AGROCLIMATIC CHARACTERIZATION OF LESOTHO FOR DRYLAND MAIZE PRODUCTION

By

Mokhele Edmond Moeletsi

Submitted in partial fulfillment of the requirements for the degree

of

Master of Science in Agriculture

in Agrometeorology

Department of Soil, Crop and Climate Sciences
Faculty of Natural and Agricultural Sciences
University of the Free State
Bloemfontein

Supervisor: Prof. Sue Walker
Co-Supervisor: Dr. Charles H. Barker

November 2004

DECLARATION

I hereby declare that this dissertation is my own work and to the best of my knowledge contains no work submitted previously as a dissertation or thesis for any degree at any other university. I further more cede copyright of the dissertation in favour of the University of the Free State.

Signed: ____

Mokhele Edmond Moeletsi

DEDICATION

This work is dedicated to my family especially, Ntate Ts'abalira Moeletsi, 'me Mamokhele Moeletsi, Seeiso, Ramoitoi and Makhate Moeletsi. Their love, encouragement and support has kept me going for my entire life.

ACKNOWLEDGEMENTS

Firstly I give thanks and praise to GOD for everything that happened in my life.

I would also like to convey my sincere gratitude and appreciation to the following:

- † I am very grateful to my supervisor Prof. S. Walker who guided this research with all the expertise, patience and constructive suggestions. Her professional comments, great knowledge of Agrometeorology and her love for all her students will never be forgotten.

- † Dr C.H. Barker my co-supervisor was very helpful with his positive comments and his contribution especially in the GIS part of the research has been enormous and I really thank him with all my heart.

- † I have to thank Mr B.T. Sekoli (Director of Lesotho Meteorological Services) to have introduced me to the world of Agrometeorology, his constant support, guidance and fatherly love have been helpful throughout my career as a meteorologist.

- † I would like to thank all the staff of the Lesotho Meteorological Services especially Mr Maletjane, Ms Phoofolo, Mr Togwane, Mrs Chapi, Mrs 'Neko and Mrs Leneea for all the data acquisition.

- † Dr H. Ogindo and Mr M. Girma (Agrometeorology students at the University of Free State) and Mr J. Van Den Berg (Envirovision – South Africa) for their assistance and constructive comments.

- † I thank Mr B. Siwela (SADC Remote Sensing Unit) and Mr L. Sekhokoana (Department of Soil Conservation, Lesotho) for providing digital Lesotho Map and digital elevation map respectively.

- † I pass my sincere gratitude to all my friends who have been supportive in all the years of my study.

- † Finally I thank the government of Lesotho for providing the funds for me to study.

Abstract

AGRO-CLIMATIC CHARECTERIZATION OF LESOTHO FOR DRYLAND MAIZE PRODUCTION

by

Mokhele Edmond Moeletsi
(MSc. in Agrometeorology, University of the Free State)

Agro-climatic characterization of Lesotho for dryland maize farming was performed using temperature and rainfall indices in a GIS environment. The temperature and rainfall meteorological parameters were patched for missing data using the UK method for the maximum and minimum temperatures. Missing daily rainfall data was patched using the inverse distance method. Statistical evaluation of the patching methods showed good performance. The spatial distributions of different temperature variables and indices were mapped. Important meteorological parameters were the frost occurrence (first day, last day and duration) and monthly and seasonal heat units. The onset of frost is early (March) over the highland areas while the low-lying areas onset can be as late as June. The last day of frost over the low-lying areas is mostly in August and on the other hand, the highlands last day of frost is in November/December at some places. Rainfall interpolation was done using the kriging method of the geostatistical analyst. Important aspects mapped include monthly averages, seasonal amounts, annual amounts and number of days of high daily rainfall. Wet season (October to April) rainfall was high (>800mm) over the north to northeastern parts of the country while some areas over the east and southern parts received less than 500mm of seasonal rainfall.

Climatic potential of maize under dryland farming in Lesotho was investigated using five climatic suitability indices namely: probability of receiving heat units of greater than 1500GDD, probability of a frost-free growing season, probability of seasonal rainfall of more than 500mm, probability of 15-day dry spells during December to February and the slope of an area. For each of the above parameters a coverage layer was prepared in GIS environment and the layers were overlaid to obtain the agroclimatic suitability map of maize in Lesotho. The districts of Butha Buthe, Leribe and Berea are shown to have areas which are highly favorable for maize cultivation under dryland farming while the unsuitable areas are mostly over the high-lying areas (Mokhotlong, Thaba Tseka and Qacha's Nek) together with other parts of the southern lowlands.

Keywords: Agro-climatic zoning, maize, climate, temperature, rainfall, patching of missing data, GIS, interpolation.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF SYMBOLS AND ABBREVIATIONS

AA	Arithmetic Averaging
Alt	Altitude
Aus BOM	Australian Bureau of Meteorology
ACE	Atmosphere, Climate and Environment
CDF	Cumulative Distribution Function
CSBSJ	College of Saint Benedict and Saint Johns
CSM	Closest Station Method
Dekad	Ten day period
$D_{\max}$	Maximum vertical distance between the hypothesized cumulative distribution function (CDF) and the empirical CDF
DD	Degree days
DEM	Digital Elevation Model
ECDF	Empirical Cumulative Distributions Function
ELEV	Elevation
ENSO	El Niño Southern Oscillation
FAO	Food and Agricultural Organization of United Nations
GDD	Growing Degree days
GA	Government of Alberta
GIS	Geographic Information System
IDW	Inverse Distance Weighting
IITA	International Institute of Tropical Africa
ITCZ	Inter-Tropical Convergence Zone

KS	Kolmogorov-Smirnov
LAI	Leaf Area Index
Lat	Latitude
LMS	Lesotho Meteorological Services
Lon	Longitude
MAE	Mean Absolute Error
MR	Multiple Regression
NR	Normal Ratio Method
O	Observed Value
P	Predicted Value
PAR	Photosynthetically Active Radiation
PODS	Probability of 15-day dry spell during December to February
POFF	Probability of a frost-free season from October to April
POHU	Probability of seasonal heat units of greater than 1500DD
POSR	Probability of seasonal rainfall of more than 500mm
RBF	Radial Basic Function
RMSE	Root Mean Square Error
RRSU	Regional Remote Sensing Unit
SADC	Southern African Development Community
SIB	Single Best Estimator
SST	Sea Surface Temperatures
UKMET	United Kingdom Meteorological Office
?	Probability value that denotes the significance level

Chapter 1 - Introduction

The agricultural productivity of a geographic area is dependent on many factors including inherent soil and terrain characteristics and climatic constraints (Liu and Samal, 2002) and these factors are interdependent and constantly evolving in time and space. Agro-climatic suitability studies of an area can help the farming community in making sound decisions on the crop selection for different localities. This research will focus on temperature and rainfall to identify suitable areas for the maize crop production in Lesotho.

Limitations in water resources, climate variability together with the increase in population motivate one to choose a useful land-use to optimize the use of the available natural resources (Antonie, 1996). Sustainable management of land resources requires sound policies and planning based on knowledge of these resources, the demands of the use to which the resources are put, and the interactions between land and land-use (Antonie, 1996). In order to achieve all this, climatic investigations are necessary (Yazdanpanah *et al.*, 2001). Climate is vital for the selection of correct crops for a given locality or site, the more detailed the knowledge, the more intelligently the land use can be planned on macro and on-farm scales according to Schulze *et al.* (1997). Climate largely determines which crops can be grown, where they are best grown, when they should be grown and the potential yields that may be expected (De Jager and Schulze, 1977). To improve food security around the country of Lesotho, it is of great importance to delineate the country into different zones according to the climatic requirements of a given crop in order that everyone (agronomist, agrometeorologists, extension workers, farmers, researchers etc) has a common goal of planting crops capable of succeeding in different areas of the country. For Lesotho it is impossible to increase financial returns by expanding cropped area as there is little available virgin land. Thus improvement can be attained by improving productivity of the available arable land by cultivation of crops with high potential in specific areas (Jayamaha, 1977). Therefore there is an urgent need for a comprehensive detailed study of the agro-climatological characteristics of the country and the agro-climatic zoning for maize as a staple food must be completed.

Zoning divides the area into smaller units based on distribution of soil, land surface and climate. The level of detail to which a zone is defined depends on the scale of the study, available data and sometimes on the power of the data processing facilities (Antoine, 1996). Agro-climatological zoning is defined as a division of a certain area into several zones, according to the degree of favourability for growing a given crop using climate factors (Todorov, 1981). As known, African farmers in the past used to grow most of their crops around their houses or huts. There was little or no trade of agricultural produce since people planted only for their own consumption. Gradually people began to realize that it was better for a farmer to grow agricultural crops for which suitable climatic conditions exist, and to exchange the excess of his produce with farmers from neighbouring areas with different climate. Thus, gradually certain zoning of agricultural crops has come into being Todorov (1981). The agro-climatological zoning of a crop passes through three main stages which are (1) Studies of the agro-climatological requirements of the crop, (2) Studies of the existing agro-climatological conditions in the area and (3) Studies of the extent of satisfaction of the crop's requirements (Yazdanpanah et al., 2001).

Maize (*Zea mays L*) is a warm climate plant and is grown over a wide range of climatic conditions. It is a fast growing crop that yields best with moderate temperatures and plentiful supply of water (Aldrich *et al.*, 1978). Some cultivars are only very short in height, others up to 6 to 8m in height; some have a very short growing season 60 to 70 days to maturity, others grow for a longer season over 200 days depending on the variety and climate of the place (Sprague and Dudley, 1988). It is a crop cultivated by many countries and in the widest range of environments going from below sea level to well over 2600m in the Africa and the Andean highlands (Frere, 1977). Based on the land area devoted to the crop, maize is the third most important crop utilized by man and the leading producers of the crop are: USA, Germany, North Italy, North China, Argentina and Brazil (Martin, 1989). The bulk of the maize crop is grown in the climatic regions transitional between marine and continental, and is mostly grown between latitudes 30° and 55° but principally in latitudes below 47° (Sprague, 1955).

Maize is the most important cereal crop in sub-Saharan Africa, the other most important cereals are rice and wheat. Maize is high yielding, easy to process, readily digested, and costs less than other cereals (IITA, 2002). It is one of the most important cereals both for human and animal consumption and is grown for grain and forage (Doorenbos and Kassam, 1988). In industrialized countries maize is largely used as livestock feed and as a raw material for industrial products, while in low-income countries it is mainly used for human consumption. In sub-Saharan Africa, maize is a staple food for over 50% of the population. In Lesotho maize is the staple food for almost all the country's population and it is mostly planted by subsistence farmers under dryland farming. It is an important source of carbohydrate, protein, iron, vitamin B, and minerals (IITA, 2002).

According to FAO data, 592 million tonnes of maize were produced worldwide in 2000, on 138 million hectares (see Table 1.1 and Table 1.2). The United States was the largest maize producer (43% of world production) followed by Asia (25%) and Latin America and the Caribbean (13%). Africa only produced 7% of the world's maize (IITA, 2002). The world average yield in 2000 was 4,255 kg per hectare. Average yield in the USA was 8600 kg per hectare, while in sub-Saharan Africa it was 1316 kg per hectare (IITA, 2002). The present world production (2003) is about 635 million tons of grain from about 141 million ha (FAOSTAT, 2003) (Table 1.2). Lesotho maize production for 2003 was estimated to be 150,000 tons from the area of around 180,000ha with the average yield of 0.8tons/ha. This value is very low compared to the South Africa's yield of around 2.9tons/ha.

Table 1.1 Maize production (tons) for the whole world, Africa, SADC, South Africa and Lesotho (Source: FAOSTAT)

Region	**1999**	**2000**	**2001**	**2002**	**2003**
World	607,436,528	592,654,010	614,751,705	604,407,521	635,708,696
Africa	42,352,470	44,350,365	41,311,744	43,292,967	44,492,035
SADC	18,352,950	22,355,187	17,067,929	19,002,894	19,147,549
South Africa	7,946,000	11,431,183	7,748,124	10,049,134	9,714,254
Lesotho	124,549	158,189	102,700	150,000	150,000

Table 1.2 Area (ha) planted to maize for the whole world, Africa, SADC, South Africa and Lesotho (Source: FAOSTAT)

Region	1999	2000	2001	2002	2003
World	138,829,369	138,248,324	139,081,441	137,830,111	141,151,308
Africa	25,876,294	25,776,863	25,606,569	26,530,159	26,767,859
SADC	12,322,920	12,618,667	11,614,496	12,028,294	12,322,038
South Africa	3,567,383	3,813,840	3,223,220	3,349,660	3,350,000
Lesotho	132,360	187,057	130,300	180,000	180,000

1.2 Study area

Lesotho is located in Southern Africa (Fig 1.1) between 28° and 31° south of the equator and 27° and 30° east of the Greenwich meridian and the country is situated at the highest part of the Drakensberg escarpment with altitude ranging from 1,500m to 3,482m above the sea level (Fig 1.2) (Chakela, 1999). Although, the climate of Lesotho is classified as temperate, it has been described as better for people than for crops due to the semi-arid conditions and atmospheric hazards that causes major constraint to agricultural production and development (Wilken, 1978; Chakela, 1999).

The climate of Southern Africa is very much governed by its geographical location and thereby its position in relation to the general circulation of the atmosphere (Hyden, 1996). The country of Lesotho's climate is greatly affected by orography. Topographical features influence the climate in many ways; winds are deflected and lifted by orographic features thus affecting rainfall, temperature and the moisture content of air masses. Lesotho is within the sub-tropical high pressure zone in which the basic air circulation is anticyclonic (Hyden, 1996). In winter, mid-latitude polar cyclones result in frontal type weather with low temperatures, some precipitation and strong winds in the west and southwest, and heavy snow falls at higher altitudes in the highlands (LMS, 2000). In summer, the southward movement of the intertropical convergence zone (ITCZ) allows an inflow of moist air of tropical origin, producing 85% of the country's total annual rainfall.

The average annual rainfall varies from area to area from as low as 500mm in the Senqu River Valley to as high as 1200mm in a few localities in the northern and eastern border. Most of the rainfall comes in the seven-month period from October to April and rainfall peaks from December to February when most of the country record over 100mm per month. The lowest rainfall occurs in June and July when the monthly totals of less than 10mm are recorded at most stations (LMS, 2000). Temperatures are highly variable, on diurnal, monthly and annual time scales. Normal monthly winter minimum temperatures range from –6.3°C in the highlands to 5.1°C in the lowlands. However extremes of monthly mean winter minimum temperatures of -10.7°C can be reached, and daily winter minimum temperatures can drop as low as -21°C at few places over the highlands. Sub-zero daily minimum temperatures can be reached even in summer both in the lowlands and in the highlands (LMS, 2000). January records the highest mean maximum temperatures throughout the country, ranging from 16.5°C at high altitudes to 29°C in the lowlands. On the other hand, mean minimum temperatures of around 0°C are common in June, the coldest month, with the lowlands recording the monthly mean temperatures ranging from -3°C to -1°C and ranging from -8.5°C to -6°C in the highlands (LMS, 2000).

The country has been divided into four agro-ecological zones (Fig. 1.2); the lowlands have elevation ranges of 1400m to 1800m, the foothills with elevations of 1800m to 2000m, the Senqu River Valley with elevations of 1400m to 1800m and the mountainous area (Highlands) occurring at the elevation of 2000m – 3400m (LMS, 1999). Apart from the limitations caused by the weather and climatic conditions only around 15% of the country is arable and the rest is composed of rocky land as well as steep slopes (Jayamaha, 1977). The mountain region of the country covers 70% of the surface and it extends from the central area and reaches the highest altitude in southern Africa in the north east. According to Jayamaha (1977), the main agricultural activities in the country (about 75%) are confined to a narrow belt, the 'lowlands' which extends along the western boundary of Lesotho from north to south and the southeast where the general elevation is of the order of 1500m to 1700m above sea level. Agricultural operations are also pursued on a limited scale along the foothills but little to no agricultural activity on a large scale is conducted at the higher elevations beyond the foothills (Jayamaha, 1977).

