in single or mixed stands for subsistence production. Besides, sesame and cowpeas were also cultivated (Figure 28).

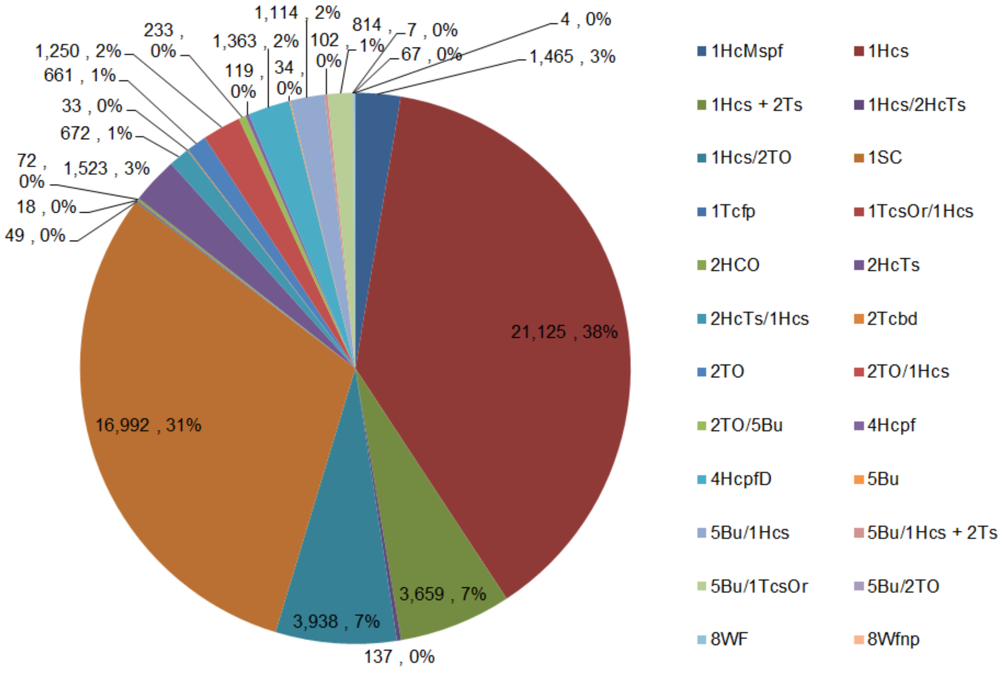


Figure 26. Land cover composition in SVIP Zones.

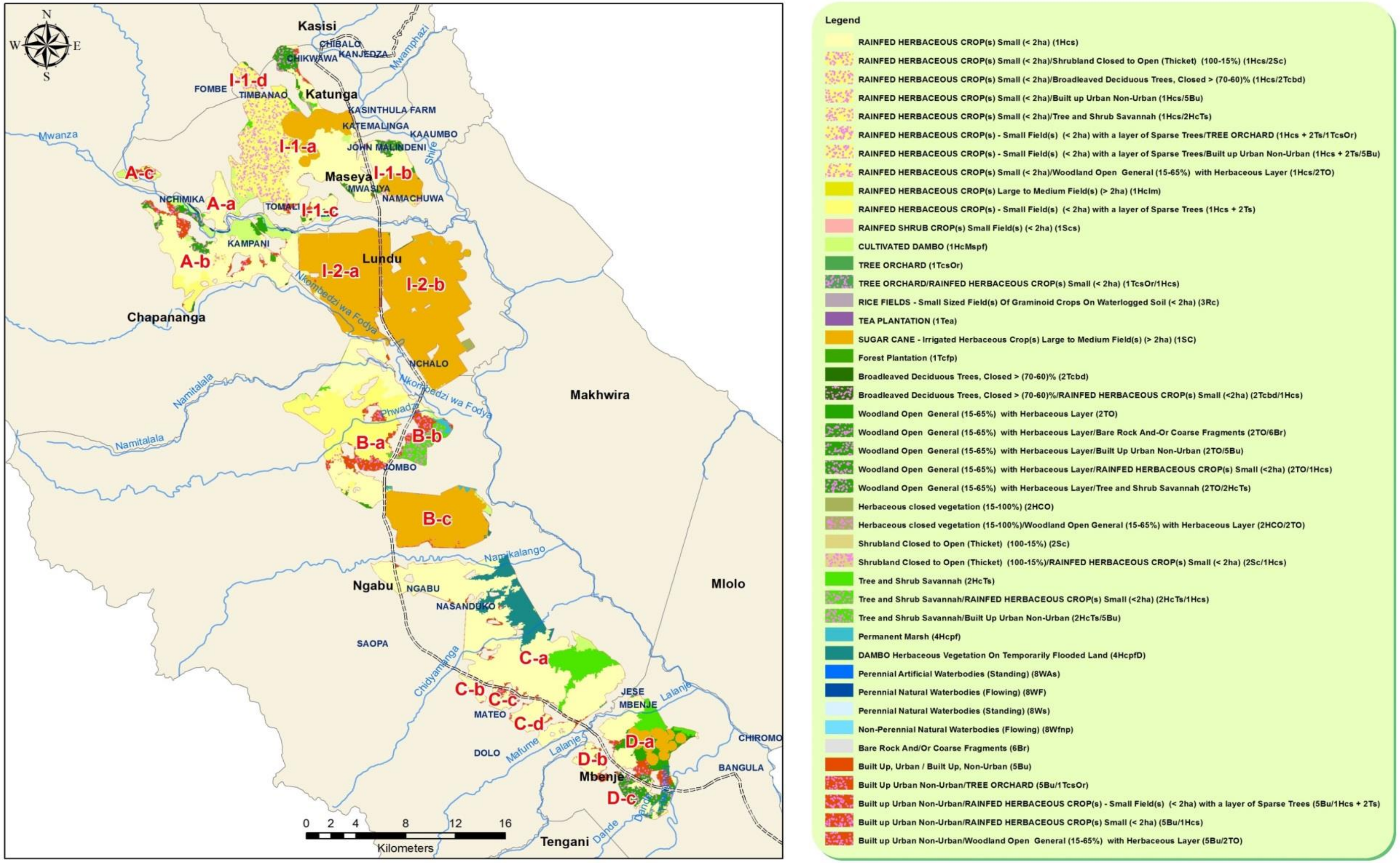


Figure 27. Land cover map of SVIP Zones.

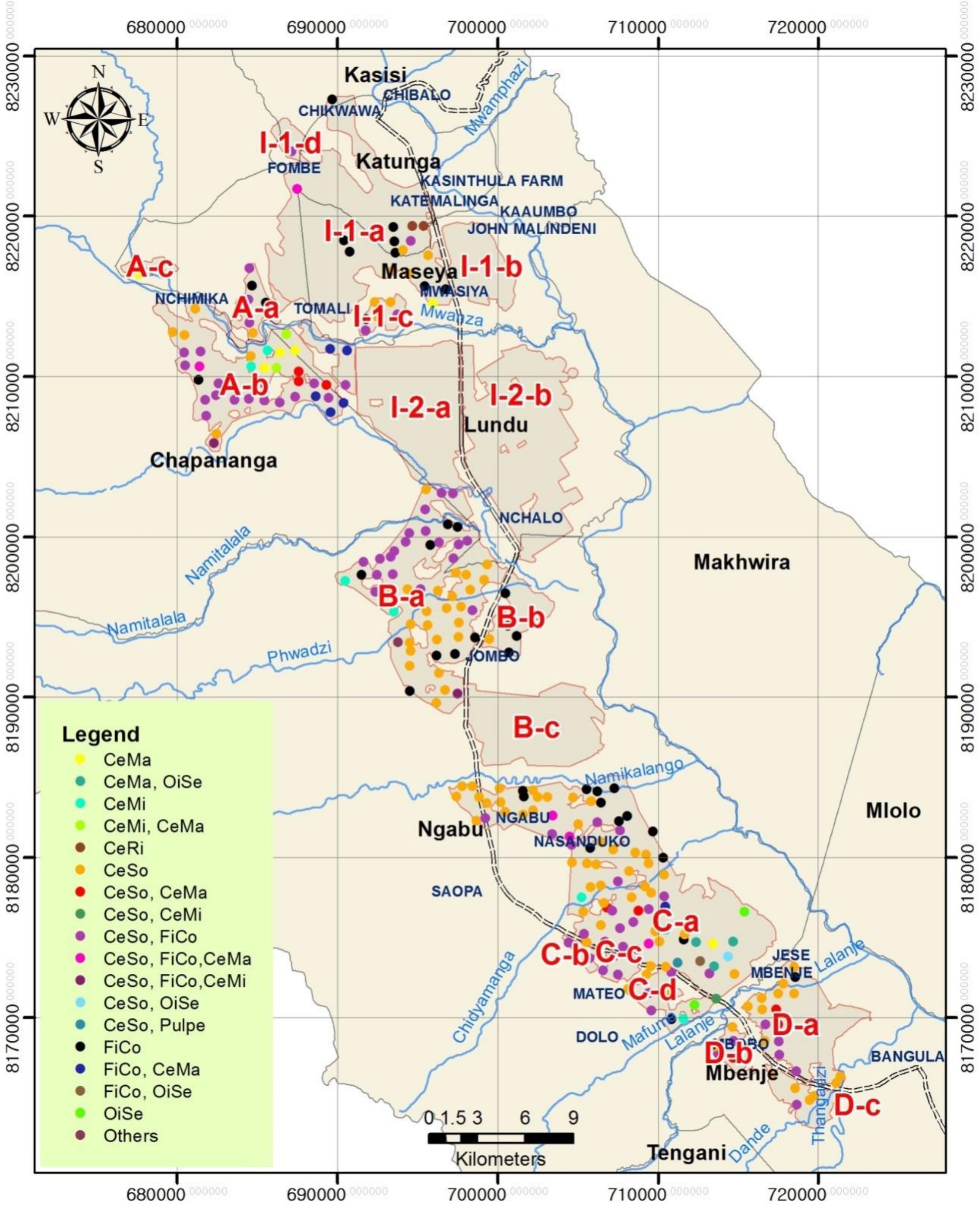


Figure 28. Crops planted in the vicinity of soil survey points in SVIP Zones.
CeMa: Maize, OiSe: Sesame, CeMi: Bulrush millet, CeRi: Rice, paddy, CeSo: Sorghum, FiCo: Cotton, Pulpe: Cowpeas

2. Crop cultivation

2.1. Planted crops

The kinds of crops currently grown in the project area include sugarcane (*Saccharum officinarum*), cotton (*Gossypium hirsulum*), sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum L*), rice (*Oryza sativa L*), cowpeas (*Vigna unguiculata*), phaseolus beans (*Phaseolus vurgaris*), soyabeans (*Glycine max*), sesame (*Sesamum indicum*), green and black grams (*Vigna aureus & Vigna mungo*), guarbeans (*Cyamopsis tetragonoloba*), maize (*Zea mays*), mangoes (*Mangifera indica*), banana (*Mussa spp.),* castor see (*Ricinus communis*), cocoa yam, cashew nut (*Anacardium occidentale*), coconut (*Cocos nucifera*), sweet potatoe (*Ipomea batatus*) and tomatoes.

However, the crops such as phaseolus beans, soybeans, onions and tomatoes are only grown in the dry season under irrigation when the temperature is low. 1969 Lockwood survey report recommended most of these crops for Shire Valley Project in three categories.

- **Category 1** – Crops that did not present technical and economic limitations and which could be established immediately included cotton, rice, maize, soy beans, tobacco, onions, mango, and macadamia, and cover trees such as gmelina, eucalyptus.
- **Category II** – Crops which were technically suitable or of economic interest but required more research on market and varieties suitability included sunflower, seed beans, green beans, sorghum, carrot, pineapple, citrus fruits (lime and grapefruits), chillies and potatoes.
- **Category III** – Crops which could not be recommended for immediate use in Shire Valley due to no evidence of economic interest or with economic value but are not ecologically suitable for the Shire Valley included sesame, sunflower, castor oil, rape, millets, wheat, cocoa, cola nut, tomatoes, ginger, asparagus and turmeric.

Following these recommendations, the Ministry of Agriculture, Irrigation and Water Development in Malawi embarked on research and development programs in some selected crops above. Out of all the crops above, sugarcane, cotton, sorghum and pearl millet, maize, rice, common beans, wheat and banana have been researched and produced intensively within the Shire Valley project area.

Cotton is the main commercial crop among smallholder farmers whilst sugarcane is the commercial crop among both commercial estates (Illovo) and out-growers in Lower Shire Valley (Kasinthula and Phata Farms). Sugarcane is both rain-fed and irrigated crop. It is also locally grown by smallholder farmers in many parts of the study area.

Cotton is an entirely dry land crop grown during rainy season (December-May) with a close season between August and November to control pests. Research studies at Kasinthula and Makhanga have shown that supplementary irrigation can increase cotton yield by more than half the normal yield under rain-fed conditions.However, most smallholder farmers still grow cotton as sole crop or intercropped with maize or sorghum under rain-fed conditions.

The most irrigated arable crops under smallholder within SVIP area are paddy rice, vegetables, common beans and maize which are grown in winter while non-irrigated part is for rain-fed cotton, maize, cowpea, mango, sesame, sorghum and pearl millet or temporary cattle-grazing.The rain-fed crops cover the largest area compared with irrigated crops, which is mainly sugarcane.

Food situation and Crop production in the project area

By the time of this study, 23,077 out of 134,775 farm households had no food in Chikwawa District, representing 17 % of the total farm households. At the same time in previous season 11,102 out of 119,864 farm households had no food, and that represented 9%. Drought and floods accelerated food insecurity in the area. Drought and floods influenced reduction of crop production in the area.

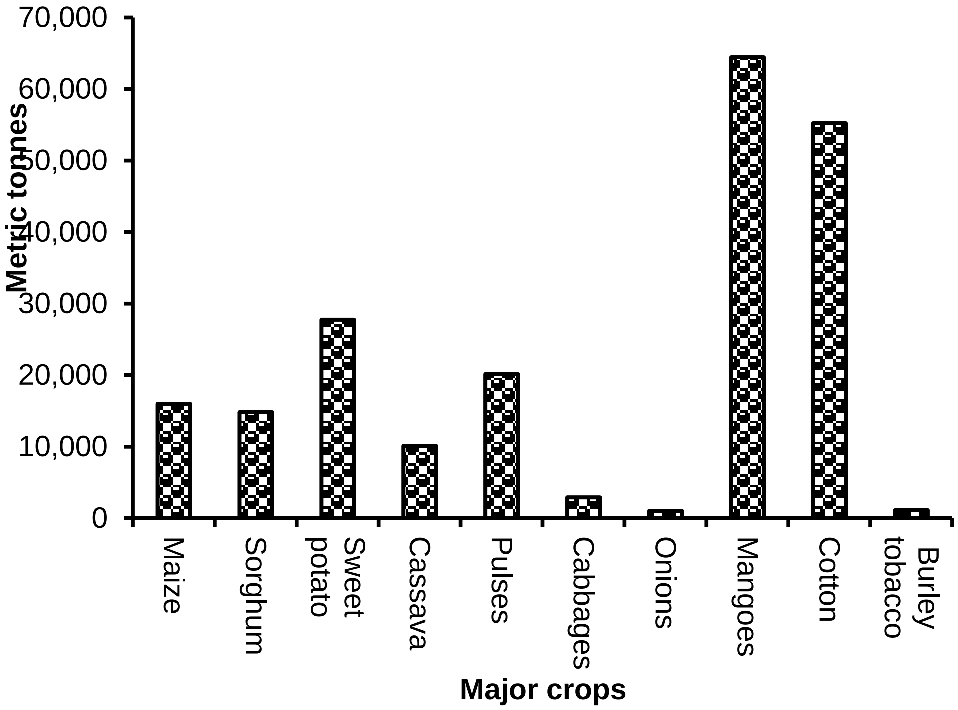


Figure 29. 2014-15 production estimates of major food crops in Chikwawa District. (Source: KARS).

2.2. Cropping patterns

In Lower Shire Valley, crops are cultivated twice a year; in the dry winter season (April-October) and wet summer season (December-March).

It is projected that sugarcane will continue to be grown by both estates and smallholder farmers in both dry and rainy season. Sugarcane can be grown continuously on the same land without rotation with other crops.

Cotton is grown once in rainy season because there is need of observing the closing season. Subsequently, maize can be rotated with cotton in dry season under irrigation. It is projected that rice grown in the predominant heavy soils will be grown continuously without rotation while that in lighter soils can be rotated with common beans or soya beans during winter season.

Maize is rarely grown in dry season but can be intercropped with cowpeas or cotton. Sorghum and pearl millet have a fair degree of drought tolerance and they are highly encouraged in the project area in order to increase farmers' resilience to the impacts of climate change. Sorghum and pearl millet is projected to be grown as a sole crop or intercropped with cowpeas and be rotated with legumes or sweet potatoes in dry season.

Banana and Mangoes are projected to be grown continuously as plantation crops, however, banana mats can be rotated after 5-6 years with other crops. Sesame is also most recommended for SVIP as an oil seed and it is projected that it will be rotated with maize or vegetables in dry season or any other cereal crop in dry season.

Table 31. Cropping patterns in Shire Valley Irrigation Project area.

District	Summer (rainy season)	Winter (dry Season)
Chikwawa	Sugarcane,	Sugarcane
	Cotton	Rice, maize
	Rice, maize	Legumes (beans, soybean)
	Sorghum, Pearl millet	Sweet potato
	Oil crops	Vegetables (tomatoes, rapes)
Nsanje	Cotton	Rice, maize
	Maize, rice	Sugarcane
	Sorghum, Pearl millet	Legumes (beans, soybean)
		Sweet potato
	Ground nut, cow peas	

(Source: KARS)

<table>
<tr><th>NOV</th><th>DEC</th><th>JAN</th><th>FEB</th><th>MAR</th><th>APR</th><th>MAY</th><th>JUN</th><th>JUL</th><th>AUG</th><th>SEP</th><th>OCT</th></tr>
<tr><td colspan="7">Sugarcane</td><td colspan="5">Sugarcane</td></tr>
<tr><td colspan="7">Cotton</td><td colspan="5">Winter maize</td></tr>
<tr><td colspan="7">Summer rice</td><td colspan="5">Winter rice</td></tr>
<tr><td colspan="7">Summer rice</td><td colspan="5">Winter maize</td></tr>
<tr><td colspan="7">Summer rice</td><td colspan="5">Winter bean</td></tr>
<tr><td colspan="7">Summer maize</td><td colspan="5">Soybean</td></tr>
<tr><td colspan="7">Summer sorghum/pearl millet</td><td colspan="5">Winter bean</td></tr>
<tr><td colspan="7">Banana</td><td colspan="5">Banana</td></tr>
<tr><td colspan="7">Maize + cowpea</td><td colspan="5">Maize seed</td></tr>
<tr><td colspan="7">Summer sorghum/pearl millet + cowpea</td><td colspan="5">Sweet potato</td></tr>
</table>

Figure 30. Cropping patterns in Chikwawa.

Rice grows through the lifecycle of nursery, tillering, panicle formation, booting, heading, and ripe stage. The rice lifecycle in the project area is as shown in Figure31.

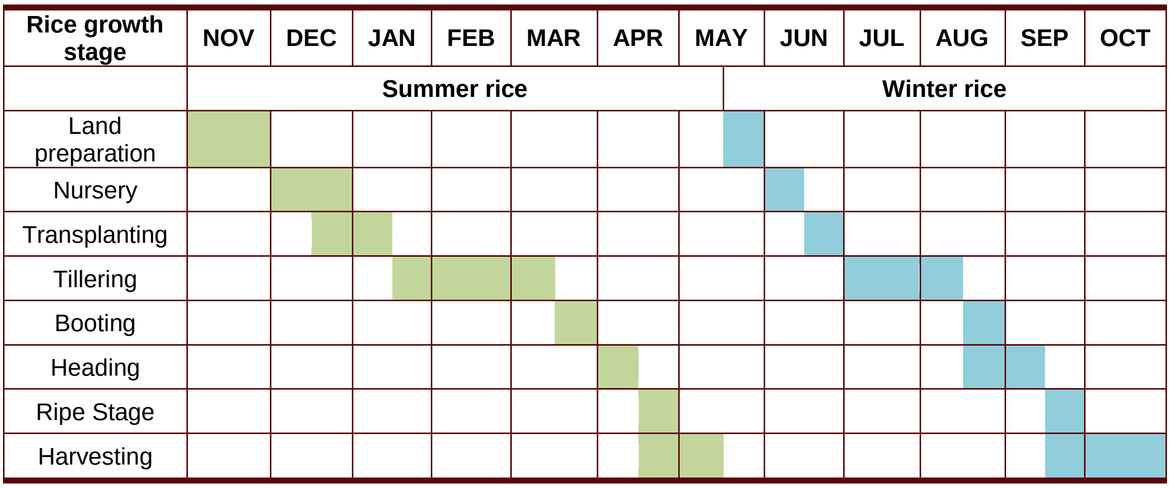


Figure 31. Cropping calendar of rice in Chikwawa.

V. LAND EVALUATION

1. Case studies

1.1. FAO project map

Land suitability in the 1969 FAO Irrigation Project Map Book was classified into nine classes; 1, 2, 3, 1R, 2R for arable land and S1, S2, S3 for limited arable land, and 6 for non-arable land. Mapping symbols for land units on the land suitability map were coined in combination of land class, soil deficiency, drainage deficiency, and land development.

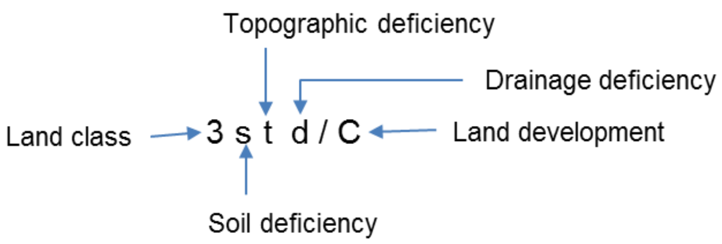


Figure 32. Compostion of land suitability symbols in the 1969 FAO Map.

Figure 33 is the land suitability digital map restored from scanned soil map sheets made in 1969. Land suitability was assessed for 55,637 ha and divided to 35 classes.

Table 32. 1969 FAO land classes.

Land class	1R	1R/A	1R/B	2R/A	2R/B	2s/B	2sd	2st	2st/B
Hacterage (ha)	3,349	361	893	123	819	1,853	53	11,941	1,314
Land class	**2t**	**2t/B**	**3d/B**	**3s**	**3s/B**	**3st/C**	**3t**	**3t/C**	**6d**
Hacterage (ha)	2,923	346	11	299	851	137	440	197	554
Land class	**6dt**	**6H**	**6H(2s)**	**6H(3s)**	**6H(3st)**	**6H(3t)**	**6s**	**6s/B**	**6sd**
Hacterage (ha)	5	19	8	30	1	0	2,963	28	19
Land class	**6st**	**6std**	**6t**	**6td**	**6V**	**S1**	**S2/A**	**S3/A**	**nc**
Hacterage (ha)	2,848	1,920	77	2,080	18	10,472	208	1,694	4,094

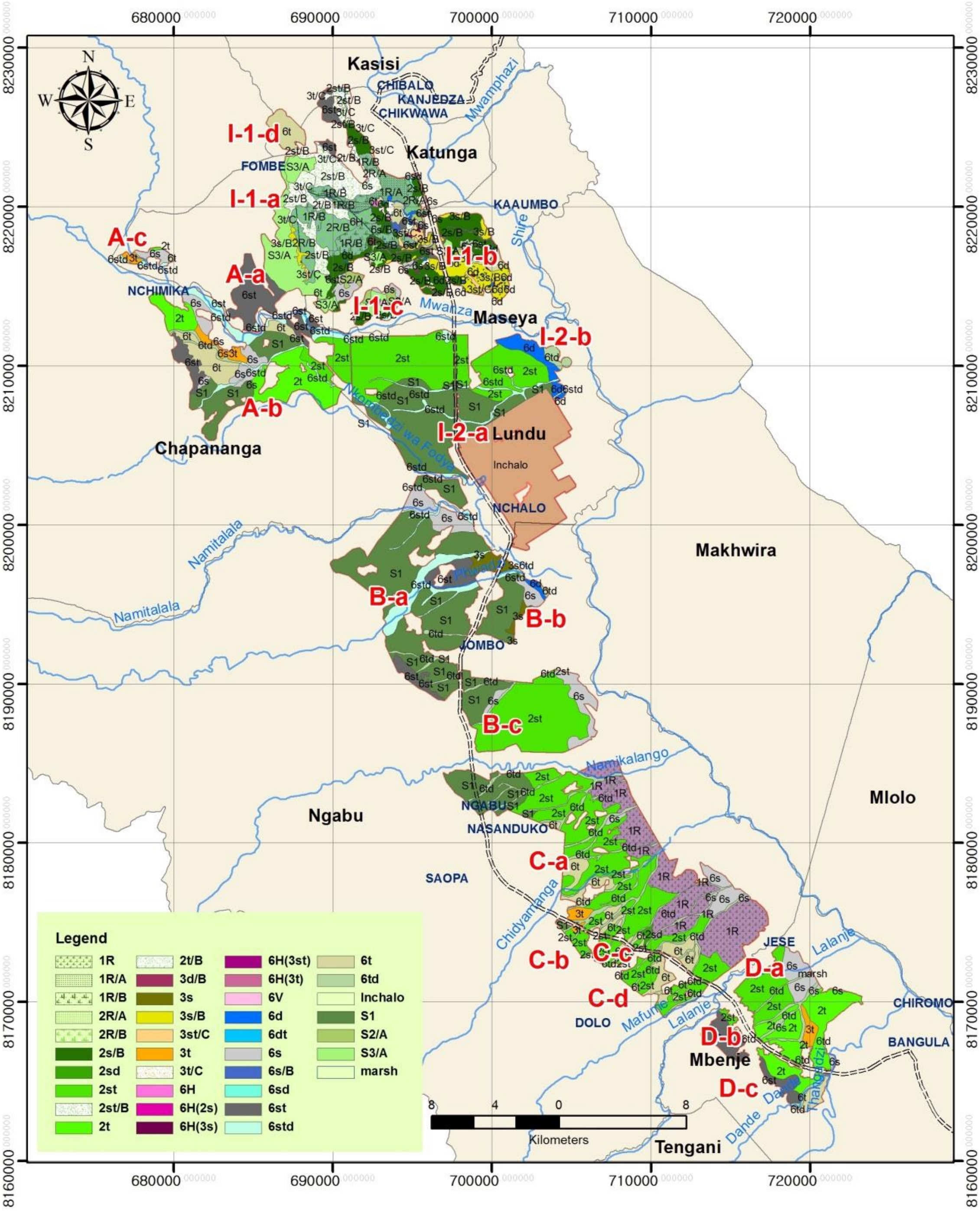


Figure 33. 1969 FAO Land Suitability Map.

1.2. FAO land evaluation report

The land suitability in survey zones for maize, bulrush millet, groundnuts and cotton under improved traditional management is shown on four maps digitized from PDF-format map sheets at scale 1:250,000, which were published in 1991 as part of land resources evaluation report by J. H. Venema.

Four suitability classes are used: Highly suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), and Not Suitable (N). The definitions of suitability classes are summarized in Table 33. Distribution of land suitability classes depends on crop so much so that N class is only 20.6% for cotton but about 90% for maize under improved traditional management. Table 33 shows the land suitability classes of four major crops in Ngabu ADD in 1991 (Table 34).

Table 33. Definitions of land suitability classes.

Symbol	Suitability class	Description	Potential Yield[18]
S1	Highly suitable	Land having no significant limitations to the sustained application of the given land use type	100-80%
S2	Moderately suitable	Land having limitations which in agreeable are small to substantial to the sustained application of the given land use type; production levels will be reduced and/or costs will be increased when compared with S1	80-50%
S3	Marginally suitable	Land having limitations which in agreeable are severe to the sustained application of the given land use type; production levels will be reduced and/or costs will be increased such that is often impracticable or uneconomic for the defined use	50-20%
N	Not suitable	Land having limitations which preclude any possibility of successful application of the given land use type. In some cases, e.g. the use of intensive soil conservation measures	< 20%
S1/2 S2/3 S3/N	Intermediate classes	Land having intermediate land suitability, or land of which the suitability is divided among two classes	

[18] As percentage of the maximum attainable yield

Table 34. Land suitability classes by crop in 1991.

