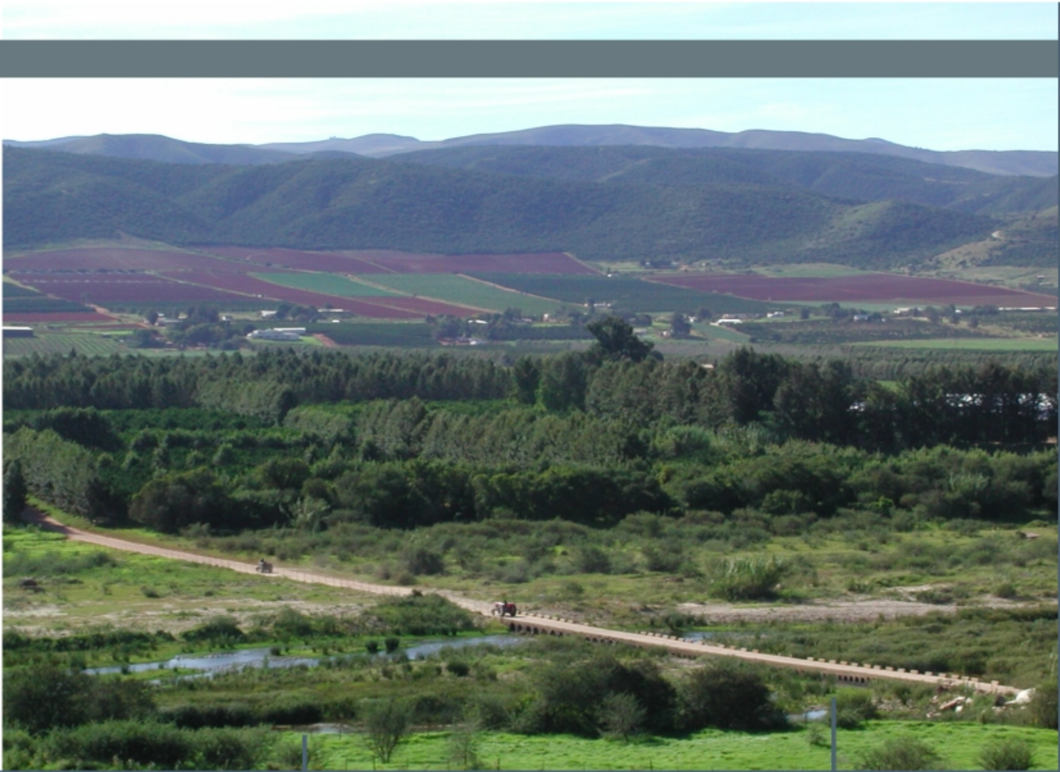
water affairs

Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA

REPORT NO: P RSA 000/00/12510



An Assessment of Rain-Fed Crop Production Potential in South Africa's Neighboring Countries

MAY 2010

W34_2010/J01330

Title	***An assessment of rain-fed crop production potential in South Africa's neighboring countries***
Author	*Dr RJ Rutherfoord (Golder)*
BKS Project No	*J00105*
Status of Report	*Final*
DWAF Report No	*P RSA 000/00/12510*
First Issue	*19 March 2010*
Final Issue	*3 May 2010*

BKS (PTY) LTD

Approved for BKS (Pty) Ltd

....

Dr MS Basson
Study Leader

DEPARTMENT OF WATER AFFAIRS
Directorate: National Water Resource Planning

Approved for the Department of Water Affairs and Forestry:

....

JA van Rooyen
Director: National Water Resource Planning

....

I Thompson
Chief Engineer: NWRP (South)

AN ASSESSMENT OF RAIN-FED CROP PRODUCTION POTENTIAL IN SOUTH AFRICA'S NEIGHBORING COUNTRIES

EXECUTIVE SUMMARY

South Africa uses 60% of its scarce water resources on irrigation, a substantial portion of which is used to irrigate crops which are regarded internationally as rain-fed crops. The question is therefore being asked about the extent of alternative production areas in southern Africa (particularly in selected neighboring countries) for the range of crops which are presently produced sub-optimally under irrigation in South Africa.

The objective of this study is therefore to provide an answer to this question with adequate confidence to allow the rational pursuit of this concept which could have far-reaching mutual benefit for southern African countries.

The countries that were considered are Mozambique, Zimbabwe, Malawi and Zambia.

The assessment was based on a broad ("desk-top") regional evaluation of soils, topography and climate, which were, in turn, used to define and demarcate agro-ecological zones in which a range of crops can be grown commercially under rain-fed conditions.

The study used two main characterization systems to define the agro-ecological zones, namely the climate-based Koppen-Geiger Climate System (KGCS) (ref. 16) and the US Department of Agriculture's, Natural Resources Conservation Service - Land Classification System (LCS) (ref. 9). The estimation of crop production areas within the agro-ecological zones was then refined by the exclusion of reserve land, areas of high population (urban and peri-urban environments) and areas of unsuitable topography for crop production. These exclusions are referred to as the "principal exclusions".

A provision was then made for secondary exclusions which include areas committed to alternative land-use such as rangeland and afforestation and scattered areas of unsuitable soils such as wetlands, riverine areas and eroded areas.

This broad assessment revealed that the four target countries possess a net area of about 26,6 million ha of high-potential rain-fed cropping land (referred to as "Premium" land use potential) with the following breakdown per country:

- *Zambia 11,1 million ha*
- *Mozambique 8,8 million ha*
- *Zimbabwe 6,3 million ha*
- *Malawi 0,4 million ha*

The rain-fed crop production potential includes a wide range of summer field crops such as maize soybean, dry bean, groundnuts and sorghum which are adapted to parts of all four of the target countries and winter rain-fed field crops such as wheat, barley and dry pea which can be grown extensively in all the countries except Mozambique.

The selected neighbouring countries therefore display a rich potential for rain-fed crop production and, in the context of the SADC countries as a whole, provide a highly significant opportunity for agricultural development in the region and an opportunity to substitute high-potential rain-fed crop production for expensive and water-inefficient irrigation of annual field crops in South Africa.

The four countries experience a number of major socio-economic constraints to the exploitation of this excellent potential. The constraints include land tenure issues (the majority of the high potential rain-fed cropping area is occupied by subsistence farmers on communally owned land), population (the high rural population spread presents a challenge to commercialisation of agriculture), present land use (widespread subsistence farming), poor or lacking infrastructure and poor agricultural support services., However the constraints are not considered insurmountable. With the appropriate vision, investment and support from the governments of the respective countries there are significant opportunities for extensive commercial agricultural development which could involve and benefit local farmers and their communities. The recent examples of South African farmers operating successfully in Mozambique and Zambia, with full government backing, have shown that these constraints can be overcome.

Whilst the principal objective of this study is to identify areas that are suited to rain-fed crop production, the existence of a considerable network of largely 'un-tapped' surface water resources, especially in Zambia and Mozambique is highlighted. There is therefore an opportunity for expanded utilisation of the water resources in these countries for irrigation where there is a higher irrigation potential, in terms of both soils and climate, than exists for many of the irrigation areas of South Africa.

AN ASSESSMENT OF RAIN-FED CROP PRODUCTION POTENTIAL IN SOUTH AFRICA'S NEIGHBORING COUNTRIES

TABLE OF CONTENTS

Page

Appendix A	Notes on Mapping
Appendix B	Eswaran's definitions of Land Quality
Appendix C	Climate Information
Appendix D	References

1 INTRODUCTION

South Africa uses about 60% of its scarce water resources on irrigation, a substantial portion of which is used to irrigate crops which are regarded internationally as rain-fed crops. The question is therefore being asked about the extent of alternative production areas in southern Africa (particularly in selected neighbouring countries) for the range of crops which are presently produced sub-optimally under irrigation in South Africa.

The objective of this study is to provide an answer to this question with adequate confidence to allow the rational pursuit of this concept which could have far-reaching mutual benefit for southern African countries. The countries that were considered are Mozambique, Zimbabwe, Malawi and Zambia.

2 METHODOLOGY

The assessment was based on a broad ("desk-top") regional evaluation of soils, topography and climate, which were, in turn, used to define and demarcate agro-ecological zones in which a range of crops can be grown commercially under rain-fed conditions.

The study used two main characterization systems to define the agro-ecological zones, namely the climate-based Koppen-Geiger Climate System (KGCS) (ref. 16) and the US Department of Agriculture's, Natural Resources Conservation Service - Land Classification System (LCS) (ref. 9). The estimation of crop production areas within the agro-ecological zones was then refined by the exclusion of reserve land, areas of high population (urban and peri-urban environments) and areas of unsuitable topography for crop production. These exclusions are referred to as the "principal exclusions".

A provision was then made for secondary exclusions which include areas committed to alternative land-use such as rangeland and afforestation and scattered areas of unsuitable soils such as wetlands, riverine areas and eroded areas.

Agro-ecological zones are shown and the area (km2) estimated. Each zone includes crop types which are grouped into the categories of "Summer rain-fed field crops" (maize, sorghum, soybean, groundnut, dry-bean and cotton), "Winter rain-fed field crops" (wheat, barley and dry-pea), "Sub-tropical fruits and nuts" (usually requiring at least supplementary irrigation) and perennial field crops (sugarcane) which may be grown under rain-fed or irrigated conditions, but where full irrigation is most common.

The study also addresses key constraints that would have to be addressed in each country if the sustainable implementation of the concept is to be achieved. Such constraints include present socio-economic circumstances, land tenure and infrastructure.

3 PRESENT AGRICULTURAL PROFILE IN THE SELECTED COUNTRIES

3.1 MOZAMBIQUE

Mozambican agriculture is characterized by smallholdings. Of the 3.6 million families in Mozambique, 87% are dependent on agriculture for their livelihoods; 98% of these families have no formal land titles. The average size of a holding is 1.24 ha and the predominant farming system is based on the rain-fed production of cereals and tubers. These smallholdings are farmed using manual labour and hand tools with only minimal use of chemical inputs, animal traction, farm machinery, and tools that are more sophisticated. Any inputs that are used are mostly acquired through the informal economy. This type of farming system imposes physical limits on the area that can be cultivated and the yields that can be generated; a natural limit is therefore also imposed on the total quantity of food that can be produced for self-consumption and/or for sale.

Over 80% of the total area of cultivated land is used for the production of staple food crops; maize and cassava are the staples produced by the overwhelming majority of holdings, with maize, cassava and cowpeas comprising 60% of the total cultivated land. Cereals (maize, sorghum, rice and millet) account for 46% of the total area cultivated, cassava for 17%, beans for 11%, and oilseeds for 9%. Horticulture is produced on only 5% of the land and cash crops (sugar cane, cotton, tea, oilseeds, tobacco) are cultivated on just 6%. In addition, 40% of all households make use of indigenous plants and herbs for food and/or medicinal purposes.

The family agriculture system is characterized by a family labour force and low levels of mechanization. In addition productivity, per hectare, is low. Hence, the potential for agricultural growth is significant.