Fig 1.1 Southern Africa map showing the geographical position of Lesotho in relation to South African provinces and other neighbouring countries. Source: Department of Geography, University of Free State, Bloemfontein

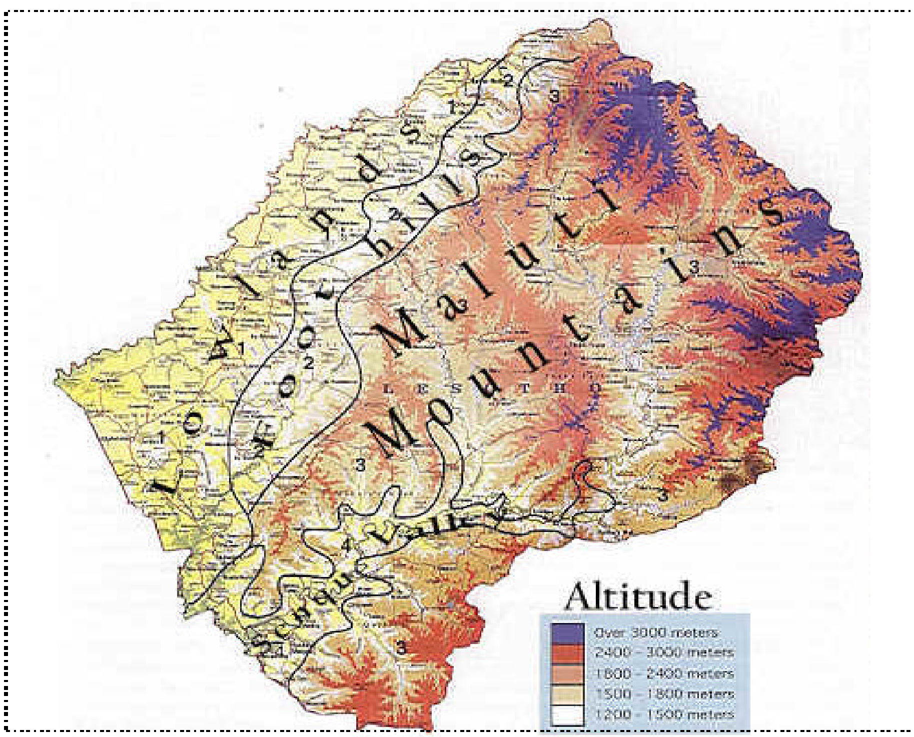


Fig 1.2 Lesotho agro-ecological map showing the highlands, foothills, Senqu River Valley and lowlands. Source: (LMS, 2000)

1.3 Objectives

This research is concerned with the spatial interpolation of meteorological data as a preliminary step prior to use in the climatic zoning as layers in a GIS. To fully complete the process of the zoning, different indices have to be developed depending on the requirements of the crop (Joerin *et al.*, 2001). For each of the indices a coverage layer should be prepared using interpolation techniques in a GIS environment. In the second stage, coverage layers are overlayed to obtaining an agro-climatic map of an area. The final agro-climatic suitability map will be reclassed to highly favourable, favourable, weak and not suitable area (Yazdanpanah *et al.,* 2001). The main goal of this research is to delineate the suitable areas for the maize crop within a GIS context, using climate indices. Although the maize crop has certain requirements for all meteorological elements, temperature and precipitation are of greatest importance and therefore the study will concentrate on them.

The main objectives of the study are:

1) To patch missing rainfall and temperature data using scientifically approved methods.

2) To characterize agro-climatology of Lesotho taking into consideration mainly rainfall and temperature variability.

3) To classify the country of Lesotho into several zones according to the climatic potential of maize grown under dryland farming.

Chapter 2 – Literature Review

2.1 Climate

Climate is the composite of all the many varied, day-to-day weather conditions in a region over a considerable time (Buckle, 1996; UKMET, undated). This time period should ideally be long enough to establish relevant statistical information necessary to describe the variations in a region's weather (Buckle, 1996; Schulze *et al.*, 1997). Kendrew (1949) as quoted by Schulze *et al.* (1997) described climate as more than average weather for it includes the dynamic and intricate variations occurring diurnally, daily, monthly, seasonally and annually and also includes evaluations of extreme events and the variability about the mean. According to Holden and Brereton (2004), climate also includes concepts of probabilities of occurrence of specific events (e.g frosts, specific winds etc). Climate is determined by three key factors: the amount of energy the climatic system receives from the sun; the way in which this energy is distributed throughout the system and the degree of interaction between the various components of the system (Buckle, 1996). Climate of a place on earth is controlled first by the region's location with respect to the major pressure belts and prevailing wind systems of the general global circulation. The general global circulation is mostly responsible for the distribution of the main climatic belts. The hot and dry climate in the subtropics corresponds to the descending limbs of the Hadley circulation (Schulze, 1965; Buckle, 1996). The second influence on a region's climate is the modifications to the general circulation that results from conditions at the surface. This include it's position relative to the distribution of land and sea and the height of the location above sea level, vegetation cover, the general nature of the surface (soil type, water, snow, ice) and orientation relative to hills or mountains (Schulze, 1965; Buckle, 1996).

The worldwide system of winds, which transports energy, moisture, momentum and mass, is called the general circulation of the atmosphere, and it gives rise to the Earth's climate zones (ACE, undated; Buckle, 1996). For example, warm air from the equator where solar heating is greatest moves towards the higher latitudes, without such latitudinal redistribution of heat, the equator would be much hotter than it is whilst the poles would be much colder. The general circulation of air is broken up into a number of cells, the most common of which is called the Hadley cell (Fig 2.1). Solar radiation is strongest nearer the equator. Air heated there rises and spreads out north and south. After cooling the air sinks back to the Earth's surface within the sub-tropical climate zone between latitudes 25° and 40° (ACE, undated; Buckle, 1996; Hyden, 1996). Located at the descending limb are Sub-tropical High Pressure Belts that dictate surface wind patterns and also influence rainfall and temperature regimes on the continent. Consequently, many of the world's desert climates can be found in the sub-tropical climate zone. Surface air from sub-tropical regions returns towards the equator to replace the rising air, so completing the cycle of air circulation within the Hadley cell (ACE, undated).

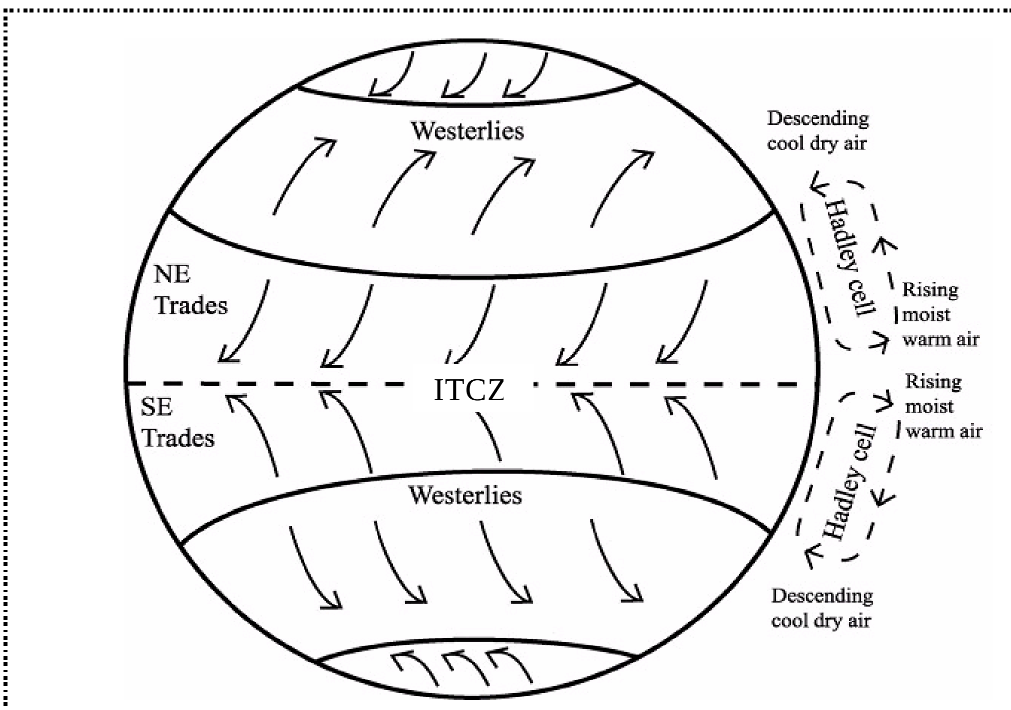


Fig 2.1 Hadley cells and the global wind systems showing the movement of air around the globe (Source :California State Institute)

The Sub-tropical High Pressure Systems on both sides of the Equator generate two wind systems that converge on the equator in a zone termed Inter-Tropical Convergence Zone (ITCZ). ITCZ is an area of low atmospheric pressure, which is generally marked by a band of cumulonimbus clouds over the ocean, formed by the rapid upward convection of moist air (Hyden, 1996). The ITCZ shifts with the seasonal movement of the sun across the tropics, In June, in the southern hemisphere winter season, the ITCZ is located few degrees north of the equator while in December: southern hemisphere summer season, the ITCZ is located south of the equator. ITCZ affects the distribution of rainfall and climatic zones (Hobbs *et al.,* 1998; Hyden, 1996).

2.2 Climate and crops

Knowledge of climatology is an invaluable aid in the agricultural development and planning of a region and climate and weather are key factors in agricultural production (De Jager and Schulze, 1977; Jones and Thornton, 2000). In some cases, it has been stated that as much as 80% of the variability of agricultural production is due to the variability in weather conditions, especially for rainfed production systems (Hoogenboom, 2000). Climate is one of the most important limiting factors for agricultural production: frost risk during the growing period and low and irregular precipitation with high risks of drought during the growing period, are common problems in agriculture (Moonen *et al.,* 2002). The critical agrometeorological variables associated with agricultural production are precipitation, air temperature and solar radiation (Hoogenboom, 2000). Because of the influence of temperature, precipitation, frost-free days, and growing degree-days on crop growth, long-term data on climatic variables are needed to predict which crops might be suitable (Young *et al*., 2000). For example, they influence what crops can be grown in a region, the annual variation in crop and pasture production, and the amount of water available for livestock. Interrelations between climatic factors and crop characteristics are an important part of agro-climatological zoning. By relating and comparing the agro-climatological requirements of the crop with the existing agro-climatic conditions in an area, one can find the extent to which the requirements are satisfied during the different phases of the crop's development (Todorov, 1981).

Solar radiation provides the energy for the processes that drive photosynthesis, affecting carbohydrate partitioning and biomass growth of the individual plant components (Hoogenboom, 2000). FAO (1978) states that, photosynthesis produces the source of assimilates which plants use for growth. Furthermore, plants have an obligatory developmental pattern in time (and space) which must be met if the photosynthetic assimilates are to be converted into economically useful yields of satisfactory quantity and quality. This developmental sequence of crop growth in relation to the calendar (i.e. crop phenology) is influenced by climatic factors. Duration of solar radiation is one of the important environment factors for maize growth and development, for the individual leaves as well as the entire canopy (Hatfield, 1977). Some crops are very sensitive to the length of day. Short-day plants would flower only when exposed to short periods of radiation while long–day plants flower only when exposed to long periods of light, without interuption. Some plants are day neutral; that is, flowering is not regulated by photoperiod. Photoperiodism also explains why some plant species can be grown only at certain latitudes (Gardner *et al.,* 1985).

In general, temperature determines the rate of growth and development; but in some crops temperature may also determine whether a particular developmental process will begin or not (e.g. chilling requirement for initiating flower buds in Pyrethrum), the time when it will begin, subsequent rate of development and the time when the process stops (FAO, 1978). It is not temperature alone that is sufficient but precipitation must also be taken into account since the magnitude and seasonal variation of either or both can limit the growth and development of crops (ICRISAT, 1980). The temperature regime is a key factor in maize adaptation and the use of the accumulated heat units (growing degree days) is of great importance (Crane *et al.,* 1977). In the equatorial and tropical regions (FAO, 1978) where temperatures are high and uniform throughout the year, soil water availability is the sole determining factor, while in the higher latitudes where water use is low due to low temperatures, the actual temperature may limit the growing season for crops. In the tropics and equatorial regions, evapotranspiration is high and thus more water is lost to the atmosphere while at the higher latitudes there is less evaporation, but in the regions within the sub-tropical high pressure zone soil water availability coupled with temperatures determines the success of the crops. Most methods of accumulating temperature in the form of day-degree are based on air temperature, but during the early stages of growth when the apical meristem is below or close to the soil surface, it is the temperature of the soil which is more important and differences of 1°C at 5cm depth can induce large changes in the early stages of the growth of crops (Milbourn and Carr, 1977).

Precipitation does not directly control any of the plant processes. It is considered to be a modifier, that indirectly affects many of the plant growth and developmental processes. In the agro-climatological evaluation of rainfall, the most important considerations are the stability of agricultural water resources, the water requirements of agricultural plants and the identification and prediction of various agriculturally significant rainfall characteristics (Green, 1966). Drought occurs during periods of insufficient rainfall, while water-logging occurs during periods of extensive rainfall (Hoogenboom, 2000). Drought can cause an increase or decrease in developmental rates, depending on the stage of development. In many cases, the response to drought stress is also a function of species or cultivar, as some species or cultivars are more drought-tolerant than others. Drought can also reduce gross carbon assimilation through stomatal closure, causing a modification of biomass partitioning to the different plant components (Hoogenboom, 2000). Water-logging stress is caused by flooding or intense rainfall events causing a lack of oxygen in the rooting zone, which is required for root growth and respiration. A decrease in oxygen content in the soil can result in a decrease in root activities, causing increase in root senescence and root death rates. The overall effect of water-logging is a reduction in water uptake; the ultimate impact is similar to the drought stress effects (Lauer, 1998; Hoogenboom, 2000).

Other weather factors that can affect crop production include soil temperature, wind, and relative humidity or dewpoint temperature. In many regions, soil temperature is important during the early part of the growing season, as it affects planting and germination. For winter crops, such as winter wheat, the soil temperature can also affect vernalization (Hoogenboom, 2000). Relative humidity, dewpoint temperature or vapor pressure deficit are similar agrometeorological factors, that express the amount of moisture present in the air. They affect transpiration and the amount of water lost by the canopy, causing drought stress under water-limited conditions. At harvest or maturity, both air and dewpoint temperature affect the dry down time of the harvestable product. Wind can also have multiple impacts on crop production. First of all, it can affect the rate of transpirational water loss by the leaves. In addition, it can affect the transport and the distribution of insects and diseases in the atmosphere, and subsequent presence in the plant canopy. Extreme wind can also affect the potential for lodging, especially for tall crops (Hoogenboom, 2000).

Microclimates influence crop growth and development (Bishnoi, 1989). For example, winds delay flower fertilization, slow down growth and causes frosty conditions. According to Bishnoi (1989), winds are also a strong factor in the spread of insects and diseases like rust and aphids. Microclimatic conditions may further generate specific problems due to topographic, physical and physiographic conditions of the region making it necessary to further delineate into areas with specific problems for agro-climatic exploitation.

2.3 Agro-climatological Descriptions

2.3.1 Growing season

The growing season is the period of time each year during which perennial crops such as pastures and forages and annual crops on the whole can grow (GA, 2003). The growing season is different for different species. It depends on water, temperature and radiation conditions (Hakanson and Boulion, 2001). White *et al.* (2001) described the length of the growing period as the time available when water and temperature permit plant growth, based on estimates of available soil water. The growing season is not necessarily the frost-free period, but for a particular plant which has the lower threshold of 0°C, its growing season corresponds to frost-free period. It is important to determine the growing season of an area or station so as to investigate whether it can match the optimum growing period of a particular crop. Caldiz *et al.* (2001) used the temperature constraints for the identification of the potential growing seasons and length of growing period for potatoes in Argentina. The growing season or period is sometimes referred to as the rainy season. When rainfall is the main constraint for agricultural production, the rainy season can be considered as the growing season. The rainy season's start and its duration have been previously investigated for agricultural, botanical, and ecological purposes: to define the effective time to plant, to estimate the growing season's length, germination and seedling emergence (Benoit, 1977). When using rainfall to define the growing season, a long dry spell after the start of the rains causes a "false start" (Veenendaal *et al.*, 1996).

2.3.2 Frost

The greatest agricultural risk in connection with low temperatures is frost, which can cause severe destruction of fruit, vegetables and crops. The sensitivity of a crop to low temperatures depends on many factors; including the severity of the temperature drop and length of time the cold persists. Plant species differ greatly in their susceptibility to chilling injury (Teitel *et al.*, 1996).

Normally two types of frost situations can be distinguished, radiation and advective frost. Advection frost occurs during situations where cold air intrudes into an area. This results in the lowest temperatures at the elevated sites. Radiation frost on the other hand, occurs on clear nights when a large amount of heat is radiated towards the sky, and its occurrence is generally patchy (Lindkvist *et al.*, 2000; Teitel *et al.*, 1996). The damage due to radiation frost differs from that due to advection frost mainly in its degree. Usually, plants that would be killed by advection frost are usually only partially damaged by radiation frost (Critchfield, 1966). Prevention of crop damage due to radiation frost is more feasible than advection frost. During radiation frost, only a thin layer of air immediately above the ground is cooled while the overlaying layers are warmer (Rosenberg *et al.*, 1983; Oke, 1987).