Crop	Land suitability class				
	S1	S2	S3	N	Sum
	Area (ha, %)				
Cotton	-	31,671 (57.7%)	11,902 (21.7%)	11,310 (20.6%)	54,883 (100%)
Maize	-	-	6,366 (11.6%)	48,517 (88.4%)	54,883 (100%)
Bulrush millet	-	34,930 (63.6%)	8,643 (15.7%)	11,310 (20.6%)	54,883 (100%)
Groundnuts	-	-	41,593 (75.8%)	13,290 (24.2%)	54,883 (100%)

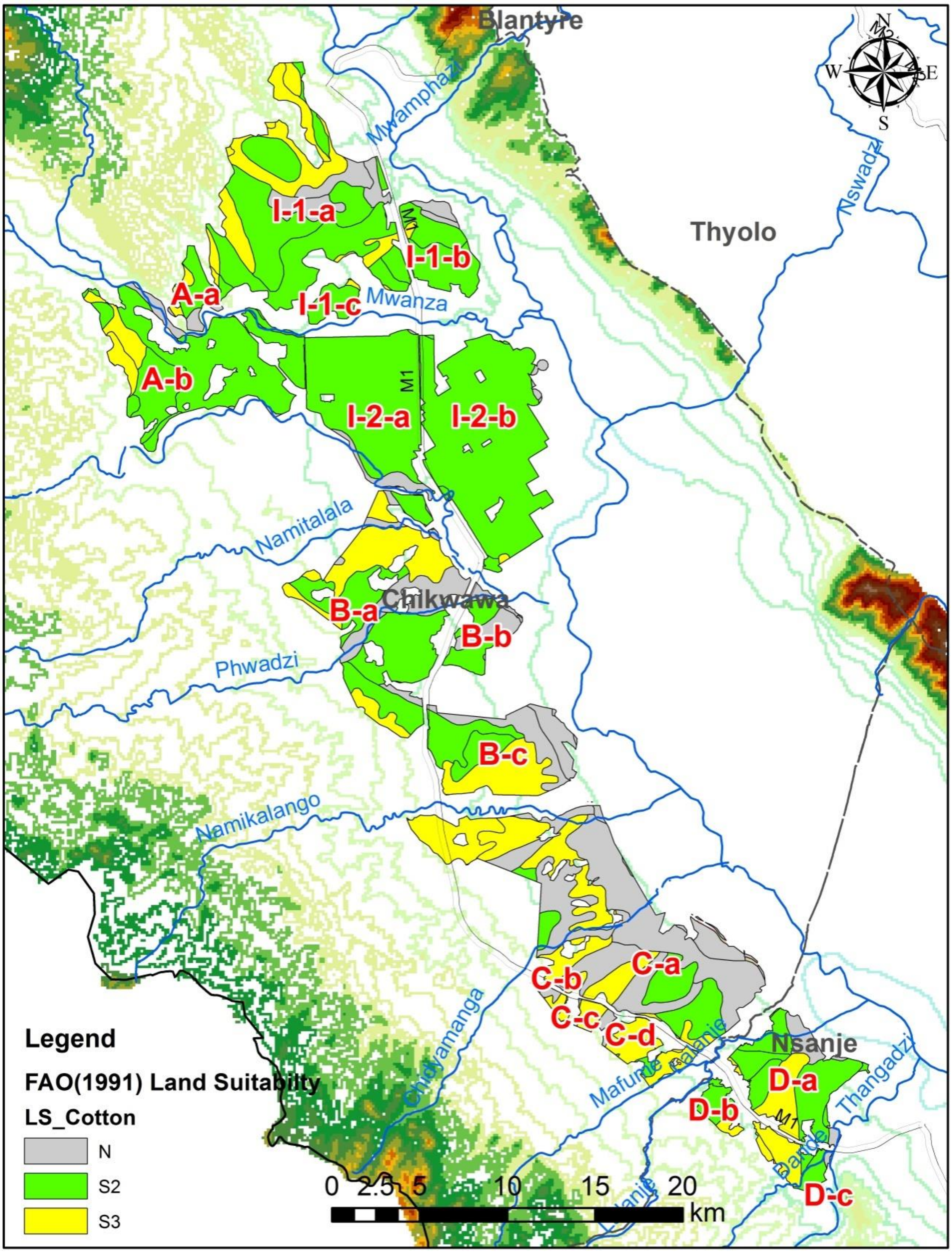


Figure 34. Land suitability map for cotton (FAO 1991).

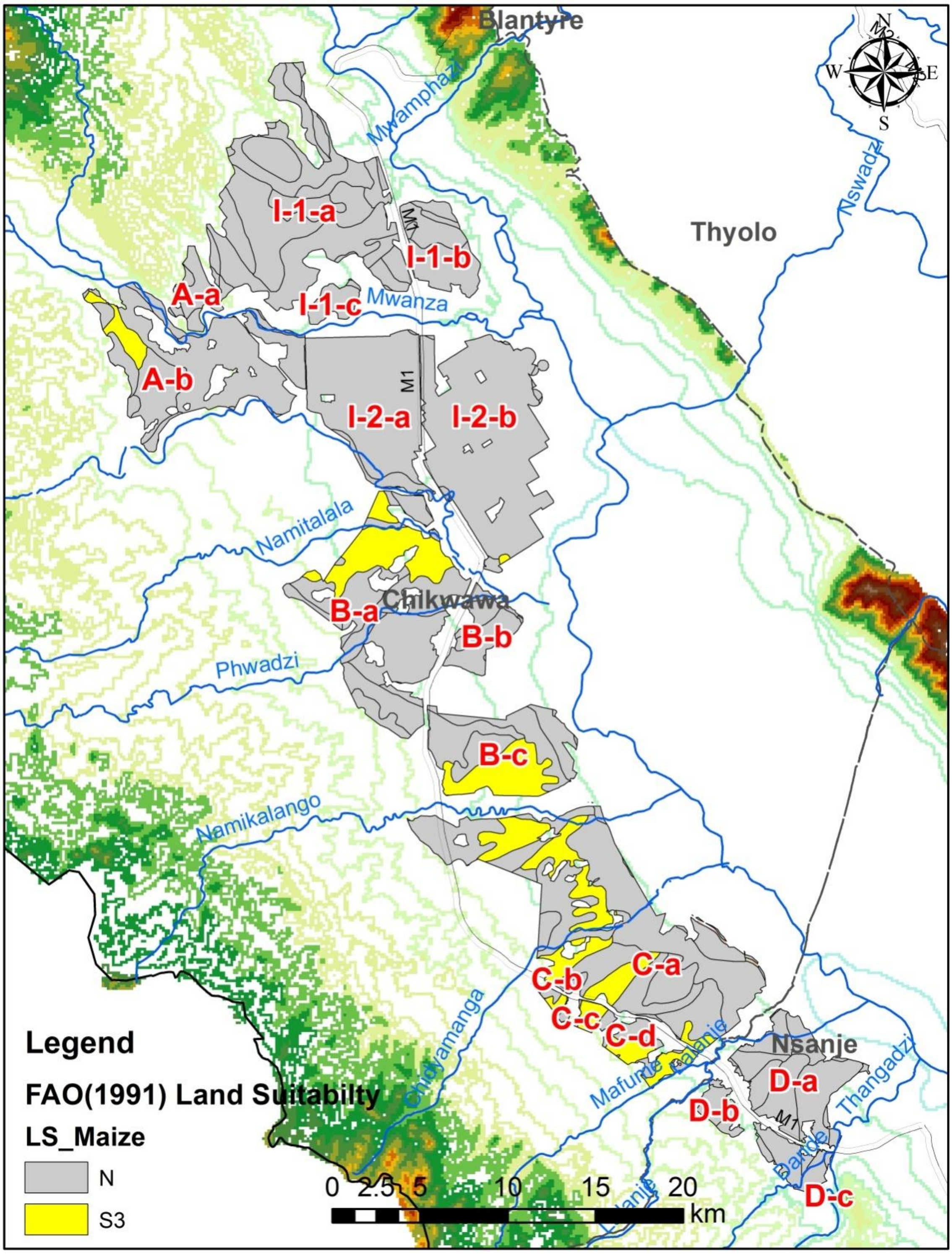


Figure 35. Land suitability map for maize (FAO 1991).

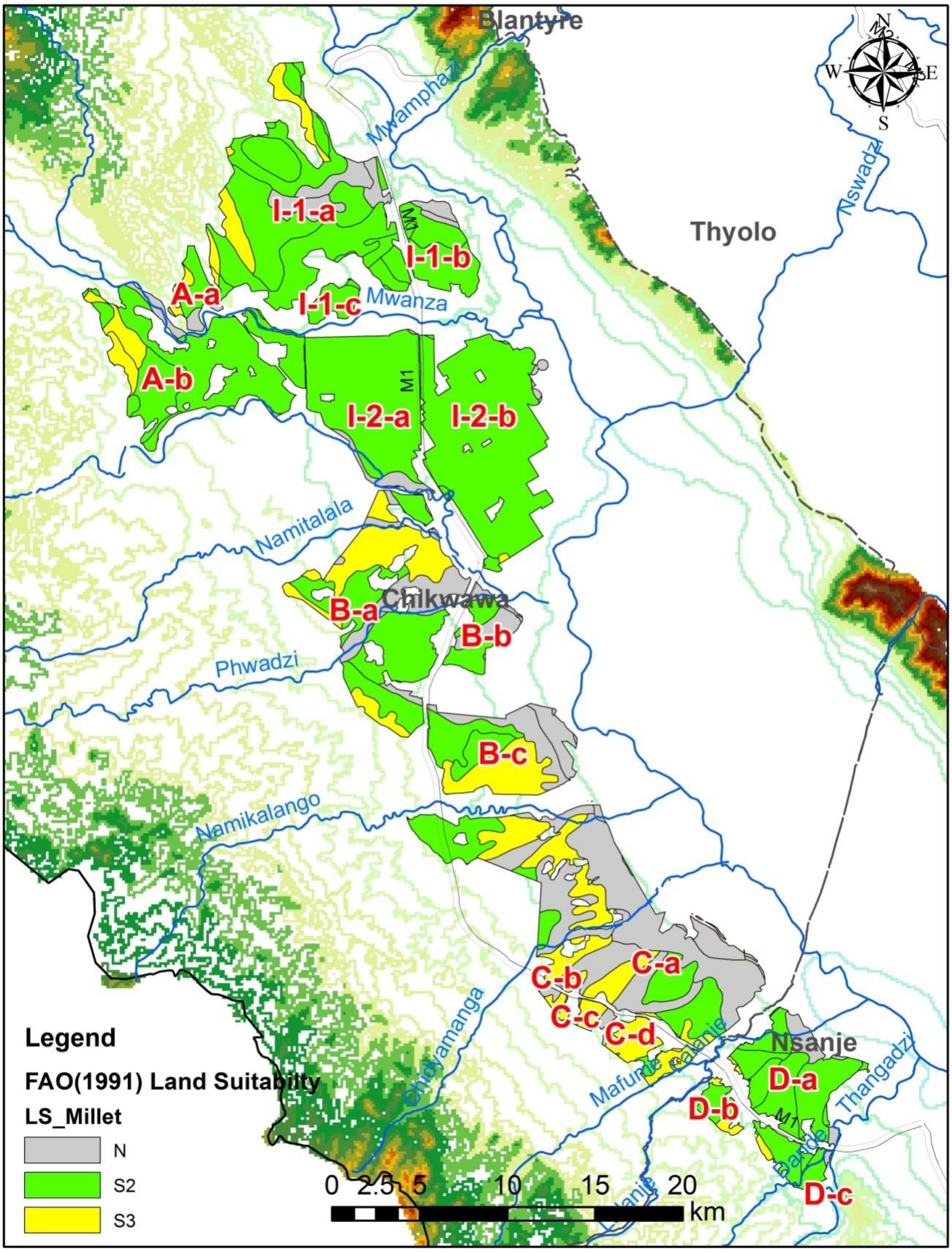


Figure 36. Land suitability map for bulrush millet (FAO 1991).

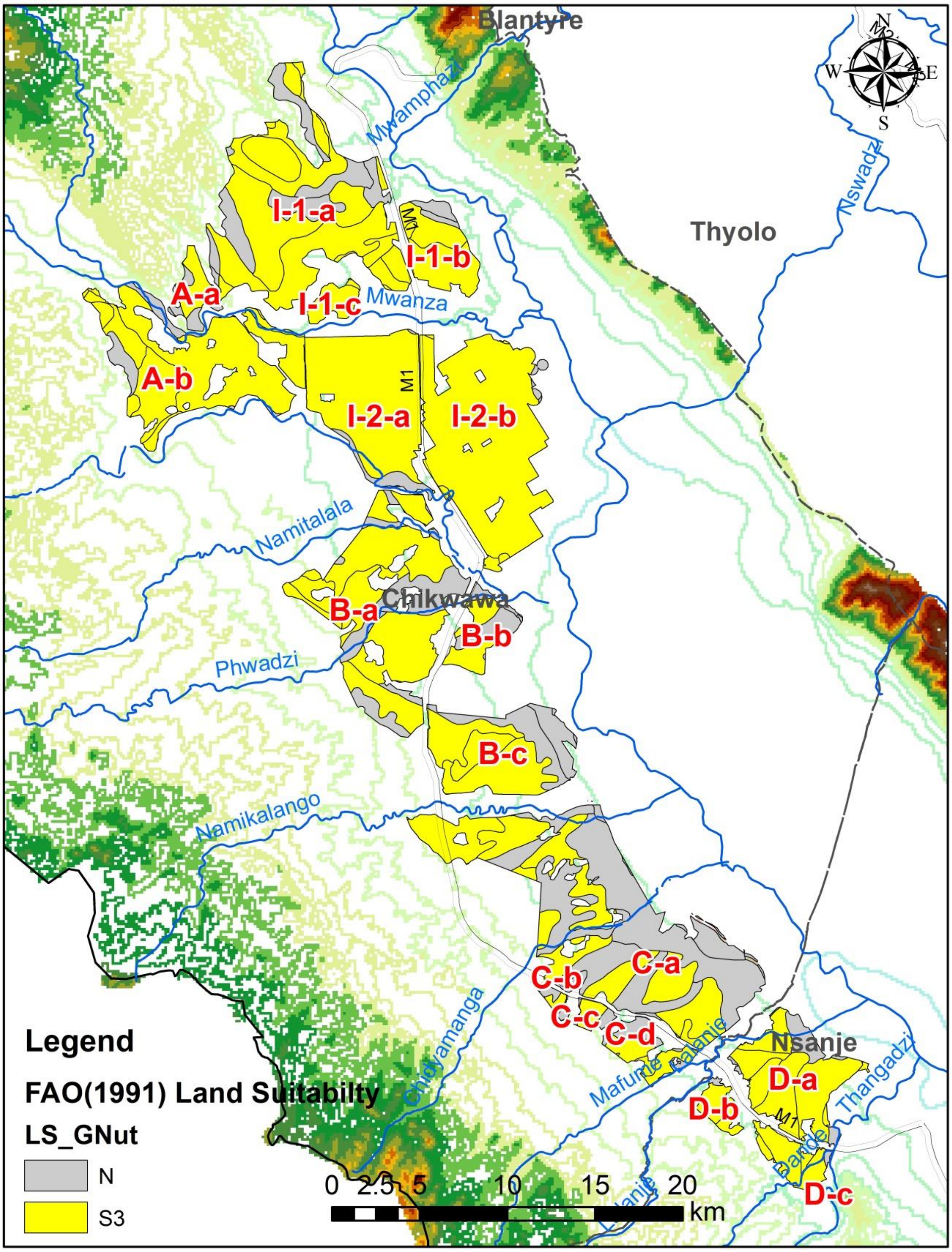


Figure 37. Land suitability map for groundnuts (FAO 1991).

1.3. CODA Report

The land suitability of four zones of I-1-a, b, c, and d was evaluated for both diversified crop production (S1: Highly suitable, S2: Moderately suitable, S3: Marginally suitable) and rice production (R1: Highly suitable, R2: Moderately suitable, N: Unsuitable).

Against the remnant (6,593 ha) except nc and mp areas, 67% was assessed to be suitable for diversified crop production and 29% for rice production. Unfortunately, the land suitability map sheets for significant area (mp, 2,371 ha) is misprinted in the CODA Drawing Book and cannot be utilized for reference (Table 35).

Limmiting factors were additionally marked after suitabilty classes: texture (g), effective depth (p), water holding capacity (w), topography (t), fertility potential (c), alkalinity (n), and salinity (s).

Table 35. Results of land evaluation by CODA.

Diverse crops			Rice			Subtotal	nc[19]	mp[20]	Total
S1	S2	S3	R1	R2	N				
Hacterage (ha, %)									
101 (2%)	2,765 (42%)	1,520 (23%)	729 (11%)	1,239 (19%)	239 (4%)	6,593 (100%)	424	2,371	9,388

[19] nc : not classified
[20] mp : misprinted

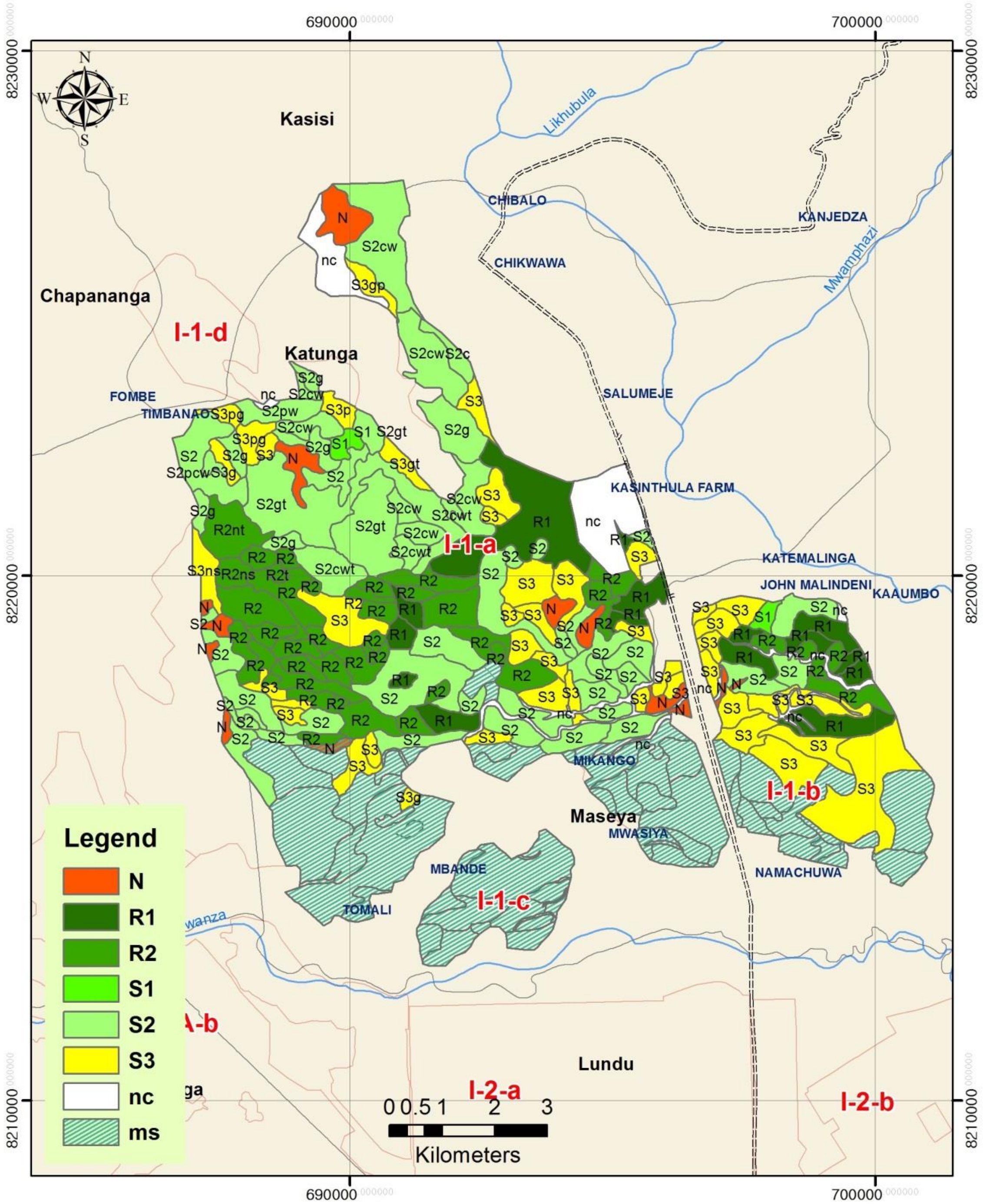


Figure 38. Land suitability map made by CODA in 2008.

1.4. Commercial farm data

Estates introduce Soil Potential to evaluate land suitability for commercial sugarcane farming. It has 8 classes of 1, 2A, 2B, 3A, 3B, 4A, 4B, and 5 in the downgrading order based on soil physical-chemical properties. pH, ESP, topsoil clay content, structure, ERD, and TAM seem to be the main reasons for many fields to take a lower potential class (Table 36). It is unclear what each class means and how much suitable for sugarcane cultivation because no main report with details has yet been provided.

Table 36. Reasons for downgrading Soil Potential classes of Estates.

Soil Potential Class	1	2A	2B	3A	3B	4A	4B	5
Downgrading reasons	none	pH Topsoil clay %	pH EC	pH Topsoil clay% ESP Structure ERD[21] TAM	pH Topsoil clay% ESP Structure ERD TAM Permeability	pH Structure ESP	pH Topsoil clay% ESP Structure ERD TAM Permeability	pH EC ESP Structure ERD TAM

The fields with Soil Potential 1, which has no soil limitation for sugarcane cultivation occupy 18.3% (3,400 ha) of the gross Estate area (18,580 ha) and the highest percentage of 26.5 % belongs to moderate Soil Potential 3B having several downgrading reasons such as pH, topsoil clay content, ESP, and so on.

Table 37. Soil potential classes of Estates.

Soil Potential Class	1	2A	2B	3A	3B	4A	4B	5	nc	Sum
Area (ha,%)	3,400 (18.3)	1,111 (6.0)	614 (3.3)	410 (2.2)	4,919 (26.5)	85 (0.5)	5,770 (31.1)	877 (4.7%)	1,394 (7.5)	18,580 (100)

[21] Effective rooting depth

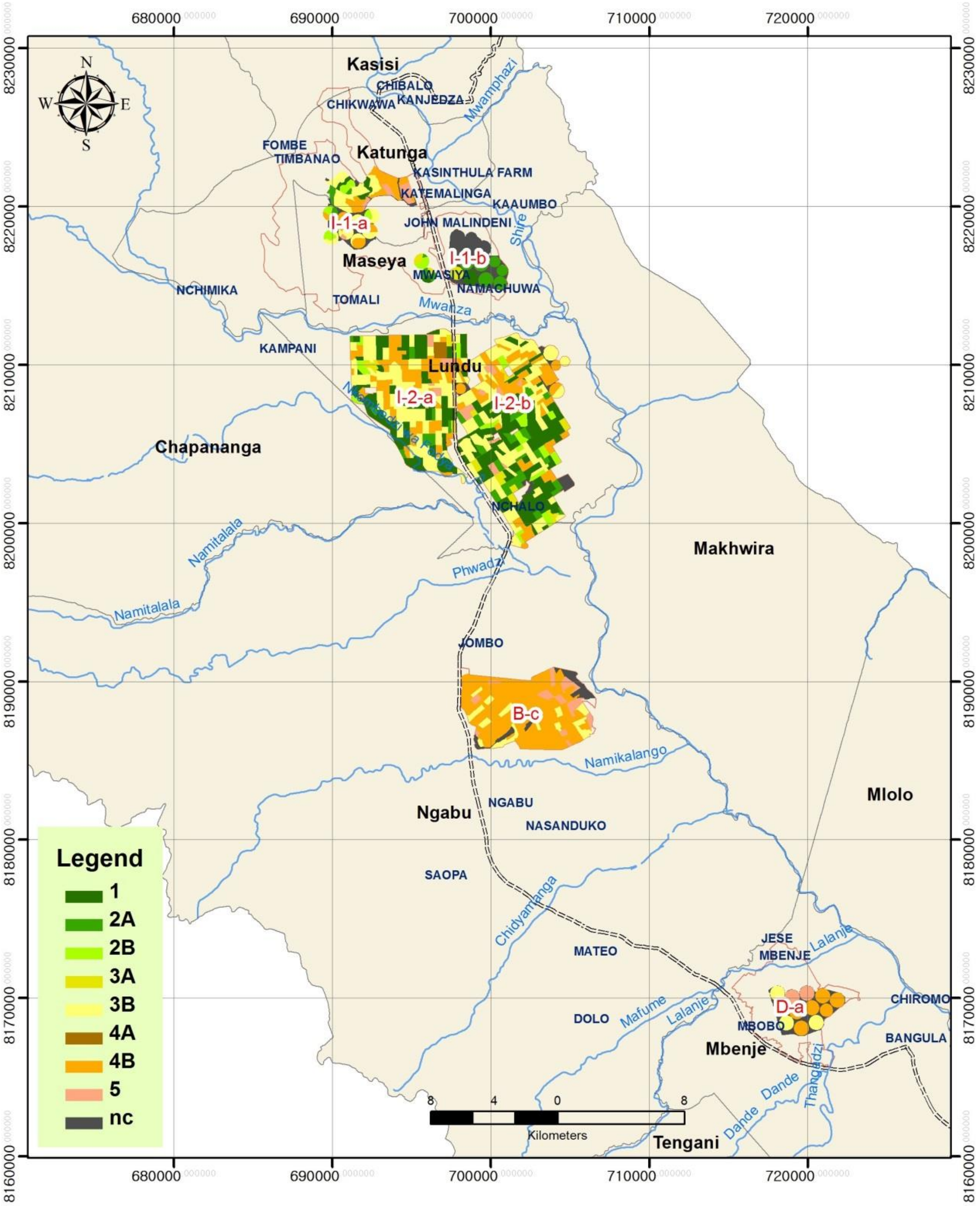


Figure 39. Land suitability map of Estates.

2. Land evaluation methodology

2.1. Introduction

Land evaluation is primarily the analysis of data about the land – its soils, climate, vegetation, etc. – in terms of realistic alternatives for improving the use of that land. Land evaluation is the process of the assessment of land performance when the land is used for specified purposes, irrigated farmland in the present project. It involves the execution and interpretation of surveys and studies of landforms, soils, climate, vegetation and other aspects of land in order to identify and compare promising kinds of land use in terms applicable to the objectives of the evaluation (FAO, 2007).

An important aspect of the methodology is that land is evaluated for a specific use (LUT). Land qualities (LQs) are determined through the use of quantified land characteristics which are then matched with the requirements of a particular land use.

In the present study, by referring to and modifying the previous performance (FAO Field Document No. 30), land suitability is evaluated for the rest of the area excluding commercial sugar farms for major crops under rain-fed and irrigated cultivations primarily based on soil characteristics such as soil texture and rock fragments, fertility (N, P, pH, salinity, etc.), effective rooting depth, drainage class, flooding hazard obtained from the above-mentioned soil survey.

2.2. Land use types

A distinction is made between major kinds of land use and land utilization types (LUTs). A major kind of land use is a major subdivision of rural land use and has clearly defined levels of technical inputs and an associated socio-economic setting.

Five major kinds of land use can be considered in the present project as follows: rain-fed cultivation under traditional management, rain-fed cultivation under improved traditional management, irrigated cultivation under traditional management, irrigated cultivation under improved traditional management, and irrigated cultivation under modern management. The main characteristics of traditional management, improved traditional management, and modern management for rain-fed cultivation or irrigated cultivation are shown in Table 38.

Table 38. Characteristics of management levels considered in land suitability evaluation for rain-fed or irrigated cultivation.