The social division of labour in agriculture involves the whole family. There is usually little use of labour from outside the household. Women are the basis of agricultural production; they are responsible for land preparation, digging, weeding and harvesting. They help to transport, store and market surplus production.

As a result of the civil war the main infrastructure has been destroyed and is in the process of reconstruction. The rural population, therefore, has "limited" access to markets. Alternative off-farm income sources are, for instance, seasonal labour and, in declining order, other forms of wage labour, fishing trade, and sale of farm products. One would expect that the off-farm income is low, but an FAO focus study on rural non-farm income in developing countries [3] points out the importance of non-rural income, which accounts for up to 25% of the total farm income.

Commercial agriculture is extremely limited at present, particularly in the context of the vast agricultural potential of the country. Exceptions include concession areas that have been made available to expatriate farming initiatives, irrigation projects (particularly in the south on the Maputo River where rice and vegetables are grown on a semi-commercial basis - ref. 5, 9, 11, 22 and 24).

3.2 ZAMBIA

Although Zambia has a relatively high urban population, approximately 45% of the total population (4.6 million people) are poor people in rural areas. Of the 950 000 rural households, 97% are involved in subsistence crop production. Most of the arable land is under a traditional/communal tenure system. Cultivation rights (rather than land ownership) are granted by the chief through the village headman. Small-scale farmers account for a large share of the maize crop (more than 60% of Zambia's cultivated area). There is a trend of increasing numbers of households in the small-scale subsistence category while the number of medium- and large-scale farmers has remained unchanged. Nevertheless Zambia boasts a far higher degree of commercial crop production than Mozambique and Malawi. Commercial agricultural production has a large export-orientated component.

Growth in the small-scale agriculture sector could potentially impact on poverty reduction and national economic growth. This assumption is based on the strong linkages between agriculture and poor people's livelihoods in Zambia, provided that sufficient numbers of the rural poor are actually able to access the benefits of agricultural commercialisation.

There would appear to be opportunities for small-scale farmers to diversify from maize into more marketable crops, and this is confirmed by a pattern of declining maize production. Commercial agricultural production in Zambia is focussed mainly on maize, soybean, coffee, tobacco, fresh flowers, fresh vegetables, cotton lint and sugar. Production areas (commercial and subsistence) for 2001 were estimated at 600 000 ha maize, 165 000 ha cassava, 135 000 ha groundnut, 50 000 ha cotton, 38 000 ha sorghum, 17 000 ha sugarcane, 13 000 ha soybean and 12 000 ha wheat (ref. 17 and 24).

3.3 MALAWI

Malawian agriculture is also characterized by smallholdings. In 2000 the agricultural population was estimated to be 11 million people, with 85% of the total population living in rural areas. Malawi is one of the most densely populated countries in sub-Saharan Africa. Population density rises from 46 persons/km^2 in the northern region to 144/km^2 in the south, with the most populated districts such as the Shire Highlands in the south containing over 265 persons/km^2. July 2006 population was estimated at 13,0 million and the growth rate 2.38%/annum.

Most of the arable land is under a traditional/communal tenure system. Cultivation rights, rather than ownership, are granted by the chief through the village headman. By the late 1980s over 56% of households were on holdings of less than 1 ha, and a further 20% on 1.0-1.5 ha. Rain-fed agriculture predominates, dependant on a single rainy season between November and April. Only 10 000 ha of land is currently irrigated, 5% of the potential irrigated area, largely on sugar estates. Other irrigated crops include rice and vegetables.

Maize is the main staple of the Malawian diet, covering 76% of smallholder farmland. Other food crops include rice, sorghum and millet. Legumes, beans, pigeon pea and groundnuts are traditionally grown by smallholders.

The area planted to cassava, often intercropped with maize, has increased sharply over the past 10 years particularly in the densely populated southern areas. Tobacco is the dominant cash crop, providing 71% of export earning from both the large-scale and small-scale farming sectors. Other cash crops include cotton, sugar, tea and coffee (ref. 2, 10 and 15).

3.4 ZIMBABWE

The Zimbabwean agricultural industry has, as is well known, undergone massive change since 2000 as a result of a government decision to confiscate land from "White" commercial farmers. This policy together with the overall collapse of the Zimbabwean economy has, over the last ten years, resulted in a dramatic decline in production of both small-scale and commercial agricultural production in the country. For the purposes of this study the production "picture" in Zimbabwe in 2000 is outlined as a measure of the agricultural potential of Zimbabwe. In that year, the farming industry consisted of about 700 000 small scale farmers on nearly 20 million hectares (28 ha average farm size). The main crops grown were maize (60% of national consumption), cotton (85% of national production) beans, groundnuts and sorghum.

In 2000 there were about 5 500 large-scale commercial farmers, occupying about 8 million hectares of land, employing 350 000 workers. The main crops grown included flue cured tobacco (250 000 t/a), maize (1 000 000 t/a for grain and the livestock industry), sugar (600 000 t/a), horticultural crops and a wide range of other grain crops.

Rain-fed agriculture predominates, dependant on a single rainy season between November and April. About 175 000 ha of land was irrigated in 2000 largely on sugar estates, orchard estates, vegetable farms and tobacco farms. The irrigation potential of Zimbabwe is estimated at about 350 000 ha in terms of available (developed water resources and favourably positioned irrigable soils).

4 CLIMATE CLASSIFICATION

4.1 INTRODUCTION

The Koppen Climate Classification system (as amended and improved over time and now commonly known as the Koppen-Geiger Climate System (KGCS) (ref. 16) is an empirical system that divides the Earth into a number of climatic zones (six in total) based on the concept that 'native' vegetation is the best expression of climate. The system also considers average annual and monthly temperatures and rainfall - and its seasonality. Thus vegetation distribution combined with this basic meteorological data defines the several climatic zones and sub-zones (see **Appendix C**).

At the 'world scale' it can be appreciated that anomalies will occur, and that approximations of zonal boundaries cannot be avoided. The presence of mountains, proximity to large bodies of water, altitude, movement of air masses, ocean currents etc strongly influence climate and introduce complexities that result in local differences to regional zones. However, the KCGS effectively integrates such sub-regional differences by incorporating the existing vegetation as the primary indicator, with temperature and rainfall influencing the groupings.

As the detail of a study increases (with mapping scale decreasing), local influences become more pronounced and other systems, better suited to local and sub-regional planning, would be more appropriate. Examples would be the Land Type mapping of South Africa, with soil surveys at 1:50 000 and mapping at 1:250 000 and land capability mapping for local planning at 1:10 000 to 1:25 000. However, at national and continental scales and taking cognizance of the extremely limited information and data available on the target countries, the KGCS is effective and gives satisfactory results.

It should be noted that the KGCS has recently been incorporated into the irrigation and water planning computer program - SAPWAT (ref. 22).

For this study, where local knowledge has identified areas that could be classified differently from a standard grouping, a change has been incorporated into the mapping. An example is the Zambezi Valley (in Zimbabwe) where the 'local' climate of the valley is decidedly different from the areas north and south. Other anomalies obviously exist, and not all have been identified or incorporated.

4.2 ZONE CODING

The KGCS employs a shorthand code of three letters designating climatic groups. There are six major groups, a sub-group for precipitation characteristics and a sub-group for temperature characteristics. The sub-groups are introduced particularly to identify seasonal differences.

Table 1 defines each of the groupings. It should be noted that only major groups A, B and C are represented in the study area.

Figure 1 shows the spatial distribution of the various groupings found in the study area.

An examination of the table and figure shows that only five Koppen climate groupings occur in the area, namely Aw, BSh, Bwh, Cfb and Cwa.

In terms of rain-fed cropping, the Zone of principal interest is Zone C. This zone has an average temperature above 10°C in the warmest months and a coldest month average between 0°C and 18°C.The sub-groupings are: Cfb (mild humid climate with sufficient rain in all seasons and a mean monthly temperature of the warmest month below 22°C) and Cwa (mild humid climate with a dry winter season and a mean monthly temperature of the warmest month being more than 22°C). Most of the principal annual crops applicable to this region can be grown under those conditions and these two climatic groupings together cover most of the study area;

Group A is also relevant from a rain-fed cropping perspective, as it defines a tropical savannah type climate with constant high temperatures, and where all 12 months of the year have average temperatures of over 18°C. Sub-group Aw is dominant in the coastal areas of Mozambique where the average annual rainfall is generally high – exceeding annual evaporation. However there is a strongly developed (albeit short) dry season with at least one month having less than 60 mm rainfall.

Table 1 Koppen Geiger Climatic Zones for selected countries

KOPPEN-GEIGER CLIMATIC ZONES - SOUTHERN AFRICA

Climatic zones	Group characteristics						Ave T all months	Ave T all max	T all min	No. months T ave > 10°C	Area covered by each climatic group per country			
	Major group		Precipitation sub-group		Temperature sub-group		(°C)	(°C)	(°C)	No.	Malawi (km²)	Mozambique (km²)	Zambia (km²)	Zimbabwe (km²)
Aw	A	Wet-Dry Tropical climate ; Pttn > PET Savanna biome No cold season	w	Dry winters Wet summers >250 mm total All months < 250 mm/month		Temp range 16°C	> 18			12	9 300 7%	441 000 56%	88 262 12%	0 0%
Bwh	B	Dry climate PET > Pttn	w	Dry winters Wet summers	h	Hot year round	> 18			> 4	0 0%	37,507 5%	0 0%	8,532 3%
BSh	B	Dry climate Steppe Biome PET > Pttn	S	Semi arid 200-750 mm rain	h	Hot year round	> 18		> 0	> 4	6 398 7%	121 000 14%	43 331 7%	127 000 39%
Cfb	C	Mild, humid climate	f	Some pptn in all months Short dry season	b	Warm summers		< 22	> 0	> 4	5 718 6%	35 861 5%	22 037 3%	131 000 29%
Cwa	C	Mild, humid climate	w	Dry winters Wet summers; 50% Pttn in warmest 6 months	a	Hot summers		> 22	> 0	> 4	73 000 79%	137 000 19%	573 000 78%	125 000 29%
											94 416	**772 368**	**726 630**	**391 532**