One way of estimating the local frost risk for a specific location is by accumulating the number of occurrence with temperatures below 0°C. Calculations of frost sum and coldness sum (cold units) below a certain threshold value are commonly used methods for quantifying the frost risk at different areas (Lindkvist *et al.*, 2000). The frost-free period is the number of days between the last date of 0°C in the spring and the first date of 0°C in autumn. It provides a measure of the period during which plant growth can occur uninterrupted by frost, and it provides a way to compare growing conditions. The first frost date is the date when the air temperature drops to 0°C. Although the screen temperature is used to estimate frost dates, the difference between the air temperature at screen level and at crop level does not generally create large discrepancies in determining the frost-free period for most crops. Actual frost damage depends on the temperature, crop type and crop condition (GA, 2003).

2.3.3 Dry spells

Semi-arid regions (including Lesotho) are characterised by dry weather spells. Occasionally these reach exceptional proportions which seriously disadvantage farming activities and require special agricultural planning strategies and management decisions (De Jager *et al.*, 1998). Although the definition of a dry spell may vary, depending on the aims and methodology used in each study, it generally refers to number of days without appreciable precipitation. A crucial aspect in this is the definition of a significant rainfall threshold in the typification of a dry day. Lazaro *et al.* (2001) employed a threshold of 1 mm, since rainfall less than this amount is usually evaporated off the surface.

2.3.4 Wet spells

The length of a wet spell is defined as the consecutive number of days with a significant rainfall. The minimum length of a wet spell is taken as one day (Herath and Ratnayake, 2004). Sharma (1996) defined a wet day as a day with rainfall of more than zero and the probability of occurrence of a wet day depends on the climatic system of a place or region. Wet spells are an inherent property of climate, and depending upon their durations and the rainfall associated with them, they can have distinct advantages as well as disadvantages (Mwangala, 2003). For instance, in agriculture, wet spells of relatively short duration, typically not exceeding 3 days with light to moderate rainfall, can be very conducive to crop growth. However, if the spells are long, crop damage can easily occur as a result of water-logging in the soil or even flooding (Mwangala, 2003).

2.3.5 Water stress

Soil water stress will occur if there is not a balance between the atmospheric demand for water and supply of water available in the soil (Shaw, 1977). Soil water availability is determined by the interaction of four factors: (1) amount of water present in the soil, (2) characteristics of the soil profile, (3) water requirements of the crop and (4) demand for water by the atmosphere (Shaw and Newman, 1991; Hoogenboom, 2000). Atmospheric demand is a function of the energy available (solar radiation), movement of water away from the evaporating surface (wind), dryness of the air (humidity), and air temperature or sensible heat level (Shaw and Newman, 1991). For crop water to be adequate, the available soil water must be more than sufficient to meet the atmospheric evaporative demand. On windy, hot, sunny days with low humidity, for instance, evaporation demand on a crop is high; and thus, a high amount of available soil water must be present if the crop is to avoid stress. Under cloudy skies, high humidity and cooler temperatures, on the other hand, atmospheric evaporative demand will be lower. Less water is needed to meet the demand, thus, plants can survive with lower amounts of available soil water (Shaw and Newman, 1991).

2.3.6 Growing degree days/Heat units

A degree day is the difference between the average temperature for a day and some base temperature. Growing degree days (GDD) are used to match crop requirements for heat to the amount of heat available. The base temperature for calculating growing degree days is the minimum threshold temperature at which plant growth starts (GA, 2003). Temperatures that are cooler than normal result in slower rate of development. If the average daily temperature is below the base temperature, the growing degree day value equals zero. Negative values are not calculated because the crop is not set back by a temperature lower than the base temperature. The calculation of growing degree days assumes that plant growth is related directly to temperature when there are no other limitations. The growing degree days is calculated from the minimum and maximum temperatures. The following formula is used for obtaining growing degree days for maize (McMaster and Wilhelm, 1997):-

$$GDD = \left[\frac{(T_{MAX} + T_{MIN})}{2} \right] - T_{BASE}$$

Where T_{MAX} and T_{MIN} are daily maximum temperatures and minimum temperatures respectively. T_{BASE} = 10°C (for maize) is the base threshold temperature.

2.4 Maize

The origin of maize remains uncertain, although it is generally agreed that its evolution into the modern forms took place primarily in Central America (Rouanet, 1987). It is assumed that maize was discovered by Christopher Columbus on the Bahamian island of San Salvador on the October 12, 1492 (Mangelsdorf, 1974). But Rouanet (1987) further suggested that maize was grown by the Indians around 5000 BC. There are a lot of theories (e.g. The pod-maize theory states that cultivated maize has been derived from a wild form of pod maize and the Teosinte theory states that Teosinte [an ancient and still flourishing wild grass from Mexico and Guatemala] is an ancestor of maize) that have been put forward regarding the evolution of maize into the present form (Rouanet, 1987; Mangelsdorf, 1974). Even in that remote past (Saunders, 1930), it constituted a staple article of food and it was held in such a high esteem by its earliest growers that it was regarded by them as a gift of the gods and played a prominent part in their religious life; so much so that the work of planting and harvesting was frequently attended with elaborate ceremony so that the gods might grant a bounteous yield. But the rapid spread of maize throughout the world was attributed to the navigators of the sixteenth and seventeenth centuries (Rouanet, 1987). Its presence in the Mediterranean, Asia and Gulf of Guinea was noted as early as the sixteenth century, and in the heart of Africa, in the seventeenth century (Rouanet, 1987). According to Saunders (1930), maize reached South Africa after the arrival of the first Dutch colonists when sent from Amsterdam on 25th October 1655.

2.4.1 Temperatures requirements

The rate of growth and development of crops from planting to maturity is dependent mainly upon temperature. Maize is a crop with a rapid growth rate that yields best under moderate to warm temperatures. Cool temperatures slow down the progress to maturity and high temperatures hasten maturity (Brown, 1997). Each plant and animal has its own specific optimum temperature for growth and a temperature range in which it thrives. Once temperatures outside this range are encountered, the animal or plant suffers and growth slows (GA, 2003). Temperature (soil and air) during the growing period is the single most important environmental factor controlling maize development.

2.4.1.1 Germination

Before germination, the seed absorbs water and swells. The ideal temperature requirement for germination is from 16°C to 32°C (Rouanet, 1987). According to Sprague and Dudley (1988), optimum germination and emergence occurs when temperatures reach 20 to 22°C. Germination proceeds faster at higher temperatures assuming that water is available (Sprague, 1955). Germination will be slow in dry soil, but will speed up as soil water increases until saturation is reached. For germination, the lowest mean daily temperature is about 10°C (Doorenbos and Kassam, 1988). Maize also requires the soil temperature at seed depth to be favourable for seedling growth. Minimum soil temperatures of 10 to 13°C are required for maize germination and seedling growth. Cooler temperatures alone are not likely to impose a stress on the seedling, but only delay its emergence. According Wallace and Bressman (1937), maize usually emerges in 8 to 10 days at an average temperature of 16 to 18°C, but it takes longer (18 to 20 days) at 10 to 13°C. If the soil is wet enough and at an average temperature of 21°C, emergence may occur in 5 to 6 days. Even frost and freezing temperatures should not cause a problem during pre-emergence (Shaw and Newman, 1991). But wet weather together with cold temperatures following planting will favour development and activity of some soil pathogens that can produce disease stress in the young seedling (Shaw and Newman, 1991).

2.4.1.2 Early vegetative growth

Young maize plants are relatively resistant to cold weather (Sprague and Dudley, 1988; Lacey and Roe, 2001). From emergence to stage V6 (when six leaves have fully emerged), the growing point is below the soil surface and therefore recovery from moderate freeze is rapid and almost complete according to Ritchie *et al*., (1986). But later on, low temperatures will kill the plants whose growing point is at or above the soil surface (V8 stage or later). Air temperatures during the early vegetative stages should be around 25 to 35°C, which is considered optimum for rapid leaf growth (Sprague and Dudley, 1988). Growth during the early vegetative stage has been related to soil temperatures. Dry matter production in maize plants is greatest when average daily soil temperature at the 10-cm depth is about 27°C (Shaw and Newman, 1991).

2.4.1.3 Late vegetative growth

Relationships between weather and yield are more significant in the late vegetative growth stages i.e., the 3 to 4 week period up to silking (Shaw and Newman, 1991; Sprague and Dudley, 1988). Temperatures of around 24°C during late vegetative stage result in yields near normal (Sprague and Dudley, 1988). The optimum temperatures for this period ranges from 21°C to 33°C. If temperatures above 33°C are experienced, water stress may also occur. Under this dual soil water-temperature stress condition, vegetative growth will be reduced (Shaw and Newman, 1991).

2.4.1.4 Tasselling, silking and pollination

This is the most critical stage in maize development for any type of stress to occur. Combined soil water-temperature stress during the reproductive period can substantially reduce final grain yield (Shaw and Newman, 1991). Although separating the effects of these two stresses is difficult, most temperature stress conditions occur on high atmospheric-water-demand days i.e., days when the daily mean temperature is above 25°C and the daily maximum is above 35°C, regardless of soil water conditions (Lacey and Roe, 2001; Shaw and Newman, 1991). Wallace and Bressman (1937) reported that the 115-day cultivar took 74 days from planting to tasseling with an average temperature of 20°C, but only 54 days with an average temperature near 23°C and thus, the higher the temperature the shorter the phenological period (see also heat units). Cool nights reduce the rate of growth before tasseling (Sprague and Dudley, 1988).

2.4.1.5 Grain-filling to maturity

For this period, the optimum minimum temperatures range is from 6°C to 21°C and the maximum temperatures from 18°C to 33°C. As seen from the wider range in this period, it is apparent that temperature has less influence on development and growth than in the previous stages (Brown, 1977). It has been well established that the longer the grain-filling period the higher the grain yields provided frost doesn't kill the plant before the kernels are filled. Thus cool temperatures help to prolong the sub-periods of development and boost yields (Brown, 1977).

2.4.2 Heat requirements

Since 1730 when Reaumur introduced the concept of heat units, or thermal time, many methods of calculating heat units have been used successfully in the agricultural sciences (McMaster and Wilhelm, 1997). Particularly in the areas of crop phenology and development, the concept of heat units has vastly improved description and prediction of phenological events compared to other approaches such as time of the year or number of days (Bloc and Gouet, 1977; Bootsma, 1977). Accumulated heat is the most important environmental factor to the growth rate of the maize plant (McMaster and Wilhelm, 1997). This includes the development of the roots, stem and leaves. The plant cannot develop from one stage to another without receiving the necessary heat units (Pannar, 2002a). The maize plant can be regarded as a starch factory. The plant utilizes water and nutrients from the soil, carbon dioxide from the atmosphere and solar radiation as the energy source to manufacture plant food of which starch is the main component. In this process heat in the atmosphere play an essential role in determining the final yield and quality of the grain (Pannar, 2002a). According to Schulze *et al.* (1997), 1500 to 1700GDD are required for growing maize for grain, but can vary according to cultivar.

2.4.3 Water requirements

Production of any agricultural crop is dependent upon an available supply of water during the growing season (Pierre *et al*., 1966). Each crop has a characteristic water use pattern throughout the season which is largely determined by the stages of the development of the plant. On the whole water use is minimal during germination and early growth of seedling and increases during the vegetative stage and is maximum during flowering to grain filling stage and decreases at maturity. The absolute amount is also a function of the seasonal demand pattern of the atmosphere, i.e. physical factors which cause evapotranspiration (Pierre *et al*., 1966; Shaw, 1977). Maize is an efficient user of water in terms of total dry matter production and among cereals it is potentially the highest yielding grain crop (Doorenbos and Kassam, 1988). For maximum production a medium maturity grain crop requires between 500 to 800mm of water depending on the climate of the area (Doorenbos and Kassam, 1988). According to Sprague and Dudley (1988), maize can be grown in areas where the annual precipitation ranges from 250mm to over 5000mm. But Nield and Newman (1990) reported that, under dryland farming, maize is generally not grown in areas receiving less than 600mm of annual precipitation. Stone *et al.* (1996) reports the maximum crop water use for maize as being around 600mm. According to studies by Du Plessis (2003) in South Africa, maize needs 450 to 600 mm of water per season.

Water stress occurring during different development stages of maize may reduce final grain yield to different degrees, and the extent of yield reduction depends not only on the severity of the stress, but also on the stage of the plant development (Zaidi *et al*., 2003; Cakir, 2004). Doorenbos and Kassam (1988) have reported that maize appears to be relatively tolerant to water deficits during the vegetative and ripening periods, and that the greatest decrease in grain yields is caused by water deficit in the soil profile during the flowering period (Zaidi *et al*., 2004; Cakir, 2004). For potential yields, adequate water should be available during the growing season (Neild and Newman, 1990).

2.4.3.1 Before planting

The influence of weather on the maize plant starts even before planting. Conditions before planting are especially important in determining the soil water reserves (Neild and Newman, 1990). These can reflected from a carryover from the previous cropping season or can be from accumulations that may occur during fallow period (Sprague and Dudley, 1988; Neild and Newman, 1990). Since evaporation rates in winter are low, precipitation during this time may be quite efficient for increasing soil-water reserves. This is the case with Lesotho especially over some of the high-lying areas. Early spring precipitation also can be quite effective in increasing the reserves, although the evaporation potential also increases as the spring progresses. The lower the soil water reserve, the greater the crop season rainfall requirements according to Sprague and Dudley (1988), due to soil water balance.

2.4.3.2 Planting to emergence

A maize seed placed in a wet soil at the right temperatures starts to swell by absorbing water (Rouanet, 1987). Adequate rainfall or water is very important during germination. Rainfall of 25mm should normally ensure that there is sufficient water in the soil to commence planting. At this stage, the water requirements of the crop are minimal due to low rate of evapotranspiration (Allen *et al*., 1998). During emergence, while soil water must be adequate, excess water as well as cool conditions increases growth of fungi.

2.4.3.3 Early vegetative growth

Shortly after emergence, the maize plant shifts from dependence on food stored in the seed to that available in the soil and from photosynthesis (Sprague and Dudley, 1988; Shaw and Newman, 1991). The water requirement improves as the crop cover increases. Excess water in the early vegetative stages may severely injure the plans or retard early-season root development as well as create aeration-nutrition problems (Sprague and Dudley, 1988). In contrast, moderate water stress at this stages is actually advantageous, since such stress may encourage early-season root growth, which would prove beneficial later if soil water supplies become limited (Shaw and Newman, 1991).

2.4.3.4 Late vegetative growth

In the late vegetative stage, the maize plant grows rapidly and thus water requirements increases. At this stage higher evapotranspiration rate is experienced by the plant and transpiration from the crop contributes more than the evaporation from the soil surface since the crop cover is high (Sprague and Dudley, 1988).

2.4.3.5 Tasseling, silking and pollination

As a maize plant grows, its demand for water increases with increasing leaf area which reaches a maximum near the tasseling stage (Neild and Newman, 1991). At this stage the water requirements are greater than other stages and thus severe water deficits may result in little or no grain yield due to silk drying (Dorenboos and Kassam, 1988). Denmead and Shaw (1960) in his pot experiments showed that water stress during the silking stage reduced yield about twice as much as when similar amounts of stress occurred during the vegetative period. The leaf area index (LAI) also reaches the climax and therefore the water requirement is at its highest approximately 2 weeks before to 2 weeks after pollination. At this time the critical stage of grain development will begin (Pannar, 2002b).

2.4.3.6 Grain filling to maturity

Shaw (1977) reported that the water requirements for maize drop after the grain formation stage and gradually decreases as the crop matures and some leaves are senescing. Thus the LAI decreases gradually to harvest. At the physiological maturity, the grain must dry to a harvestable moisture level. Dry weather conditions are ideal for proper maturity and excess rainfall or wet day can severely deteriorate the yield quality (Hoogenboom, 2000).