Management level	Traditional management	Improved traditional management	Modern management
Production system	Rain-fed cultivation of presently grown crop mixture	Rain-fed cultivation of crops grown usually in pure stands	Irrigated cultivation of crops grown usually in pure stands
Technology employed	Local cultivars. No fertilizers, or chemical pest, disease and weed control. Use of poorly aligned ridges with sub-optimal spacing or planting on the flat. Sub-optimal plant densities and generally poor cultivation practices.	Improved cultivars. Early land preparation and timely planting. Limited use of fertilizers and pesticides. Composting and manuring. Correct plant spacing and plant densities. Cultivation on correctly spaced contour-aligned ridges. Adequate weeding. Extension advice is followed.	High-quality improved cultivars. Early land preparation and timely planting. Sustainable and integrated nutrient and pesticide management. Correct plant spacing and plant densities. Cultivation on correctly spaced contour-aligned ridges. Adequate weeding. Proper embankments and drainage channels are constructed.
Power sources	Exclusive use of manual uncosted family labor with hand tools.	Use of (hired) manual labor with hand tools or animal traction with improved implements.	Use of agricultural machinery combined with minimal manual labor
Water sources	Only rain	Rain, river or underground water manually delivered.	River water transported by pump stations and channels.
Labor intensity	High, but only family labor.	High, family labor as well as hired labor	Low, hired labor
Capital intensity	Low, no use of credit.	Intermediate, access to and use of credit facilities.	High, equity capital and free access to and use of credit facilities.
Market orientation	Basically subsistence farming, although some cash crops may be grown.	Subsistence production and commercial sale of cash crops and excess food crops.	Professional farming. Commercial sale of cash crops.
Infrastructure requirement	Limited access to markets and agricultural services.	Free access to market facilities and agricultural services.	Progressive access to market facilities and agricultural services.
Land tenure	Customary land with traditional rights.	Customary land with traditional rights.	Purchased or leased private land.
Land holding	Small and usually fragmented.	Small but often consolidated.	Large and consolidated.
Recurrent inputs required	Traditional seed, human labor.	Improved seed, human (costed) labor and animal power, fertilizers and pesticides.	Improved seed, human (costed) labor and machinery, fertilizers and pesticides.

A land use type (LUT) is a specific kind of land use defined in more detail and refers to the cultivation/production of a crop/product or a combination of crops/products within a specified technical and socio-economic setting (FAO, 199b).

2.3. Land qualities and land characteristics

A land quality (LQ) is a complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use (FAO, 1976). It represents properties of the land which can be matched with the requirements for a specific land use. Most LQs refer to the physiological requirements of specific plants, but some refer to management requirements.

2.4. Land use requirements

Land use requirements (LURs) are the conditions of the land necessary or desirable for the successful and sustained practice of a given LUT. LURs can be subdivided into crop requirements, management requirements, and conservation requirements.

LURs must be described in a parametric way, each parameter corresponding with a LQ. In addition, in the case of crop requirements, each parameter must be rated in a number of classes for each crop in terms of its suitability. Critical values must be assigned to the suitability class-limits, which at least in theory correlate with yield levels. The land use requirements are derived mainly from Field Document No. 30. Factor ratings are based on the land use requirements of a specific LUT (FAO, 1991a).

2.5. Matching

Matching is the process of comparing the requirements of a specific type of land use with the land qualities of a certain land unit. Matching results in a suitability assessment of a specific type of land use for a specific land unit.

After comparison of the LURs of the given LUT with all diagnostic LQs of the given land unit, a list of partial land suitability ratings comes out. The lowest partial suitability rating determines the final land suitability class for the LUT/land unit combination.

Automated Land Evaluation System (ALES) can be used for matching procedure, which was developed at Cornell University and follows the principles of the 1976 Framework. ALES is a computer program that is intended for use in project or regional scale land evaluation.The entities evaluated by ALES are map units, which may be defined either broadly (as in reconnaissance surveys and general feasibility studies) or narrowly (as in detailed resource surveys and farm-scale planning). Since each model is built by a different evaluator to satisfy local needs, there is no fixed list of land use requirements by which land uses are evaluated, and no fixed list of land characteristics from which land qualities are inferred. Instead, these lists are determined by the evaluator to suit local conditions and objectives (ALES User's Manual, 1997).The ALES program used in the present study is Version 4.65 released in December 1996.

2.6. Land suitability classes

Suitability for a specific LUT is expressed in seven classes, related to the maximum attainable crop yields for that LUT (Table 33). Maximum attainable yields refer to the highest average yields obtainable on farmers' fields under a specified level of management when all conditions are optimal.

In addition to land suitability classes, land suitability subclasses can be used to distinguish types of land having the same degree of suitability but differing in the nature of the limitations which determine the suitability class.

The suitability class of a certain land unit for a specific LUT is determined by the degree of limitation the various LQs impose on the specified use. In case of more than one limitation, the most severe limitation determines the final suitability class

3. Land evaluation results

3.1. Land units

3.1.1. Introduction

Land units are specific combination of a soil unit and an agro-climatic zone (FAO, 1991b). It is understood that there is only one agro-climatic zone (Lower Shire and Mwanza Valley Zone) in SVIP Zones. However, land units correspond to soil units and the symbol for a land unit can be expressed as a serial number.

3.1.2. Land unit map

Land mapping units are defined by one land unit, that is, one soil unit. The Land Unit Map has no legend. 533 land units (LU001-LU533) are indicated in the survey zones, excepting for Estates, in Figure 40.

3.2. Land use types

The 67LUTs have been selected in the combination of managements (inputs) and crops on the basis of their agro-climatic suitability, present existence within the ADD and in some cases on the basis of market demand and Government policy (Table 39).

Table 39. Land use types.

Rain-fed cultivation, traditional management (RCTM-model)	Rain-fed cultivation, improved traditional management (RITM-model)	Irrigated cultivation, traditional management (ICTM-model)	Irrigated cultivation, improved traditional management (ICIM-model)	Irrigated cultivation, modern management (ICMM-model)
Bulrush millet	Bulrush millet	Bulrush millet	Bulrush millet	Bulrush millet
Cashew	Cashew	Cashew	Cashew	Cashew
Cassava[22]	Cassava[23]	Cassava[22]	Cassava[22]	Cassava[22]
Cotton	Cotton	Cotton	Cotton	Cotton
Cowpea	Cowpeas	Cowpea	Cowpea	Cowpea
Groundnuts[22]	Groundnuts[24]	Groundnuts[22]	Groundnuts[22]	Groundnuts[22]
Maize[22]	Maize[24]	Maize[22]	Maize[22]	Maize[22]
Rice	Sorghum	Rice	Sorghum	Sorghum
Sorghum	Soya beans	Sorghum	Soya beans	Soya beans
Soya beans	Sunflower	Soya beans	Sunflower	Sunflower
Sunflower		Sunflower	Sweet potato	
Sweet potato		Sweet potato		

[22] Short and long cycle varieties
[23] Long cycle varieties
[24] Short cycle varieties

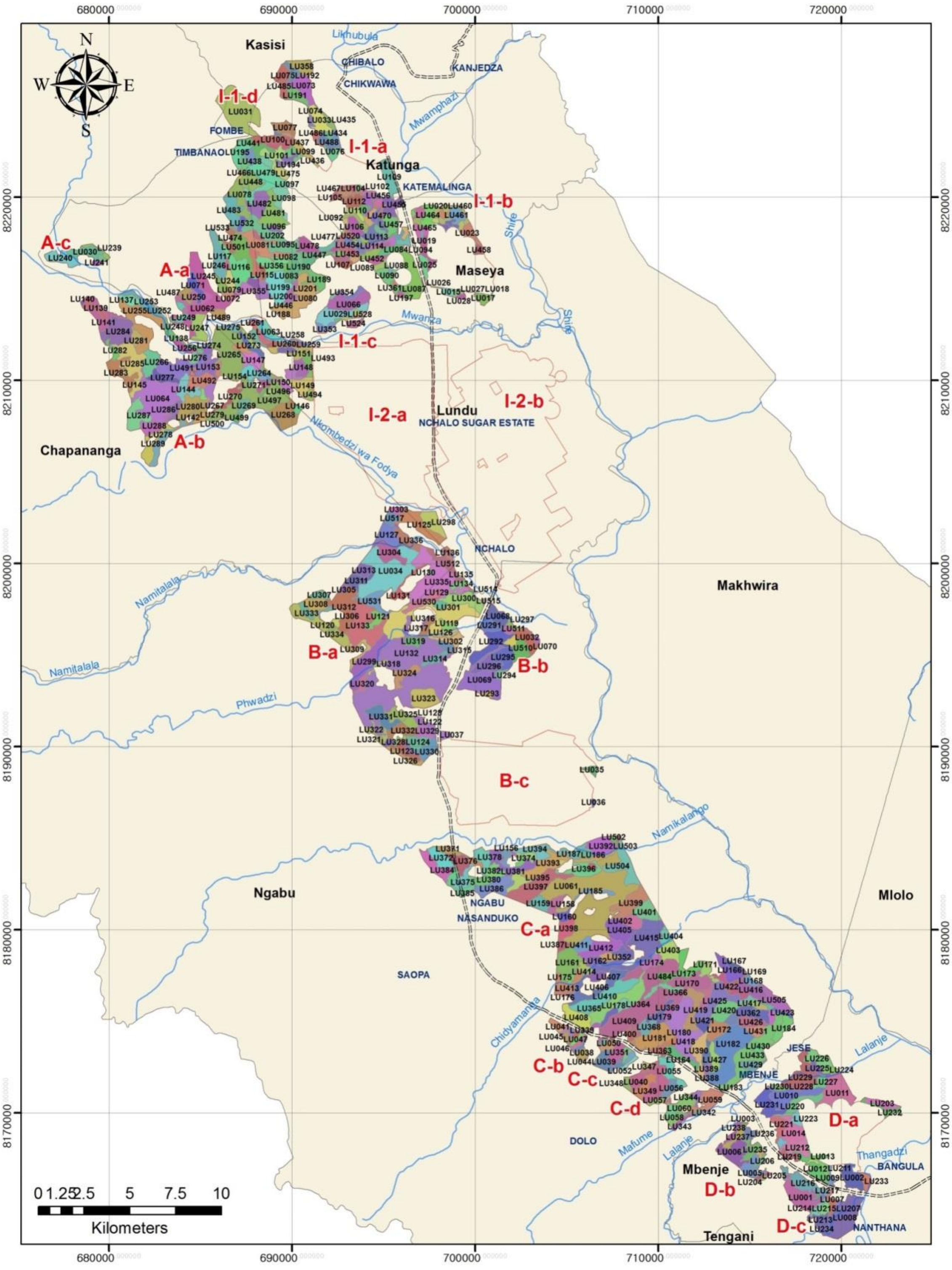


Figure 40. Land unit map.

3.3. Land qualities and characteristics

Nine LQs can be determined through an inventory of relevant 22 land characteristics, which are attributes that can be measured or estimated (FAO, 1976). The land characteristics used in the definition of the various LQs are listed in Tables 39 and 40.

3.3.1. Climate

Climate plays an important role in the evaluation of major kinds of land use. Climate data for land suitability appraisals were analyzed in terms of some parameters such as length of growing period (LGP), pattern of the growing period, P/PET ratios, mean temperature during the growing period, and the average starting date of the growing period. Agro-climatic zones and some climatic parameters are presented in Figure 41.

① Length of growing period

The climatic aspect of moisture availability is expressed through the LGP. The LGP is the period of the year when moisture supply and temperature permit crop growth and can be calculated on the basis of a water balance model.

② Pattern of the growing period

To determine the year-to-year variation in the number of lengths of growing periods per year, a historical profile was compiled showing groups of years each with a different number of growing periods per year. There may be more than one growing period in a single year due to the occurrence of one or more dry spells.

A total of 5 patterns have been recognized in Malawi. The pattern with highest risk of having dry spells during rainy season, pattern 1-2-3, is found in the project zones.

③ Quality of moisture supply

The quality of moisture supply is defined as the ratio P/PET during the growing period. When the ratio is less than 1.0 it means that P is less than PET for most of the time during the growing period. Crops are likely to suffer from water stress and soil moisture is usually very low. Areas having a P/PET ratio of less than 1.0 are found in Nsanje, Chikwawa.

④ Mean temperature during the growing period

Most farmers grow annual crops. It is therefore important to know what the mean temperature is during the LGP.

⑤ Average starting dates of the growing period

The computed average starting date of the growing period determines the point in time when field preparations, and all activities prior to planting, should have been completed. The average starting date of the growing period in the project zones falls within the second half of November.

⑥ Mean annual rainfall

The mean annual rainfall is of importance for perennials and it is calculated as 700.1 mm in the project zones.

⑦ Mean number of dry months per year

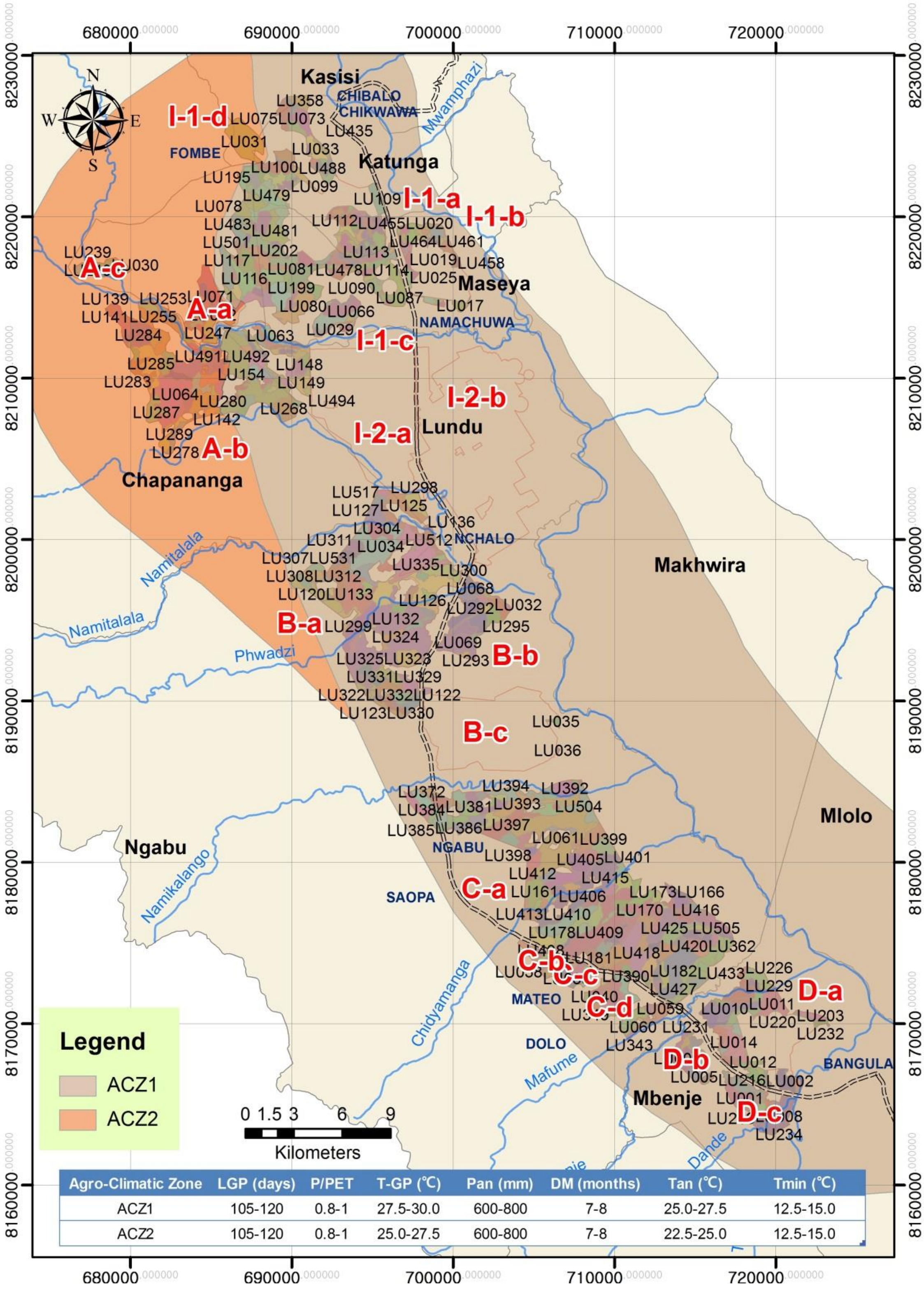
The mean number of dry months per year is of importance for perennials. A dry month has been defined as having less than 50 mm of precipitation. It is 8 from April to November.

⑧ Mean annual temperature

The mean annual temperature is closely related to altitude and is of importance for perennials. It is calculated as 26 ºC.

⑨ Mean minimum temperature of the coolest month

The mean minimum temperature of the coolest month is mainly of importance for perennials. It is calculated as 15 ºC.



Agro-Climatic Zone	LGP (days)	P/PET	T-GP (℃)	Pan (mm)	DM (months)	Tan (℃)	Tmin (℃)
ACZ1	105-120	0.8-1	27.5-30.0	600-800	7-8	25.0-27.5	12.5-15.0
ACZ2	105-120	0.8-1	25.0-27.5	600-800	7-8	22.5-25.0	12.5-15.0

Figure 41. Agro-climatic Zones.

Table 40. Land qualities and land characteristics by land use.

Land use		Land qualities	Land characteristics
Rain-fed cultivation, traditional management	c	Temperature regime	T-an, T-GP, T-min
	f	Flooding hazard	Fl
	k	Soil workability	St, Sr, Ver
	m	Moisture regime	DM, LGP, P-an, P/PET, Sd, Sl
	n	Nutrient availability	N, P
	r	Rooting conditions	St, Sd, Sr, Ver
	w	Oxygen availability	Dr
	x	Toxicity/acidity	pH, Sal
Rain-fed cultivation, improved traditional management	c	Temperature regime	T-an, T-GP, T-min
	f	Flooding hazard	Fl
	k	Soil workability	St, Sr, Ver
	m	Moisture regime	DM, LGP, P-an, P/PET, Sd, Sl
	r	Rooting conditions	St, Sd, Sr, Ver
	t	Nutrient retention capacity	CEC
	w	Oxygen availability	Dr
	x	Toxicity/acidity	pH, Sal
Irrigated cultivation, traditional management	c	Temperature regime	T-an, T-GP, T-min
	f	Flooding hazard	Fl
	k	Soil workability	St, Sr, Ver
	n	Nutrient availability	N, P
	r	Rooting conditions	St, Sd, Sr, Ver
	w	Oxygen availability	Dr
	x	Toxicity/acidity	pH, Sal
Irrigated cultivation, improved traditional management	c	Temperature regime	T-an, T-GP, T-min
	f	Flooding hazard	Fl
	k	Soil workability	St, Sr, Ver
	r	Rooting conditions	St, Sd, Sr, Ver
	t	Nutrient retention capacity	CEC
	w	Oxygen availability	Dr
	x	Toxicity/acidity	pH, Sal
Irrigated cultivation, modern management	c	Temperature regime	T-an, T-GP, T-min
	k	Soil workability	St, Sr, Ver
	r	Rooting conditions	St, Sd, Sr, Ver
	t	Nutrient retention capacity	CEC
	w	Oxygen availability	Dr
	x	Toxicity/acidity	pH, Sal

Table 41. Diagnostic land characteristics.

Land characteristics: group	symbol	name	Rain-fed cultivation, traditional management	Rain-fed cultivation, improved traditional management	Irrigated cultivation, traditional management	Irrigated cultivation, improved traditional management	Irrigated cultivation, modern management
	DM	Mean number of dry months/year	✓	✓			
	LGP	Reference length of growing period	✓	✓			
	P-an	Mean annual precipitation	✓	✓	✓	✓	✓
Climate	P/PET	Quality of moisture supply	✓	✓			
	T-an	Mean annual temperature	✓	✓	✓	✓	✓
	T-GP	Mean temp. during growing period	✓	✓	✓	✓	✓
	T-min	Mean minimum temp. of coolest month	✓	✓	✓	✓	✓
	CEC	Cation exchange capacity (0-50 cm)		✓		✓	✓
	Dr	Median soil drainage class	✓	✓	✓	✓	✓
	N	Nitrogen (0-50 cm)	✓		✓		
	P	Phosphorus (0-50 cm)	✓		✓		
	pH	Median soil reaction (0-50 cm)	✓	✓	✓	✓	✓
	Rmf	Rock and mineral fragments profile	✓	✓	✓	✓	✓
Soil✓	Sal	Salinity (0-50 cm)	✓	✓	✓	✓	✓
	Sd	Effective soil depth	✓	✓	✓	✓	✓
	Sr	Surface stoniness and rockiness	✓	✓	✓	✓	✓
	Tex-p	Texture profile	✓	✓	✓	✓	✓
	Tex-t	Texture topsoil	✓	✓	✓	✓	✓
	St	Stagnic soil properties	✓	✓	✓	✓	✓
	Ver	Vertic soil properties	✓	✓	✓	✓	✓
Topography	Fl	Frequency of flooding	✓	✓	✓	✓	
	Sl	Dominant slope class	✓	✓	✓	✓	

3.3.2. Soil

① CEC

More than half of the soil survey area (19,313 ha) has very low level of CEC (<5 cmol/kg). In Zone C with larger clayey soils than the others, however, CEC level increases to medium to very high overall in many land units (Figure 42).

② Median soil drainage class

In approximately 92% out of the soil survey area, soil drainage class belongs to well or moderately well or imperfect. Lots of land units in Zones I-a, A, and B present much better drainage classes of somewhat excessive, well, moderately well compared with Zone C (Figure 43). Almost all land units in Zone C are classified to have imperfect or poor drainage class, because of high rainfall intensity in the rainy season, low elevations and flat landforms near rivers, and clayey soils with very low permeability.

③ Nitrogen

Almost all land units in every Zone, 95.2% of the soil survey area, contain very low (<0.08 %) level of nitrogen in the top 50cm (Figure 44), which is likely to result from intense cropping and low fertilizer application.

④ Phosphorus

In comparison with the very low levels of nitrogen content, lots of land units hold medium to very high (>18 ppm) level of phosphorus in the top 50 cm (Figure 45) probably by phosphorus fixation by clay particles.

⑤ Median soil reaction

Significant number of land units, the area of which reaches to 22,000 ha, are alkaline due to secondary carbonate minerals in several soils such as Cambisols, Vertisols and Luvisols. Especially, the soil reactions of almost land units in Zone C are slightly or moderately alkaline (Figure 46).

⑥ Rock and mineral fragments in soil profile

3.5%, i.e., 1,279 ha out of the entire soil survey area is skeletal that has over 40% of rock and fragments in soil profile. The skeletal area incorporates only 33 land units (Figure 47).

⑦ Salinity

Generally, salinity is not a significant problem in the top 50 cm. However, 2,304 ha of 41 land units are saline, adversely affecting normal crop growth . Furthermore, 1,295 ha of 20 land units is strongly saline, which is very harsh condition for almost crops to absorb water and grow (Figure 48).

⑧ Effective soil depth

More than 90 % (33,457 ha) of the soil survey area including 489 land units has very deep effective soil depth without any root–limiting factor in soil profile (Figure 49).

⑨ Surface stoniness and rockiness

69.3% in the entire soil survey area, which is 25,438 ha consisting of 397 land units, is non-stony in the surface soil (0-30 cm). 28.7% is stony and only 2.0% very stony (Figure 50).

⑩ Texture of soil profile

Soil profile texture varies from sandy to heavily clayey depending on land units. On average, it is sandy clay loam which takes the highest percentage (32.6%) out of the soil survey area. Fine-textured land units number 191 (the area of 16,254 ha) as per Figure 51.

⑪ Topsoil texture

Topsoil texture in the top 30 cm is more various in comparison with soil profile texture but it is sandy clay loam on average as well which takes the highest percentage (32.2%) out of the soil survey area. Fine-textured land units number 175 (the area of 14,206 ha) as per Figure 52.

⑫ Stagnic and vertic properties

64.5% (23,665 ha) in the entire soil survey area has no stagnic or vertic properties. The 24 land units located in 3,329 ha area, however, are very disadvantageous for cultivation due to stagnic and vertic properties (Figure 53).

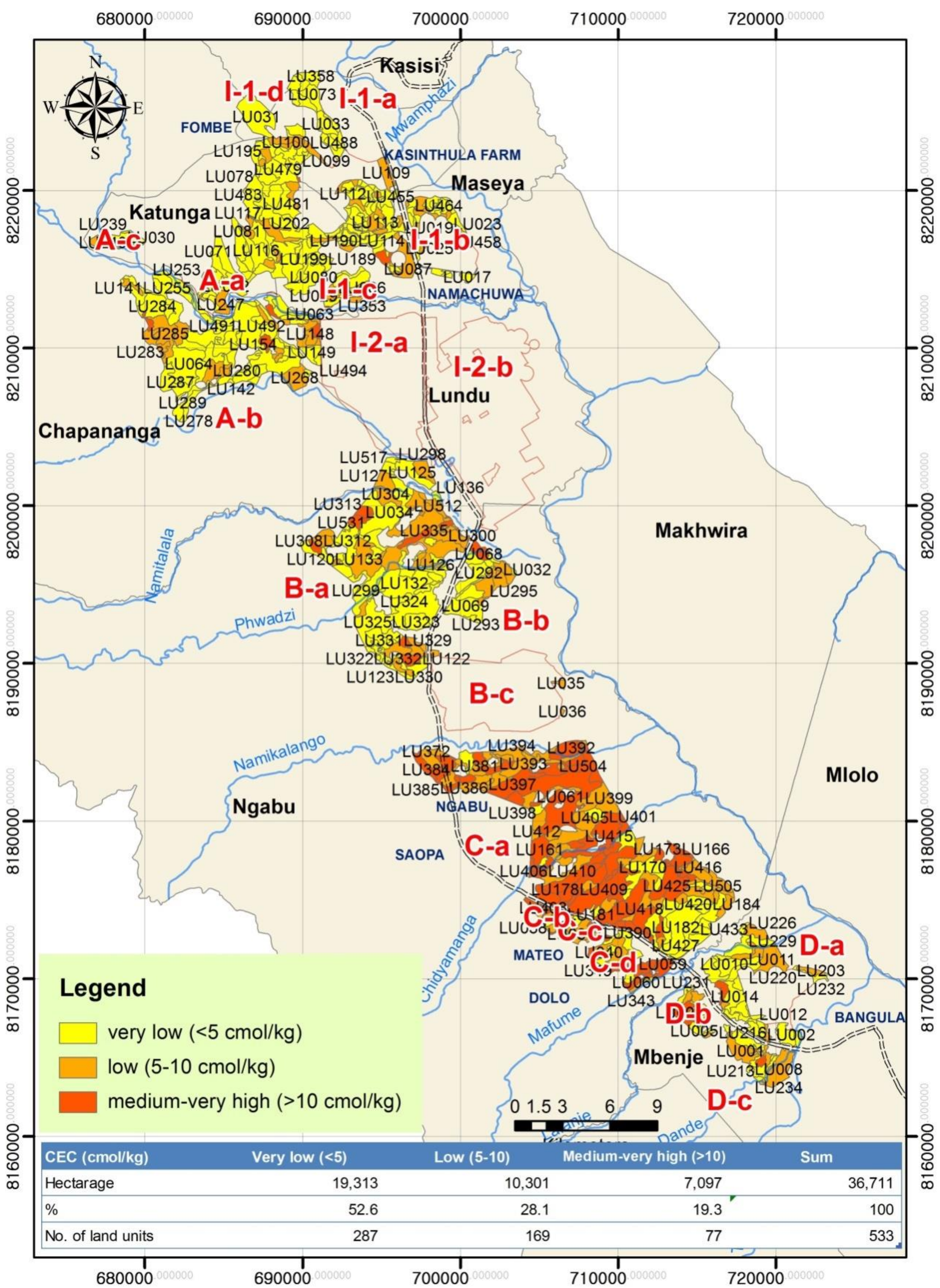
3.3.3. Topography

① Frequency of flooding

Frequency of flooding is estimated empirically from landforms, soil profiles, 2015 flooded area, and field observation. Approximately 50% (18,058 ha) out of the entire soil survey area is divided to non-flooded area and only 4.8% located in the lower or depressed area frequently-flooded and very vulnerable to flooding (Figure 54).