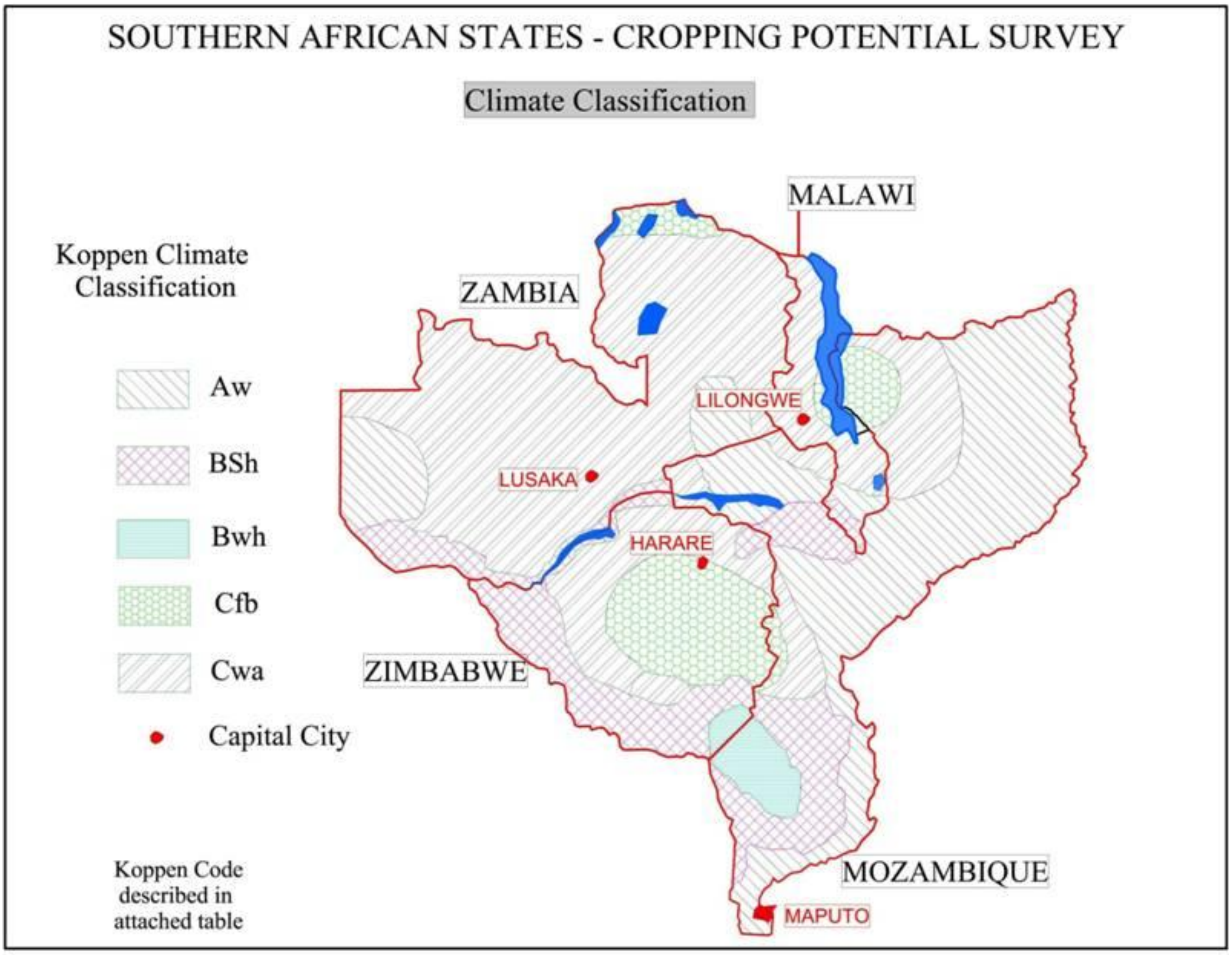


Figure 1 Classification of climate in selected countries

Group B, which does not provide sustainable rain-fed cropping conditions, comprises arid and semi-rid areas where precipitation is less than potential evapotranspiration. Sub-group BWh occurs in southern Zimbabwe and in the south-western region of Mozambique. BSh occurs in the south-west of Zambia, western Zimbabwe and southern and central Mozambique.

5 SOIL AND LAND USE MAPPING

5.1 INTRODUCTION

Relatively detailed soil mapping, at scales of 1:1 million or greater, has been carried out on an *ad hoc* basis over most of the study area (some 2 000 000 km^2). Some isolated mapping, particularly as the basis for agricultural development, has been carried out at the detailed scales of 1:10 000 and up to 1:2 000. However, the pedological systems used in all four countries have differed considerably. To consolidate these maps would require significant input from pedologists.

For this specific exercise of determining the cropping potential of the four countries, it was necessary to adopt a common soil identification approach. Scale is important as the larger the scale the more soil types appear, and the complexity of analysis dramatically increases. Too small a scale results in a reduction of usefulness of the maps and data.

During the 1990s, the United States Department of Agriculture (USDA) undertook an exercise to accumulate soil survey data to produce a world soils map, based on the twelve principal taxonomic units of the USDA pedological system. The data base incorporated a variety of soil surveys carried out over time and employing many different classification systems. The soils of Africa were mapped at a scale of 1:12 million.

The 1:12 million mapping – which covers the four-country study area, was considered to be the best available map for the detail required for this study. Unfortunately, the USDA Soil Taxonomy system is not widely used in southern Africa or well understood by agronomists in this region. Correlation with the South African Soil Taxonomic System is not straightforward, and no attempt is made in this report to match the systems. The USDA system has, however, been adapted and expanded from a "Soil Types" to a "Land Capability" type system or "Agro-Ecological" zoning system. This can then be related to cropping potential. The expansion of the USDA pedology system has been effectively carried out by Eswaran et.al. (ref. 9) and this approach has been adopted in this study to classify the arable potential of the soils in the target countries.

5.2 THE USDA LAND CLASSIFICATION SYSTEM (LCS)

In 1996, under the auspices of the World Soil Resources Survey Division, USDA Natural Resources Conservation Service, an important publication authored by Eswaran et al, (ref. 9) related the 1:12 million soils maps to a 'Soil Quality' maps. This identified soil areas with similar potentials for sustainable development, and had the effect of converting the pedology map into a readily understandable Land Capability map.

Eswaran identified five land classes, and whilst accepting that the mapping scale was relatively small, it was considered that the classes so identified were reasonably accurate when the results were compared to individual maps of greater detail.

The five classes are: Premium land, High potential land, Medium potential land, Low potential land and areas which are defined as Unsustainable land. The LSC classes are described in **Table 2**, their distribution in the study area is shown in **Figure 2** and the estimated area (ha) of each class in the four countries is given in **Table 3**.

Table 2 Land classification system for southern Africa (after Eswaran, ref. 9)

Land classification	Main soil types found showing dominant characteristics (USDA taxonomy system)	
General potential	**Soil groups include**	**Some characteristics**
Premium land	Alfisols	Moderate to high base status Clay (Argillic) B horizon
High potential land	Ultisols Some Oxisols	Clay horizon but low base status; high rainfall areas Highly weathered, red colouration, low clay
Medium potential land	Oxisols Some Ultisols	Highly weathered, red colouration, low clay Acid; low base status
Low potential land	Inceptisols Some Aridisols Some Entisols	Undeveloped soils Dry, light coloured, some saline/sodic. Young mineral soils
Unsustainable	Mixed	Many soil types. Degraded with low cropping potential

The International Soil Reference and Information Centre (ISRIC) mapping series of 2003 (ref. 15) provides a very much more detailed study of Southern Africa, where geology, soil type and terrain are included to produce 'Soster Units', but these classification units are too detailed for the requirements of this study. Similarly, the FAO (UNESCO) 'Major Soils for Africa', 2007, at a scale of 1:5 million is available, but is considerably more detailed than the USDA mapping, and is also too detailed for the requirements of this study. However these systems could be valuable for any follow-up work that may arise from this study.

Table 2 Land classification showing areas per country (km^2 and %)

Land classification	Malawi		Mozambique		Zambia		Zimbabwe	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Premium land	19 064	20	266 427	35	143 369	20	220 729	57
High potential land	0	0	0	0	250 355	35	0	0
Medium potential land	21 960	23	143 973	19	100 632	14	5 672	1
Low potential land	52 952	56	147 969	19	150 240	21	77 001	20
Unsustainable	0	0	213 874	28	79 435	11	87 096	22
Total	**93 976**		**772 244**		**724 031**		**390 498**	

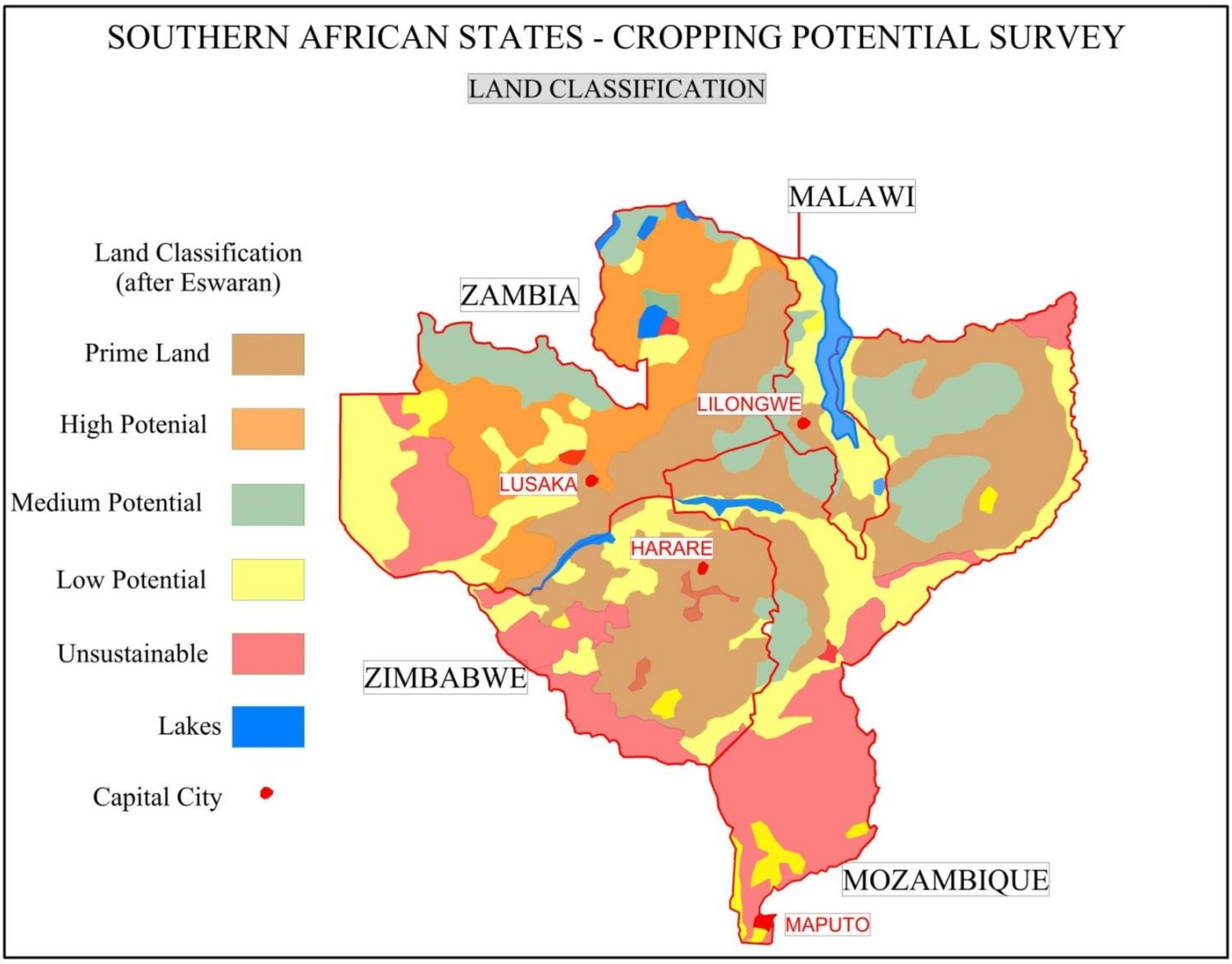


Figure 2 Land classification

5.3 AREAS EXCLUDED FROM THE LAND CLASSES IN THE STUDY AREA

In order to estimate the area of available land with high potential for growing rain-fed field crops, two main assumptions were made. Firstly only the two of the land classes, “Premium land” and “High potential land” are considered in the analysis and certain area exclusions are made for other forms of land use

5.3.1 Principal exclusions

- **Reserve land**

There is a considerable area of land that has been set aside within each of the four countries for conservation purposes, including environmentally sensitive areas, tourist attractions and other protected areas of national and international interest. This study has adopted the mapping delineations of the International Union for the Conservation of Nature (IUCN) (ref. 13). These maps delineate existing conservation areas (e.g. game reserves, national parks, wetlands, etc) but also include areas that are deemed ecologically sensitive, and are targeted for inclusion or expansion in terms of existing protected areas. **Figure 3** shows the principal IUCN reserve areas.