2.4.4 Nutrients requirements

Maize requires at least 13 elements from the soil for its normal growth and development; another three, Carbon, Hydrogen and Oxygen are supplied by air and water (Sprague and Dudley, 1988). Among the 13, Nitrogen, Phosphorus and Potassium are needed in greatest amounts and are classed as major or primary nutrients. Calcium, Magnesium, and Sulfur are taken up in fairly large quantity and are regarded as secondary nutrients. The remainder including Iron, Manganese, Copper, Boron, Molybdenum and Chlorine are needed in small amounts and are classed as micronutrients (Sprague and Dudley, 1988). Maize has a high demand for nutrients shortly after germination; any shortage will limit the growth and yield potential. Due to the small root system in the early stages of growth the plants require nutrients close to the seed at planting. The average maize crop (40t/ha fresh weight) will remove 160kg/ha of N (occasionally up to 210kg/ha) from the soil, however applications of more than 100kg/ha are rarely necessary due to the efficiency of maize crops at removing N stored in the soil. Nitrogen is the nutrient most often lacking in maize production (Hoeft, 1992; Floyd *et al.*, 2002). Nitrogen may be applied before planting, at planting time, as a side-dressing after maize has emerged, and through an irrigation sprinkler system. Phosphate removal of the average crop of maize is in the region of 55kg/ha, almost 360kg/ha of Phosphorus is required along with 175kg/ha of Potassium (K) for the average yielding crop. The assimilation of nitrogen, phosphorus and potassium reaches a peak during flowering (Du Plessis, 2003). Magnesium will be required at around 40kg/ha and sulfur may still be required in small quantities depending on manure applications (Hoeft, 1992; Floyd *et al.*, 2002). Also if manure is not applied regularly small quantities of boron, copper, zinc, manganese and iron may be necessary (Floyd *et al.*, 2002). Maize is sensitive to zinc deficiency, and to some extent sulphur and magnesium shortages (Lacey and Roe, 2001). A beneficial strategy to keep the soil nutrients at a required level is the use of a combination of fertilizing techniques with green manure fallow plus stable farmyard manure, or compost plus modest quantities of chemical fertilizers (Wokabi, undated). Crop rotation, based on the inclusion of legumes, should be included in the management practices as the system maintains soil fertility (Wokabi, undated).

2.4.5 Soil requirements

Maize will grow on a wide range of soil types, provided they are well aerated and well drained to allow for the maintenance of sufficient oxygen for good root growth and activity, and enough water-holding capacity to provide adequate water throughout the growing season (Pierre *et al.*, 1966; Hoeft, 1992). Successful maize cultivation is achieved on soils which are of light to medium texture but their organic status and fertility should be high and capable of providing the nutrients needed by the crop. Maize can be successfully cultivated on moderately acid soils and gives the range of pH 5 – 8 as optimum, but best growth is achieved in the range of pH 5.6 – 7.5 (Sprague, 1955; Milbourn,1968). Maize does not grow well in saline soils. Although large-scale maize production takes place on soils with a clay content of less than 10 % (sandy soils) or in excess of 30 % (clay and clay-loam soils), the texture classes between 10 and 30 % have air and water regimes that are optimal for healthy maize production (Du Plessis, 2003).

2.4.6 Radiation requirements

Radiation is one of the important environmental parameters in maize growth and development, it is responsible for the formation of dry matter through photosynthesis. The roles of radiation within maize are not limited only to photosynthesis, but, are also necessary for photo-hormonal reactions (Hatfield, 1977). Maize is a short-day plant and thus flowers faster under shorter days. Yield increases with an increase in available photosynthetic active radiation (PAR) absorbed by the maize crop (Kumidini and Tollenaar, 1998).

2.5 Geographic Information System (GIS)

Geographic Information Systems (GIS) is a discipline devoted to the acquisition, storage, management, analysis, and visualization of spatial data in a computer environment (Longley et al., 2001). But according to Hall (2004), GIS is “a collection of information technology, data and procedures for collecting, storing, manipulating, analyzing, and presenting maps and descriptive information about features that can be represented on maps.” The unique features that distinguish GIS from other types of information systems as (1) data of entities and relationships are managed within a spatial framework and (2) ability to perform spatial analyses (Hall, 2004).

2.5.1 Spatial interpolation

GIS applications often require spatio-temporal interpolation of an input data set. Spatio-temporal interpolation requires the estimation of the unknown values at unsampled location-time pairs with a satisfying level of accuracy. Using measured temperature or rainfall at the stations one could then use the spatio-temporal interpolation to estimate these parameters at unsampled locations and times (Longley *et al*., 2001; Li and Revesz, 2003). In many fields, spatial interpolation is used to evaluate physical data in a continuous domain (Chapman and Thorns, 2002; Taylor *et al*., 2004). It is most commonly applied as a precursor to isoline or contour mapping, the drawing of lines of equal value for generation of a realistic surface between observation points (Taylor *et al*., 2004). A wide range of automated procedures have been developed, differing in their assumptions, local or global perspective and deterministic or stochastic nature (Collins and Bolstad, 1996; Taylor *et. al.,* 2004). Spatial interpolation uses one principle, Tobler's law which states "all places are related but nearby places are more related than distant places" (Dubois, 1997; Longley *et al*., 2001). There are a variety of interpolation methods which can generate continuous surfaces starting from irregularly distributed data, but the difficulty lies in the choice of the one that best reproduces the actual surface. Each method has its own advantages and drawbacks, which depend strongly on the characteristics of the set of point data: a method that fits well with some data can be unsuited for a different set of data points, or if measured in different locations of the same surface (Collins and Bolstad, 1996; Caruso, 1997; Taylor *et al*., 2004).

The spatial interpolation of temperature and precipitation climate data is increasingly important in the development of agricultural, hydrological, and ecological models. Spatially explicit modeling of ecosystem structure, for example, requires estimates of climate variables at unsampled locations, usually on a regularly spaced grid (Skirvin *et al*., 2003). In addition to those involved in temperature modeling, temperature prediction at unsampled sites is of interest to individuals involved in fire management, resource management, and spraying or seeding operations. High resolution estimates of spatial variability in rainfall fields are important in solving problems for hydrologic analysis and designs especially for the identification of locally intense storms which could lead to floods or flash floods (Goovaerts, 2000). According to Skirvin *et al*. (2003) in the mountainous regions precipitation and temperature are strongly influenced by elevation through orographic effects and lapse rate; thus a digital elevation model (DEM) can supply both an independent variable for climate interpolation and a convenient regularly spaced grid.

Many researchers have evaluated various methods for interpolation of point climate data. In several studies, geostatistical methods have been rated superior over techniques such as Thiessen polygons, inverse distance weighting, least-squares polynomial regression, and spline surface fitting (Collins and Bolstad, 1996; Skirvin *et al*., 2003). The choice of spatial interpolator is especially important in mountainous regions where data collection are sparse and variables may change over short spatial scales (Collins and Bolstad, 1996). One of the problems facing meteorologists and hydrologists studying spatial rainfall patterns is the interpolation of data from irregularly spaced rain gauges in order to determine mean areal rainfalls or to characterise rainfall variability within a region or catchment (Dirks *et al*., 1998). Rainfall is intermittent and spatially discontinuous, frequently with zero accumulations; for this reason the reliable spatial interpolation of rainfall is inherently more difficult than for many other variables. Over short integration times, interpolation may be impossible so spatial interpolation of data has potential problems that need to be taken into consideration when dealing with this type of data (Dirks *et al*., 1998).

There are two main groupings of interpolation techniques: deterministic and geostatistical. Deterministic interpolation techniques create surfaces from measured points, based on either the extent or similarity. Deterministic interpolation techniques can be divided into two groups, global and local. Global techniques calculate predictions using the entire dataset (Johnston *et al*., 2001). Geostatistical interpolation techniques (e.g. Kriging) utilize the statistical and mathematical methods properties of the measured points. Because geostatistics is based on statistics, these techniques produce not only prediction surfaces but also error or uncertainty surfaces, giving you an indication of accuracy of the predictions (Johnston *et al*., 2001).

2.5.1.1 Kriging method

Kriging is an advanced interpolation procedure that generates an estimated surface from an x-y scattered set of points with z values. It is a weighted moving averaging method of interpolation derived from regionalized variable theory, which assume that the spatial variation of a property, known as a ‘regionalized variable’, is statistically homogenous throughout the surface (Salih *et al*., 2003).The Kriging estimate is known as the Best Linear Unbiased Estimate, because it is a linear combination of the weighted sample values, whose expected value for error equals zero and whose variance is at a minimum (Caruso, 1997; Johnston *et al*., 2001). Kriging uses a semi-variogram, a measure of spatial correlation between two points, so the weights change according to the spatial arrangement of the samples. The variogram then describes the weighting factors that will be applied for the interpolation and also defines variation as a function of distance (Nalder and Wein, 1998; Salih *et al*., 2003; Sakata, 2004).

$$g(h)=\frac{1}{2N(h)}\sum_{k=1}^{N(h)}\left[Z(x_k+h)-Z(x_k)\right]^2$$

where ?(h) is the semi-variance of variable Z at separation distance h and N(h) is the number of pairs of points in the distance interval h + ?h. Values are calculated for each possible pair of stations and the mean values of the semi-variance are plotted for successive distance intervals to produce the experimental variogram. A model variogram is fitted to these points, and this model is used in generating an auto-covariance matrix. Estimates for the test sites are calculated by summing weighted values for each climate station where the weights are determined so that the estimation variance is minimized (Nalder and Wein, 1998; Goovaerts, 2000).

2.5.1.2 Inverse distance weighting (IDW)

Inverse distance weighting (IDW) is a deterministic estimation method where values at unsampled points are determined by a linear combination of values at known sampled points (Collins and Bolstad, 1996). It employs the Tobler Law by estimating unknown measurements as weighted averages over the known measurements at nearby points, giving the greatest weight to the nearest points (Collins and Bolstad, 1996; Longley *et al* 2001; Johnston *et al.*, 2001). More specifically, IDW assumes that each measured point has a local influence that diminishes with distance (Li and Revesz, 2003). Weights change according to the linear distance of the samples from the unsampled point. The spatial arrangement of the samples does not affect the weights (Collins and Bolstad, 1996). The weighting function is the inverse square of the distance, so that the predicted value for a site is given by (Li and Revesz, 2003):

$$w(x, y) = \sum_{i=1}^{N} l_i w_i \qquad \text{where} \qquad l_i = \frac{\left(\frac{1}{d_i}\right)}{\sum_{k=1}^{N}\left(\frac{1}{d_k}\right)^p}$$

where w(x,y) is the predicted value at location (x,y), N is the number of nearest known points surrounding (x,y), $?_i$ are the weights assigned to each known point value w_i at location (x_i,y_i), d_i are the Euclidean distances between each (x_i,y_i) and (x,y), and p=2 is the exponent, which influences the weighting of w_i on w (Johnston *et al.*, 2001). If it is used to determine w at a location where w has already been measured it will return the measured value, because the weight assigned to a point at zero distance is infinite, and for this reason IDW is described as an exact method of interpolation because its interpolated results honor the data points exactly (Longley *et al.,* 2001).

Compared with other methods like Kriging and Spline, the IDW method is simpler to program and does not require pre-modeling assumption in selecting a semi-variogram model (Johnston *et. al.*, 2001; Longley *et al.*, 2001; Mebrhatu, 2003). But because IDW is an average it always return a value that is between the limits of the measured values i.e. no point in the interpolated surface that is more than the largest measured value or less than the smallest value (Longley *et al.*, 2001). In other words it does not notice the trend where one exist and thus it is not ideal to use it with the surfaces like elevation which has peaks and pits.

2.5.1.3 Spline Method

Spline interpolation consists of the approximation of a function by means of series of polynomials over adjacent intervals with continuous derivatives at the end-point of the intervals. Spline is a form of radial basic functions (RBF). RBF methods are a series of exact interpolation techniques; that is, the surface must go through each measured sample value (Johnston *et al*., 2001). RBFs are conceptually similar to fitting a rubber membrane through the measured sample values while minimizing the total curvature of the surface (Hutchinson, 1995; Mebrhatu, 2003). Many researchers (Hutchinson, 1995; Guenni, 1997; Price *et al*., 2000: Boer *et al.*, 2001) used the thin plate smoothing spline method in the interpolation of climate related data.

In the next chapter the filling or patching of meteorological data will be discussed at full length as it is important to fill the gaps in the meteorological datasets before climatological analysis is done. Temperature and rainfall parameters are the main meteorological datasets being used for describing agro-climatology of Lesotho and further identifying potential areas for dryland maize production.

Chapter 3 – Patching of the Missing Meteorological Data

3.1 Introduction

Data records which are collected over a long period of time will contain gaps and the number of gaps in the records usually increases with increase in the length of the dataset. This is certainly the case with most rainfall data in Africa (Makhuvha *et al*., 1997). LMS climatological data is no exception. The frequency of gaps in the climate data for Lesotho makes it difficult to make sound conclusions since some of the important climatological events maybe missed. Several circumstances contribute to the prevalence missing data, for example loss of records, vandalism, instrument malfunction or failure of the observer to make the necessary visit to the raingauge (Tang *et al*., 1996; Makhuvha *et al*., 1997).

Whatever the reasons for their occurrence, gaps in climatological data are problematic in a number of ways. Hydrologists and engineers require complete rainfall records for the purpose of planning and design (Makhuvha, *et al*., 1997) and complete and accurate climate data is a prerequisite for the efficient modelling of a wide variety of environmental processes (see, Jeffrey *et al*., 2001; Xia *et al*., 2001). Missing data makes it difficult for the agronomists to estimate crop yield using crop models. Other applications in which gaps in rainfall records are inconvenient include the estimation of drought risk and severity and the estimation of the frequencies and severity of storms (Makhuvha, *et al*., 1997). Three common approaches often used in treating the missing gaps are: (a) using only continuous records and ignoring the prior events and (b) ignoring the missing gaps based on the assumption that the data is one continuous series of records (Tang *et al*., 1996) or (c) data patching. The main disadvantage to the former approach is wasting valuable and previous information and true statistical inferences cannot be made whereas the second approach will shrink the period of recorded events available for analysis, thus over or under-estimating the likelihood of occurrence of major events (Tang *et al*., 1996).

Estimation of missing values in climatological time series is an important task (Xia *et al.*, 1999). There are several methods that can be used to estimate the missing values. Simple methods in common use include the replacement of missing values at the target site by (Makhuvha *et al.*, 1997):

(1) Concurrent values at a neighbouring site.

(2) The average amount at the target site i.e. not using information from the neighbouring sites.

(3) The average of the concurrent values at a small number (usually 3 or 4) of the neighbouring sites.

These three procedures are special cases of linear regression methods in which the missing values at a target site are estimated as a linear combination of the concurrent values at respectively, one, none or several neighbouring sites (Makhuvha *et al.*, 1997). The best methods of estimating missing data will, in general, depend upon the statistical properties of the data. In climatology, the two most important factors are the inter-correlations in the station network and the seasonal variations in the relations between the stations (Xia *et al.*, 1999).

The problem of missing data is not new in Lesotho, researchers (Hyden, 1996; Jayamaha, 1979; Wilken, 1978) in the past also experienced the same problem. Hyden (1996) in his book 'Meteorological Droughts and Rainfall Variability in the Lesotho Lowlands' used nearby South African stations to fill the missing data with a nearest station method to fill the gaps at some stations. The specific stations he used were as follows: Fouriesburg records were used to fill gaps in Butha Buthe records, Ficksburg for Leribe, Ladybrand for Maseru, Wepener for Mafeteng and Zastron for Mohale's Hoek (Hyden, 1996).

3.2 Methods of Patching Data

3.2.1 Absence of concurrent records

3.2.1.1 The use of the mean value

When only a sample series with missing values is available and no related data from other stations exist, an easy approach is to insert a long period mean value into the missing gap (Tang *et al*., 1996). However, this estimation method is not advisable as the variance of the series will reduce significantly (Tang *et al*., 1996).

3.2.2 Presence of concurrent records

3.2.2.1 The closest station method (CSM)

The CSM is a simple method. Firstly, usually the closest station is identified, and then the data at a specific site would be replaced with data from the closest station for that specific day. In some studies the observations from this station were adjusted by the ratio of the long-term means between the 2 stations for precipitation and/or by a constant lapse rate (0.65°C/100 m) for air temperatures (Xia *et al*., 2001).

3.2.2.2 Simple arithmetic averaging (AA)

This is one of the simplest methods which are commonly used to fill the missing data in meteorology and climatology. The missing data are obtained by arithmetically averaging data of the two to five closest weather stations around a station (Tang *et al*., 1996; Xia *et al*., 1999). For example, the arithmetic mean method is proposed for areas where station to station variation of the average rainfall is small (< 10%) (Tang et *al*., 1996).

3.2.2.3 Inverse Distance (ID)

The inverse distance method is used to estimate missing data because of its simplicity.

$$y_t = \frac{\sum_{i=1}^{m} x_t^i / D_i^b}{\sum_{i=1}^{m} 1 / D_i^b}$$

Where y_t is the estimated value of the missing data, $x^i{}_t$ is the value of the ith nearest weather station, and D_i is the distance between the station of missing dataset and the ith nearest weather station (Tang *et al.*, 1996; Xia *et al.*, 1999).