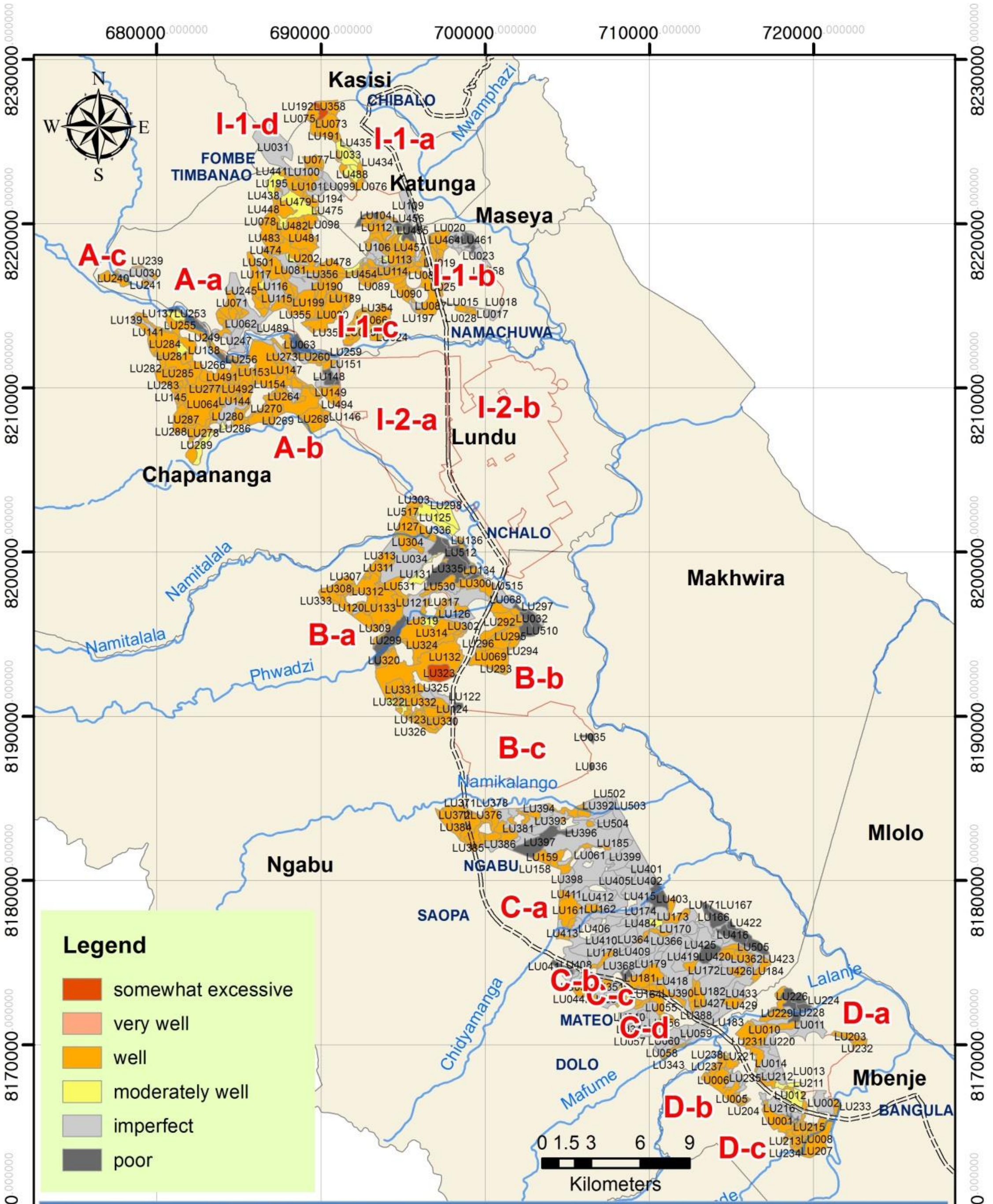
② Dominant slope gradient

Slope gradient is classified by three classes. SVIP Zones are spread over flat to level plains, and approximately 95% (34,799 ha) out of the entire area with 488 land units is flat to almost flat. Part of Zones I-1 and A (455 ha) is sloping and can be unsuitable for irrigation (Figure 55).



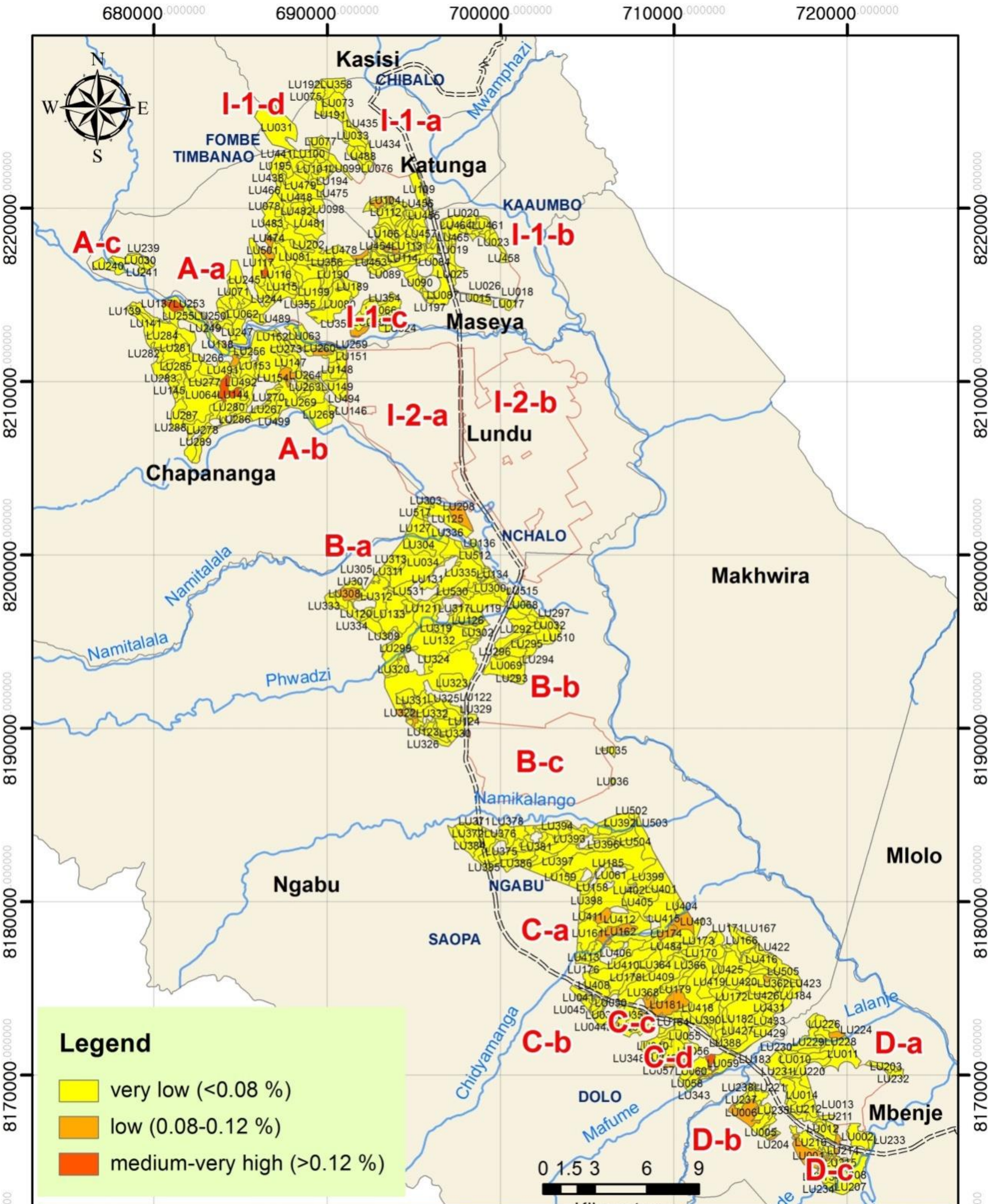
CEC (cmol/kg)	Very low (<5)	Low (5-10)	Medium-very high (>10)	Sum
Hectarage	19,313	10,301	7,097	36,711
%	52.6	28.1	19.3	100
No. of land units	287	169	77	533

Figure 42. CEC classes by land unit.



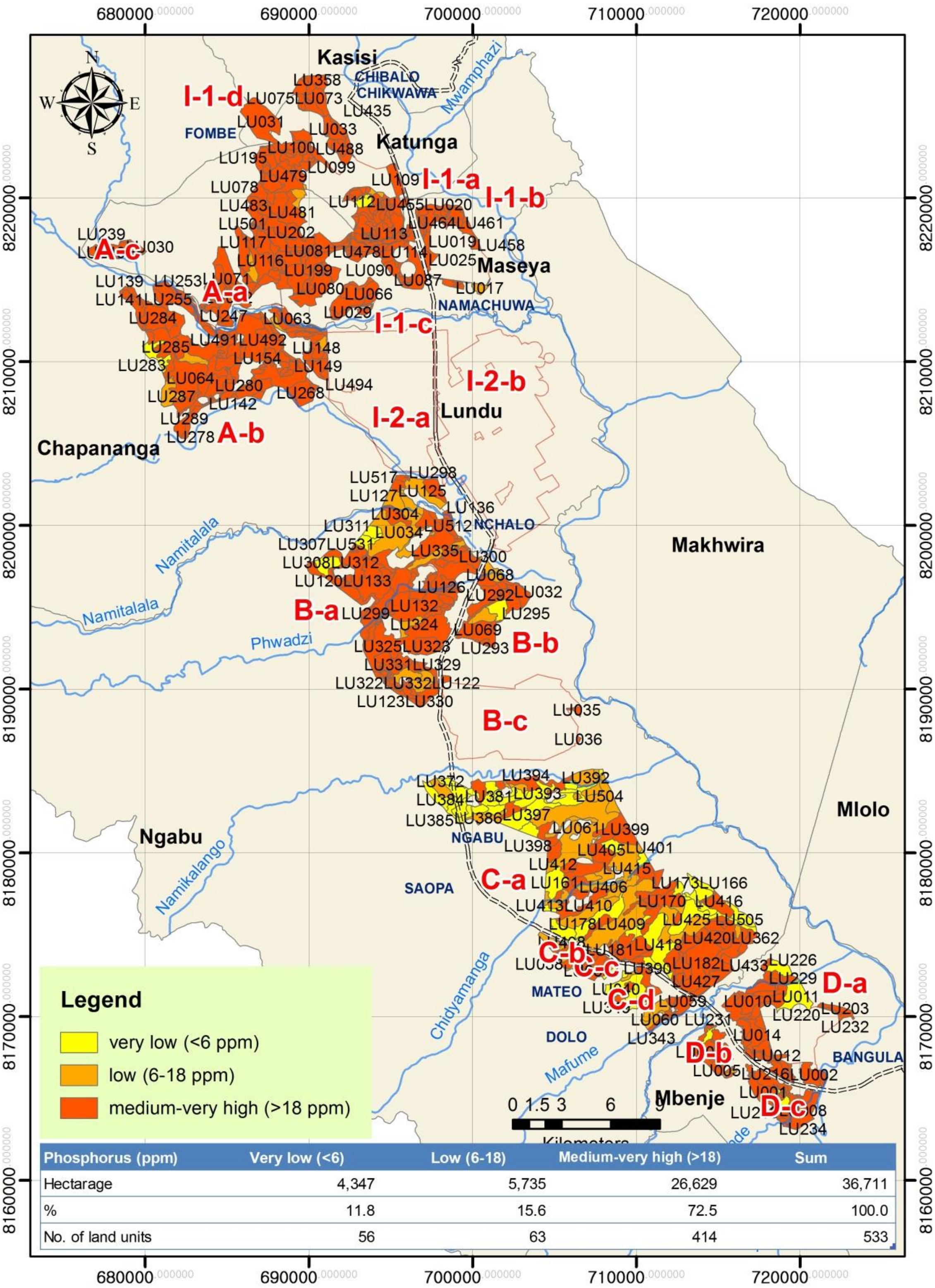
Drainage class	Somewhat excessively well	Very well	Well	Moderately well	Imperfect	Poor	Sum
Hacterage	185	59	19,335	1,391	13,094	2,647	36,711
%	0.5	0.2	52.7	3.8	35.7	7.2	100
No. land units	2	1	314	24	147	45	533

Figure 43. Soil drainage classes by land unit.



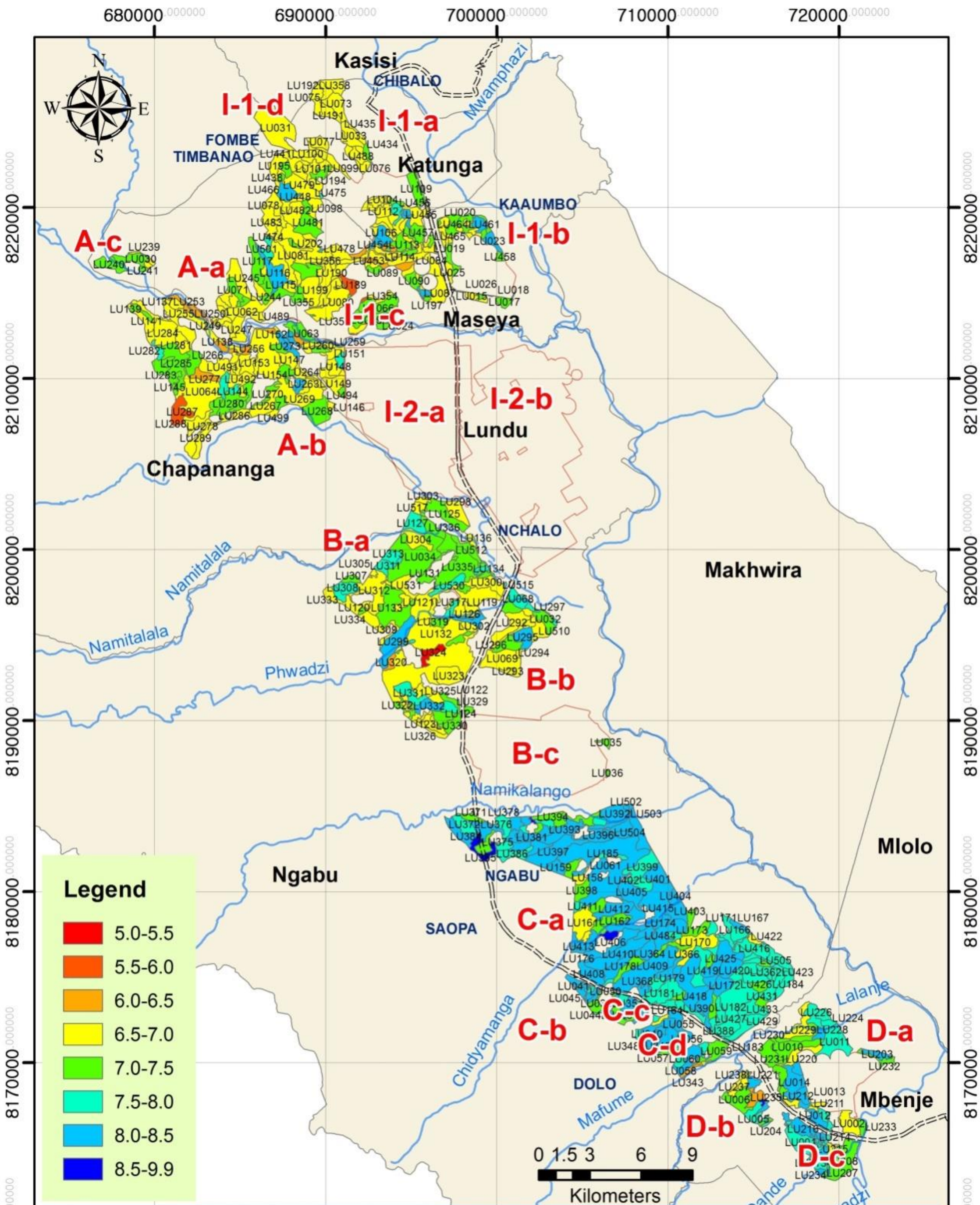
Nitogen (%)	Very low (<0.08)	Low (0.08-0.12)	Medium-very high (>0.12)	Sum
Hectarage	34,955	1,567	189	36,711
%	95.2	4.3	0.5	100
No. of land units	495	33	5	533

Figure 44. Nitogen classes by land unit.



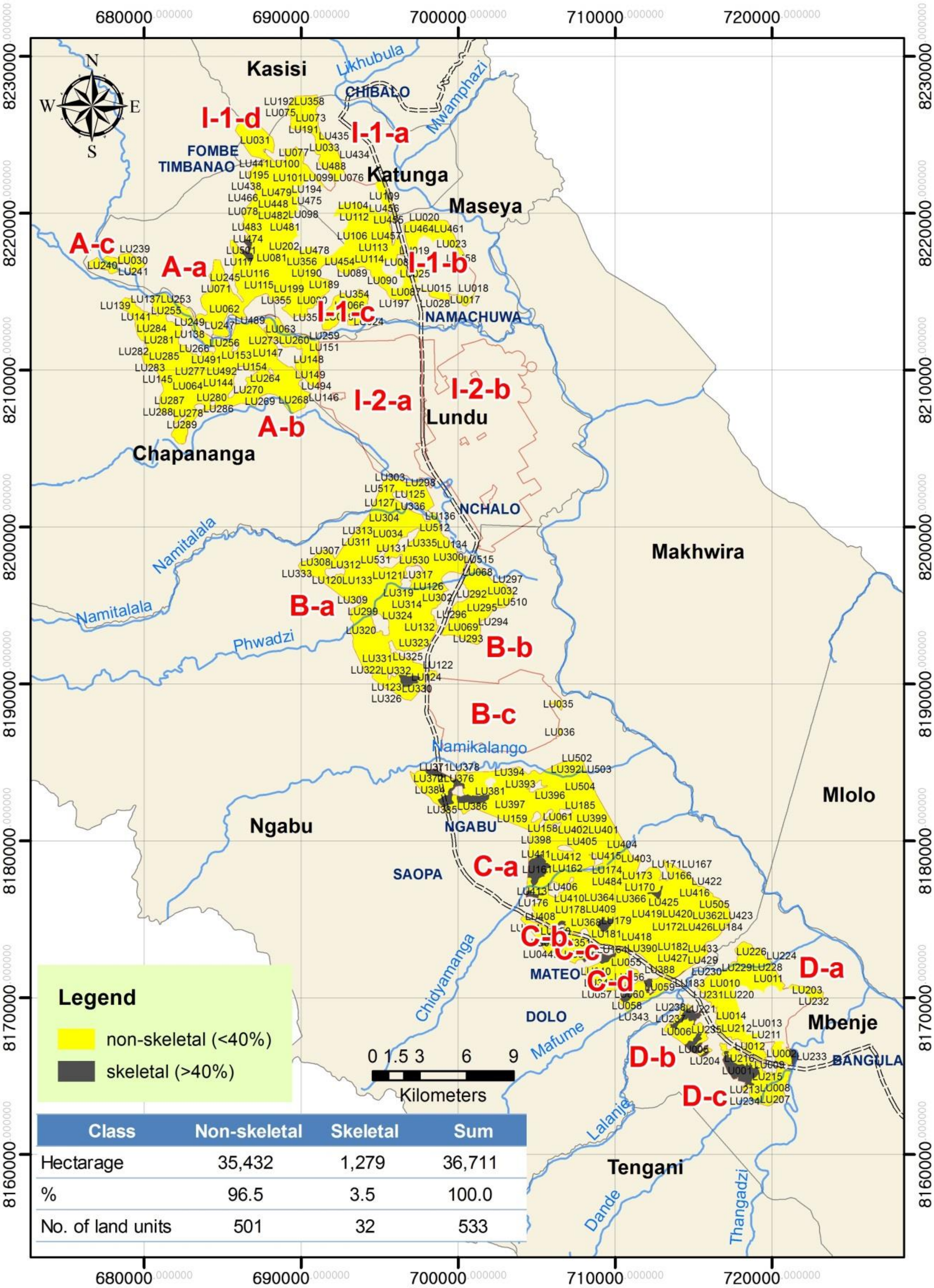
Phosphorus (ppm)	Very low (<6)	Low (6-18)	Medium-very high (>18)	Sum
Hectarage	4,347	5,735	26,629	36,711
%	11.8	15.6	72.5	100.0
No. of land units	56	63	414	533

Figure 45. Phosphorus classes by land unit.



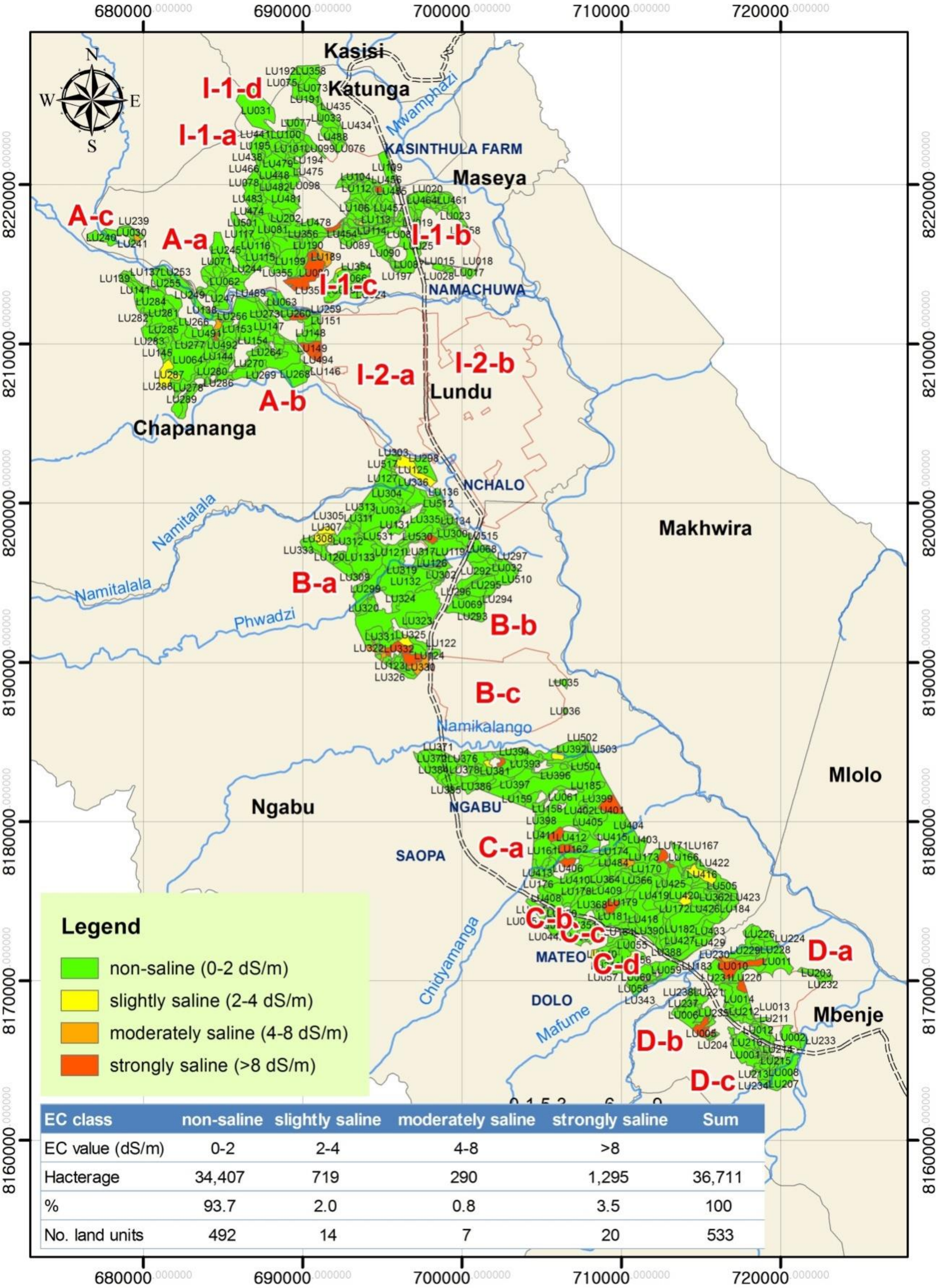
pH class	acid	moderately acid	slightly acid	alomost neutral	very slightly alkaline	slightly alkaline	moderately alkaline	strongly alkaline	Sum
pH value	5.0-5.5	5.5-6.0	6.0-6.5	6.5-7.0	7.0-7.5	7.5-8.0	8.0-8.5	8.5-9.9	
Hacterage	78	205	529	13,900	8,107	5,094	8,648	150	36,711
%	0.2	0.6	1.4	37.9	22.1	13.9	23.6	0.4	100
No. land units	1	3	17	196	131	89	92	4	533

Figure 46. pH classes by land unit.



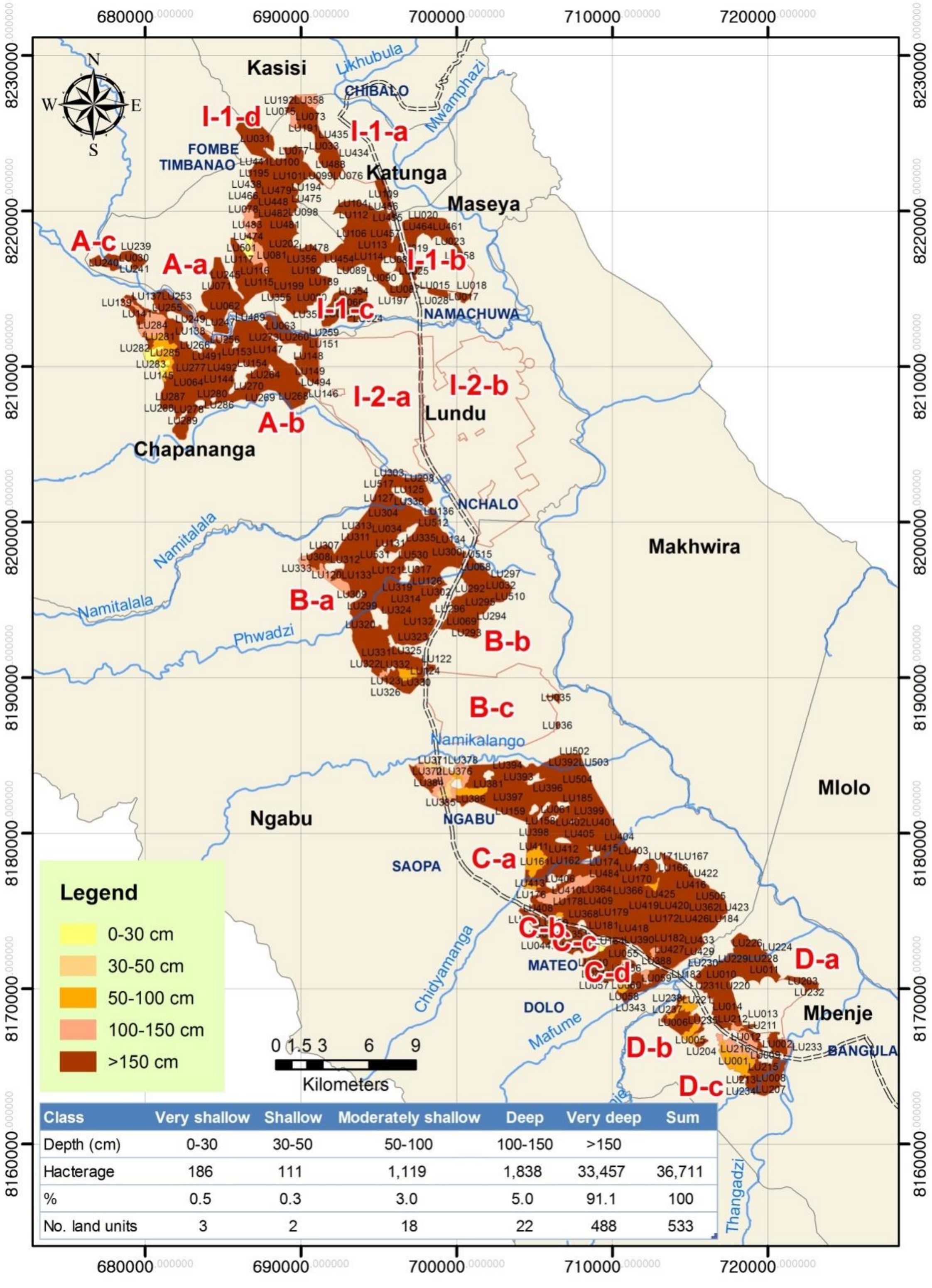
Class	Non-skeletal	Skeletal	Sum
Hectarage	35,432	1,279	36,711
%	96.5	3.5	100.0
No. of land units	501	32	533

Figure 47.Rock and fragments in soil profile by land unit.