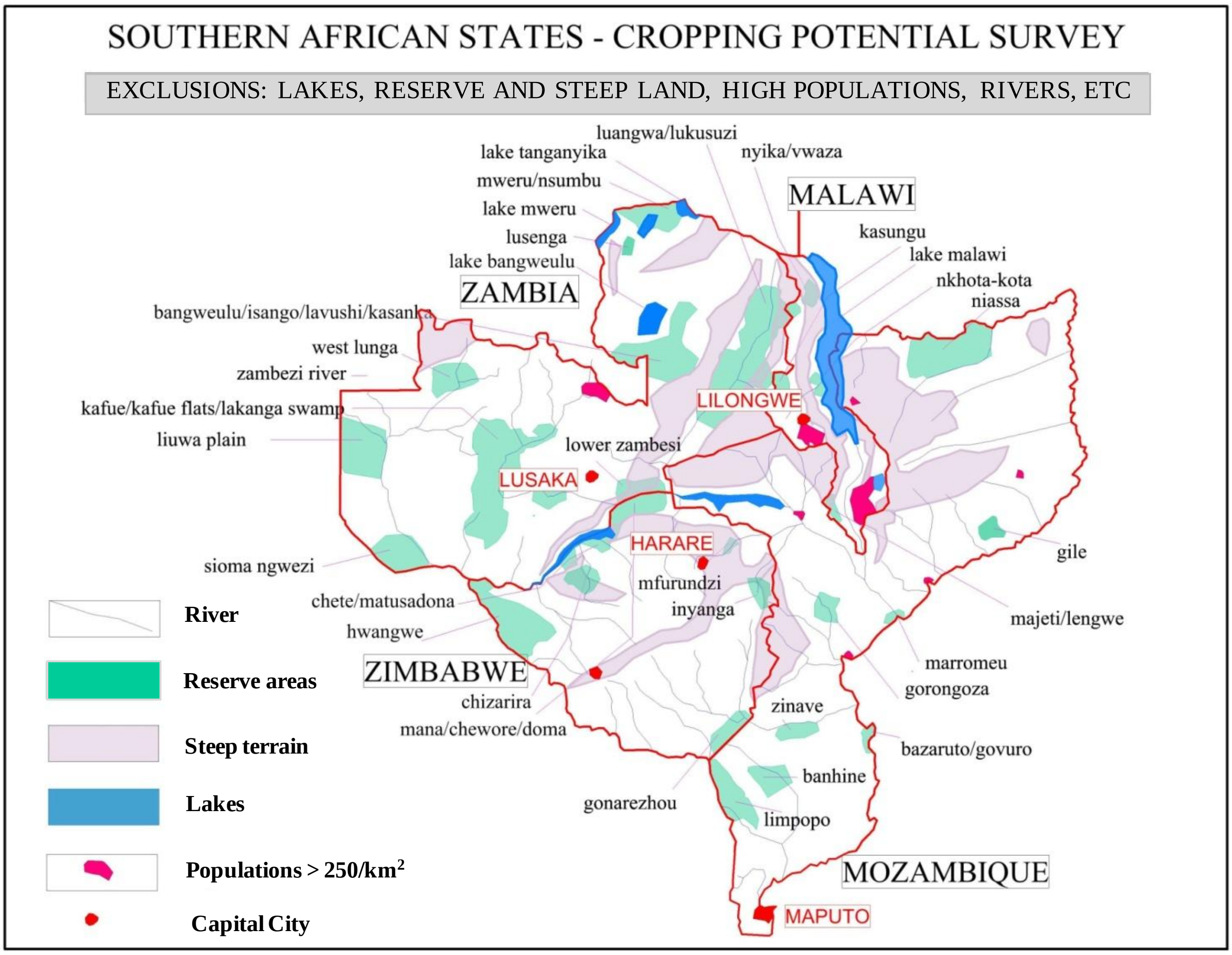


Figure 3 Principal exclusion from possible cropping areas

- **Population concentrations**

Another land use that must be considered is urban development and population density. A gridded population map of Africa produced by CIESIN (Columbia University – compiled in 2005) was used as the basis for assessing population distribution in this study area (**Figure 3** and **Figure 4**).

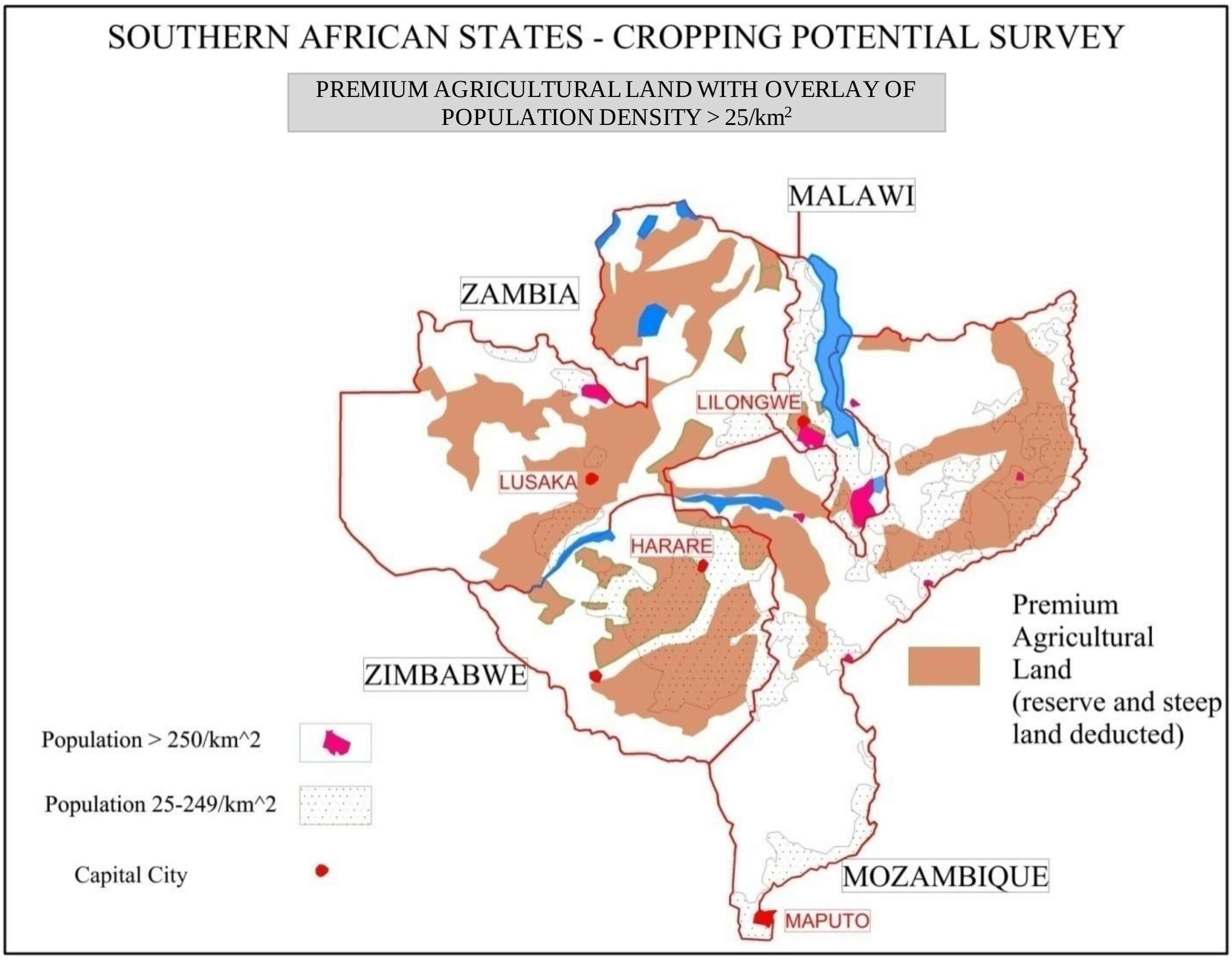


Figure 4 Premium agricultural land and population distribution

CIESIN has defined six population density groups (persons per km^2):

<1; 1-4; 5-24; 25-249; 250-999 and >1 000.

The capital cities of the four countries (Harare, Maputo, Lilongwe and Lusaka) all have more than 1 000 persons per km^2. Many of the bigger towns (e.g. Bulawayo, Blantyre, Beira, Nampula, Kitwe/Ndola etc.) have similar large populations, but such densities within consolidated urban areas are not widespread in these countries. The populations are mostly rural, which includes many smaller towns and villages.

The number of urban areas (spatial areas where population groupings >5 000) together with total populations is given in **Table 4** (latest dependable data for all four countries is at year 2000).

Table 4: Population details for four southern African countries

Country	Number of urban areas	Population (2000)	Country area (km^2)
Malawi	31	11 308 000	94 958
Mozambique	69	18 292 000	777 123
Zambia	35	10 421 000	745 317
Zimbabwe	23	12 627 000	389 055

The large majority of land in Zambia (>80%) has an average population in the CIESIN grouping 5-24 people/km^2. Zimbabwe has approximately equal areas of 5-24 and 25-249 people/km^2. Mozambique has 45% of 5-24 people/km^2, 35% 5-24 people/km^2 and 20% 25-249 people/km^2. Malawi has by far the highest density of people over their area, with 88% 25-249 people/km^2, 7% 1-4 people/km^2 (in the mountainous areas) and 5% 250-999 people/km^2.

It can be seen that a very small percentage of the study area has population densities in the groupings larger than 249 people/km^2.

The CIESIN map shows that in some areas – particularly Malawi (as a whole), the Zimbabwe highveld and the Mozambique coastal areas are densely populated. Other areas, including northern and central Zambia and the Mozambique interior, have low populations.

Whilst population density is important in respect of availability of land for cropping purposes, it is also important in terms of land tenure, land occupation patterns and labour availability. In general, small numbers of people would indicate that a relatively large area is available for cropping. However, at the scale of mapping used for this study, population distribution (apart from towns and cities) is not considered to have a significant influence on demarcating agricultural land use, and is only shown as an overlay to indicate population pressure on the land.