3.2.2.4 Normal Ratio (NR)

The normal ratio method of spatial interpolation was first proposed by Paulhus and Kobler, 1952 (see Xia *et al.*, 1999). The estimated data are considered as a combination of variables with different weights, i.e.

$$V_0 = \frac{\sum_{i=1}^{n} W_i V_i}{\sum_{i=1}^{n} W_i}$$

where V_o is the estimated value, W_i is weight of the ith nearest weather station and V_i is the observational data of the ith nearest weather station. Weights for the surrounding stations used in the estimation algorithm are calculated according to (Xia *et al.*, 1999; Tang *et al.*, 1996):

$$W_i = \left[r_i^2 \left(\frac{n_i - 2}{1 - r_i^2} \right) \right]$$

where r_i is the correlation coefficient between the target station and the ith surrounding station, n_i is the number of points used to derive the correlation coefficient, and Wi is the resultant weight. It has been proven to perform well for monthly and annual rainfall datasets (Tang *et al.*, 1996).

3.2.2.5 Single best estimator (SIB)

The single best estimator is simple and analogous to using the CSM as an estimate for a target station. Target station conditions are estimated using data from the neighboring station that has the highest positive correlation with the target station (Xia *et al*., 1999).

3.2.2.6 Multiple Regression (MR)

The multiple regression analysis is a traditional interpolation approach (Xia et al., 1999; Makhuvha *et al*., 1997). The stepwise regression is used to select the best variable that can be included into the regression model. The station with missing values has been assigned as the dependent variable (Tang *et al*., 1996). Missing data (V_0) were estimated as:

$$V_0 = a_0 + \sum_{i=1}^{n} (a_i v_i)$$

where a_0, a_1, …, a_n are regression coefficients. v_i is the value at ith weather station.

3.2.2.7 UK traditional method (UK)

The method traditionally used by the UK Meteorological Office to estimate missing temperature and sunshine data was based on comparisons with a single neighbouring station. For temperature, a constant difference between stations was assumed. Thus, if the January temperature at Station A was 0.1°C above that at Station B averaged over a period of overlapping records, then 0.1°C was added to the values at Station B to give the estimated values at Station A (Xia *et al*., 1999). These differences had to be calculated for each pair of stations before using the method.

3.2.3 Methods used in patching the Lesotho meteorological data

All the LMS stations had missing data and in this study the simple and yet reasonably sound technique of patching the missing meteorological data was used. The simple but yet more or less reasonable method for estimating the daily rainfall and temperature depending on the overall characteristics of the climate of the country and results determined from past studies by Tang *et.al.* (1996) and Xia *et al.* (1999). The method used for patching daily rainfall values was the inverse distance interpolation (ID). This method was chosen for its simplicity and reasonable score from the past research. Results by Xia *et al*. (1999) show that the inverse distance interpolation method of estimating daily precipitation gave less deviation from the actual data followed by the arithmetic averaging and normal ratio methods. While the daily maximum and minimum temperatures were patched using the UK method, which according to Xia *et al*. (1999) results gave more accurate estimates. The UK method was chosen because it indirectly incorporates the difference in the altitude and local effects.

In this study, ID method used in the estimation of daily rainfall was modified in that, the ratio of the long-term rainfall between the stations were used as multipiers where there was a large difference (less than 0.9 or greater than 1.1) in monthly or annual precipitation between neighbouring stations. According to Buckle (1996), in mountainous regions rainfall varies significantly within a small distance, caused by both the orographic and rainshadow effect. The orographic effect occurs on the windward side of the mountain where precipitation increases moving up the mountain while on the leeward side of the mountain precipitation is reduced. The ID method was modified because of the fact that some close stations might have large difference in rainfall amounts because of the topographic nature of the country of Lesotho. The adjustment gave good estimation than the normal ID method for all the stations where long-term mean rainfall of the estimated site is quite different from that of the neighboring station.

In using the UK method, the monthly differences are used instead of daily differences because of the great variation in daily temperature compared to an averaged monthly temperature. Thus if on average the monthly temperature of station say E is 0.2°C greater than say station F then their daily values difference should be in the neighborhood of that value (0.2°C) since the cause of difference in daily temperature within a period of a month is more or less the same owing to the climatology of an area. Therefore this traditional UK method was used in the estimation of missing daily maximum and minimum temperature readings. The method usually uses one neighbouring station but in this study 2 to 5 nearest stations with concurrent data were used. The reasons for the adjustment being as follows:-

1) The average of more than one station resulted in estimated values which had less deviation from the actual data.
2) The neighbouring stations also had missing values, thus some other stations will help in filling the gaps when one or other stations had gaps
3) There is too much ‘human’ error in the measurements of temperatures especially in the climate stations in the rural areas where the observers had little training in meteorological measurements. Some observations had clearly showed that observers have a problem in the winter months, especially where the minimum values go below zero.
4) The station network with temperature measuring instruments is very sparse and thus the nearest station at times will be a great distance away (over 30 km). Due to the high gradient in topographical changes more than one station in the estimation will tend to eliminate the local effects.

3.3 Statistical Evaluation

The methods of evaluation of simulation models is not well established because many of them result to different conclusions thus making it difficult for the researcher to conclude on the accuracy of model used in the predictions (Yang *et al.*, 2000). There are many tests to signify the similarity between two distributions. These may be parametric tests and non-parametric tests (such as rank-sum test, Kolmogorov-Smirnov (KS) test, etc.). In the parametric tests, the parameters such as mean and variance of the two distributions to be compared play important roles whereas in the non-parametric tests, the empirical cumulative distributions functions (ECDFs) are compared which is calculated by arranging the data in ascending order. The KS test is a non-parametric and distribution free goodness-fit-test (Kar and Mohanty, 2004). It is important to include absolute error measures (such as mean absolute error (MAE) and root mean square error (RMSE)) in a model evaluation because they provide an estimate of model error in the units of the variable (Quiring and Papakryiakou, 2003).

3.3.1 Kolmogorov- Smirnov (KS) Test

The Kolmogorov-Smirnov test (KS-test) determines if two datasets differ significantly (CSBSJ, undated). The Kolmogorov–Smirnov (KS) test statistic D_{max}, is defined by (Wang *et al*., 2004)

$$D_{\max} = \max_{1 \le i \le n-1} \{ |F(x_i) - G(x_i)|, |F(x_{x+1}) - G(x_i)| \}$$

$D_{\max}$ measures the maximum deviation between the hypothesized cumulative distribution function (CDF) and the empirical CDF at the same observation point or among a pair of consecutive observation points (Wang *et al*., 2004). The KS test is used which tests the statistical similarity between the distribution of two samples (Kar and Monhanty, 2004). $D_{\max}$ value and corresponding *?* value (probability value) has been considered for decision-making. The *?* value means probability value that denotes the significance level (and hence confidence level) for which the critical values of $D_{\max}$ need not be calculated (Kar and Monhanty, 2004). The null hypothesis here is that both the datasets (measured data and estimated data) have the same population or they are statistically similar (Kar and Monhanty, 2004). The low *?* value rejects the null hypothesis that the datasets compared are statistically similar thus the two-distribution functions are different if the maximum vertical distance $D_{\max}$ between them exceeds the critical value for a given level of significance chosen as 0.05 (Mebrhatu, 2003; Kar and Mohanty, 2004; Wang *et al*., 2004). Thus when the $D_{\max}$ is less than the *?* value then the two datasets are statistically similar.

3.3.2 Mean absolute error (MAE)

The MAE is an error measure used to represent the average differences between model predicted (*P*) and observed (*O*) values. The MAE provides a more robust measure of average model error than the RMSE, since it is not influenced by extreme outliers (Willmott, 1982; Quiring and Papakryiakou, 2003). The mean absolute error is calculated using the equation:-

MAE = ¦ P - O¦

3.4 Testing of Patching Methods

Five stations were chosen across the country to verify the accuracy of the methods used to patch the missing daily data, including three stations from the lowlands and two stations from the highlands. The period of 1980 to 2003 was chosen for this exercise. This period was chosen because of the minimal gaps in meteorological data. The five station used are Moshoeshoe I, Leribe, Mohale's Hoek, Qacha's Nek and Mokhotlong (Table 3.1). For each stations, daily maximum and minimum temperature values were generated for the whole period using the UK method while the daily rainfall values were generated using the ID method with data from 1980 to 2003.

Neighbouring stations within 50km radius were selected and given priority. But since the distribution of the stations with air temperature observations is sparse, in some cases especially over the highlands the stations within 75km radius were also considered. Two to five nearest stations with adequate data were selected for the purpose of generating a daily estimate value for that particular station. Table 3.2 to 3.6 shows which stations are used for estimating maximum and minimum daily values for each station while Table 3.9 shows stations used for estimating daily rainfall. Note that the stations used in the estimation of rainfall and temperatures are slightly different, due to the fact that there are more rainfall stations in the country than climate stations (with temperature measurements).

The statistical characteristics of the generated and measured values were then compared (Appendix 1, 2 and 3) and the KS test was used in testing whether the two datasets (the generated monthly values and measured monthly values) belong to the same population. Also the average of the annual mean absolute error for the daily minimum temperatures, daily maximum temperatures and daily rainfall were calculated. Note that the statistical results given in this chapter are only from the data starting from 1980 to 2003, but the method used (coefficients and neighbouring stations) in patching in the demonstration is the same as in the actual patching of the missing data and also the patching of other stations not shown in this chapter followed the same procedure.

Table 3.1 Geographical coordinates and altitude of the stations used to test the patching methods.

Identification	Latitude	Longitude	Altitude (m)
Leribe	28.88 S	28.05 E	1740
Mohale's Hoek	30.15 S	27.47 E	1620
Mokhotlong	29.28 S	29.07 E	2230
Moshoeshoe I	29.45 S	27.57 E	1628
Qacha's Nek	30.12 S	28.70 E	1970

3.4.1 Generation of maximum and minimum temperatures

3.4.1.1 Methodology

The monthly averages of both maximum and minimum temperatures were determined using the Instat+ and Microsoft Excel programs. The differences in the monthly means of two stations were calculated for each year and averaged over the whole period of the dataset. This averaged differences forms the basis of the patching of data with the UK method by giving a disagreement factor that needs to be added to the station monthly temperature to estimate the missing data point. If more than one station is used in the estimation, an average of these estimates is used to give the final estimate for the missing data point. The results for each of the five stations are shown in Table 3.2 to 3.6.

Table 3.2 Station disagreement factor for estimation of Leribe minimum and maximum temperatures from each of the adjacent stations per month

	Minimum Temperature disagreement factor (°C)				Maximum Temperature disagreement factor (°C)			
	Teyateyaneng	**Pitseng**	**Mapoteng**	**Butha - Buthe**	**Maputsoe**	**Pitseng**	**Mapoteng**	**Butha - Buthe**
January	-1.2	-0.1	0.5	-1.7	-0.2	1.1	-0.6	0.8
February	-1.0	0.2	0.5	-1.7	0.1	0.7	-0.9	0.5
March	-1.6	0.2	-0.1	-2.4	-0.8	-0.5	-0.3	-0.3
April	-2.8	-0.1	-0.8	-3.0	0.1	0.6	-1.1	-1.6
May	-3.1	-1.1	-1.8	-4.2	0.2	0.6	-1.2	-0.1
June	-4.2	-3.2	-1.6	-4.5	-0.3	0.5	-0.4	-0.7
July	-1.6	-4.0	-2.1	-4.6	0.1	0.6	-0.8	-0.1
August	-4.9	-2.4	-2.1	-4.1	0.3	0.4	-1.4	0.1
September	-2.3	-0.7	-1.4	-3.4	0.1	0.7	-1.1	0.2
October	-1.8	0	-0.2	-2.4	-0.1	0.8	-0.5	0.4
November	-1.3	-0.5	0.4	-1.9	-0.2	0.8	-0.8	0.5
December	-1.1	-0.5	-0.3	-1.7	-0.2	1.1	-0.4	0.8
Average	-2.2	-1.0	-0.8	-3.0	-0.1	0.6	-0.8	0.1
Std Dev.	1.3	1.4	1.0	1.1	0.3	0.4	0.4	0.7

In Table 3.2, Teyateyaneng station was used instead for minimum temperatures of Maputsoe (nearer station), which is used in the estimation of maximum temperatures because of the many errors in the minimum temperatures recorded at Maputsoe station especially during the winter months.

Table 3.3 Station disagreement factor for estimation of Mohale's Hoek Station minimum temperature and maximum temperatures from each of the adjacent stations per month

	Minimum Temperature disagreement factor (°C)				Maximum Temperature disagreement factor (°C)			
	Quthing	**Nohana**	**Thabana Morena**	**Paul VI**	**Quthing**	**Nohana**	**Thabana Morena**	**Mafeteng**
January	-0.6	0.0	-1.3	-1.2	0.7	1.5	1.7	0.9
February	-0.3	0.3	-1.5	-0.5	1.0	0.9	1.8	1.0
March	-0.4	0.0	-1.7	-1.4	1.2	0.7	1.3	0.9
April	-0.6	0.1	-2.5	-2.3	0.9	0.4	1.0	0.6
May	-1.1	-0.5	-2.9	-2.9	1.5	0.8	1.1	1.0
June	-1.4	-1.2	-3.9	-2.9	1.2	0.5	0.5	1.0
July	-0.8	-0.7	-2.0	-2.8	0.6	0.2	1.1	1.0
August	-1.0	-0.7	-2.6	-2.8	0.9	0.6	0.9	0.8
September	-0.9	0.0	-2.0	-2.2	0.9	0.9	0.8	0.5
October	-0.7	-0.2	-1.5	-1.7	0.8	0.8	1.2	0.7
November	0.5	-0.8	-1.0	-1.4	0.9	0.9	1.3	0.8
December	-0.4	-1.1	-1.5	-1.1	0.6	0.8	1.5	0.9
Average	0.1	-2.0	-1.9	-0.4	0.9	0.8	1.2	0.8
Std Dev.	0.6	0.8	0.8	0.5	0.3	0.3	0.4	0.2

Table 3.4 Station disagreement factor for estimation of Mokhotlong minimum and maximum temperatures from each of the adjacent stations per month

	Minimum Temperature disagreement factor (°C)				Maximum Temperature disagreement factor (°C)			
	Malefiloane	**Lets'eng la Terai**	**St James**	**St Matins**	**Malefiloane**	**Lets'eng la Terai**	**St James**	**St Matins**
January	3.5	4.5	0.8	2.1	4.0	6.1	0.4	2.9
February	3.8	3.8	0.5	2.0	4.3	8.1	0.3	2.7
March	3.4	3.4	0.1	1.2	3.4	8.2	-0.1	1.3
April	2.1	1.9	-0.6	0.4	3.2	7.7	-0.1	2.3
May	0.3	2.0	-0.4	-0.8	2.9	7.6	-0.1	1.4
June	1.1	1.3	-0.7	-1.2	2.5	6.6	-0.1	1.3
July	0.3	-3.2	-0.9	-1.1	2.4	7.0	0.1	1.0
August	1.1	-0.6	-1.0	-0.7	3.2	8.0	0.4	2.5
September	0.8	2.3	0.3	0.7	3.2	7.8	0.6	2.1
October	2.0	6.2	0.9	1.3	3.4	8.2	0.4	2.0
November	2.0	4.6	0.6	1.4	3.7	8.6	0.4	2.4
December	2.0	2.2	0.3	1.3	4.0	8.3	0.5	2.3
Average	1.9	2.4	0.0	0.5	3.3	7.7	0.2	2.0
Std Dev.	1.2	2.5	0.7	1.2	0.6	0.8	0.3	0.6

Table 3.5 Station disagreement factor for estimation of Moshoeshoe I minimum and maximum temperatures from each of the adjacent stations per month

	Minimum Temperature disagreement factor (°C)				Maximum Temperature disagreement factor (°C)			
	Roma	Thaba Bosiu	Mejametalana	Matela	Roma	Thaba Bosiu	Mejametalana	Matela
January	0.5	0.0	0.0	1.3	0.5	-1.4	-0.9	0.8
February	0.8	0.2	0.1	1.7	0.3	-1.1	-1.0	0.9
March	0.6	0.0	0.3	1.5	-0.3	-1.1	-1.0	0.4
April	-0.1	0.3	0.1	0.7	0.2	-1	-1.0	1.2
May	0.3	-0.5	0.2	-0.5	-0.4	-1	-1.1	0.9
June	-1.1	0.8	1.5	-0.8	-0.3	-1.2	-1.2	0.0
July	0.2	-0.5	0.8	-0.4	-0.4	-1.2	-1.2	0.0
August	-0.5	-0.1	1.1	0	0.3	-1.7	-1.2	0.7
September	-0.3	0.3	0.9	0.4	0.2	-0.4	-0.9	0.5
October	0.3	0.3	0.5	1.2	0	-0.1	-0.8	0.3
November	0.3	0.2	0.2	1.1	0.4	-1	-0.9	0.7
December	0.3	0.5	0.2	1.2	0.4	-1.9	-1.1	0.8
Average	0.1	0.1	0.5	0.6	0.1	-1.1	-1.0	0.6
Std Dev	0.5	0.4	0.5	0.9	0.3	0.5	0.1	0.4

Table 3.6 Station disagreement factor for estimation of Qacha's Nek minimum and maximum temperatures from each of the adjacent stations per month

	Minimum Temperature disagreement factor (°C)		Maximum Temperature disagreement factor (°C)	
	Sehlabathebe	Mokhotlong	Sehlabathebe	Mokhotlong
January	4.6	1.4	4.1	0.0
February	4.2	1.7	3.4	-0.8
March	4.4	2.2	2.5	-0.3
April	3.8	3.2	3.7	0.2
May	4.0	4.2	3.1	0.7
June	4.3	5.0	2.3	0.2
July	4.0	5.2	3.0	0.3
August	3.8	4.0	3.1	0.3
September	4.0	2.8	3.9	-0.1
October	4.3	1.6	3.4	-0.3
November	4.1	1.9	3.7	-0.2
December	4.4	1.9	4.3	0.0
Average	4.2	2.9	3.4	0.0
Std Dev	0.3	1.4	0.6	0.4

For example:- Let a = missing daily minimum temperatures at Qacha's Nek station in January, b = concurrent daily minimum temperature at Sehlabathebe station and c = concurrent daily minimum temperature at Mokhotlong. Then, using the values given in table 3.6, the equation for estimating daily minimum temperatures at Qacha's Nek station will be a **= [(b+4.6)+(c+1.4)]/2.** This method was applied to all the stations with their own disagreement factor.