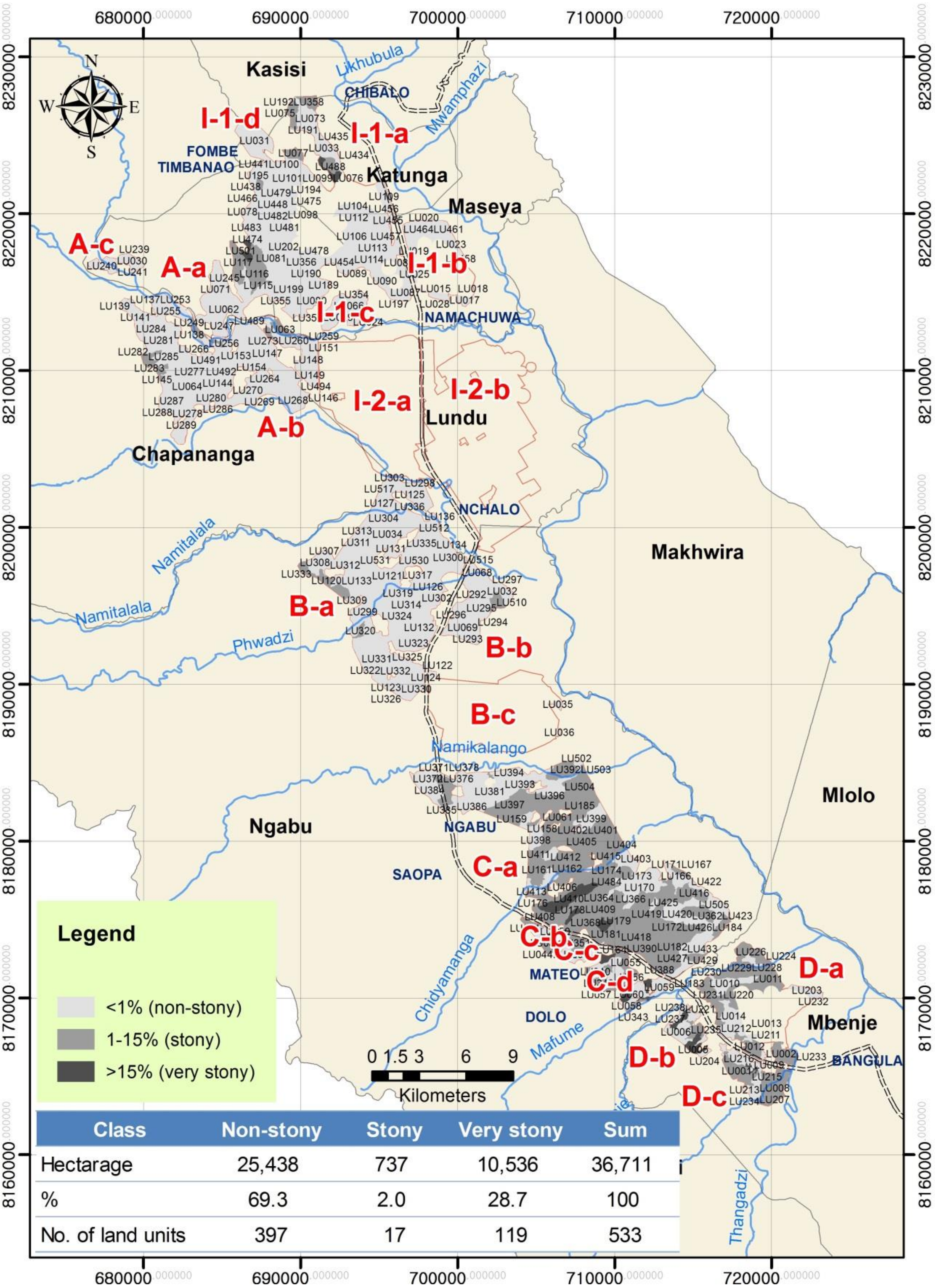
EC class	non-saline	slightly saline	moderately saline	strongly saline	Sum
EC value (dS/m)	0-2	2-4	4-8	>8	
Hacterage	34,407	719	290	1,295	36,711
%	93.7	2.0	0.8	3.5	100
No. land units	492	14	7	20	533

Figure 48. Salinity classs by land unit.



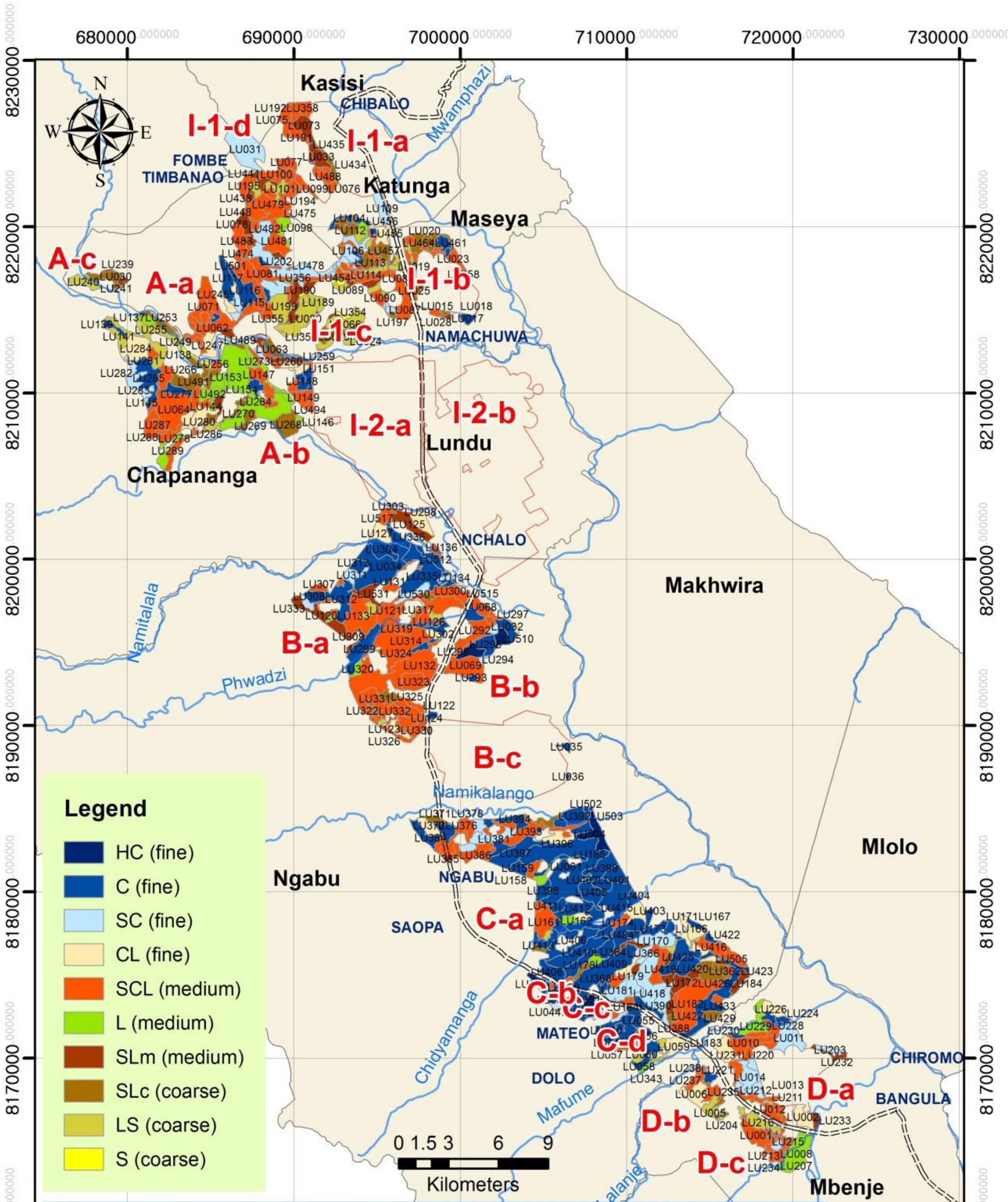
Class	Very shallow	Shallow	Moderately shallow	Deep	Very deep	Sum
Depth (cm)	0-30	30-50	50-100	100-150	>150	
Hacterage	186	111	1,119	1,838	33,457	36,711
%	0.5	0.3	3.0	5.0	91.1	100
No. land units	3	2	18	22	488	533

Figure 49. Effective soil depth by land unit.



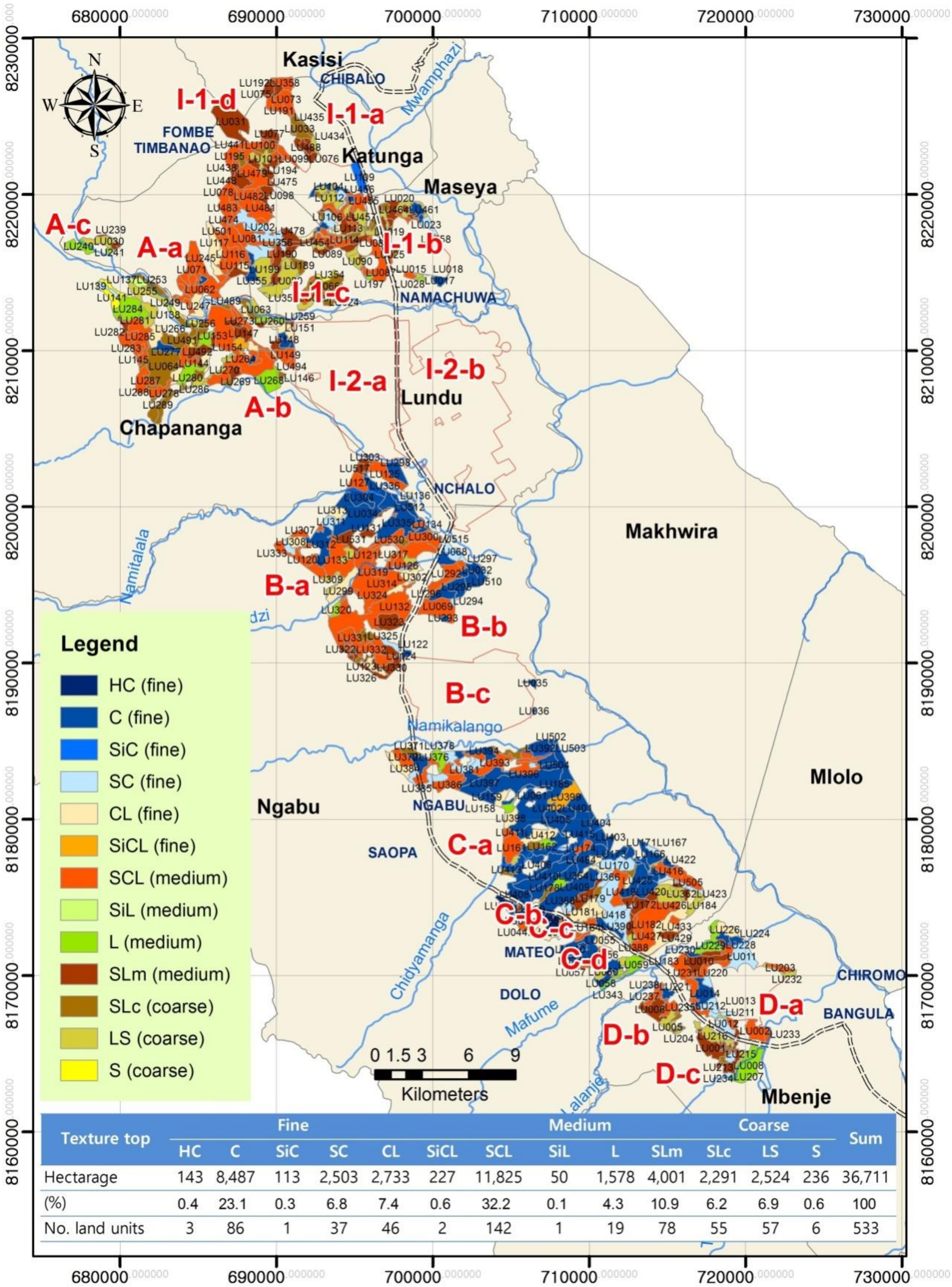
Class	Non-stony	Stony	Very stony	Sum
Hectarage	25,438	737	10,536	36,711
%	69.3	2.0	28.7	100
No. of land units	397	17	119	533

Figure 50. Surface stoniness and rockiness by land unit.



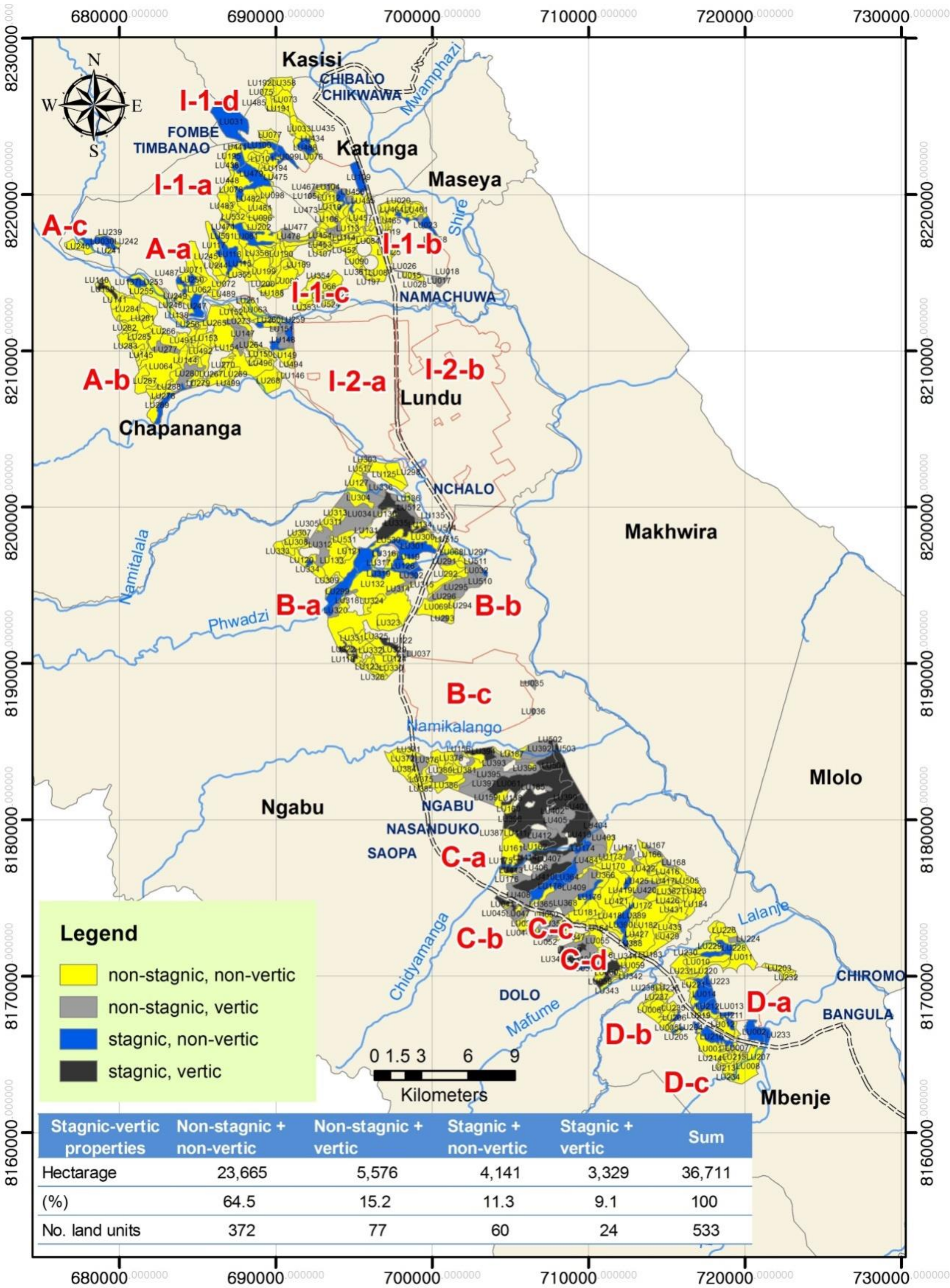
Texture profile	Fine				Medium			Coarse			Sum
	HC	C	SC	CL	SCL	L	SLm	SLc	LS	S	
Hectarage	441	9,992	3,602	2,219	11,976	1,988	1,993	2,216	2,132	152	36,711
(%)	1.2	27.2	9.8	6.0	32.6	5.4	5.4	6.0	5.8	0.4	100
No. land units	5	109	47	30	173	21	44	50	47	7	533

Figure 51. Texture of soil profile by land unit.



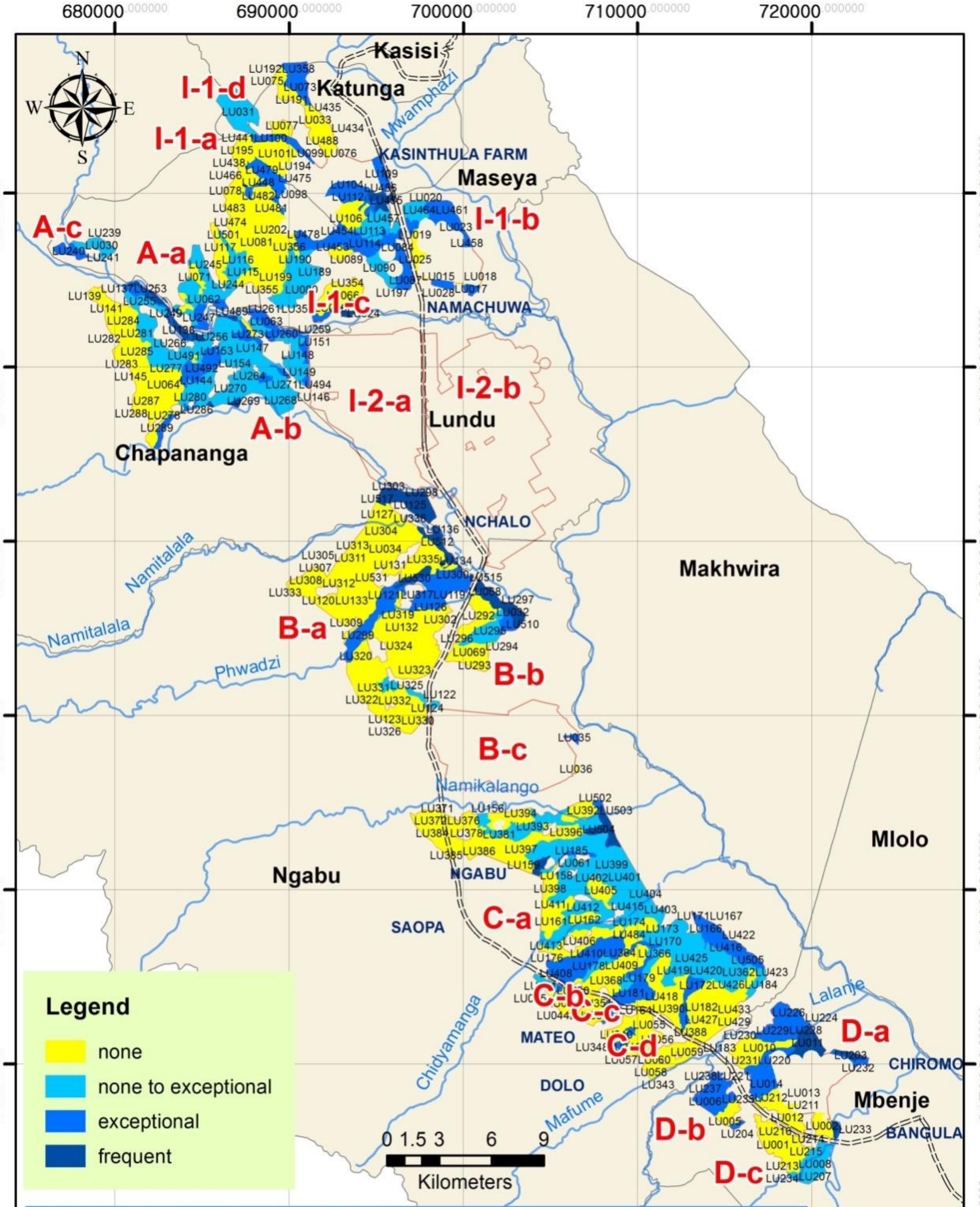
Texture top	Fine							Medium			Coarse			Sum
	HC	C	SiC	SC	CL	SiCL	SCL	SiL	L	SLm	SLc	LS	S	
Hectarage	143	8,487	113	2,503	2,733	227	11,825	50	1,578	4,001	2,291	2,524	236	36,711
(%)	0.4	23.1	0.3	6.8	7.4	0.6	32.2	0.1	4.3	10.9	6.2	6.9	0.6	100
No. land units	3	86	1	37	46	2	142	1	19	78	55	57	6	533

Figure 52. Topsoil texture by land unit.



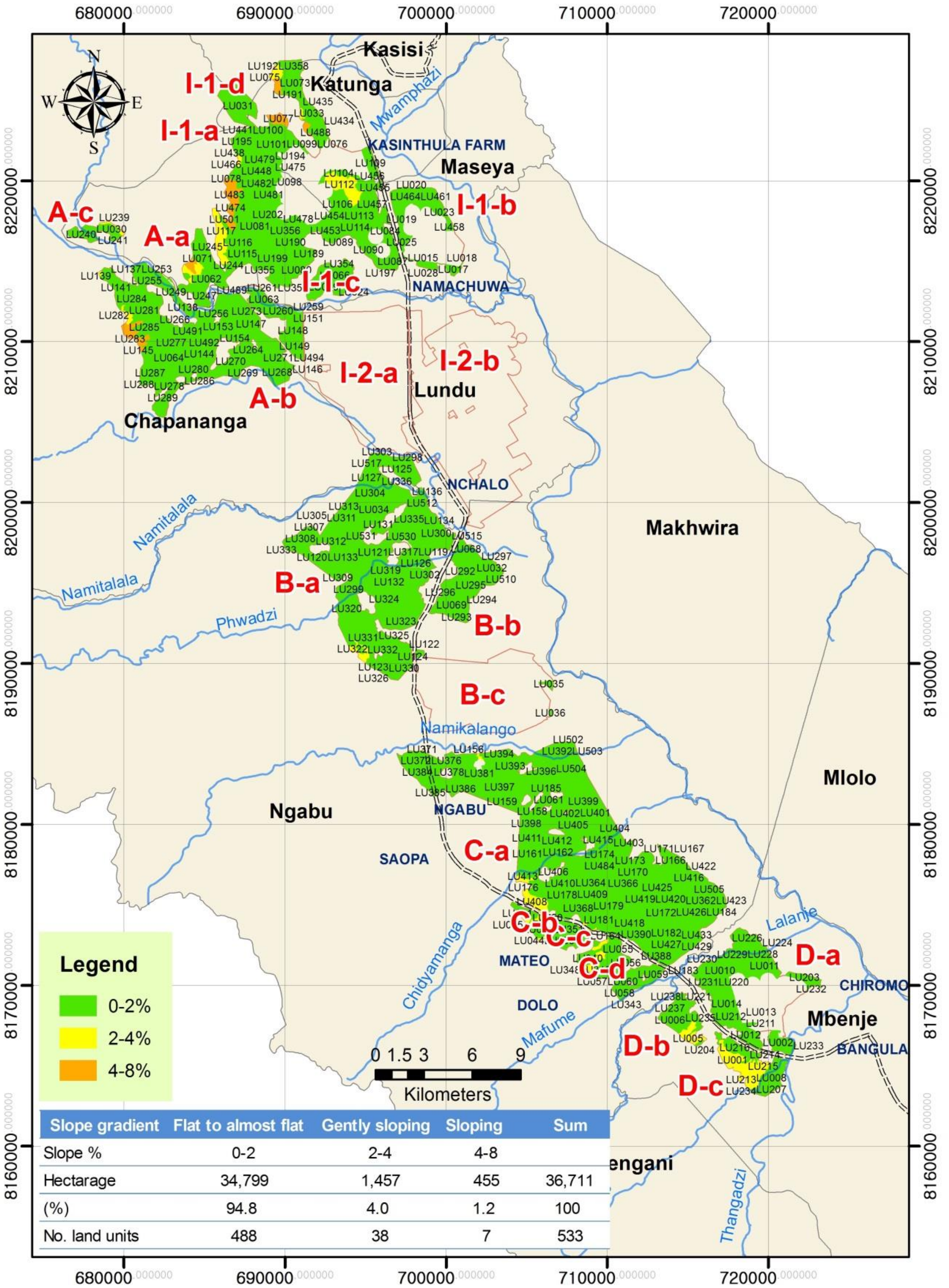
Stagnic-vertic properties	Non-stagnic + non-vertic	Non-stagnic + vertic	Stagnic + non-vertic	Stagnic + vertic	Sum
Hectarage	23,665	5,576	4,141	3,329	36,711
(%)	64.5	15.2	11.3	9.1	100
No. land units	372	77	60	24	533

Figure 53. Stagnic and vertic properties by land unit.



Frequency of flooding	None	None to excptional	Exceptional	Frequent	Sum
Hectarage	18,058	9,788	7,093	1,772	36,711
(%)	49.2	26.7	19.3	4.8	100
No. land units	248	116	128	41	533

Figure 54. Frequency of flooding by land unit.



Slope gradient	Flat to almost flat	Gently sloping	Sloping	Sum
Slope %	0-2	2-4	4-8	
Hectarage	34,799	1,457	455	36,711
(%)	94.8	4.0	1.2	100
No. land units	488	38	7	533

Figure 55. Slope gradient by land unit.

3.4. Land use requirements

A total of 9 land qualities and 22 diagnostic land characteristics have been identified for consideration in the evaluation (See Tables 39 and 40). The factor ratings which are given for each land quality refer to the effects of individual land qualities on crops. These are based on the land use requirements of a specific LUT.

3.4.1. Temperature regime (c)

Diagnostic land characteristics are T-GP for annuals and T-an and Tmin for perennials. In Table 42, factor ratings of mean temperature during the growing period are presented for various crops. For perennials the mean annual temperature is used for comparison with their temperature requirement.

Table 42. Factor ratings of mean temperature for various crops (all models).

Crop	Mean temperature (℃) during the growing period						
	12.5-15.0	15.0-17.5	17.5-20.0	20.0-22.5	22.5-25.0	25.0-27.5	27.5-30.0
Maize[13]	n	n	s3	s2	s1	s1	s1/s2
Bulrush millet	n	n	n	s3	s2	s3	n
Rice, paddy	n	n	n	s3/s2	s1	s1	s1
Sorghum	n	n	s3	s2/s1	s1	s1	s1
Groundnuts[25]	n	n	n	s3/s2	s1	s1	s2
Groundnuts[26]	n	n	s3/s2	s1	s1	s2	s3
Soya beans	n	n	s3	s2	s1	s1	s1
Sunflower	n	s3	s2	s1	s1	s1	s1
Cowpea	n	n	s3	s2	s1	s1	s1
Sweet potato	n	s3	s3	s2	s1	s1	s2
Cassava[13]	n	n	n	s3	s2/s1	s1	s1
Cotton	n	n	n	s3	s2	s1	s1
	mean annual temperature (℃)						
	12.5-15.0	15.0-17.5	17.5-20.0	20.0-22.5	22.5-25.0	25.0-27.5	
Cassava[14]	n	n	s3	s2	s1	s1	
Cashew	n	n	n	n/s3	s2	s1	

[25] Short cycle varieties

[26] Long cycle varities

In addition, the mean temperature of the coolest month is considered and these factor ratings are present in Table 43.