- **Topography**

The soil types and their availability for cropping are strongly influenced by topography.

Land with slopes above 8% is usually excluded from row-crop agriculture. Malawi and Mozambique are especially penalized in terms of slope. Zambia and Zimbabwe benefit from their extensive plateau areas and are mainly affected by their escarpments bracketing major river valleys. Much of the steeper land is forested, either indigenous (including dense bush) or under plantation. More of this land is expected to be planted to commercial forests in future.

Allied to topography, but also a factor on its own, is soil depth. In Africa in general, it has been estimated that more than 50% of the soils are problematic in terms of effective depth for intensive crop production (Eswaran) (ref. 9).

A soil map at the scale used in this study will not usually be able to discriminate against steepness of slope in the pedology groupings. A broad delineation of steep and or broken terrain has therefore been mapped for removal from the high-potential cropping areas. The identification and delineation of these areas has been sourced from a number of topographic maps, principal amongst which are the ISRIC depository of Africa maps at Wageningen in the Netherlands and Wikipedia relief maps (internet).

Crops such as tea, coffee, orchard crops and some food security crops could be grown in these "excluded" areas, but for commercial-scale growing of grains and other field crops, these areas would be unsuitable. The areas excluded, based on topography, are shown in Figure 3.

6 COMBINED SUITABILITY ANALYSIS

6.1 PREMIUM LAND USE POTENTIAL AND POPULATION OVERLAY

Figure 4 shows a combination of the Premium and High potential land-use classes which have been combined, and for the purposes of this study, have been termed the "Premium agricultural land-use" class. The "Premium" land-use class, in turn, overlays the population grouping 25 to 249 persons per km^2. This grouping is considered to be significant in that it indicates some pressure on the land (but not excessive), but also indicates the availability of labour and probably some usable infrastructure.

6.2 AGRO-ECOLOGICAL ZONES BASED ON "PREMIUM" LAND-USE POTENTIAL, CLIMATIC ZONES AND PRIMARY EXCLUSIONS

Figure 5 shows the combination of (a) the Premium land-use class, (b) the climatic zones that are suitable for rain-fed crop production (Cfb, Cwa and Aw optimal and BSh sub-optimal) and (c) the primary exclusions that are described above. The result is four agro-ecological zones, three of which are optimal and one sub-optimal for rain-fed crop production.

6.3 SECONDARY EXCLUSIONS

Secondary exclusions from the high-potential crop production areas are discussed here because they cannot be incorporated into the above GIS component of the analysis as they can only be quantified on a percentage-of-land-area basis.

The secondary exclusions contain such items as: small towns, villages and various infrastructure, heavily populated rural areas, afforestation, scattered areas of broken land and rocky outcrops, badly eroded (degraded) areas, local wetlands, streams and rivers, saline and sodic areas, drainage-ways, flood plains, dams, roads and other servitudes, land established for grazing and rangelands and forests.

For the purposes of this study the secondary exclusions have been estimated at 50% of the Premium land-use class. This is an arbitrary estimate based on experience and a wide range of practical evidence in southern Africa.

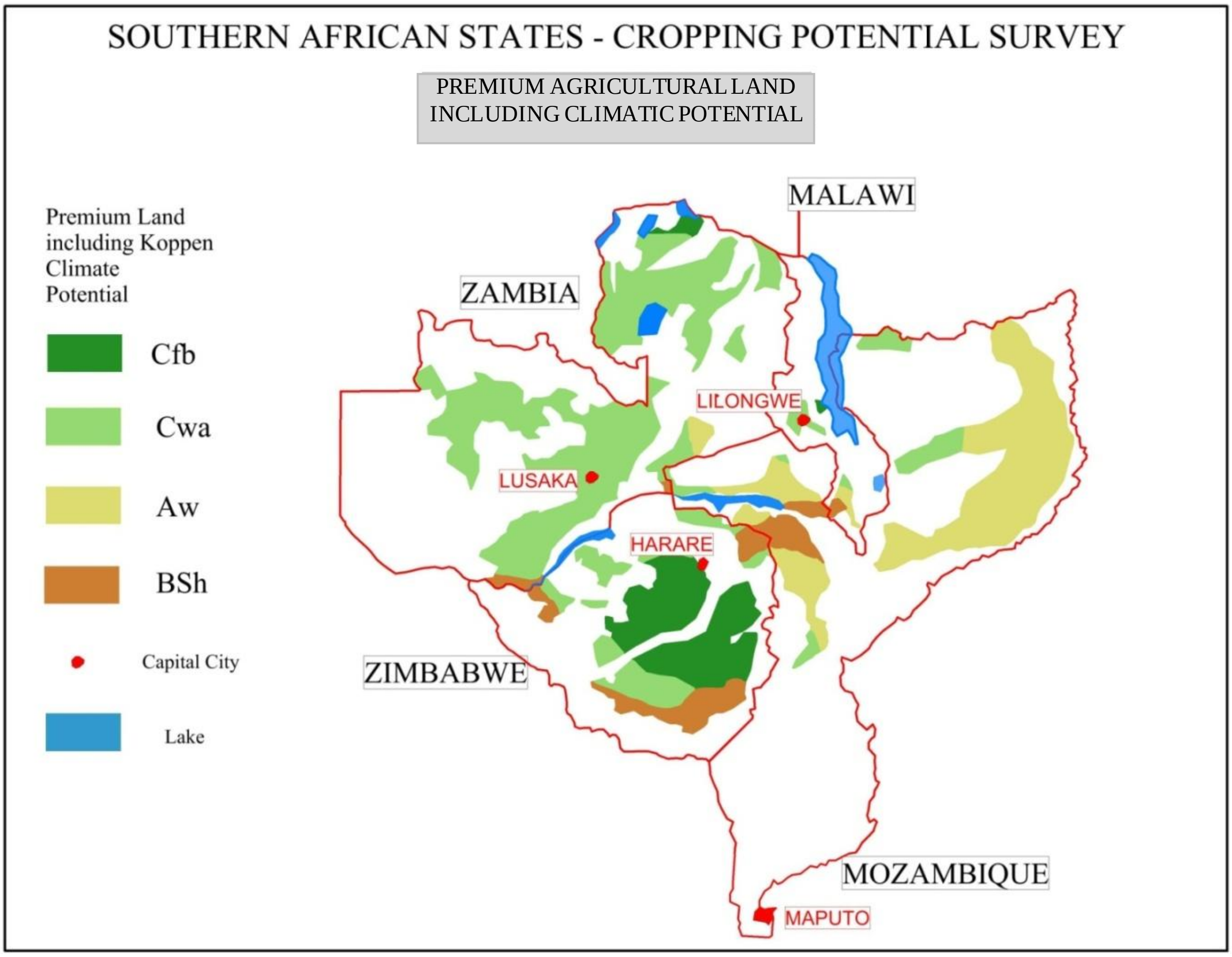


Figure 5 Premium agricultural land including climatic suitability

6.4 NET HIGH-POTENTIAL CROPPING AREAS (km^2)

The net high-potential cropping area (km2) for each of the selected countries, based on the three high-potential climatic zones Cbf, Cwa and Aw , the "Premium" land-use class and secondary reductions, is shown in **Table 5**.

Table 5 Net high potential cropping areas (km^2)

Country	Net area for high potential cropping (km^2)
Malawi	4 022
Mozambique	88 722
Zambia	110 828
Zimbabwe	63 261
Total	**266 832**

The total net area of 266 832 km^2 (26,6 million ha) of high-potential cropping area, constitutes about 13% of the total land area of the four countries. This compares with about 3,2 million ha (3.0%) for South Africa.

The net area (km^2) of high-potential cropping area for each of the main climatic zones is shown in **Table 6**. The table includes the area (km^2) of high potential before the secondary exclusions are deducted.

Table 6 Net high potential cropping areas (km^2) for each of the high potential climatic zones

Country	Secondary reduction of Premium land area (%)	Climatic zones			Total
		Aw	Cfb	Cwa	
Malawi	**0**	3 437	476	4 129	8 042
	50	1 719	238	2 065	4 022
Mozambique	**0**	157 480	0	19 964	177 444
	50	78 740	0	9 982	88 722
Zambia	**0**	3 372	3 723	214 559	221 654
	50	1 686	1 862	107 280	110 828
Zimbabwe	**0**	0	84 982	41 539	126 521
	50	0	42 491	20 770	63 261
Total	**0**	**164 289**	**89 181**	**280 191**	**533 661**
	50	**82 145**	**44 591**	**140 096**	**266 832**

Expressed in hectares, the countries possess the following areas of high-potential cropping land:

- Zambia 11,1 million ha
- Mozambique 8,8 million ha
- Zimbabwe 6,3 million ha
- Malawi 0,4 million ha

Clearly, the study area has a rich potential for rain-fed crop production and, in the context of the SADC countries as a whole, provides a highly significant opportunity for agricultural development in the region and an opportunity to substitute high-potential rain-fed crop production for expensive and water-inefficient irrigation of annual field crops in South Africa.

7 CROP SUITABILITY

A range of crops has been considered for their suitability to the climatic zones defined above. The crops have been grouped into the following broad categories:

(1) Summer annual crops which include maize, soybean, groundnuts, cotton and sorghum. Of these, maize and groundnuts are the most widely grown under irrigation in South Africa;

(2) Winter annual crops which include wheat, barley and dry pea. Of these, wheat is the most widely grown under irrigation in South Africa;

(3) Perennial sub-tropical fruit and nuts and sugarcane. Most of these crops are grown under irrigation in South Africa

Table 7 lists these crops and describes the climatic and soil conditions that are required for their optimum production. A suitability matrix between crops, climate and soil is derived from the data contained in this table.

Table 8 shows the adaptability of these crops to the selected high-potential climatic zones. Adaptability is described in terms of four categories; “Suitable”, “Marginal”, “Not Suited” and “Suitable under Irrigation” It should be noted that all crops would probably benefit from supplementary irrigation, especially where rain is concentrated in a limited number of months. However, rain-fed agriculture is commonly practiced in the Cwa and Cfb areas, as the rain mostly is derived from the Inter-Tropical Convergence Zone influence which (with the obvious exception of drought years) is a relatively reliable rain bearing system.

However, in respect of cotton and sugarcane, excellent growing areas do exist but irrigation is essential – not the least because they have a long growing period and are ‘inter-seasonal’.

Table 9 lists those crops that are well adapted to the high-potential climatic zones of each country and quantifies the area available on high-potential soils for their production. The crops considered in the table are summer annual crops, winter annual crops and sugarcane.

It should be noted that winter cropping is made viable in the “suitable’ areas through specialized cropping practices as the area is dominated by long dry periods and/or where temperatures may not be low enough for flowering or frosts may occur after flowering. For example, early planting of short season wheat and barley varieties is practiced where soil moisture levels from the previous rainy season are high enough.