3.4.1.2 Results and Discussion

Appendix 1 shows the descriptive statistics (median, mean, skewness, 10^{th}, 20^{th}, 80^{th} and 90^{th} percentile) of both the actual and generated monthly minimum temperatures. As seen from those tables the generated monthly minimum temperatures are more or less similar to the measured monthly minimum since the mean, median, 10^{th}, 20^{th}, 80^{th} and 90^{th} percentile have deviations of less than 1°C with very few exceptions. Also both the measured and generated values skewness has fairly similar orientation. The statistical evaluation was done using the Kolmogorov-Smirnov (KS) test (Table 3.7). The monthly values from all the stations show that the distribution of the monthly minimum temperatures of the actual and generated values is similar as evidenced by the D-statistic which is smaller than the critical value (?). All the values were calculated with the 95% confidence interval. The mean absolute error (MAE) for each of the stations is less than 1.8°C with the minimum value of 1°C at Moshoeshoe I station (Fig. 3.1).

Appendix 2 shows the descriptive statistics (median, Mean, skewness, 10^{th}, 20^{th}, 80^{th} and 90^{th} percentile) of the actual and generated monthly maximum temperatures. The values obtained from the estimating equations are a good representation of the measured monthly maximum temperatures. The deviations from the actual or measured values are also less than 1°C. The statistical evaluation was done using the Kolmogorov-Smirnov (KS) test (Table 3.8). With the 95% confidence interval, the calculated D-statistic is less than the critical value for all the months showing that the generated and measured values don't differ significantly. The MAE for daily maximum temperatures for all the stations is less than 1.6°C and the minimum of 0.8°C is observed at Moshoeshoe I station (Fig. 3.1).

Table 3.7 Kolmogorov – Smirnov (KS) test for estimation of monthly minimum temperatures at the five chosen stations (D_{max} = Maximum vertical distance between the hypothesized cumulative distribution function (CDF) and the empirical CDF and ? = Probability value that denotes the significance level)

Location	Leribe		Mohale's Hoek		Mokhotlong		Moshoeshoe I		Qacha's Nek	
	D_{max}	?	D_{max}	?	D_{max}	?	D_{max}	?	D_{max}	?
January	0.18	0.82	0.17	0.95	0.26	0.36	0.24	0.67	0.27	0.33
February	0.14	0.98	0.19	0.91	0.24	0.53	0.18	0.93	0.25	0.50
March	0.14	0.98	0.16	0.96	0.22	0.59	0.18	0.93	0.25	0.63
April	0.17	0.84	0.18	0.93	0.18	0.82	0.18	0.93	0.21	0.74
May	0.13	0.98	0.17	0.99	0.23	0.56	0.13	0.98	0.23	0.56
June	0.26	0.36	0.26	0.46	0.29	0.30	0.31	0.35	0.27	0.33
July	0.26	0.36	0.19	0.91	0.27	0.33	0.27	0.59	0.21	0.74
August	0.21	0.62	0.20	0.89	0.17	0.86	0.19	0.91	0.14	0.97
September	0.14	0.98	0.23	0.83	0.26	0.36	0.13	0.98	0.15	0.97
October	0.17	0.84	0.13	1.00	0.23	0.56	0.13	1.00	0.16	0.96
November	0.17	0.84	0.12	1.00	0.29	0.30	0.18	0.93	0.22	0.59
December	0.17	0.86	0.13	1.00	0.25	0.39	0.18	0.93	0.26	0.46

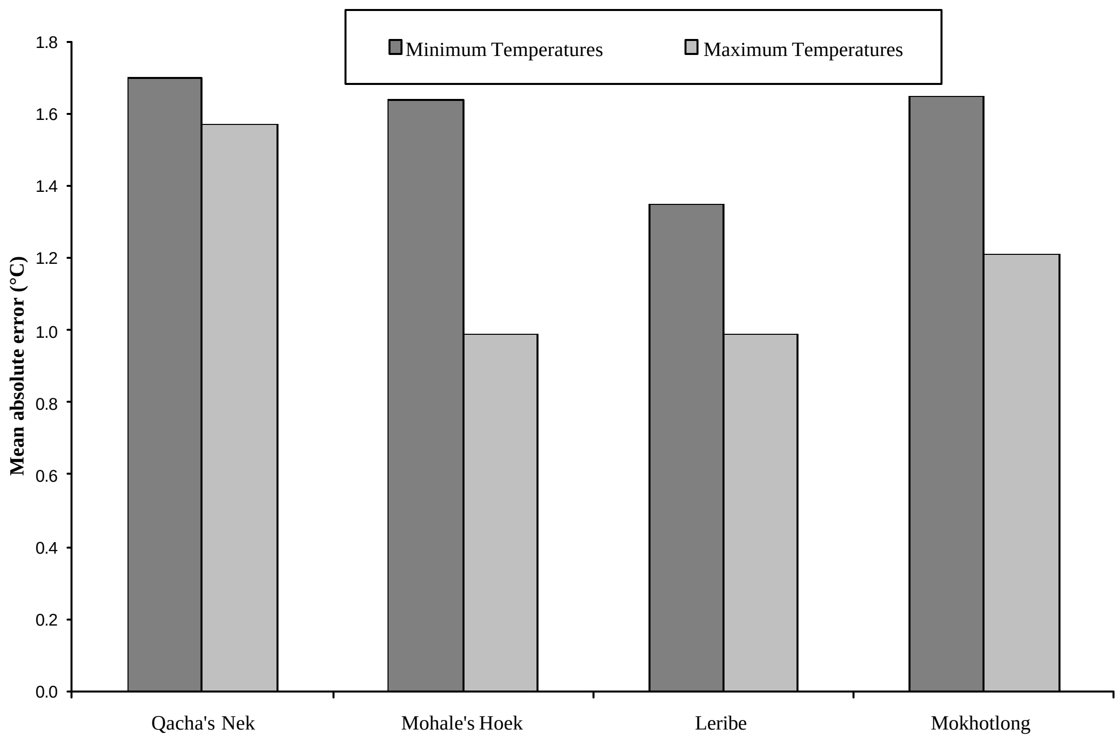


Fig 3.1 Average mean absolute error for daily minimum and maximum temperatures

Table 3.8 Kolmogorov – Smirnov (KS) test for estimation of monthly maximum Temperatures at the five chosen stations (D_{max} = Maximum vertical distance between the hypothesized cumulative distribution function (CDF) and the empirical CDF and ? = Probability value that denotes the significance level)

	Leribe		Mohale's Hoek		Mokhotlong		Moshoeshoe I		Qacha's Nek	
	D_{max}	?	D_{max}	?	D_{max}	?	D_{max}	?	D_{max}	?
January	0.19	0.80	0.13	0.98	0.13	0.99	0.24	0.67	0.14	0.98
February	0.18	0.82	0.19	0.80	0.22	0.59	0.24	0.67	0.16	0.96
March	0.23	0.56	0.15	0.97	0.21	0.62	0.18	0.93	0.26	0.46
April	0.19	0.80	0.29	0.30	0.18	0.82	0.24	0.67	0.14	0.98
May	0.24	0.53	0.22	0.71	0.22	0.59	0.20	0.93	0.17	0.84
June	0.23	0.56	0.25	0.50	0.27	0.33	0.25	0.63	0.17	0.86
July	0.22	0.59	0.20	0.77	0.26	0.36	0.21	0.86	0.19	0.80
August	0.21	0.62	0.25	0.50	0.25	0.39	0.25	0.63	0.29	0.30
September	0.15	0.97	0.21	0.74	0.17	0.84	0.20	0.89	0.14	0.97
October	0.18	0.84	0.22	0.71	0.13	0.98	0.19	0.91	0.25	0.50
November	0.26	0.36	0.16	0.96	0.17	0.84	0.18	0.93	0.09	1.00
December	0.25	0.39	0.16	0.96	0.21	0.62	0.18	0.93	0.11	1.00

3.4.2 Generation of rainfall values

3.4.2.1 Methodology

The two to five closest stations within the 50km buffer zone were used to predict the daily rainfall for that particular station. The inverse distance method (ID) was used for the estimation of daily precipitation. The monthly rainfall values were determined using Instat+ and Microsoft Excel programs. The ratio of the long-term average monthly/ annual rainfall was determined for each of the stations. These ratios were used as coefficients of rainfall values at that particular neighbouring station in the estimation of daily rainfall. As seen from Table 3.9, the monthly and annual rainfall for both Leribe and Moshoeshoe I stations did not show much deviation from the neighbouring stations while Mohale's Hoek, Mokhotlong and Qacha's Nek showed greater variation in the monthly and annual rainfall totals (Table 3.9). Thus the traditional ID method was used for Moshoeshoe I and Leribe station whereas in Mohale's Hoek, Mokhotlong and Qacha's Nek the ID method was adjusted by the ratios. For example:- Let a = missing daily rainfall at Qacha's Nek, b = concurent rainfall at Tsoelike, c = concurent rainfall at Rapase, d = concurent rainfall at Whitehill, e = concurent rainfall at Ramats'eliso thus using the values given in table 3.9, the equation for estimating rainfall at Qacha's Nek station if all the stations have daily values at that particular day will be a = (1.5b/11.6+ 1.4c/16.2+1.3d/22.2+1.5e/23.7)/4. Far away stations like that of Sehlabathebe are used in cases when most of the concurent rainfall data for nearer stations are also missing.

Table 3.9 Leribe, Mohale's Hoek, Mokhotlong, Moshoeshoe I and Qacha's Nek neighbouring stations distance and rainfall ratio used for ID method of estimation of daily rainfall missing values

Leribe			**Mohale's Hoek**			**Mokhotlong**		
Stations	**Dist. (km)**	**Ratio**	**Stations**	**Dist. (km)**	**Ratio**	**Stations**	**Dist. (km)**	**Ratio**
Qoqolosing	9.7	1.0	**Maphuts'eng**	7.6	1.1	**St James**	6.4	1.4
Maputsoe	11.5	1.0	**Paul VI**	22	1.3	**Libibing**	6.7	0.7
Mapoteng	17.8	1.0	**Mt Carmel**	20.1	1.2	**Malefiloane**	15.6	1.0
Pitseng	17.9	1.0	**Thabana Morena**	25	1.1	**Lelingoana**	19.5	1.1
Butha Buthe	23.4	1.0	**Seaka**	28.0	1.4	**St Martins**	30.7	0.8
Teyateyaneng	41.0	1.0	**Mafeteng**	42.6	1.0	**Lets'eng la Terai**	41.2	0.9
			Quthing	38.2	0.8	**Paray**	49.9	1.3
Moshoeshoe I			**Qacha's Nek**					
Stations	**Dist. (km)**	**Ratio**	**Stations**	**Dist. (km)**	**Ratio**			
Mazenod	4.0	1.0	**Tsoelike**	11.6	1.5			
Thaba Khupa	7.4	0.9	**Rapase**	16.2	1.4			
Bots'abelo	10.5	0.9	**Whitehill**	22.2	1.3			
Thaba Bosiu	14.8	1.0	**Ramats'eliso**	23.7	1.5			
Roma	16.2	1.1	**Sehlabathebe**	43.9	1.1			
Ts'ilo	17.2	0.9						
Mejametalana	17.9	0.9						

3.4.2.2 Results and Discussion

The statistical parameters (mean, median, skewness, kurtosis, 10^{th}, 20^{th}, 80^{th} and 90^{th} percentile) are represented for all the five stations (see Appendix 3). Almost all the parameters compare well and thus the generated daily rainfall is a good match for the observed daily rainfall. The results also show that, monthly rainfall to be positively-skewed with the observed value more or less similar to the generated values with few exceptions. Looking at Mohales' Hoek statistics (Appendix 3.2) for October, November and December, the 90^{th} percentile values show a great difference even though the median, mean values and the other statistics have less difference when compared to the generated values.

Table 3.10 shows the result of the KS test at 95% confidence interval for mean monthly rainfall total. In all the months with the exception of July, the D-statistic is less than the ? value for the stations Leribe, Mokhotlong and Mohale's Hoek While the results of Qacha's Nek show April to be the only month in which the D-statistic is more than the ?-value. The high D-statistic indicates that the two datasets (measured and generated) are not statistically similar. During the months of April to August the country receives low amount of rainfall and thus small differences in the values becomes statistically significant. For example, in July the measured median and mean monthly rainfall are 3.9mm and 10.8 mm respectively in Mohale's Hoek while the generated median and mean values are 3mm and 9mm. Also looking at the mean and median values at these months, there are high deviations between the measured and generated values. Moshoeshoe I station has all the months with D-statistic being less than ? value implying a good representation of the measured rainfall values. Fig 3.3 shows that the MAE for daily rainfall is small with the maximum of 2.1mm obtained at Qacha's Nek.

Table 3.10 Kolmogorov – Smirnov (KS) test for monthly rainfall totals at the five chosen stations (D_{max} = Maximum vertical distance between the hypothesized cumulative distribution function (CDF) and the empirical CDF and ? = Probability value that denotes the significance level)

	Qacha's Nek		**Mokhotlong**		**Mohale's Hoek**		**Moshoeshoe I**		**Leribe**	
	D_{max}	?	D_{max}	?	D_{max}	?	D_{max}	?	D_{max}	?
January	0.17	0.84	0.21	0.62	0.27	0.33	0.22	0.71	0.15	0.97
February	0.14	0.98	0.27	0.33	0.18	0.82	0.18	0.93	0.24	0.53
March	0.14	0.98	0.17	0.86	0.25	0.50	0.18	0.93	0.17	0.86
April	0.32	0.18	0.17	0.84	0.14	0.98	0.12	1.00	0.14	0.98
May	0.17	0.86	0.25	0.39	0.29	0.30	0.11	1.00	0.24	0.53
June	0.17	0.86	0.13	0.99	0.19	0.80	0.22	0.71	0.17	0.84
July	0.17	0.84	0.30	0.20	0.30	0.28	0.11	1.00	0.43	0.03
August	0.14	0.98	0.14	0.98	0.15	0.97	0.11	1.00	0.18	0.82
September	0.14	0.97	0.29	0.30	0.17	0.86	0.12	1.00	0.15	0.97
October	0.15	0.97	0.21	0.62	0.22	0.59	0.11	1.00	0.19	0.80
November	0.23	0.56	0.18	0.82	0.18	0.82	0.17	0.95	0.23	0.56
December	0.16	0.96	0.23	0.56	0.19	0.80	0.17	0.95	0.18	0.82

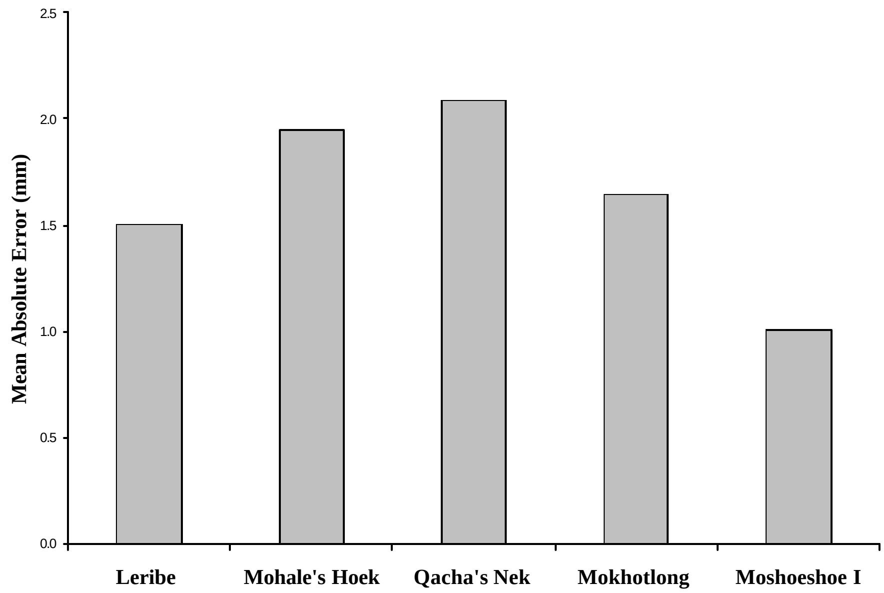


Fig 3.3 Average mean absolute error for average daily rainfall

3.5 Conclusions

The generation of weather data to use for patching of missing data in the climatological data record of Lesotho had been done using two different methods for the elements of temperature and rainfall. The daily maximum and minimum temperatures were filled using the modified UK method which showed little deviation from the measured data as shown by the KS tests in which the D-statistic was always less than the critical value (?-value). Other statistical parameters showed a good match. The MAE also showed on the whole values that were less than 1.8°C and 1.6°C for daily minimum and maximum temperatures. On average the maximum temperatures estimation was better than the minimum value estimations. Thus the linear equations used for the estimation of the daily maximum and minimum temperatures from the neighbouring stations data are reliable for patching the missing daily figures to a certain extent. This method was used for all stations in this study.