Table 43. Factor ratings of minimum temperature requirement for perennials (all models)

Crop	Mean minimum temperature (℃) of the coolest month						
	0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0	15.0-17.5
Cassava[14]	n	s3	s2	s1	s1	s1	s1
Cashew	n	n	n	s3	s3	s2	s2

3.4.2. Moisture regime (m)

Moisture availability is affected by so many factors such that diagnostic land characteristics are various and complicated, according to crop and management level.

- Monthly (for the calculation of LGP) and mean annual rainfall (P-an)
- Potential evapotranspiration (PET-modified Penman) monthly values (for the calculation of LGP)
- Mean number of dry months/year (DM)
- Dominant slope class (Sl)
- Soil drainage class (Dr)
- Frequency of flooding (Fl)

① RCTM and ICTM

Factor ratings of LGP requirements for annual crops are presented in Table 44. For water-receiving sites they are taken as the final ones but for water--shedding they are adjusted by P/PET ratio, the infiltration capacity, and AWHC of the soil for annuals.

For SVIP Zones, P/PET is 0.8-1.0 signifying that rainfall does not fully meet the PET requirements so creating a moderate moisture stress during a considerable part of the growing period.

Table 44. Factor ratings of LGP requirements for annual crops (RCTM and ICTM).

Crop	LGP (days)												drought resistance
	105-120	120-135	135-150	150-165	165-180	180-195	195-210	210-225	225-240	240-270	270-300	300-330	
Maize	s3	s3	s2	s1	s1	s1	s1	s1	s2	s2	s3	s3	low
Bulrush millet	s2	s2	s1	s1	s1	s2	s2	s2	s3	s3	n	n	moderate
Sorghum	s3	s3	s3	s1	s1	s1	s1	s2	s3	s3	n	n	high
Groundnuts	s3	s3	s2	s1	s1	s1	s1	s1	s2	s3	s3	n	moderate
Soya beans	s3	s2	s2	s1	s1	s2	s2	s2	s3	s3	s3	n	low
Sunflower	s3	s2	s2	s1	s1	s1	s2	s2	s3	s3	s3	n	moderate
Cowpea	s3	s2	s2	s1	s1	s1	s1	s1	s2	s2	s3	n	moderate
Sweet potato	s3	s3	s3	s2	s1	s1	s1	s2	s2	s2	s3	s3	moderate
Cassava	s3	s3	s3	s3	s3	s3	s2	s2	s2	s2	s1	s1	high
Cotton	s3	s2	s2	s1	s1	s1	s1	s2	s3	s3	s3	n	moderate

For perennials the mean annual rainfall in combination with the mean number of dry months per year is used in the assessment of LQ "m". In Table 45, the factor rating for cashew is indicated and adjusted for the mean number of dry months per year in Table 46.

Table 45. Factor rating of mean annual precipitation for perennials (RCTM and ICTM).

Crop	Mean annual precipitation (mm)				
	600-800	800-1,200	1,200-1,600	1,600-2,000	>2,000
Cashew	s3	s2/s3	s1	s1	s2

Table 46. Factor ratings of mean number of dry months/year for perennials (RCTM and ICTM).

Crop	Mean number of dry months/year[27]			
	1-2	3-4	5-6	7-8
Cashew	n	s2/s3	s1	s2/s3

[27] A dry month is defined as having <50 mm rainfall.

② ICTM,ICIM, and ICMM

Procedures are the same as outlined for annual crops in Section

Precedures are the same as outlined for annual crops in Section ①. Table 47 lists the factor ratings for LGP requirements .

Table 47. Factor ratings of LGP requirements and drought rsistance for annuals (RITM , ICIM, and ICMM).

Crop	LGP (days)												drought resistance
	105-120	120-135	135-150	150-165	165-180	180-195	195-210	210-225	225-240	240-270	270-300	300-330	
Maize[28]	s3	s2	s2	s1	s1	s1	s1	s1	s2	s2	s3	n	low
Maize[29]	n	s3	s3	s2	s2	s1	s1	s1	s1	s1	s2	s3	low
Bulrush millet	s2	s2	s1	s1	s1	s1	s2	s2	s3	n	n	n	moderate
Sorghum	s3	s3	s1	s1	s1	s1	s1	s2	s2	s2	n	n	high
Groundnuts[27]	s3	s2	s1	s1	s1	s1	s2	s2	s3	s3	n	n	moderate
Groundnuts[28]	n	s3	s2	s1	s1	s1	s1	s1	s2	s2	s3	n	moderate
Soya beans	s3	s2	s2	s1	s1	s1	s1	s1	s1	s2	s3	n	low
Sunflower	s3	s2	s2	s1	s1	s1	s1	s2	s2	s2	s3	s3	moderate
Cowpea	s3	s2	s2	s1	s1	s1	s1	s1	s1	s2	s3	n	moderate
Cassava[27]	n	n	n	n	n	s3	s3	s2	s2	s1	s1	s1	high
Cassava[28]	s3	s3	s3	s3	s3	s3	s3	s3	s2	s2	s1	s1	high
Cotton	n	s3	s2	s1	s1	s1	s1	s2	s3	n	n	n	moderate

The procedure is the same as outlined for annual crops in Section ①. Factor ratings for mean annual precipitation and mean number of dry months per year have been indicated in Tables 48 and 49, respectively. For perennials the mean annual rainfall in combination with the mean number of dry months per year is used in the assessment of LQ “m”. In Table 49, the factor rating for cashew is indicated and adjusted for the mean number of dry months per year.

[28]Short cycle varieties
[29]Long cycle varieties

Table 48. Factor rating of mean annual precipitation for perennials (RITM, ICIM, and ICMM).

Crop	Mean annual precipitation (mm)				
	600-800	800-1,200	1,200-1,600	1,600-2,000	>2,000
Cashew	s3	s1/s2	s1	s1	s1

Table 49. Factor ratings of mean number of dry months/year for perennials (RITM, ICIM, and ICMM).

Crop	Mean number of dry months/year			
	1-2	3-4	5-6	7-8
Cashew	n	s2/s3	s1	s2/s3

In addition, Table 50 is on the factor ratings of moisture regime for rice, paddy in the condition of P-an less than 1,200 mm.

Table 50. Factor ratings of moisture regime for rice, paddy (RCTM and RITM).

Frquency of flooding	Soil drainage class			
	very poor	poor	imperfect	moderately well to excessive
none	n	n	n	n
non to exceptional	n	n	n	n
exceptional	s2	n	n	n
frequent	s2	s1	n	n

3.4.3. Oxygen availability (w)

Oxygen availability is rated for individual LUTs irrespective of management level. The oxygen requirements of the crops have been matched with applied soil drainage classes as per Table 51. Under ICMM, the numbers of classes is upgraded by a full class except very poor soils.

Table 51. Factor ratings of oxygen availability for various crops (all models).

Crop	Drainage class				
	very poor	poor	imperfect	moderately well	well to excessive
Maize	n	n	s3	s1	s1
Bulrush millet	n	n	s3	s1	s1
Sorghum	n	n	s2	s1	s1
Groundnuts	n	n	s3	s1	s1
Soya beans	n	n	s2	s1	s1
Sunflower	n	n	s3	s1	s1
Cowpea	n	n	s3	s1	s1
Sweet potato	n	n	s3	s1	s1
Cassava	n	n	s3	s1	s1
Cotton	n	n	s3	s1	s1
Cashew	n	n	n	s2	s1

3.4.4. Nutrient availability (n)

LQ “n” applies to the evaluations for rain-fed cropping under RCTM and ICTM. Diagnostic land charcteristics are available nitogen (N) and available phosphorus (P) measured in the top 50 cm of the soil. Exchangeable potassium (k) is supposed to be low. Table 52 lists the ratings which resulted from matching the macro-nutrient requirements of the two crop groups with three defined classes for each macro-nutrient.

Table 52. Factor ratings of nutrient availability (RCTM and ICTM).

N	P	K	Crop group		
(%)	(ppm)	(cmol/kg)	1[30]	2[31]	3[32]
very low (<0.8)	very low	low	s3	s3/s2	s3
	low	low	s2/s3	s2	s2
	medium-very high	low	s2/s3	s2	s2
low	very low	low	s2/s3	s2	s2
	low	low	s2	s1/s2	s2
	medium-very high	low	s2	s1/s2	s1/s2
medium-very high	very low	low	s2/s3	s2	s2
	low	low	s2	s1/s2	s1/s2
	medium-very high	low	s1/s2	s1	s1

3.4.5. Nutrient retention capacity (t)

This land quality applies to the evaluation for rain-fed or irrigated cropping under improved traditional management and irrigated cropping under modern management. The factor ratings are presented in Table 53. A differentiation has been made into two crop groups.

Table 53. Factor ratings of nutrient retention capacity.

CEC (cmol/kg)	Crop group	
	1[33]	2[34]
very low : <5	s2	s3/s3
low : 5-10	s1/s2	s2
medium-very high : >10	s1	s1

3.4.6. Rooting conditions(r)

LQ “r” is applied in the evaluations for all models. Rooting conditions refer to the conditions for the development of rhizosphere, including the growth of tubers and bulbs. Diagnostic land characteristics are effective soil depth (Sd), surface stoniness and

[30]All crops except cashew, millet, and rice, paddy
[31]Cashew and millet
[32] Rice, paddy
[33] Crop group 1 : all crops except maize, cotton, sweet potato
[34] Crop group 2 : maize, cotton, sweet potato

rockiness (Sr), and presence of vertic (Ver) and stagnic (St) soil properties. Table 54 shows the factor ratings for all LUTs under all models. Exceptionally, downgradings are not applied only for rice, paddy.

Table 54. Factor rating of rooting conditions for various crops (all models).

Crop	Soil property[35]	Crop group				
		<30	30-50	50-100	100-150	>150
Maize		n	s3	s1	s1	s1
Bulrush millet		n	s2/s3	s1	s1	s1
Sorghum		n	s3	s1	s1	s1
Groundnuts		n	s3	s1	s1	s1
	vertic or stagnic	n	n	n	s2	s2
Soya beans		n	s3	s1	s1	s1
Sunflower		n	s3/n	s1	s1	s1
Cowpea		n	s2/s3	s1	s1	s1
Sweet potato		n	s3	s1	s1	s1
	vertic or stagnic or >15% surface stoniness/rockiness	n	n	s2	s2	s2
Cassava		n	n	s1/s2	s1	s1
	vertic or stagnic or >15% surface stoniness/rockiness	n	n	s2/s3	s2	s2
Cotton		n	n	s1/s2	s1	s1
Cashew		n	n	s3	s2	s1
Rice, paddy		n	s2/s3	s1	s1	s1

3.4.7. Flooding hazard (f)

LQ “f” applies to the evaluation for four models except ICMM. Flooding hazard refers to the damage by water on the ground surface. This may be caused by either the effect of running water, or due to ponding for a relatively short period. Diagnostic land characteristic is frequency of flooding. Factor ratings for LQ “r” are presented in Table 55 under RCTM, RITM, ICTM, and ICIM models.

[35] All crops except rice, paddy should be downgraded by half a class for stagnic soils, apart from those cases as indicated above (groundnuts, sweet potato, and cassava have been downgraded by a full class).

Table 55. Factor rating of flooding hazard for various crops (RCTM, RITM, ICTM, and ICIM).

Frequency of flooding[36]	Annuals	Perennials
none	s1	s1
none to exceptional	s1	s1
exceptional	s1/s2	s3
frequent	n	n

3.4.8. Toxicity/acidity (x)

This land quality applies to the evaluations for all crops under five models. Salinity affects crops through inhibiting the uptake of water by osmosis. Sodicity has two effects on crops; firstly, through direct toxicity of sodium ion and secondly, by giving rise to massive or coarse columnar soil structure and low permeability. Diagnostic characteristics are soil reaction (pH) and salinity (Sal) which are measured in the top 50 cm soil. The factor ratings for LQ “x” are indicated in Table57.

3.4.9. Soil workability (k)

LQ ”k” applies to the evaluations for rain-fed and irrigated annual cropping (all models). Workability is the ease with which the soil can be cultivated.

Diagnostic land characteristics are surface stoniness and rockiness (Sr) and presence of vertic (Vr) pr stagnic (St) soil properties in the top soil. It has not been considered in the evaluation of perennials and rice. The factor ratings of soil workability are presented in Table 56, irrespective of management level.

Table 56. Factor ratings of soil workability for annuals under all models.

Surface stoniness, boulders and rock outcrops (%)[37]	Soil property	Rating
<15	- Vertic or stagnic	s1 s2
>15	-	s2/s3

[36]None to exceptional : less than once in 10 years, exceptional : less than once in 2 years but more than once in 10 years, frequent : at least once in two years.

[37]Measured in the upper 0-30 cm soil.

Table 57. Factor ratings of toxicity/acidity for various crops under all models.

Crop	pH																						
	3.5-4.0	4.0-4.5	4.5-5.0	5.0-5.5	5.5-6.0	6.0-6.5	6.5-7.0	7.0-7.5					7.5-8.0					8.0-8.5					>8.5
								Salinity level (dS/m)															
								<2	2-4	4-8	8-16	>16	<2	2-4	4-8	8-16	>16	<2	2-4	4-8	8-16	>16	
Maize	n	n	s3	s2	s1	s1	s1	s1	s1	s3	n	n	s2	s2	s3	n	n	s3	s3	n	n	n	n
Bulrush millet	n	n	s3	s2	s1	s1	s1	s1	s1	s2	n	n	s2	s2	s2	n	n	s3	s3	n	n	n	n
Rice, paddy	n	n	s3	s2	s1	s1	s2	s2/s3	s2/s3	s2/s3	n	n	s3	s3	s3	n	n	n	n	n	n	n	n
Sorghum	n	n	s3	s2	s1	s1	s1	s1	s1	s1	s3	n	s2	s2	s2	n	n	s3	s3	s3	n	n	n
Groundnuts	n	n	s3	s3	s2	s1	s1	s1	s1	s3	n	n	s2	s2	s3	n	n	s2	s3	s3	n	n	n
Soya beans	n	n	n	s3	s2	s1	s1	s1	s1	s2	n	n	s2	s2	s2	n	n	s3	s3	n	n	n	n
Sunflower	n	n	n	s3	s2	s1	s1	s1	s1	s2	n	n	s2	s2	s2	n	n	s3	s3	n	n	n	n
Cowpea	n	n	n	s3	s3	s1	s1	s2	s2	s3	n	n	s3	s3	s3	n	n	n	n	n	n	n	n
Sweet potato	n	n	s3	s2	s1	s1	s1	s1	s2	s3	n	n	s2	s2	s3	n	n	s3	n	n	n	n	n
Cassava	n	s3	s3	s2	s1	s1	s1	s2	s3	n	n	n	s3	s3	n	n	n	n	n	n	n	n	n
Cotton	n	n	n	s3	s2	s1	s1	s1	s1	s1	s3	n	s3	s3	s3	n	n	n	n	n	n	n	n
Cashew	n	n	s3	s2	s1	s1	s1	s2	s2	s3	n	n	s3	s3	s3	n	n	n	n	n	n	n	n

3.5. Land suitability

Land suitability has been assessed for 533 land units of 36,771 ha in the soil survey area, except Estates, by use of ALES program. LUT/Crop models were determined in consideration of water sources, management levels, and crops cultivated now or potentially growing well in the future as per Table 58. Due to no recent cropping data collected for SVIP, crop characteristics in the 1991 FAO Report (FAO, 1991a) were very usefully applied and modified for setting LURs in the present evaluation.

Table 58. LUT/Crop description.

LUT/Crop	Water source	Management level	Crop
RCTM-BM	rain-fed	traditional	bulrush millet
RCTM-CA2	rain-fed	traditional	cassava, long cycle varieties
RCTM-CA1	rain-fed	traditional	cassava, short cycle varieties
RCTM-CS	rain-fed	traditional	cashew
RCTM-CO	rain-fed	traditional	cotton
RCTM-CP	rain-fed	traditional	cowpea
RCTM-GN1	rain-fed	traditional	groundnuts, short cycle varieties
RCTM-GN2	rain-fed	traditional	groundnuts, long cycle varieties
RCTM-MA2	rain-fed	traditional	maize, long cycle varieties
RCTM-MA1	rain-fed	traditional	maize, short cycle varieties
RCTM-RI	rain-fed	traditional	rice, paddy
RCTM-SO	rain-fed	traditional	sorghum
RCTM-SB	rain-fed	traditional	soya beans
RCTM-SP	rain-fed	traditional	sweet potato
RCTM-SU	rain-fed	traditional	sunflower
RITM-BM	rain-fed	improved	bulrush millet
RITM-CA2	rain-fed	improved	cassava, long cycle varieties
RITM-CS	rain-fed	improved	cashew
RITM-CO	rain-fed	improved	cotton
RITM-CP	rain-fed	improved	cowpea
RITM-GN1	rain-fed	improved	groundnuts, short cycle varieties
RITM-MA1	rain-fed	improved	maize, short cycle varieties
RITM-SO	rain-fed	improved	sorghum
RITM-SB	rain-fed	improved	soya beans
RITM-SU	rain-fed	improved	sunflower
ICTM-BM	irrigated	traditional	bulrush millet
ICTM-CA2	irrigated	traditional	cassava, long cycle varieties
ICTM-CA1	irrigated	traditional	cassava, short cycle varieties
ICTM-CS	irrigated	traditional	cashew
ICTM-CO	irrigated	traditional	cotton
ICTM-CP	irrigated	traditional	cowpea

LUT/Crop	Water source	Management level	Crop
ICTM-GN1	irrigated	traditional	groundnuts, short cycle varieties
ICTM-GN2	irrigated	traditional	groundnuts, long cycle varieties
ICTM-MA2	irrigated	traditional	maize, long cycle varieties
ICTM-MA1	irrigated	traditional	maize, short cycle varieties
ICTM-RI	irrigated	traditional	rice, paddy
ICTM-SO	irrigated	traditional	sorghum
ICTM-SB	irrigated	traditional	soya beans
ICTM-SP	irrigated	traditional	sweet potato
ICTM-SU	irrigated	traditional	sunflower
ICIM-BM	irrigated	improved	bulrush millet
ICIM-CA2	irrigated	improved	cassava, long cycle varieties
ICIM-CA1	irrigated	improved	cassava, short cycle varieties
ICIM-CS	irrigated	improved	cashew
ICIM-CO	irrigated	improved	cotton
ICIM-CP	irrigated	improved	cowpea
ICIM-GN1	irrigated	improved	groundnuts, short cycle varieties
ICIM-GN2	irrigated	improved	groundnuts, long cycle varieties
ICIM-MA2	irrigated	improved	maize, long cycle varieties
ICIM-MA1	irrigated	improved	maize, short cycle varieties
ICIM-SO	irrigated	improved	sorghum
ICIM-SB	irrigated	improved	soya beans
ICIM-SP	irrigated	improved	sweet potato
ICIM-SU	irrigated	improved	sunflower
ICMM-BM	irrigated	modern	bulrush millet
ICMM-CA2	irrigated	modern	cassava, long cycle varieties
ICMM-CA1	irrigated	modern	cassava, short cycle varieties
ICMM-CS	irrigated	modern	cashew
ICMM-CO	irrigated	modern	cotton
ICMM-CP	irrigated	modern	cowpea
ICMM-GN1	irrigated	modern	groundnuts, short cycle varieties
ICMM-GN2	irrigated	modern	groundnuts, long cycle varieties
ICMM-MA2	irrigated	modern	maize, long cycle varieties
ICMM-MA1	irrigated	modern	maize, short cycle varieties
ICMM-SO	irrigated	modern	sorghum
ICMM-SB	irrigated	modern	soya beans
ICMM-SU	irrigated	modern	sunflower

Land suitability classes depend greatly on management levels and crop types. Except for Class N, S3 are generally dominant under RCTM (22,138 ha on average for all crops) and RITM (23,165 ha). S2 is predicted to increase obviously from 2,300 ha to 14,666 ha as land suitability classes become divided further through ICTM, ICIM, and ICMM. Detailed land suitability results are presented in Table 59 and Figure 56.

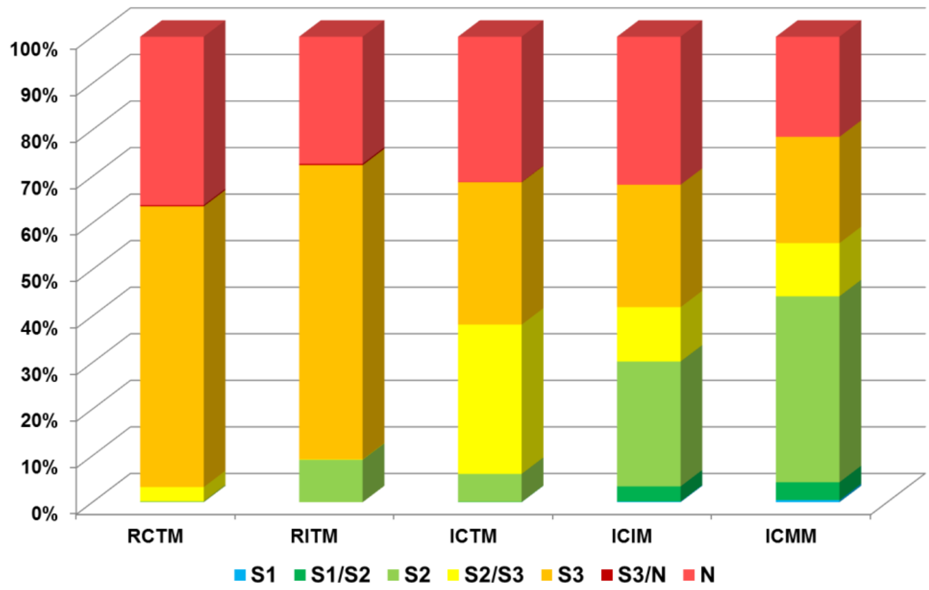


Figure 56. Composition of land suitability classes by LUT.

Table 59. Land suitability classes by LUT/Crop.

LUT/Crop	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
RCTM-BM	0	0	985	16,493	14,014	0	5,219	36,711
RCTM-CA2	0	0	0	0	23,941	0	12,770	36,711
RCTM-CA1	0	0	0	0	3,777	0	32,934	36,711
RCTM-CS	0	0	0	0	16,953	1,160	18,598	36,711
RCTM-CO	0	0	0	0	24,572	0	12,139	36,711
RCTM-CP	0	0	0	0	31,492	0	5,219	36,711
RCTM-GN1	0	0	0	0	31,492	0	5,219	36,711
RCTM-GN2	0	0	0	0	31,492	0	5,219	36,711
RCTM-MA2	0	0	0	0	3,777	0	32,934	36,711
RCTM-MA1	0	0	0	0	31,492	0	5,219	36,711
RCTM-RI	0	0	232	188	20	0	36,271	36,711
RCTM-SO	0	0	0	0	31,938	189	4,584	36,711
RCTM-SB	0	0	0	0	31,492	0	5,219	36,711
RCTM-SP	0	0	0	0	24,237	0	12,474	36,711
RCTM-SU	0	0	0	0	31,381	111	5,219	36,711
RITM-BM	0	0	17,766	294	13,432	0	5,219	36,711
RITM-CA2	0	0	0	0	23,941	0	12,770	36,711
RITM-CS	0	0	0	0	16,593	1,160	18,578	36,331
RITM-CO	0	0	15,607	183	8,782	0	12,139	36,711
RITM-CP	0	0	0	0	10,998	0	25,713	36,711
RITM-GN1	0	0	0	0	31,492	0	5,219	36,711

LUT/Crop	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
RITM-MA1	0	0	0	0	31,492	0	5,219	36,711
RITM-SO	0	0	0	0	31,938	0	4,773	36,711
RITM-SB	0	0	0	0	31,492	0	5,219	36,711
RITM-SU	0	0	0	0	31,492	0	5,219	36,711
ICTM-BM	0	50	935	16,493	14,014	0	5,219	36,711
ICTM-CA2	0	0	116	12,533	11,292	0	12,770	36,711
ICTM-CA1	0	0	74	2,773	930	0	32,934	36,711
ICTM-CS	0	0	12,456	0	5,657	0	18,598	36,711
ICTM-CO	0	50	398	15,060	9,064	0	12,139	36,711
ICTM-CP	0	50	348	14,984	16,110	0	5,219	36,711
ICTM-GN1	0	0	935	16,301	14,256	0	5,219	36,711
ICTM-GN2	0	0	166	2,806	28,520	0	5,219	36,711
ICTM-MA2	0	0	0	0	3,777	0	32,934	36,711
ICTM-MA1	0	50	885	16,379	14,178	0	5,219	36,711
ICTM-RI	0	46	14,384	8,268	5,029	0	8,984	36,711
ICTM-SO	0	50	935	16,493	14,460	189	4,584	36,711
ICTM-SB	0	0	166	23,016	8,310	0	5,219	36,711
ICTM-SP	0	0	398	15,062	8,777	0	12,474	36,711
ICTM-SU	0	50	935	16,415	13,981	111	5,219	36,711
ICIM-BM	238	3,280	14,412	294	13,268	0	5,219	36,711
ICIM-CA2	0	172	2,481	10,168	11,120	0	12,770	36,711
ICIM-CA1	0	1,040	14,481	183	8,237	0	12,770	36,711
ICIM-CS	0	0	12,456	0	5,657	0	18,598	36,711
ICIM-CO	66	3,452	12,089	183	8,782	0	12,139	36,711
ICIM-CP	0	63	4,577	148	6,210	0	25,713	36,711
ICIM-GN1	0	485	17,281	183	13,543	0	5,219	36,711
ICIM-GN2	0	485	17,281	183	13,543	0	5,219	36,711
ICIM-MA2	0	0	0	0	3,777	0	32,934	36,711
ICIM-MA1	0	604	4,524	12,821	13,543	0	5,219	36,711
ICIM-SO	238	3,280	20,355	253	7,812	0	4,773	36,711
ICIM-SB	0	485	3,292	20,271	7,444	0	5,219	36,711
ICIM-SP	0	0	398	15,062	8,777	0	12,474	36,711
ICIM-SU	238	3,280	14,334	183	13,457	0	5,219	36,711
ICMM-BM	544	3,189	21,687	364	10,162	0	765	36,711
ICMM-CA2	0	1,146	19,172	190	6,288	0	9,915	36,711
ICMM-CA1	0	172	5,619	14,717	6,288	0	9,915	36,711
ICMM-CS	0	0	20,259	0	6,722	0	9,730	36,711
ICMM-CO	372	3,361	16,856	190	6,648	0	9,284	36,711
ICMM-CP	0	63	6,948	155	6,026	0	23,519	36,711
ICMM-GN1	0	485	24,304	253	10,458	0	1,211	36,711
ICMM-GN2	0	485	24,304	253	10,458	0	1,211	36,711
ICMM-MA2	0	0	0	0	3,998	0	32,713	36,711

LUT/Crop	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
ICMM-MA1	0	604	7,852	16,586	10,458	0	1,211	36,711
ICMM-SO	692	5,045	19,237	253	10,719	0	765	36,711
ICMM-SB	0	602	3,256	21,291	10,351	0	1,211	36,711
ICMM-SU	544	3,189	21,163	253	10,351	0	1,211	36,711

Comparing the land suitability classes of 15 crops through five models and averaging the areas of each class, maize (long cycle varieties) and rice, paddy are found to have the highest percentage of N against the other crops: 90% and 92%, respectively. On the other hand, the crops with over 20% of (S1+S1/S2+S2) are bulrush millet, cotton, cashew, groundnuts (short cycle and long cycle varieties), sorghum and sunflower (Figure 57).