Table 3 Requirements for optimum growth of crops selected for consideration in the study area

Crop	Water req. mm	Sensitivity to moisture stress	Growth period days	Optimum daily temp range oC	Average daily temp range oC	Min. temp oC	Soil type (minimum requirements)	Soil pH	Special needs
summer									
maize	500-900	high	100-140+	24-30	15-35		well drained, deep	5.0-7.0	**no frost**/dry season needed
sorghum	250-650	med-low	90-210	24-30	15-35		light to medium/heavy	6.0-8.0	**no frost**, periodic waterlogging is OK
soybean	450-700	med-low	80-130	20-25	18-30		wide range but not sandy; well drained	6.0-6.5	**no frost**, dry season
groundnut	400-700	low	90-140	22-28	18-33		well drained, friable, medium text.	5.5-7.0	**no frost**, dry season
dry-bean	300-500	medium-high	90-120	15-20	10-27		deep friable, well drained	5.5-6.0	**no frost**; sensitive to excessive heat and waterlogging
cotton	700-1300	medium-low	150-220	20-30	16-35		deep medium to heavy	6.5-8.0	**no frost**/dry season needed; sensitive to strong or cold winds
winter									
winter wheat	180-250	medium-high	120-210	15-20	10-25	5	medium to heavy	6.0-8.0	dry season; needs cold for flowering but sensitive to frost post flowering;
barley	180-250	medium-high	120-210	15-20	10-25	5	medium to heavy	6.0-8.0	dry season; needs cold for flowering but sensitive to frost post flowering;
dry-pea	350-500	medium-high	85-120	15-18	10-23		well drained	5.5-6.5	slight frost tolerance when young
sub.trop fruit									
sweet orange	900-1200	medium	240-365	23-30	15-35		well drained,deep; light to medium	5.0-8.0	**no frost**/short dry season; sensitive to strong winds and high humidity
mango				27-32			well drained,deep		**no frost**
sugarcane	1300-1600	high	250-540	22-30	15-35	15	deep, light to heavy, well drained	5.5-8.0	**no frost**; dry season of 5 months + to ripen and harvest

Table 8 Crop adaptability to the high-potential climate zones of the study area

Koppen Geiger climate groups	Annual crops									Perennial crops		
	Summer						Winter			Sub-tropical fruit		Plantation
	maize	sorghum	soybean	groundnut	dry-bean	cotton	wheat	barley	dry-pea	orange	mango	sugarcane
Cwa	suitable	suitable	suitable	suitable	suitable	not suited	not suited	not suited	not suited	suit.+ irrig.	not suited	marginal
Cfb	suitable	suitable	suitable	suitable	suitable	not suited	suitable	suitable	suitable	suitable	not suited	not suited
Aw	suitable	suitable	marginal	marginal	marginal	marginal	not suited	not suited	not suited	not suited	suitable	suit.+ irrig.
BSh	not suited	marginal	not suited	not suited	not suited	suit.+ irrig.	suit.+ irrig.	suit.+ irrig.	suit.+ irrig.	not suited	suit.+ irrig.	suit.+ irrig.
Bwh	not suited	marginal	not suited	not suited	not suited	suit.+ irrig.	not suited	not suited	not suited	not suited	suit.+ irrig.	suit.+ irrig.

suitable (in red): grown as an 'out of season' crop in Spring or Autumn

Table 9 The adaptability and area (km^2) of summer annual crops winter annual crops and sugarcane in the high-potential climatic zones in each of the countries in the study area

Country	Cwa	Cfb	Aw	BSh	Total (km^2)
	(km^2) / suitable crops				
Malawi	**2 065**	**238**	**1 719**	**474**	**4 496**
	maize sorghum soybean groundnut dry-bean	maize sorghum soybean groundnut dry-bean wheat barley dry pea	maize sorghum sugarcane	Cotton Wheat Barley dry-pea Sugarcane	
Mozambique	**9 982**	**0**	**78 740**	**6 546**	**95 268**
	maize sorghum soybean groundnut dry-bean		maize sorghum sugarcane	Cotton Wheat Barley dry-pea Sugarcane	
Zambia	**107 280**	**1 862**	**1 686**	**2 735**	**113 563**
	maize sorghum soybean groundnut dry-bean	maize sorghum soybean groundnut dry-bean wheat barley dry pea	maize sorghum sugarcane	Cotton Wheat Barley dry-pea Sugarcane	
Zimbabwe	**20 770**	**42 491**	**0**	**13 539**	**76 800**
	maize sorghum soybean groundnut dry-bean	maize sorghum soybean groundnut dry-bean wheat barley dry-pea		Cotton Wheat Barley dry-pea Sugarcane	
Total	**140 097**	**44 591**	**82 145**	**23 294**	**290 127**

Notes:

- (green) **requires significant irrigation**
- (orange) **summer crop**
- (blue) **winter crop**

8 CONSTRAINTS TO THE DEVELOPMENT OF THE EXTENSIVE RAIN-FED CROPPING POTENTIAL

The socio-economic constraints to the development of the extensive rain-fed cropping potential that exists in the selected neighbouring countries, though not insurmountable, should not be underestimated. Of particular importance is:

- The communal land tenure system that exists throughout the study area and the wide-spread population sprawl that mitigates against large-scale commercial crop production. This can to some extent be overcome through joint-venture arrangements between local communities and commercial operators or land leasing from the government/communities (particularly in low-population areas)
- The poor infrastructure (or lack of infrastructure in some areas) with respect to roads, power supply, storage facilities and agricultural support infrastructure and services such as input supplies, transport, operating credit facilities, mechanical equipment maintenance etc, places a special challenge on any commercial agricultural development initiative. However, South African farmers operating in countries like Mozambique and Zambia, with full government backing, have shown that these constraint can be overcome, but at a substantial cost.
- The lack of a supportive political environment in Zimbabwe does, for the foreseeable future, place a serious constraint on commercial investment of any meaningful scale. The lack of any security of land tenure implies no financial backing from banks for infrastructure development and production loans which effectively stifles commercial agricultural development. However, the situation in Mozambique and Zambia is far more positive with many examples of agricultural commercialisation emerging.

9 IRRIGATION

Whilst the principal objective of this study is to identify areas that are suited to rain-fed crop production, the existence of a considerable network of largely ‘un-tapped’ surface water resources (streams and rivers), especially in Zambia and Mozambique must, be noted.

Table 10 indicates the low level of exploitation of water resources for irrigation in the four study countries. Figures are for 2004 (ref. 8).

There is clearly an opportunity for expanded utilisation of the water resources in these countries for irrigation where there is a higher irrigation potential, in terms of both soils and climate, than exists for many of the irrigated areas of South Africa.

Table 10: Irrigated land and water consumption

Country	Irrigated land (2004) as a % of cultivated land	Annual water consumption as a % of total water resources	Estimated irrigation demand (million m^3/annum)
Malawi	1.7	2.0	1 820
Mozambique	4.0	1.0	3 000
Zambia	0.9	1.0	1 580
Zimbabwe	7.0	5.0	4 980

10 CONCLUSIONS

The key conclusions drawn from this study are summarised as follows:

- The four countries possess about 26,6 million ha of high-potential cropping land:
    - Zambia 11,1 million ha
    - Mozambique 8,8 million ha
    - Zimbabwe 6,3 million ha
    - Malawi 0,4 million ha
- The rain-fed crop production potential includes a wide range of summer field crops such as maize soybean, dry bean, groundnuts and sorghum which are adapted to parts of all four of the target countries and winter rain-fed field crops such as wheat, barley and dry pea which can be grown extensively in all the countries except Mozambique.
- The study area therefore displays a rich potential for rain-fed crop production and, in the context of the SADC countries as a whole, provides a highly significant opportunity for agricultural development in the region and an opportunity to substitute high-potential rain-fed crop production for expensive and water-inefficient irrigation of annual field crops in South Africa.
- The four countries experience a number of major socio-economic constraints to the exploitation of this excellent potential. The constraints include land tenure issues (the majority of the high potential rain-fed cropping area is occupied by subsistence farmers on communally owned land), population (the high rural population spread presents a challenge to commercialisation of agriculture), present land use (widespread subsistence farming), poor or lacking infrastructure and poor agricultural support services., However the constraints are not considered insurmountable. With the appropriate vision, investment and support from the governments of the respective countries there are significant opportunities for extensive commercial agricultural development which could involve and benefit local farmers and their communities. The recent examples of South African farmers operating successfully in Mozambique and Zambia, with full government backing, have shown that these constraints can be overcome.

- Whilst the principal objective of this study is to identify areas that are suited to rain-fed crop production, the existence of a considerable network of largely 'un-tapped' surface water resources, especially in Zambia and Mozambique, is highlighted. There is therefore an opportunity for expanded utilisation of the water resources in these countries for irrigation where there is a higher irrigation potential, in terms of both soils and climate, than exists for many of the irrigated areas of South Africa.

APPENDIX A

Notes on Mapping

Notes on mapping

The maps used in this report are derived from maps published by:

- Melbourne University (Koppen Geiger Map Of Africa)
- USDA (Hari Eswaran report of 1996 showing soils and land quality maps)
- CIESIN, Columbia University (Africa: Population Density, 2000)

The maps were all published on A4 sized paper, and were subsequently copied and adjusted to show the Southern Africa Region in more detail. The polygons on the maps were abstracted and re-drawn in CAD. The scale of the original maps was in the order of 1:35 000 000. It must be noted, therefore, that the maps published in this document will have lost some accuracy in the abstraction process. The maps shown in this report are approximately 1:12 500 000, approximately three times larger than the original mapping.

APPENDIX B

Eswaran's definitions of Land Quality

Premium land

Within the study area, this land type mainly comprises Alfisols with some Ultisols – which are not as fertile as the Alfisols as they are more weathered and acidic. Alfisols comprise relatively young, deep, permeable soils (generally without impermeable horizons) with loamy to clayey textures and good tilth characteristics. They usually have an adequate supply of nutrients. Lands are mostly level to gently undulating. Water holding capacity is more than 150 mm/m. Cropping performance is generally good, and they respond well to good management. They have high resilience to degradation and can readily be brought back to previous productivity levels.

High potential land

Mostly Oxisol soils of low activity, highly weathered, crumbly and eluviated, having no argillic (clay rich) horizon. They have distinctly red-coloured subsurface horizon. Also intermixed with Ultisols, which have an argillic horizon, but with low base saturation, often very acidic. These soil types have some minor limitations. These may include, for example, root restricting horizons (often laterite) and sandy or gravelly layers.