The inverse distance (ID) method used to estimate the daily rainfall resulted in fairly good result taking into consideration the spatial variability of rainfall. There was one month, namely July, at some stations which showed considerable difference in the measured and generated values, but overall the two datasets do not differ significantly. During the months when there is lack of match between the measured and generated values, the long-term values are very low and thus small deviations become statistically significant. One can conclude that the Inverse Distance method can be used in the estimation of the daily rainfall however, further investigations are needed to improve the estimations for specific months (April for Qacha's nek, July for Mohale's Hoek, Mokhotlong and Leribe). This method was used to patch all the daily rainfall values in Lesotho.

The whole exercise was performed in order to patch the missing daily maximum, minimum and rainfall values. Thus the data used for further analysis in this thesis is the measured values compensated by the generated values in cases of missing meteorological data.

Even though the monthly or dekadal totals compare well with the measured totals, the ID tends to level off the high daily amounts of rainfall and also increases the number rainy days within a certain period. For further research, determination of the number of rainy days within a given period and the ratio of rainfall during those days to the total rainfall at a neighbouring station can be investigated in order to alter the daily values with periodical sum staying the same.

Chapter 4 – Temperature Analysis

4.1 Introduction

Temperature is a basic climatological parameter frequently used as an index to the energy status of an environment (De Jager and Schulze, 1977). It is sometimes defined as the measure of the degree of heat or internal energy held in a substance (Buckle, 1996). Air temperatures taken at weather stations and quoted in climatic records are known as dry bulb recordings and are always shade measurements (Buckle, 1996). According to Tyson and Preston-Whyte (2000), the readings are made in degree Celsius (°C) on the scale from 0 (melting point of ice) to 100 (boiling point of water) or above the absolute zero of temperature (-273°C). The thermometers are housed in a specially ventilated wooden cabinet called a Stevenson screen (Buckle, 1996). The most commonly used temperature readings are the highest and lowest temperatures of the day which are usually measured with a maximum and minimum thermometer respectively in a standard manual weather station.

Temperature is a major environmental factor that changes from season to season and undergoes daily fluctuations with short, erratic lows and highs (Browse and Xin, 2001). Air temperature is determined by the rate at which solar radiation is received at any given point. Surface temperature anywhere is dependent on latitude, decreasing more or less steadily towards the poles in the southern and northern hemisphere. In tropical regions temperature is uniform whereas in the mid-latitudes like in Southern Africa there is more variability in temperature due to the seasonally varying air masses and winds (Linacre and Geerts, 1997; Hobbs *et al*., 1998). Continentality (distance from sea or ocean) affects the temperature regime in that, the temperatures near large lakes and oceans are generally moderated, while those over the continents experience extremes (Buckle, 1996; Linacre and Geerts, 1997; Schulze *et al*., 1997). Advection of heat in winds may affect surface temperature, especially when winds flow directly from high latitudes or from the poles. This is an important cause of day to day changes of temperatures at the mid-latitudes (Linacre and Geerts, 1997). Over much of southern Africa, temperature variations in time and space are largely dependent on topography (both the altitude and configuration of the land surface) according to Hobbs *et al*. (1998). The vertical temperature decrease of air on a mountainside is known as the topographic lapse rate (Buckle, 1996).

Temperature has a direct effect on all forms of life on earth, affecting a wide range of processes and activities ranging from human comfort and consequent energy supply and demand for heating and cooling, to crop and domestic animal responses, the incidence of pests and diseases and also rates of evaporation (Schulze *et al*., 1997; Jayamaha, 1979). Air temperature also has important influences on other weather elements, especially pressure, wind and humidity, and plays a role in the classification of climatic types (Buckle, 1996). In areas of high latitudes and high altitudes, temperature can be a limiting factor for plant growth and development. These areas are marked by extremely low temperatures. Plants can grow and thrive only between certain limits of temperature and between these limits (upper and lower temperatures) there is an optimum temperature which assures the most rapid growth for a particular species provided soil water and other requirements like nutrients are available (Jayamaha, 1979). These cardinal temperatures (upper, lower and optimal) differ from species to species and even within a given species from one stage of life cycle to next (Schulze *et al*., 1997).

4.2 Data and methods

4.2.1 Data

The daily maximum and minimum temperature measurements from 30 meteorological stations were used in the analysis of temperature. These data was obtained from the Department of Lesotho Meteorological Services (LMS). Fig 4.1 shows the network of the stations around the country with the majority of the stations situated in the lowlands and very few over the highlands and Senqu River Valley areas. The data from these stations is variable in that some stations have temperature readings from 1962 to date while a few stations only have records dating from 1990 (Table 4.1). The digitital elevation map in Lambert Equal-Area Azimuthal projection with the 1km by 1km resolution was obtained from the Southern African Development Community (SADC) Regional Remote Sensing Unit (RRSU).

Fig 4.1 Map showing location of Lesotho network of climate stations to be used for temperature analysis.

Table 4.1 Detailed information about climate stations in Lesotho to be used for the temperature analysis

Station	Lat.	Lon.	Alt. (m)	Period	Station	Lat.	Lon.	Alt. (m)	Period
Butha Buthe	-28.77	28.25	1770	1967 – 2004	**Nohana**	-30.05	27.85	1770	1989 – 2004
Kolbere	-29.28	28.50	2650	1979 – 2004	**Oxbow**	-28.72	28.62	2660	1961 – 2004
Lekubane	-29.42	27.93	2360	1970 – 2004	**Pitseng**	-28.95	28.22	1780	1975 – 2004
Leribe	-28.88	28.05	1740	1967 – 2004	**Qachas Nek**	-30.12	28.7	1970	1968 – 2004
Letseng la Terai	-29.00	29.00	3050	1963 – 1991	**Quthing**	-30.42	27.72	1740	1968 – 2004
Mafeteng	-29.82	27.25	1610	1987 – 2004	**Roma NUL**	-29.45	27.73	1650	1968 – 2004
Malefiloane	-29.33	29.22	2887	1990 – 2004	**Sani Pass**	-29.58	29.28	2440	1992 – 2004
Mapoteng	-29.02	27.95	1725	1984 – 2004	**Sehlabathebe**	-29.88	29.07	2320	1975 – 2004
Matela	-29.38	27.75	1775	1980 – 2004	**Semonkong**	-29.83	28.1	2458	1977 – 2004
Matsieng	-29.62	27.57	1800	1990 – 2004	**St James**	-29.35	28.02	2250	1971 – 2004
Mejametalana	-29.3	27.5	1530	1968 – 2004	**St Martins**	-29.28	28.75	2270	1978 – 2004
Mohales Hoek	-30.15	27.47	1620	1971 – 2004	**Teyateyaneng**	-29	28	1690	1968 – 1992
Mokhotlong	-29.28	29.07	2230	1967 – 2004	**Thaba Bosiu**	-29.35	27.67	1600	1990 – 2004
Moshoeshoe I	-29.45	27.57	1628	1985 – 2004	**Thaba Tseka**	-29.93	27.4	2160	1976 – 2004
Mt Moorosi	-30.27	27.88	1625	1990 – 2004	**Thabana Morena**	-29.55	28.58	1680	1985 – 2004

4.2.2 Data processing

The complete dataset of maximum and minimum temperatures were processed using different computer packages. Instat+ software was used in the generation of both maximum and minimum monthly averages and the generation of monthly heat units in degree days. Determination of the onset of frost, cessation and duration of frost were done in both Microsoft Excel and the Instat+ software.

4.2.3 Interpolation of monthly values

The interpolation of monthly maximum and minimum temperature values was done using Arcview 8.3. First the point values were converted to the shape file. The converted layer was then changed to the raster format with 1 km resolution to match the resolution of the elevation map. The regression model for every month for all the parameters was determined using the monthly values and altitude of the station (Yazdanpanah *et al*., 2001). The model was used to create the surface from the DEM using raster calculator. The two resultant maps were merged giving priority to the actual values at the stations.

4.3 Results and Discussion

4.3.1 Minimum temperatures

Mean monthly minimum temperature for January ranges from 4.8°C recorded in Letse'eng la Terai to the highest of 15.6°C in Thabana-Morena (appendix 4.1). Sani Pass, Oxbow and Sehlabathebe stations also recorded low mean monthly minimum temperatures of 6°C, 7°C and 8°C respectively. In contrast, high mean monthly minimum temperatures recorded at Moshoeshoe I, Matsieng and Mapoteng with 14.9°C, 14.9°C and 15.5°C respectively were considerably higher. As seen in Fig. 4.2, the northeastern and eastern part of the country experience low (less than 6°C) minimum temperatures. This area of low temperature is mostly evident in Butha Buthe, Thaba Tseka and Mokhotlong districts. The highlands of Qacha's Nek, Maseru, Mohale's Hoek, Berea and Leribe districts also experience minimum temperatures below 8°C in January. In general, the western part of the country experience relatively high minimum temperatures as compared to the rest of the country with temperatures exceeding 14°C. Area of high temperature is also evident at the Senqu River Valley in the south along the boundaries of Mohale's Hoek and Quthing districts.

Spatial distribution of mean monthly minimum temperatures for February is more or less the same as that of January (Fig. 4.2). On average the northeastern, eastern parts and the central parts experience lower mean monthly minimum temperatures while the north-western to southwestern parts recorded high mean monthly temperatures. This area is comprised of the lowlands and some part of the Senqu River valley regions. The foothills and the northern part of the Senqu River valley experienced moderate mean monthly minimum temperatures. The measured mean monthly mimimum temperatures ranges from 5.5°C to 15.5°C during the month of February (Appendix 4.1).

The minimum temperatures show a drastic decrease during the month of March with a range of 4°C to 13.6°C (Appendix 4.1). On average the highlands record a mean monthly minimum temperatures of less than 6°C while the lowlands and southern part of the Senqu River Valley record higher temperatures of greater than 12°C (Fig. 4.3). In April the range from the observed data ranges from 0.8°C to 10.8°C (Appendix 4.2). As seen from Fig. 4.3, April minimum temperatures are lower than that of March with the whole area of the districts of Mokhotlong and Thaba Tseka experiencing less than 6°C. The lowlands are also experiencing relatively low temperatures in April.

On the whole mean monthly mimimum temperatures for May are below 6°C throughout the country (Fig. 4.4). The range is from -2.8°C in the Highlands to 7.1°C in the Lowlands (Appendix 4.2). The higher temperature values are still biased towards the western part of the country while the eastern part experiences relatively low minimum temperatures. In June the spatial distribution of temperature is the same as May but the values have dropped significantly. Almost the entire country is having minimum temperature of less than 2°C with the exception of a few places in the Lowlands and Senqu River Valley (Fig. 4.4). The range in the observed data is from -6.1°C to 4.3°C (Appendix 4.2). In July the temperature range dropped to -6.5°C to 3.6°C (Appendix 4.3).

The whole country is recording mean monthly minimum temperature of less than 2°C (Fig. 4.5). In August the minimum temperatures are starting to rise with the range of -3.8°C to 6.1°C. The low-lying areas recorded temperatures in excess of 2°C while the high-lying areas still have their monthly minimum temperatures of less than 2°C.

In September the mean monthly minimum temperatures ranges from -0.2°C to 9.2°C (Appendix 4.3) and over the high-lying layers the temperatures are less than 4°C while a few of the low-lying areas record temperatures greater 6°C (Fig. 4.6). In October the country is starting to experience warm weather with the reduction in area of monthly minimum temperature with less than 4°C. The range from the observed values ranges is from 1.5°C to 11.6°C (Appendix 4.4). Mean monthly minimum temperatures in the month of November are also high in the western parts of the country and low over the north eastern and eastern highlands. The lowlands (Mafeteng, Maseru, Berea, Leribe, Butha Buthe, Mohale’s Hoek and Quthing) are experiencing temperatures in the excess of 10°C while the highlands temperatures are still below 6°C. The observational range is from 3.1°C to 13°C (Appendix 4.4). The temperatures in December are relatively higher than that observed in November with the range from 4.5°C to 14.9°C. Some places over Berea, Maseru, Mafeteng, Mohale’s Hoek and Quthing are having minimum temperatures higher than 14°C (Fig. 4.7).