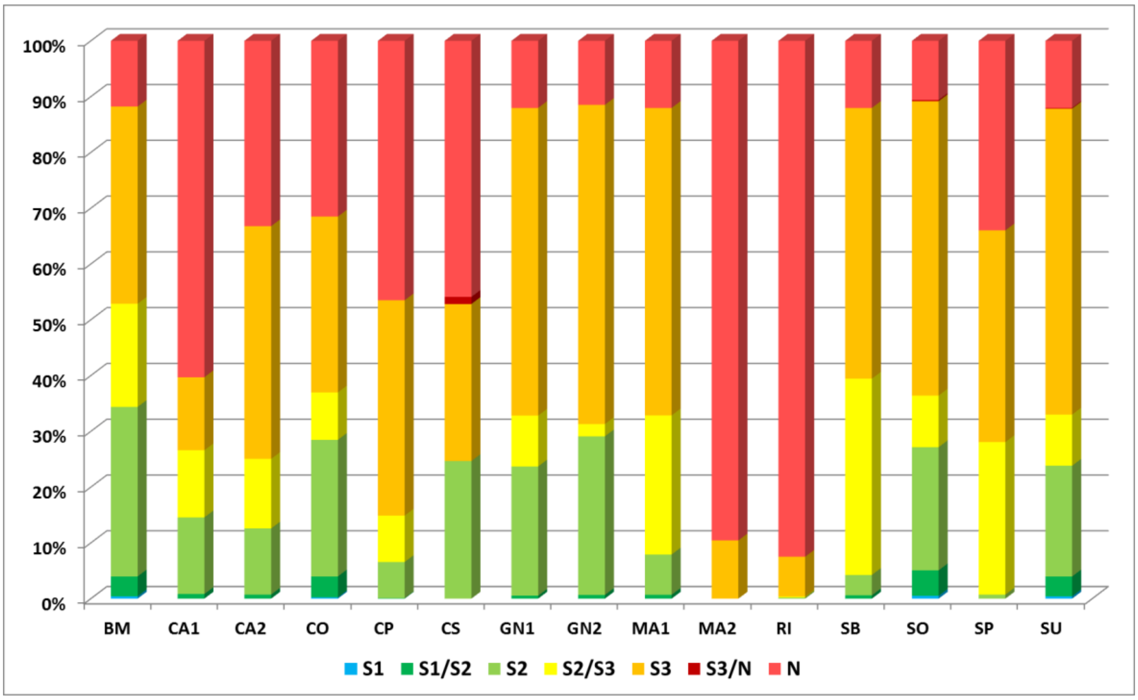


Figure 57. Composition of land suitability classes by crop.

Besides, unsuitable land units, for instance, lots of lower clayey imperfectly to very poorly-drained ones, in Zone C are disadvantageous for cultivation. Therefore, some additional measures such as soil amendments to improve soil properties, site-specific irrigation/drainage plans are necessary for them to be cultivated better.,

3.5.1. Land suitability for rain-fed cultivation under traditional management

The most important charateristics of traditional rain-fed cultivation is the low input, consisting of manual labor, hand tools, and autogenic seeds. The suitability of 15 LUT/Crops have been studied for rain-fed cultivation under traditional management (Table 58). A total of eight land qualities is used in the RCTM model, defined by more than 20 land characteristics (Tables 40 and 41).

The area of Class N is 36% of 36,711 ha on average for 15 LUT/Crops and S3 (marginally suitable) 60%. Bulrush millet is the most suitable crop for the RCTM model with >80% of S2 (moderately suitable) and S2/S3 (marginally suitable) while rice, paddy almost unsuitable (Figure 58).

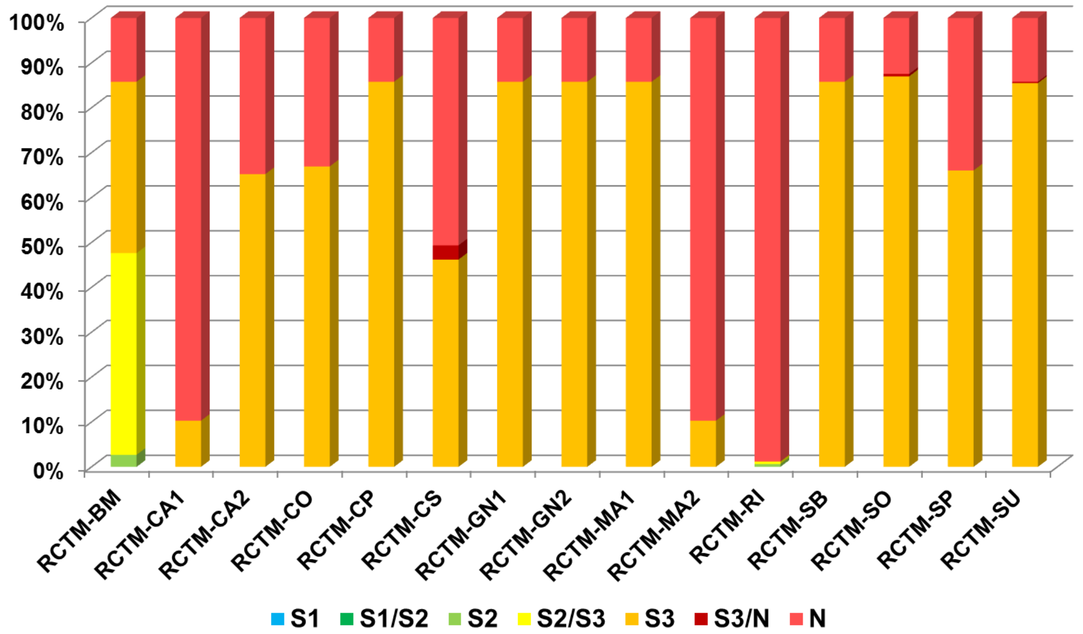
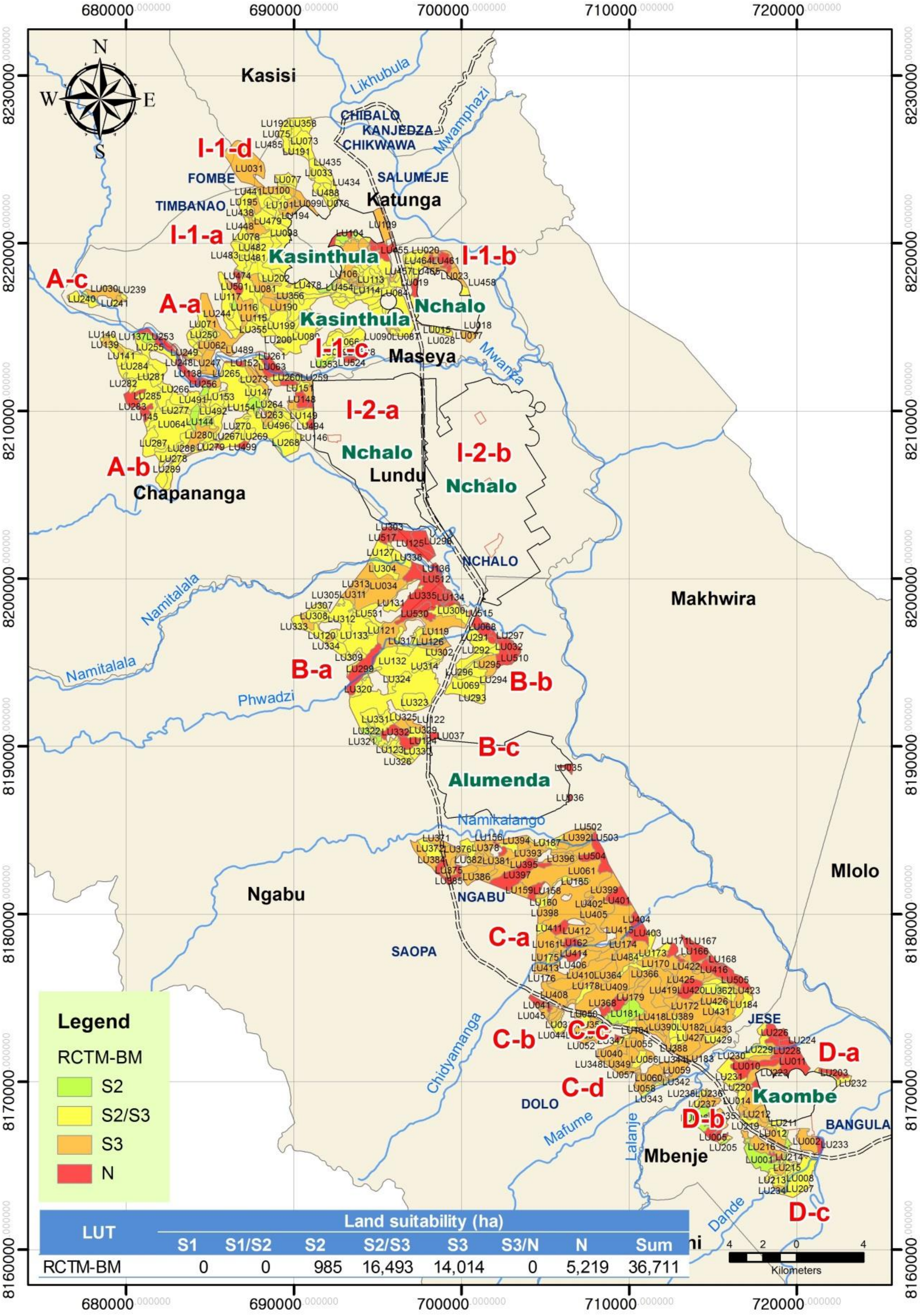


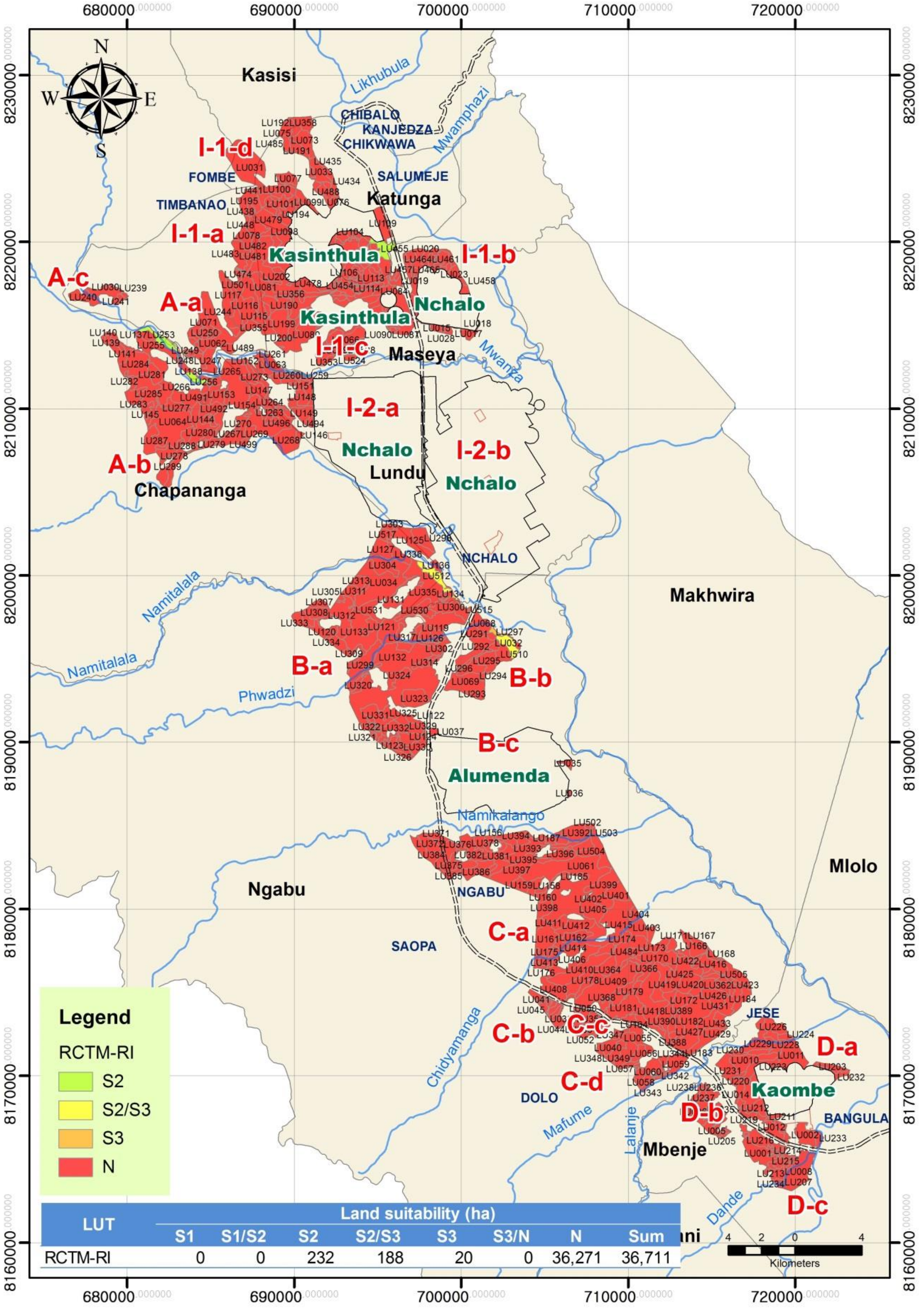
Figure 58.Composition of land suitability classes by crop for RCTM model.

For bulrush millet, S2 and S2/S3 generally occurs in all Zones, differently from the other crops with only S3 (Figure 59). Bulrush millet turns out again to be a crop tolerant of a wide range of conditions such as drought and low soil fertility. Rice, paddy with high water demand is unsuitable overall for RCTM, while it is found moderately suitable in part of Zones I-1-b and A-b (Figure 60).



LUT	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
RCTM-BM	0	0	985	16,493	14,014	0	5,219	36,711

Figure 59. Land suitability map for RCTM-BM.



LUT	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
RCTM-RI	0	0	232	188	20	0	36,271	36,711

Figure 60. Land suitability map for RCTM-RI.

3.5.2. Land suitability for rain-fed cultivation under improved traditional management

Under improved management farmers grow the crop with the best economic return and will practice soil conservation methods. They willingly practice agricultural activities such as timely garden preparation and planting, use of improved seeds, pesticides and fertilizers, adequate weeding, proper harvesting and storage, and so on.

The suitability of 10 LUT/Crops have been studied for rain-fed cultivation under improved traditional management (Table 58). A total of eight land qualitiesis used in the RITM model and nutrient retention capacity instead of nutrient availability, defined by more than 20 land characteristics (Tables 40 and 41).

The area of Class N is 27% of 36,711 ha on average for 10 LUT/Crops, which means the overall land suitability improved by more input, and S3 (marginally suitable) 63%. Bulrush millet is still the most suitable crop for the RITM model with >45% of S2 (moderately suitable) while cowpea unsuitable for 70% area (Figure 61). Groundnuts, soya beans, sorghum, and sunflower are S3 in around 80% as the same as for the RCTM. Outstandingly, the land suitability of cotton gets improved by RITM so that 43% is moderately suitable, found in the significant area of Zones I-1, A, and B (Figure 62).

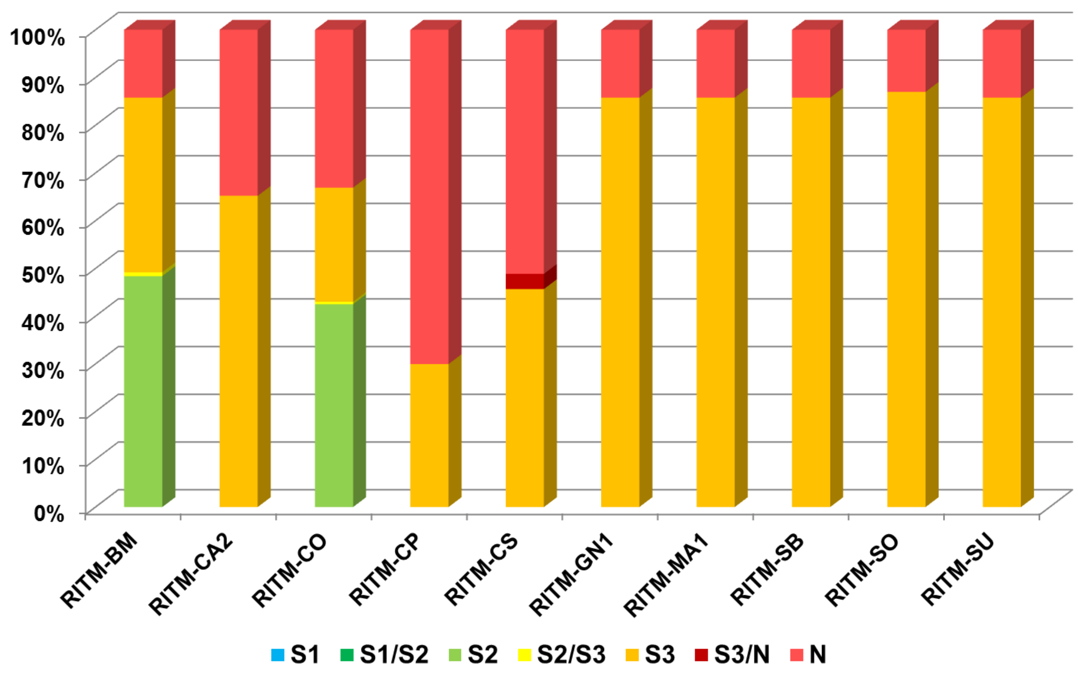
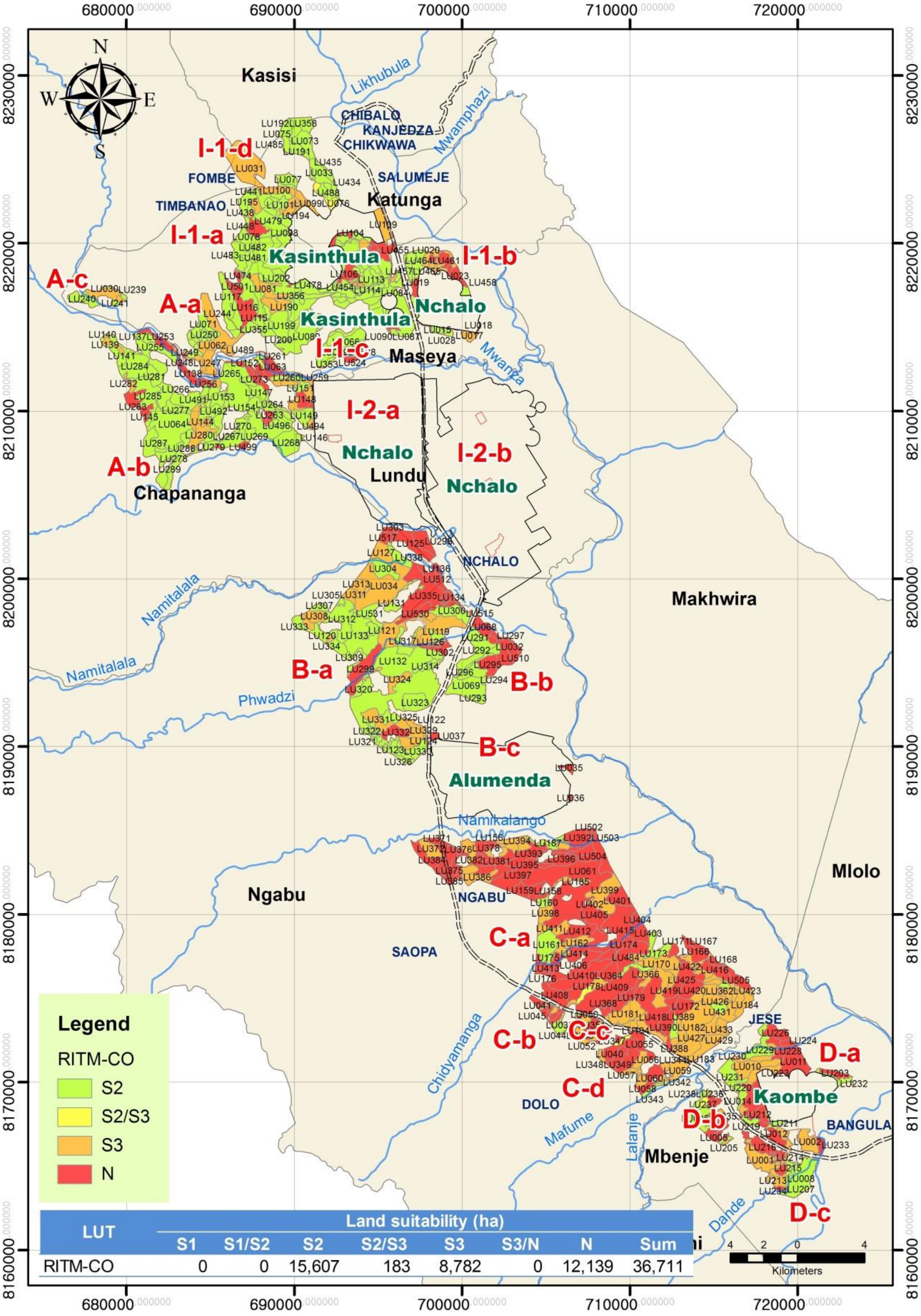


Figure 61.Composition of land suitability classes by crop for RITM model.



LUT	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
RITM-CO	0	0	15,607	183	8,782	0	12,139	36,711

Figure 62. Land suitability map for RITM-CO.

3.5.3. Land suitability for irrigated cultivation under traditional management

Irrigated cultivation under traditional management adds irrigation as water source to RCTM model supposing that sufficient water is timely provided for agriculture.

The suitability of 15 LUT/Crops have been studied for irrigated cultivation under traditional management (Table 58). A total of seven land qualities is used in the ICTM model, defined by 17 land characteristics (Tables 40 and 41).

The area of Class N is 31% of 11,463 ha on average for 15 LUT/Crops, which is much less proportion in comparison with RCTM case. S2/S3 (moderately to marginally suitable) and S3 (marginally suitable) is 32 and 31%, respectively. For cashew and rice, >30% area is S2 (moderately suitable) and the proposition of S2/S3 of almost crops is much increased compared with the RCTM model, while unsuitable area decreased (Figure 63). S1 and S1/S2 areas of cashew and rice occur in the significant area of Zones I-1, A, and B (Figures 63 and 64).

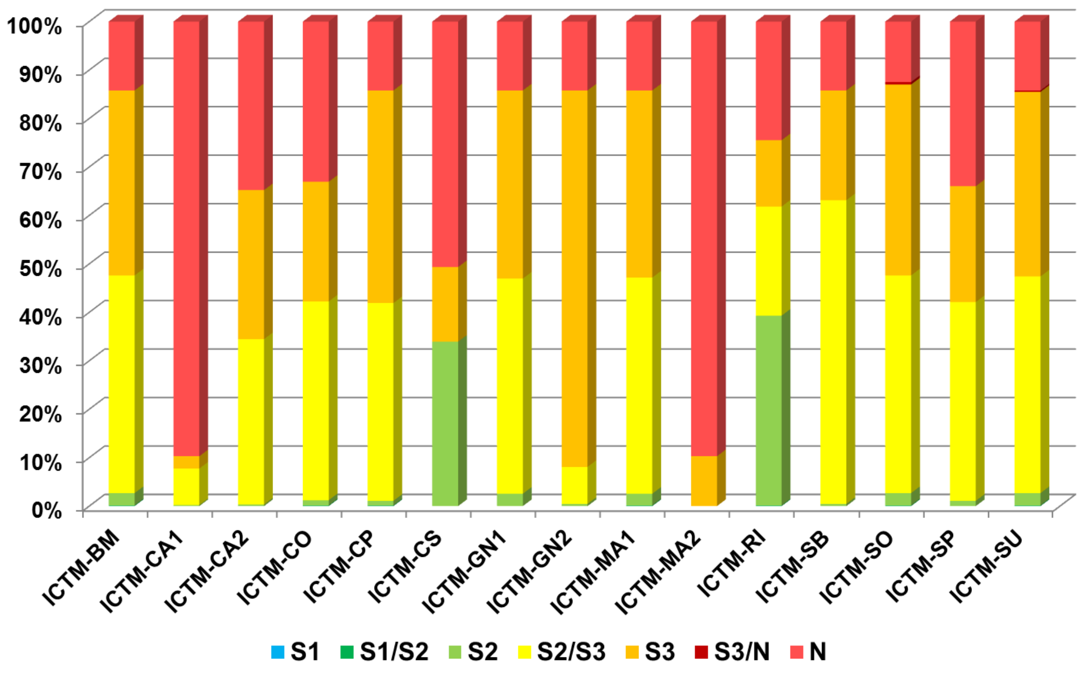
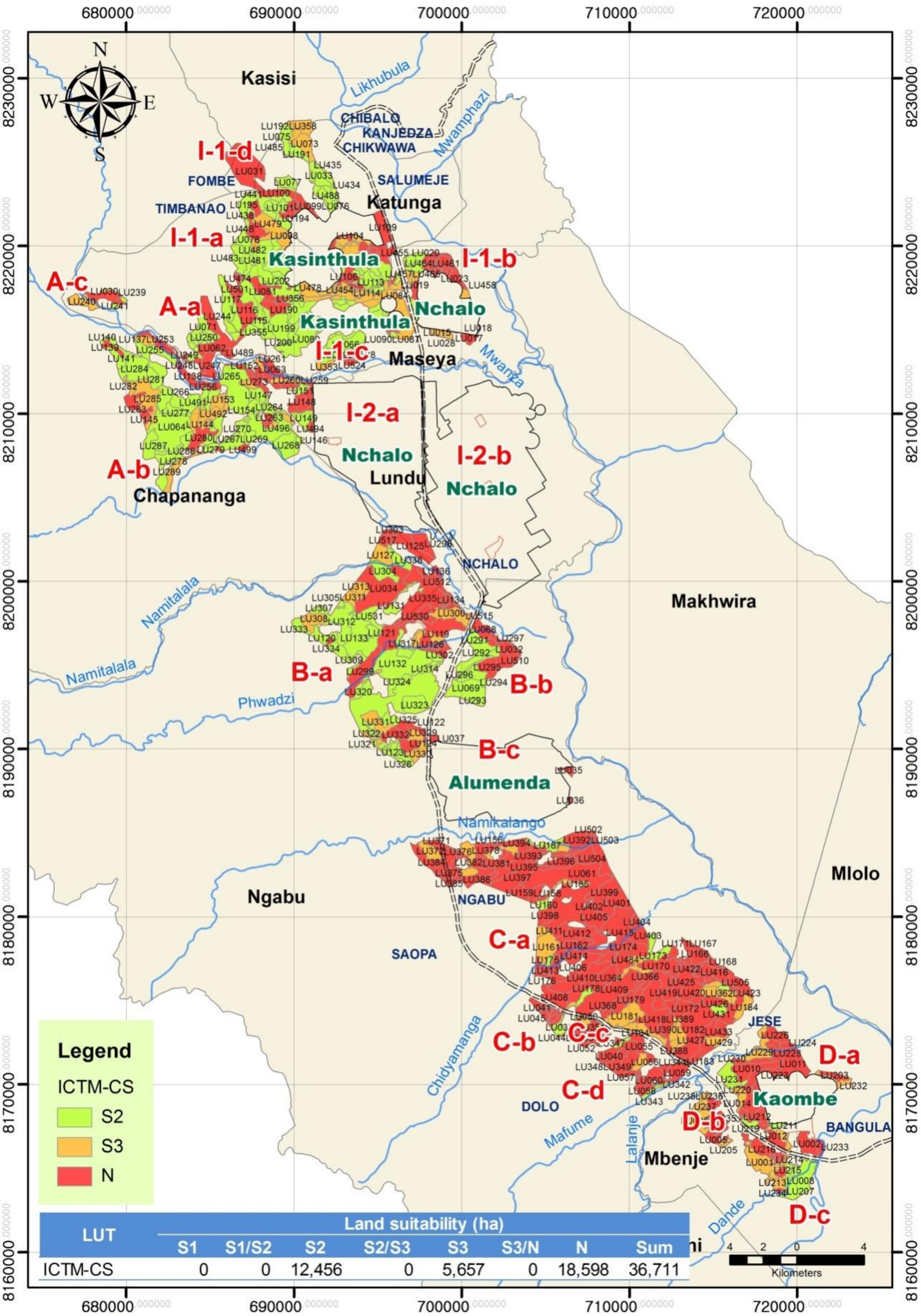
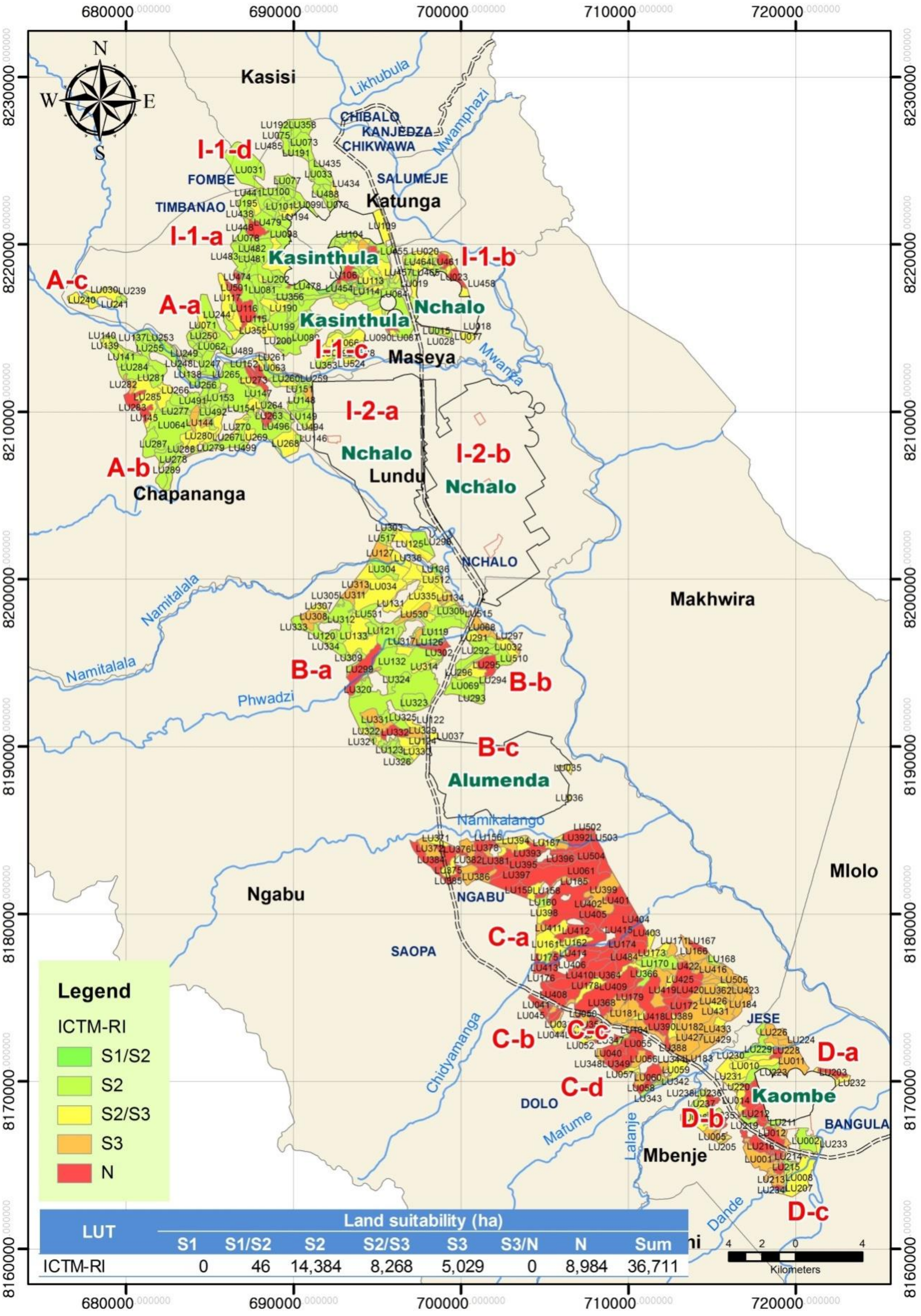