They have the potential to be highly productive with proper management – but where this is sub-optimal and inputs are limited, they can be severely stressed. Their resilience is less than the Prime Lands, and so can be permanently damaged with mismanagement

Medium and Low potential lands

These lands have major constraints for low-input agriculture. There are high risks for resource-poor farmers, and the probability of crop failure is high. Soil limitations include some of the following – low organic matter, impermeable layers, surface crusting, acidity or salinity, low water holding capacity, shallow depths. The phosphate fixing characteristics of the more acid soils can be severe. They often have high water and wind erosion risks. Soil types include Aridisols (dry soils, with light coloured surface horizons that may be saline or sodic), Inceptisols (young soils of low fertility), Entisols (light soils having minimal profile development, often shallow and with low clay content and low water-holding capacity) and vertisols. The latter are included due to the difficulties of their management (heavy, black swelling clays)

Unsustainable

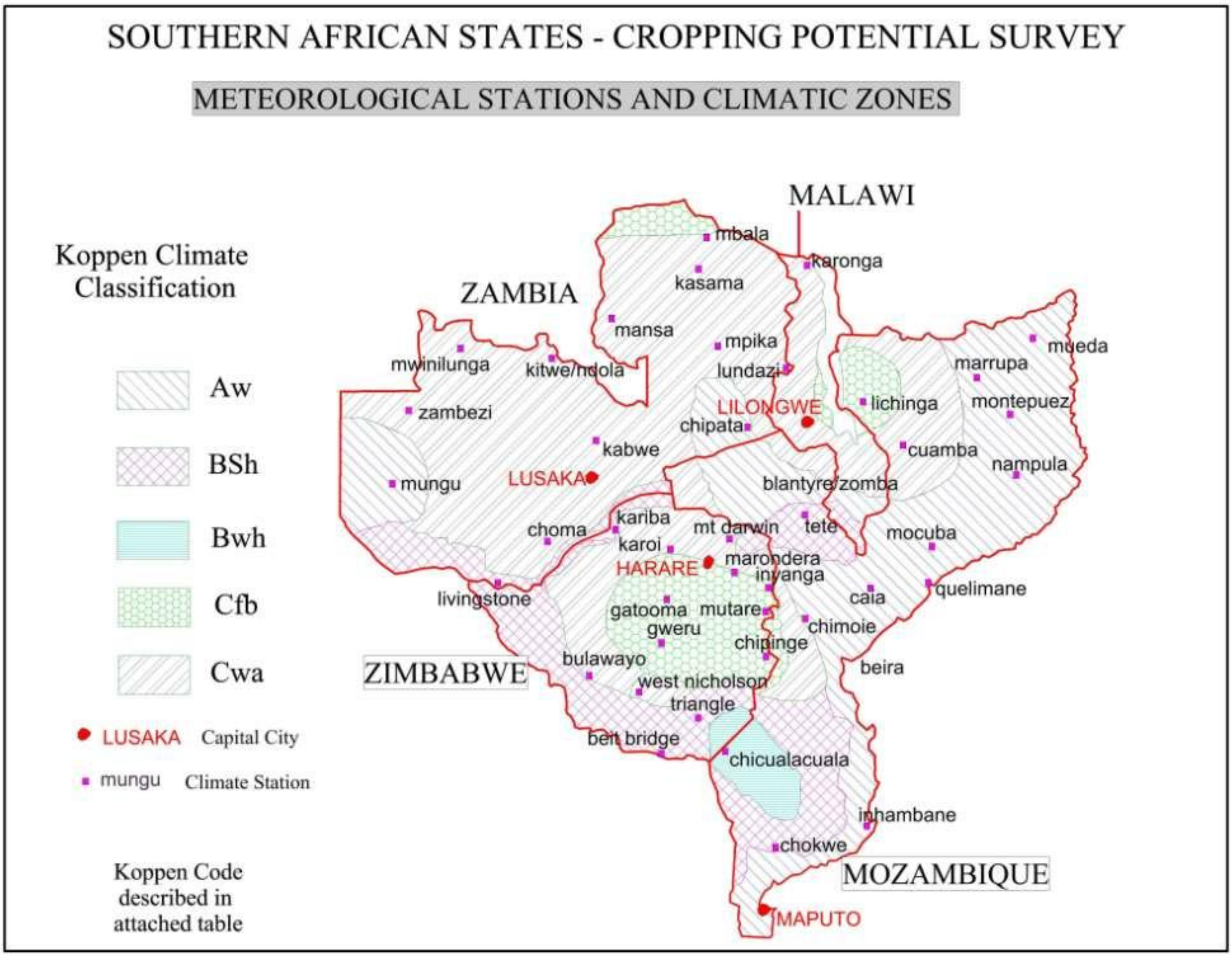
These lands are considered very fragile in terms of agricultural development and are easily degraded. They are not productive and do not respond well to management. They require very high investments in order to make them productive (eg intensive drip irrigation, wind breaks etc). They include some saline, sodic and waterlogged areas. Soils included are aridisols, entisols inceptisols, vertisols and Oxisols – but all have been ‘downgraded’ by severe climatic or erosive influences.

APPENDIX C

Climate Information

Meteorological data

Temperature and rainfall data from a number of weather stations within the study area was compiled (see table on next page) by way of a further check on the validity of the Koppen-Geiger system and to indicate the rainfall quantities available during the planting season. These stations were chosen to represent, where possible, the several climatic zones in the area. The coverage is not comprehensive, however, as the stations with reliable long term data are limited. The choice of station was also made in an effort to achieve a spatially widespread network. The figure below shows the Koppen-Geiger climate zones together with the spread of meteorological stations. The majority of zones comply with the parameters set by the system's guidelines.



Meterological stations showing Characteristic zonal data

Southern African States: Climate Stations with Characteristic Zonal Data

Zambia	chipata				choma				kasama				livingstone				lundazi				lusaka				mongu			
	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain
	Aw				Cwa				Cwa				BSh				Cwa				Cwa				Aw			
Jan	27	18	23	259	27	16	22	200	26	16	21	277	29	19	24	180	27	17	22	219	26	17	22	215	28	18	23	223
feb	27	18	23	233	27	16	22	185	26	16	21	249	29	19	24	159	27	17	22	197	26	17	22	175	28	19	24	218
Mar	28	18	23	155	27	14	21	80	26	16	21	256	30	17	24	98	27	17	22	158	26	16	21	111	29	18	24	147
Apr	28	16	22	51	27	12	20	23	26	15	21	69	30	15	23	24	27	14	21	29	26	14	20	15	30	16	23	46
May	27	14	21	3	25	7	16	6	26	13	20	13	28	10	19	4	26	11	19	5	25	12	19	2	28	12	20	2
Jun	25	12	19	1	23	4	14	6	25	10	18	0	25	7	18	0	25	8	17	0	23	10	17	0	27	10	19	1
Jul	25	12	19	0	23	3	13	0	25	10	18	1	25	7	18	0	24	7	16	0	23	10	17	0	28	10	19	0
Aug	27	14	21	0	25	5	15	0	27	11	19	0	28	9	19	0	25	9	17	0	25	12	19	0	30	12	21	0
Sep	30	17	24	0	29	9	19	1	29	14	22	1	32	14	23	2	29	12	21	1	29	15	22	0	33	15	24	1
Oct	32	20	26	1	31	13	22	22	31	16	24	18	35	18	27	19	31	15	23	9	31	18	25	13	34	17	26	28
Nov	31	20	26	94	29	16	23	93	29	17	23	147	32	19	26	80	30	17	24	66	29	18	24	85	31	18	25	122
Dec	28	18	23	217	28	17	23	209	27	16	22	257	30	19	25	170	28	17	23	193	27	17	22	188	29	18	24	213
ave	**28**	**16**		**1014**	**27**	**11**		**825**	**27**	**14**		**1288**	**29**	**14**		**736**	**27**	**13**		**877**	**26**	**15**		**804**	**30**	**15**		**1001**

Zambia	mbala				mwinilunga				zambezi				kabwe				mansa				mpika				ndola			
	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain
	Cwa				Cwa				Cwa				Cwa				Cwa				Cwa				Cwa			
Jan	23	15	19	250	26	16	21	237	28	18	23	221	27	17	22	250	27	17	22	258	25	16	21	278	26	17	22	277
feb	23	15	19	215	26	16	21	208	28	18	23	204	27	17	22	194	27	17	22	218	25	16	21	226	26	17	22	237
Mar	24	15	20	222	26	16	21	257	28	18	23	152	27	16	22	118	27	16	22	189	25	16	21	187	27	16	22	188
Apr	25	15	20	120	27	14	21	84	29	16	23	31	27	14	21	25	27	15	21	49	25	15	20	28	27	14	21	31
May	25	12	19	9	27	10	19	8	28	12	20	2	25	11	18	6	26	11	19	3	24	12	18	4	26	10	18	4
Jun	24	11	18	2	26	7	17	1	27	9	18	1	24	9	18	0	25	9	17	0	23	10	17	1	24	7	16	0
Jul	24	11	18	0	26	6	16	0	27	8	18	0	23	9	18	0	25	9	17	0	22	9	16	0	25	6	16	0
Aug	26	12	19	0	28	9	19	1	30	11	21	1	26	11	19	0	27	11	19	0	22	11	17	1	27	9	18	0
Sep	27	14	21	3	31	13	22	15	33	15	24	6	29	14	22	0	30	14	22	6	24	14	19	0	30	13	22	1
Oct	28	15	22	12	30	15	23	94	33	17	25	45	32	17	25	20	31	16	24	39	27	16	22	7	32	15	24	19
Nov	25	15	20	143	27	16	22	217	30	18	24	131	29	18	24	98	28	17	23	168	30	16	23	96	29	17	23	130
Dec	23	15	19	243	26	16	21	255	28	18	23	214	27	18	23	260	26	17	22	283	28	16	22	237	27	17	22	260
ave	**25**	**14**		**1219**	**27**	**13**		**1377**	**29**	**15**		**1008**	**27**	**14**		**971**	**27**	**14**		**1213**	**26**	**14**		**1065**	**27**	**13**		**1147**

Zimbabwe	beitbridge				bulawayo				gweru				harare				kariba				mount darwin				triangle			
	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain
	BSh				Cwa				Cfb				Cfb				BSh				Cwa				BSh			
Jan	33	22	28	70	27	16	22	138	26	15	21	130	26	16	21	198	31	22	27	170	28	18	23	214	32	20	26	129
feb	33	21	27	50	27	16	22	108	25	15	20	119	26	16	21	170	31	21	26	155	28	18	23	161	32	20	26	106
Mar	32	20	26	36	27	15	21	70	25	13	19	72	26	14	20	109	31	20	26	61	28	17	23	107	31	18	25	82
Apr	30	17	24	24	26	13	20	22	25	11	18	25	26	13	20	29	30	18	24	22	27	14	21	20	31	15	23	25
May	28	12	20	5	24	9	17	8	23	7	15	5	24	9	17	11	28	14	21	4	26	10	18	5	29	10	20	7
Jun	25	8	18	4	22	7	15	1	20	5	13	5	21	7	14	2	26	11	19	1	24	7	16	3	26	7	18	13
Jul	25	8	18	1	22	7	15	0	20	4	12	0	21	7	14	0	26	11	19	0	24	6	15	1	26	6	18	5
Aug	28	11	20	1	24	9	17	0	23	6	15	1	24	9	17	2	29	14	22	1	26	8	17	1	28	8	19	4
Sep	30	15	23	8	28	12	20	5	26	9	18	7	27	12	20	5	33	19	26	1	29	12	21	3	31	12	22	8
Oct	32	19	26	21	30	15	23	24	28	13	21	34	29	15	22	28	35	23	29	10	32	17	25	9	34	17	26	19
Nov	32	20	26	39	28	16	22	87	27	14	21	92	27	15	21	95	33	23	28	67	30	18	24	75	33	19	26	77
Dec	33	21	27	66	27	16	22	131	26	15	21	153	26	16	21	165	31	22	27	178	29	18	24	162	33	20	27	111
ave	**30**	**16**		**325**	**26**	**13**		**594**	**25**	**11**		**643**	**25**	**12**		**814**	**30**	**18**		**670**	**28**	**14**		**761**	**31**	**14**		**586**