Figure 63.Composition of land suitability classes by crop for ICTM model.



LUT	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
ICTM-CS	0	0	12,456	0	5,657	0	18,598	36,711

Figure 64. Land suitability map for ICTM-CS.



LUT	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
ICTM-RI	0	46	14,384	8,268	5,029	0	8,984	36,711

Figure 65. Land suitability map for ICTM-RI.

3.5.4. Land suitability for irrigatedcultivation under improved traditional management

Irrigated cultivation under improved traditional management (ICIM) adds irrigation as water source to RITM model supposing that sufficient water is timely provided for agriculture.The suitability of 14 LUT/Crops have been studied for irrigated cultivation under traditional management (Table 58). A total of seven land qualities is used in the ICTM model, defined by 15 land characteristics (Tables 40 and 41).

The area of Class N is 32% of 11,678 ha on average for 15 LUT/Crops, which is much less proportion in comparison with RITM case. S1/S2 (highly to moderately suitable), S2 (moderately suitable), S2/S3 (moderately to marginally suitable) and S3 (marginally suitable) is 3, 27, 12 and 26%, respectively. Especially, the proportion of S2 is increased from 6 % to 27% compared with RITM model.

For maize (short cycle varieties), the land suitability class is divided to five classes in the ICIM model, whereas it is unsuitable or mariginally suitable in the RITM. Besides, the proportion of S2 areas of most crops is much increased, which is 55% for sorghum (Figure 66). S1/S2 and S2 areas of maize and sorghum occur mainly in Zones I-1, A, and B but they are found also in Zones C and D (Figures 67 and 68).

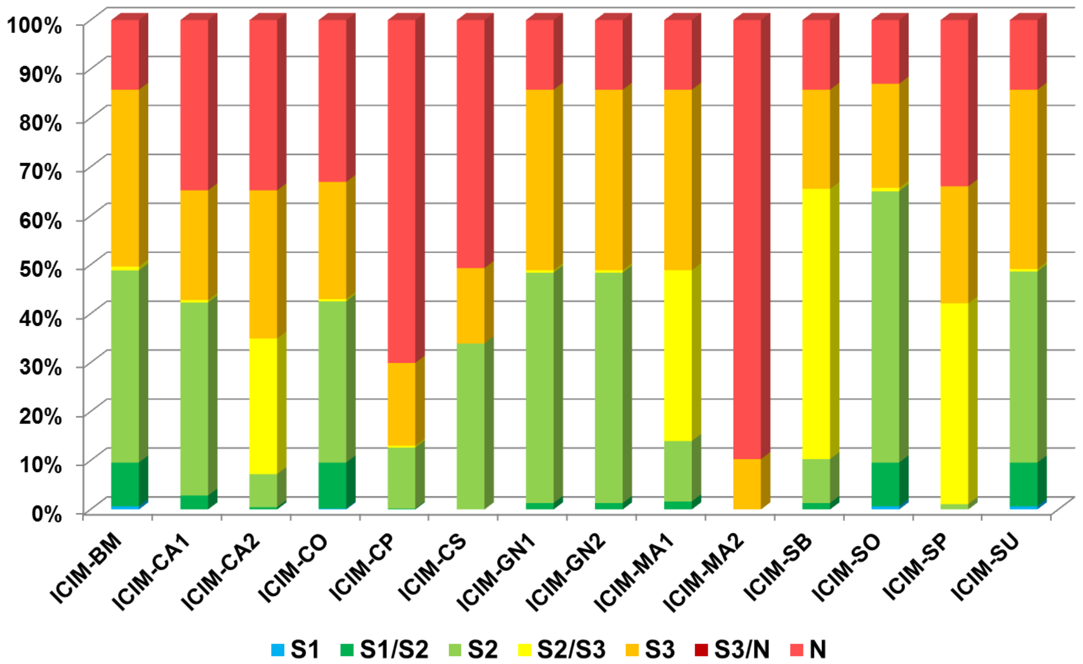
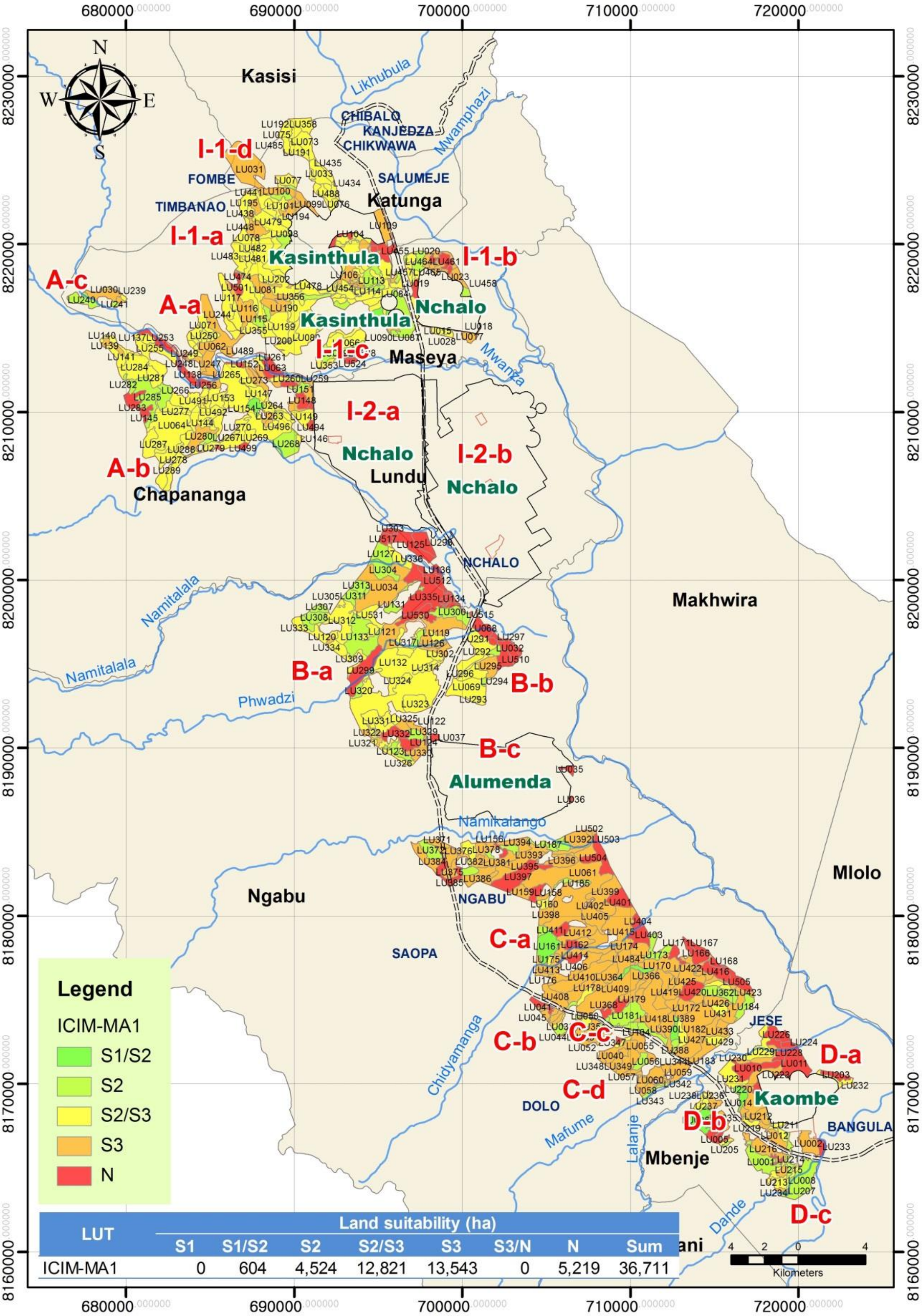
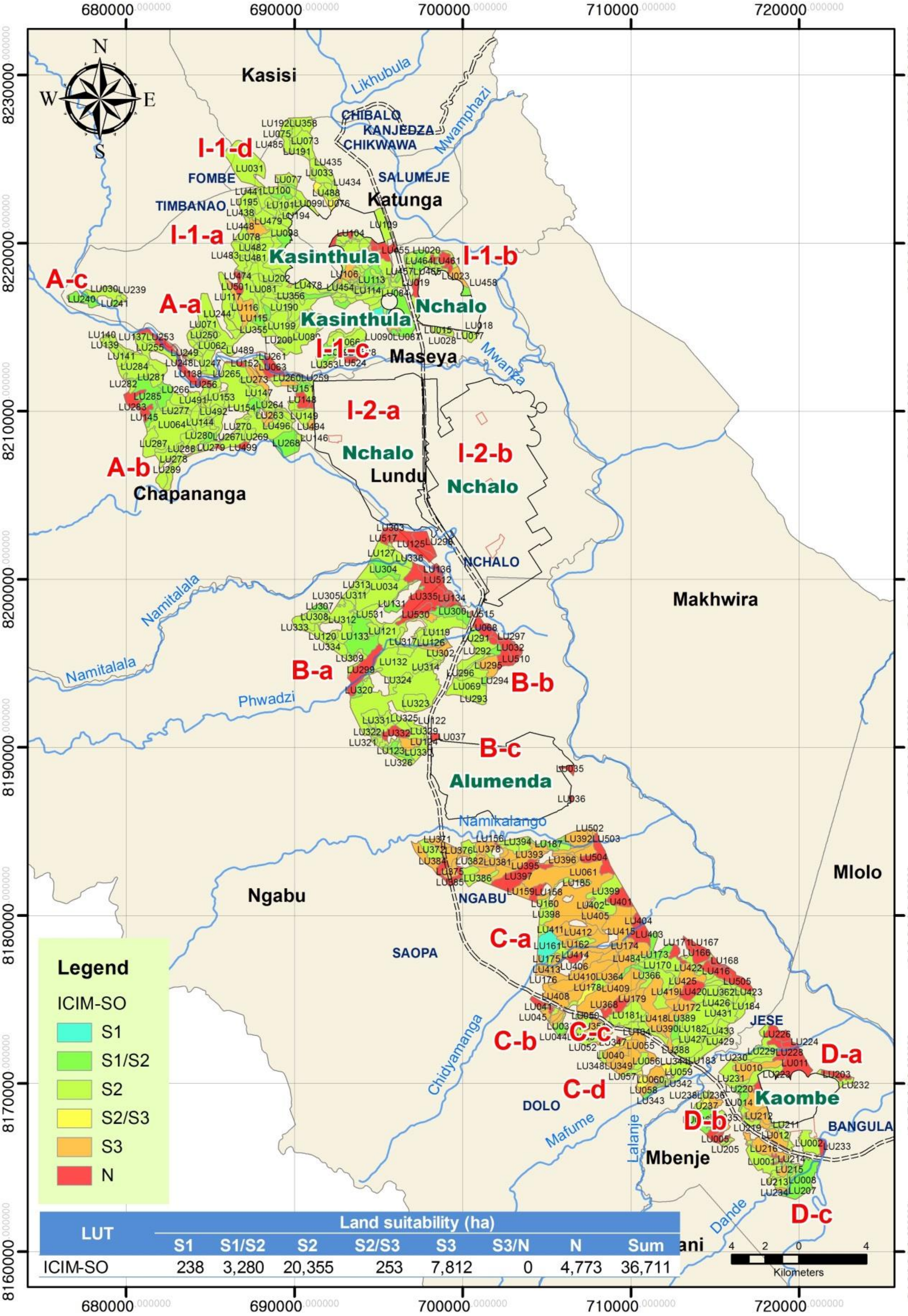


Figure 66. Composition of land suitability classes by crop for ICIM model.



LUT	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
ICIM-MA1	0	604	4,524	12,821	13,543	0	5,219	36,711

Figure 67. Land suitability map for ICIM-MA1.



LUT	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
ICIM-SO	238	3,280	20,355	253	7,812	0	4,773	36,711

Figure 68. Land suitability map for ICIM-SO.

3.5.5. Land suitability for irrigated cultivation under modern management

Irrigated cultivation under modern management (ICMM) adds proper embankment and drainage channel construction to ICIM model supposing that land units are safe from flooding and drainage can become better after construction. The suitability of 13 LUT/Crops have been studied for ICMM (Table 58). A total of six land qualities is used in the ICTM model, defined by 14 land characteristics (Tables 40 and 41).

The area of Class N drops down below 20% of 7,897 ha on average for 13 LUT/Crops, which is much less proportion in comparison with the other four models. S1/S2 (highly to moderately suitable), S2 (moderately suitable), S2/S3 (moderately to marginally suitable) and S3 (marginally suitable) is 4, 40, 11 and 23%, respectively. The proportions of both S1/S2 and S2 continue to increase as S3 and N fall down, even when compared with ICIM model. However the areas which are not suitable for some crops could be suitable for other crops. Therefore there is no area which is not suitable for any crop.

For cassava (short cycle varieties), the proportion of S2 plus S2/S3 exceeds 50% of 18,859 ha. For sunflower, groundnuts, sorghum as well as bulrush millet, the proportion of (S1+S1/S2+S2+S2/S3) is over 60% (Figure 69). S1/S2 and S2 areas of cassava and sunflower occur mainly in Zones I-1, A, and B but they are found also in Zones C and D (Figures 70 and 71).

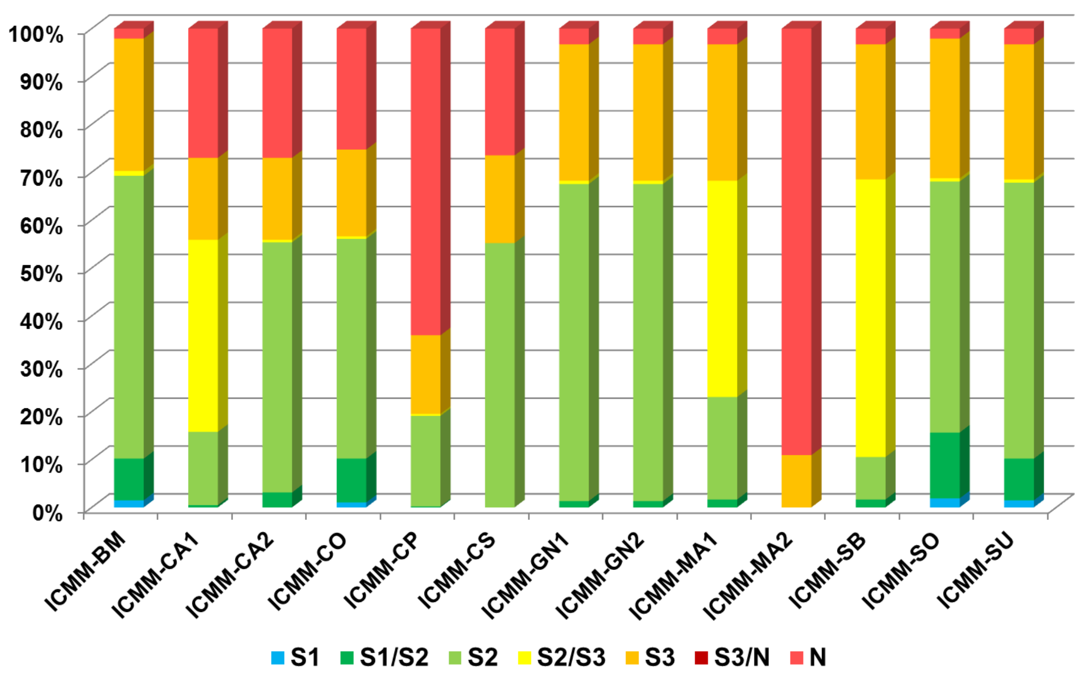
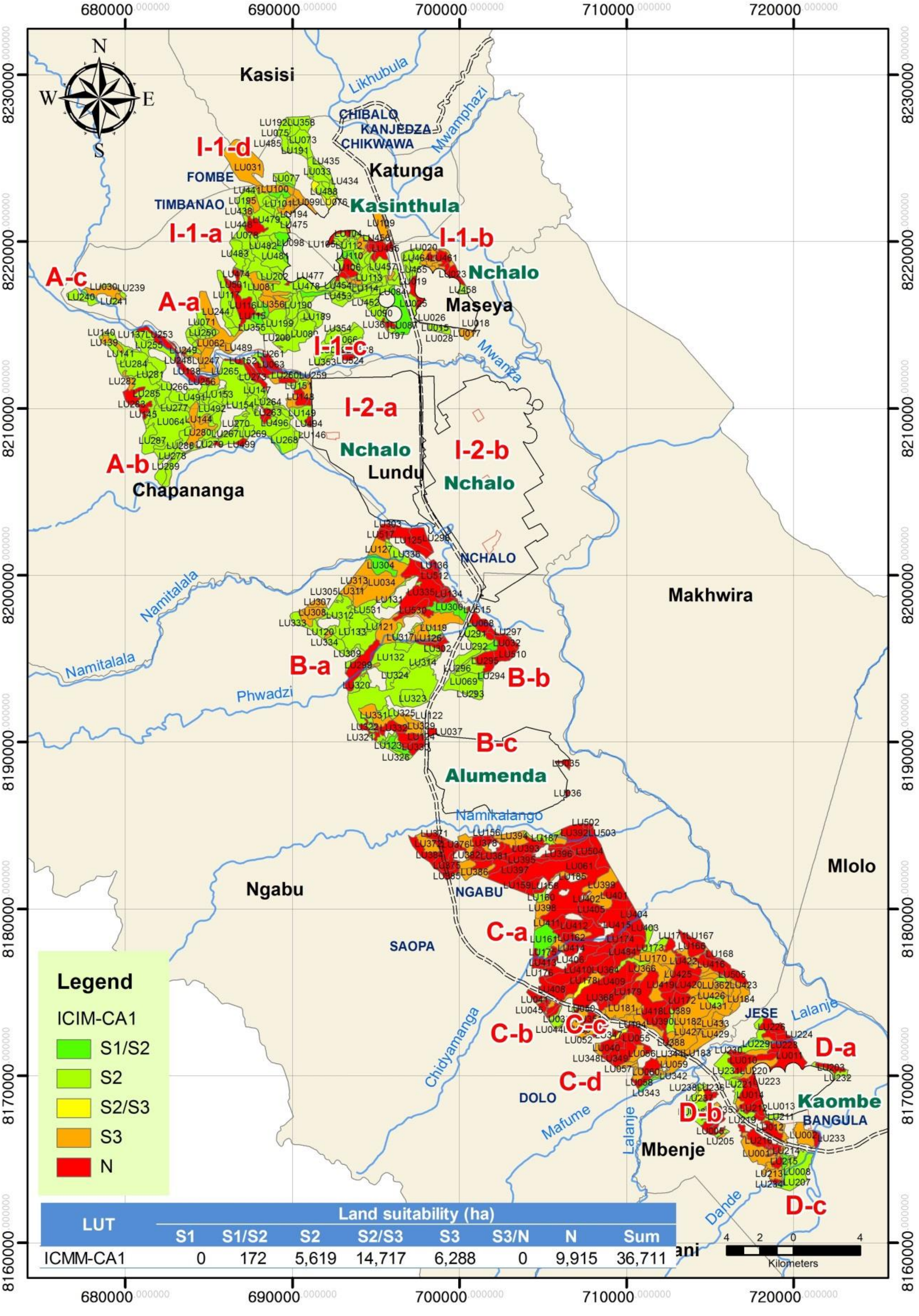
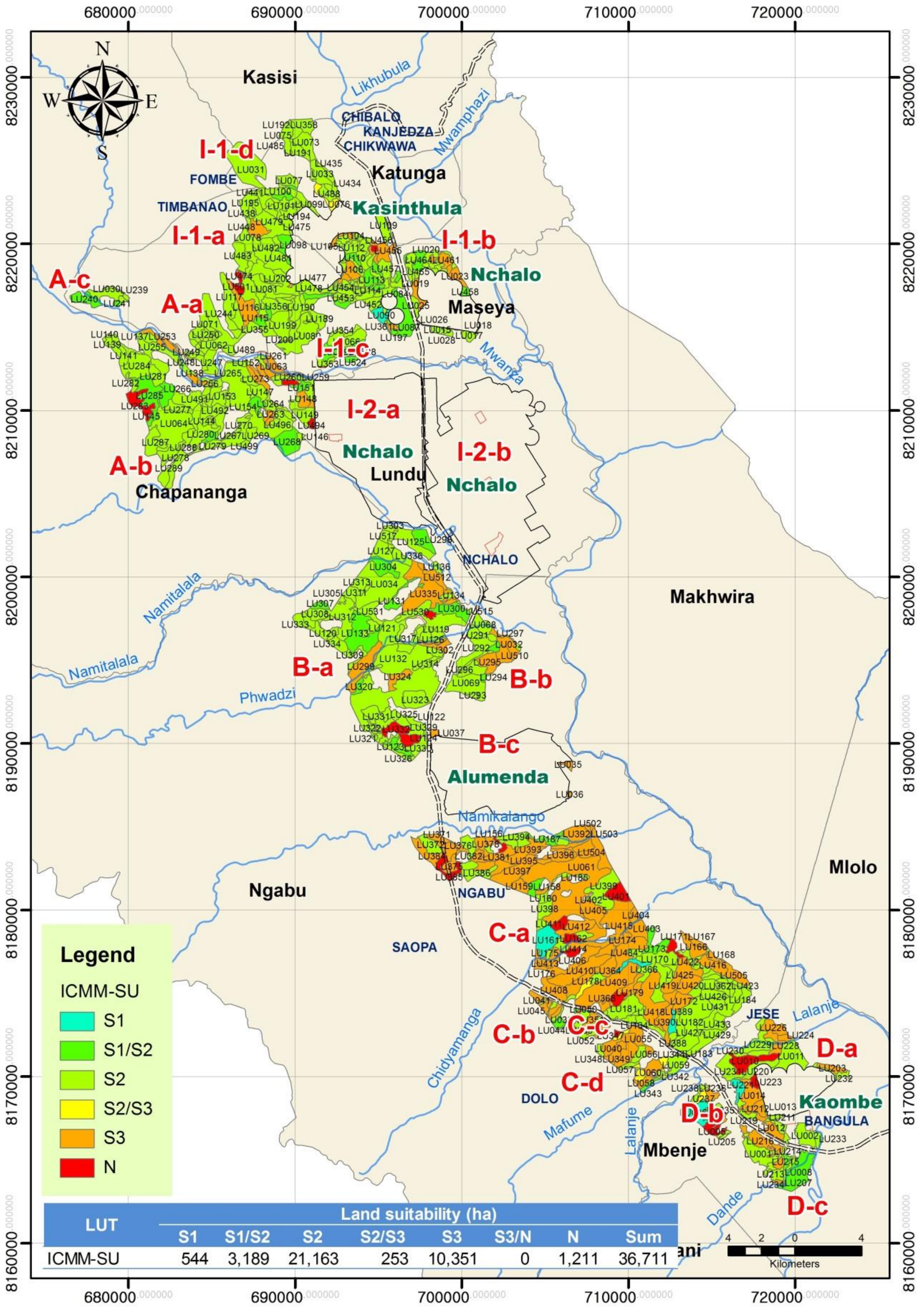


Figure 69. Composition of land suitability classes by crop for ICMM model.



LUT	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
ICMM-CA1	0	172	5,619	14,717	6,288	0	9,915	36,711

Figure 70. Land suitability map for ICIM-CA1.



LUT	Land suitability (ha)							
	S1	S1/S2	S2	S2/S3	S3	S3/N	N	Sum
ICMM-SU	544	3,189	21,163	253	10,351	0	1,211	36,711

Figure 71. Land suitability map for ICIM-SU.

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ANNEXES

1. SOIL PIT DESCRIPTION
2. RESULTS OF SOIL ANALYSIS
3. SOIL UNIT AND LAND UNIT INVENTORY
4. LAND SUITABILITY INVENTORY
5. LAND SUITABILITY MAPS

ANNEX 1.SOIL PIT DSCRIPTION

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ANNEX4. LAND SUITABILITY INVENTORY

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