Zimbabwe	chipinga				inyanga				karoi				west nicholson				mutare				marondera			
	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain	Tmax	Tmin	ave max+min	rain
	Cfb				Cfb				Cfb				Cwa				Cfb				Cfb			
Jan	26	17	22	232	21	13	17	257	26	17	22	221	30	18	24	114	28	17	23	171	25	14	20	186
feb	25	17	21	206	21	13	17	219	26	17	22	193	30	18	24	88	27	17	22	134	24	15	20	158
Mar	25	16	21	162	21	12	17	135	26	16	21	103	29	16	23	51	26	16	21	99	24	13	19	99
Apr	24	14	19	56	20	10	15	51	26	14	20	36	28	13	21	28	26	15	21	26	24	11	18	46
May	22	12	17	25	18	8	13	17	24	11	18	8	26	9	18	6	24	11	18	10	22	8	15	13
Jun	20	10	18	22	16	6	11	16	22	9	16	3	23	5	14	10	21	9	15	9	20	6	13	7
Jul	20	10	18	17	16	6	11	14	22	8	15	0	24	5	15	1	21	9	15	7	20	5	13	1
Aug	22	11	17	20	18	7	13	15	25	10	18	1	26	7	17	1	23	10	17	11	22	7	15	3
Sep	25	13	19	21	21	9	15	13	28	13	21	4	29	11	20	6	26	13	20	10	25	9	17	10
Oct	26	15	21	45	23	11	17	43	30	16	23	14	31	16	24	21	29	15	22	27	27	12	20	39
Nov	26	16	21	113	22	12	17	125	28	17	23	89	31	17	24	64	28	16	22	91	25	14	20	114
Dec	26	16	21	208	22	13	18	215	26	17	22	183	30	18	24	95	28	17	23	161	24	14	19	197
ave	**24**	**14**		**1127**	**20**	**10**		**1120**	**26**	**14**		**855**	**28**	**13**		**485**	**26**	**14**		**756**	**24**	**11**		**873**

Climate Variability

Climate variability concerns seasonal and annual variations in temperature and rainfall patterns within and between regions. Many factors come into play; important in this region are the wind circulation systems, seasonal pressure systems, the ITCZ and the strength and timing of its southward progression, sea temperatures – and especially the cyclical El Niño Southern Oscillation (ENSO) phenomenon.

Droughts and flooding, especially of major river flood plains, are common; southern Africa is characterized by considerable climatic variation, both spatially and temporally and this affects both low and high rainfall areas, more especially the latter.

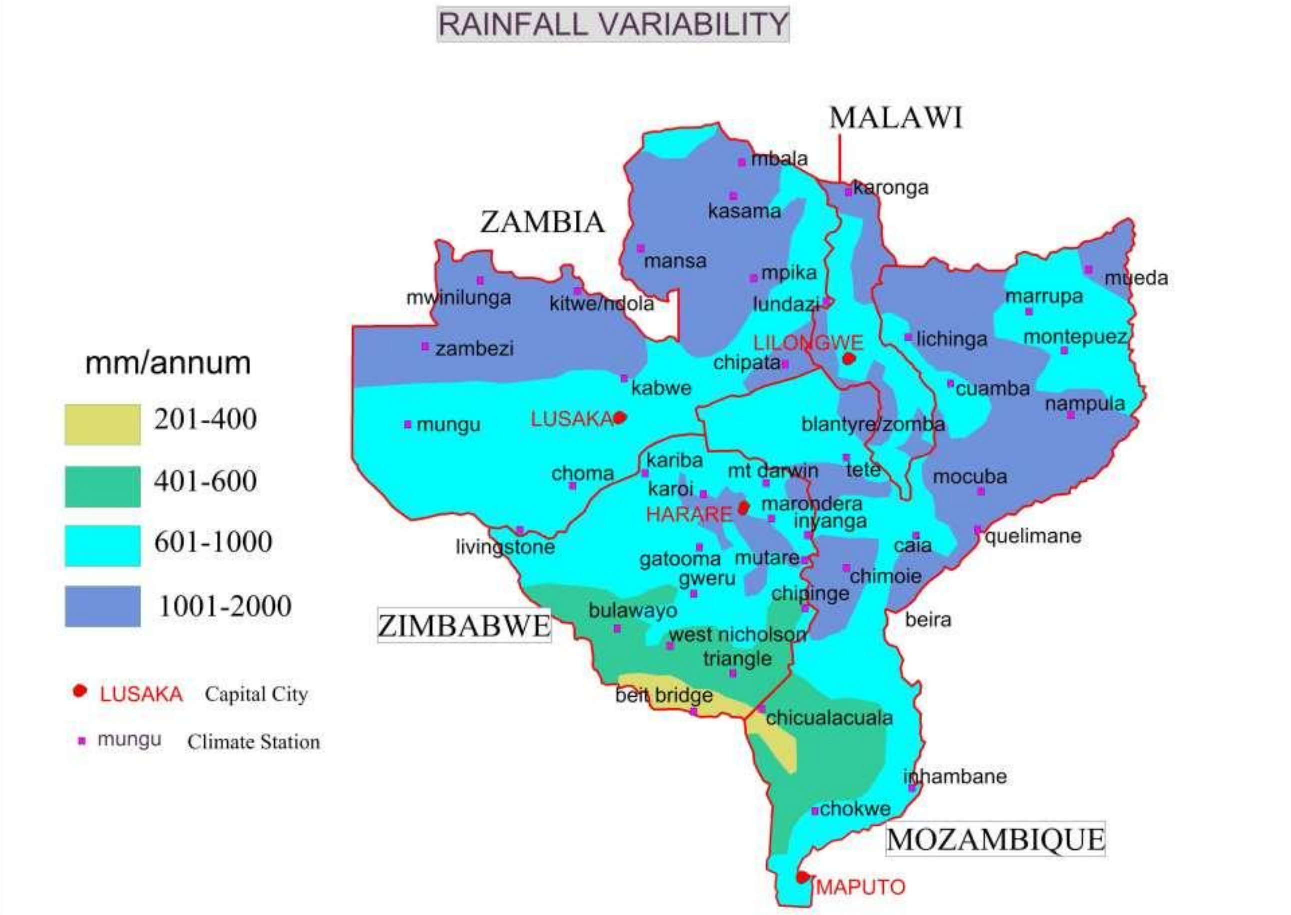
This can be seen to add a degree of uncertainty to ‘dry-land’ farming. However, farming practice throughout the world accepts weather-related risk as normal.

The figure below gives an indication of the long-term variability of rainfall in the study area (data records from over 80 years). The wide variation will have affected the natural vegetation and so influenced the Koppen approach to climatic zoning. However, this relatively short timescale (in comparison to global changes) may well not represent an equilibrium state.

The agro-ecological zones – which include the effects of other factors such as temperature fluctuations, soils etc, are an integration of these influences and crop suitability, for any particular area - are influenced by a combination of these limitations.

Most of the summer annual crops of commercial importance require between 500-700 mm of moisture; winter crops about half this amount. Considering the long-term average rainfall figures, it can be seen that most of the study area receives more than 600 mm, which can be considered a positive indicator for expanded commercial cropping. However, the temporal distribution of this rain has not been assessed. This may be problematical in some areas – particularly in regard to the affect of moisture stress on crop sensitive growth periods.

SOUTHERN AFRICAN STATES - CROPPING POTENTIAL SURVEY



APPENDIX D

References

1. AGRHYMET Network, (2001). Information Center, FAO Rome. http://www.agrhymet .
2. Agriculture and Food – Country profile – Malawi. World resource Institute website.
3. Aquastat – FAO Information System on Water and Agriculture, www.fao.org/nr/water/aquastat/dbases.
4. Archive of Soil Maps (EuDASM) - Soil Maps of Africa. EUR 21657 EN, 386 pp.
5. Bowen, Merle L. 2000. The State Against Peasantry. Rural Struggles in Colonial and Postcolonial Mozambique. Charlottesville, VA: University Press of Virginia.
6. Bot AJ, Nachtergaele FO and Young A, (2000). Land Resource Potential and Constraints at Regional and Country Levels. FAO 90, Rome.
7. Brady N and Weil RR, (1999). The Nature and Property of soils. Twelfth Edition, Prentice Hall International.
8. Chenje M and Johnson P (edit.). (1996). Water in Southern Africa (Report by SADC, IUCN and SARDC), ISBN 0-7974-1672-2
9. Eswaran H et al, (1996). An Assessment of the Soil Resources of Africa in Relation to Productivity, USDA Natural Resources Conservation Service, Washington DC.
10. FAO, 2005/2006. Database – Malawi (website http://apps.fao.org/)
11. FAO/UNESCO Soil Map of the World for Africa; Grid Version, UNEP/Grid-Geneva.
12. FitzPatrick EA, (1983). Soils, Their Formation, Classification and Distribution, Longmans Group Ltd. ISBN 0-582-30116-5
13. Green MJB and Paine J, (1997). State of the worlds protected areas at the end of the twentieth century, IUCN Commission on Protected Areas Symposium, Albany, Australia.
14. ISRIC depository of Africa maps at Wageningen in the Netherlands and Wikipedia relief maps (internet).
15. National Statistical Office, 2000. GoM, Lilongwe, Malawi
16. Peel, MC et al, (2007), Updated World Map of the Koppen-Geiger Climate Classification. Hydrology and Earth System Sciences, 11. 1633-1644, Copernicus Publications.
17. SEEPA, 2006. Climate change and African agriculture- Zambia. Policy note No.39.
18. Selvaradjou SK, Montanarella L, Spaargaren O and Dent D, (2005). European Digital
19. Smith M, Climwat for Cropwat, (1993). FAO Irrigation and Drainage Paper 49, FAO Rome.
20. The World Bank. 2000. World Development Report 2000/2001. Attacking Poverty. New York, N.Y.: Oxford University Press. The complete report is available on-line: http://worldbank.org/poverty/wdrpoverty/report/
21. UN System in Mozambique. 2000. Mozambique: District Development Profiles. http://www.unsystmmoz.org/
22. Van Heerden PS, Crosby CT et al, (2009). Integrating and upgrading of Sapwat and Planwat, Water Research Commission report no TT391/08.

23. Westerink RM, 1995. Potential rainfed crop production and land suitability for Mozambique. Nota tecnica No. 7. Do Instituto Nacional de Investigacao Agronomica.

24. Zulu, B. et.al. 2007. Smallholder household maize production and marketing behavior in Zambia and its influence on policy. Department of agricultural Economics, Michigan State University. http://www.aec.msu.edu/fs2/zambia/wp_22.pdf