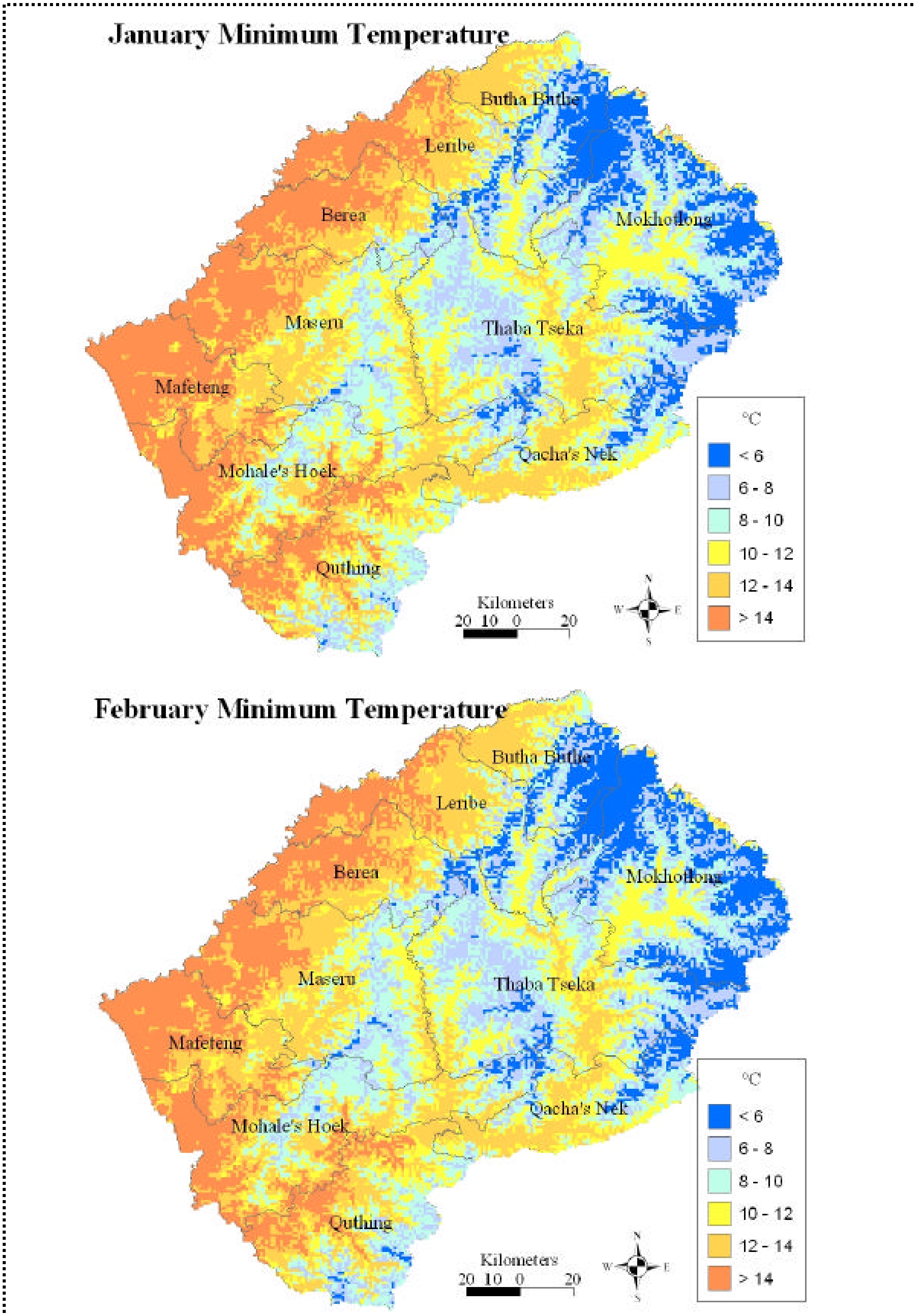


Fig 4.2 Maps of mean monthly minimum temperature for January and February

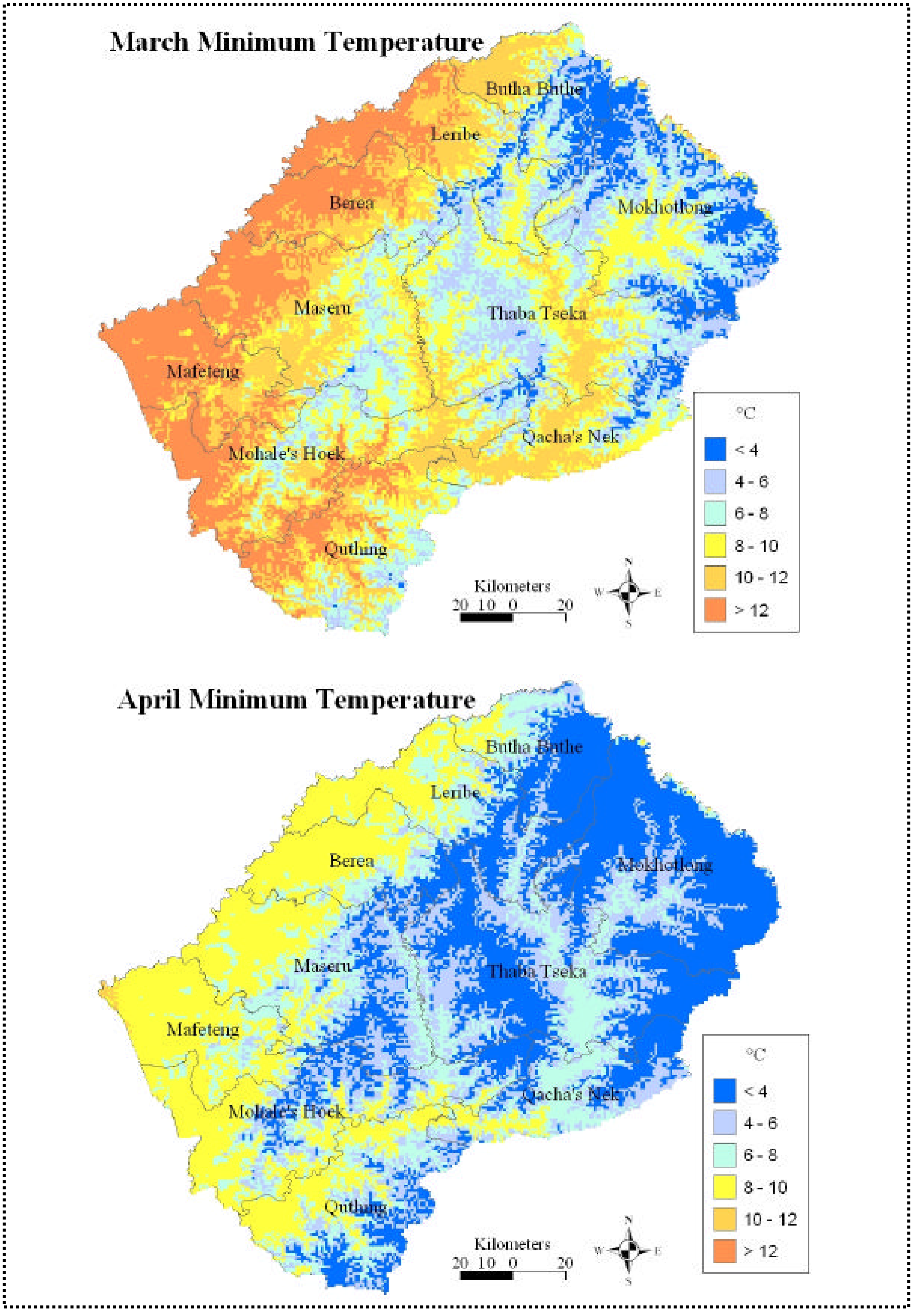


Fig 4.3 Maps of mean monthly minimum temperature for March and April

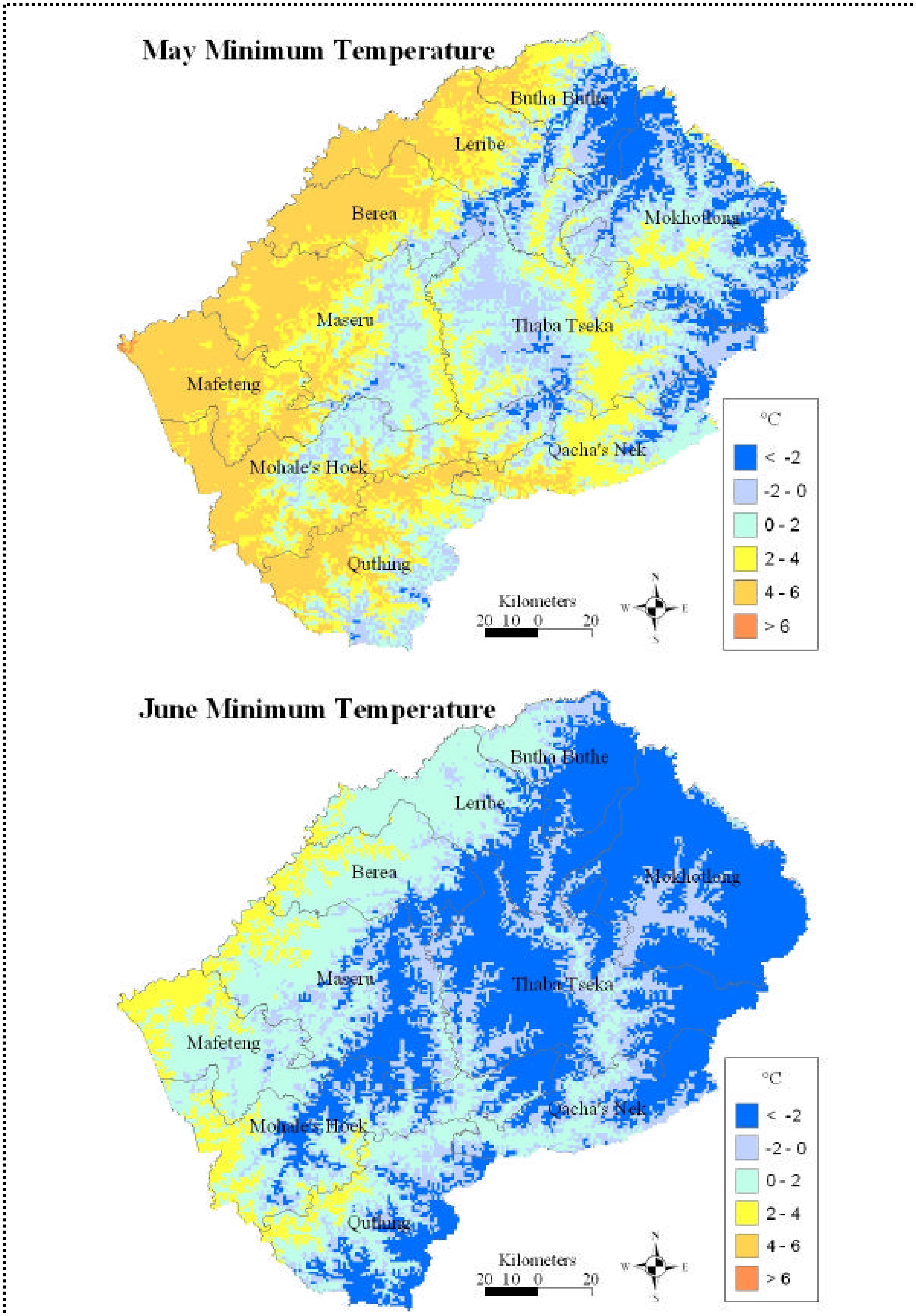


Fig 4.4 Maps of mean monthly minimum temperature for May and June

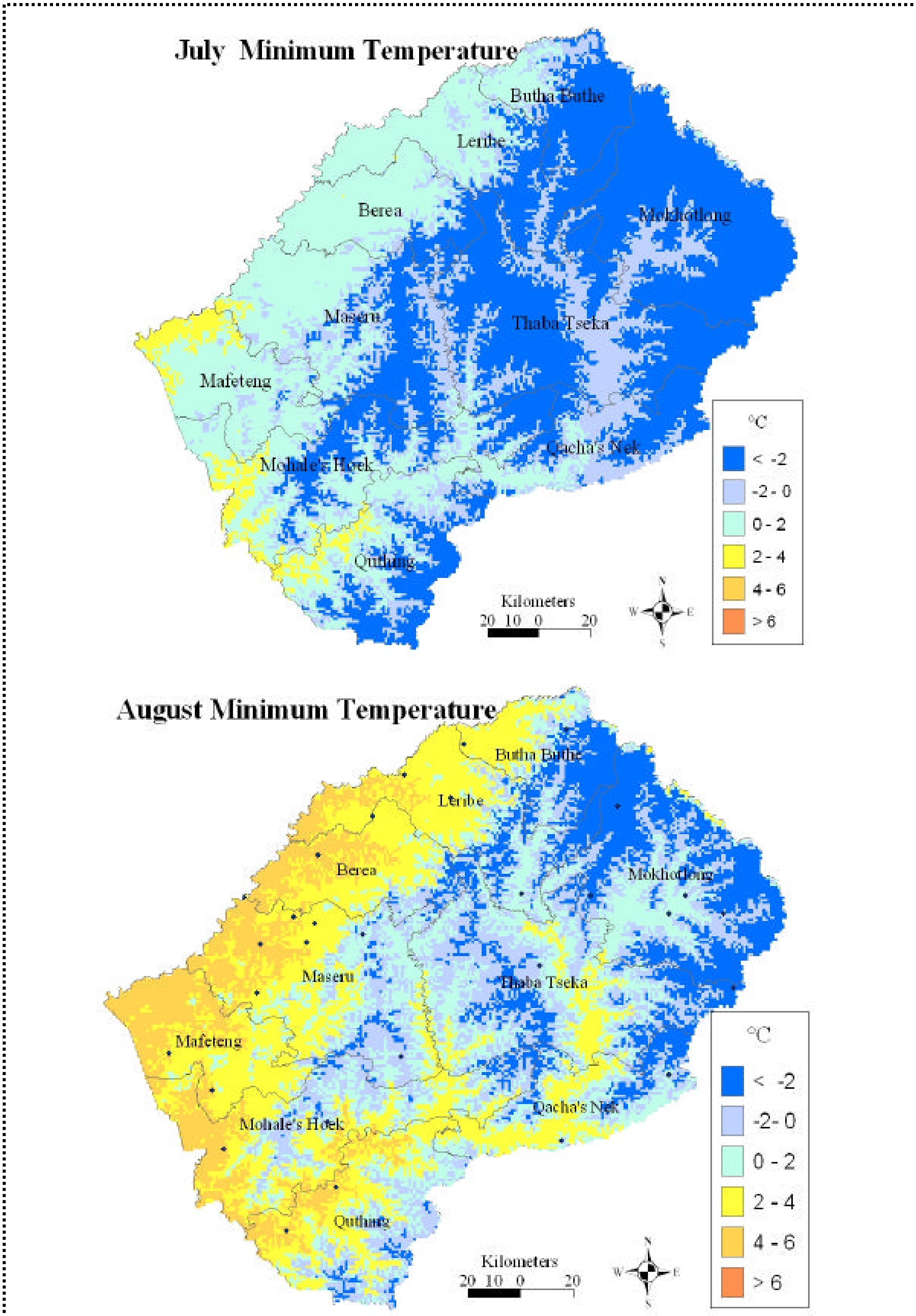


Fig 4.5 Maps of mean monthly minimum temperature for July and August

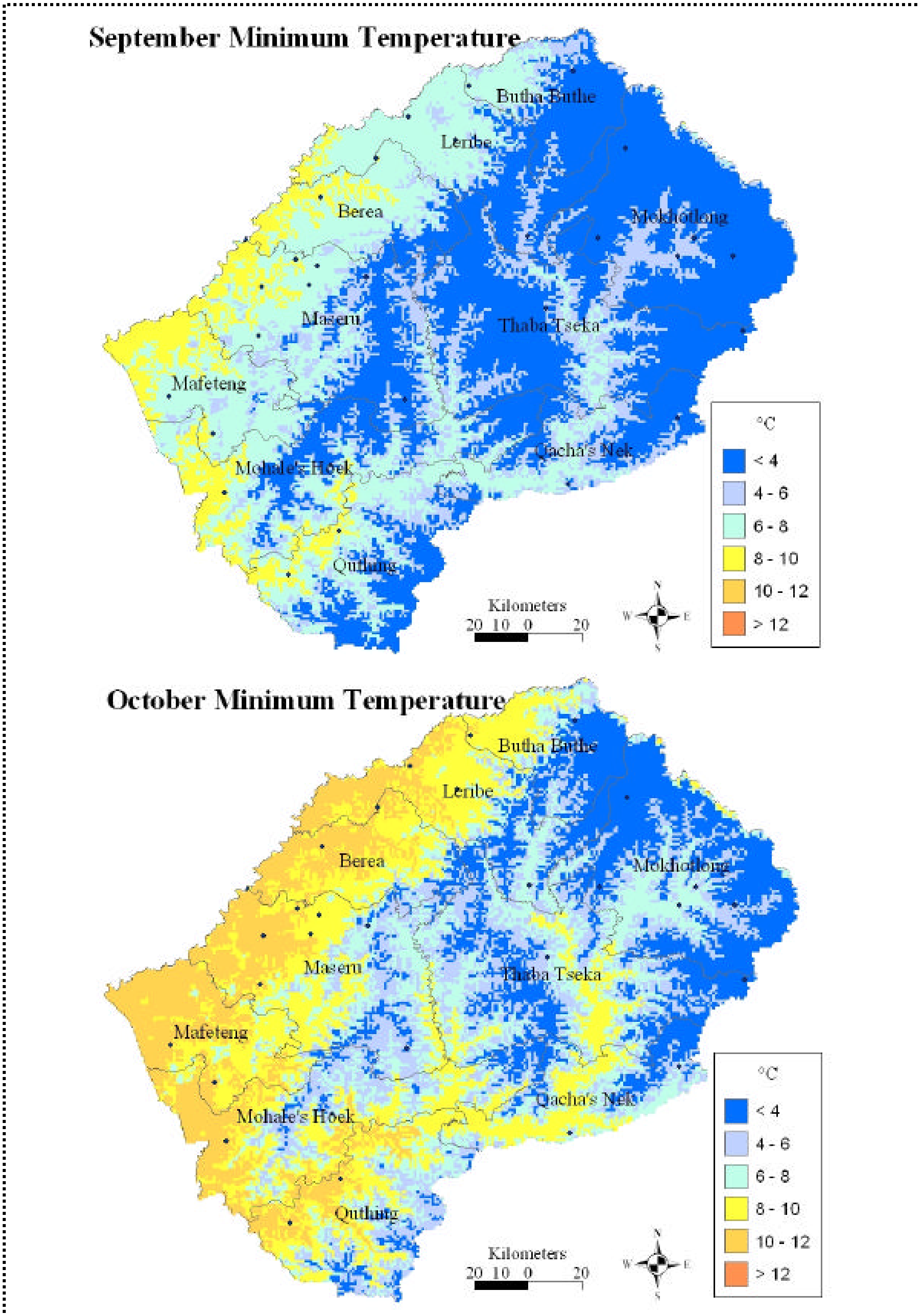


Fig 4.6 Maps of mean monthly minimum temperature for September and October

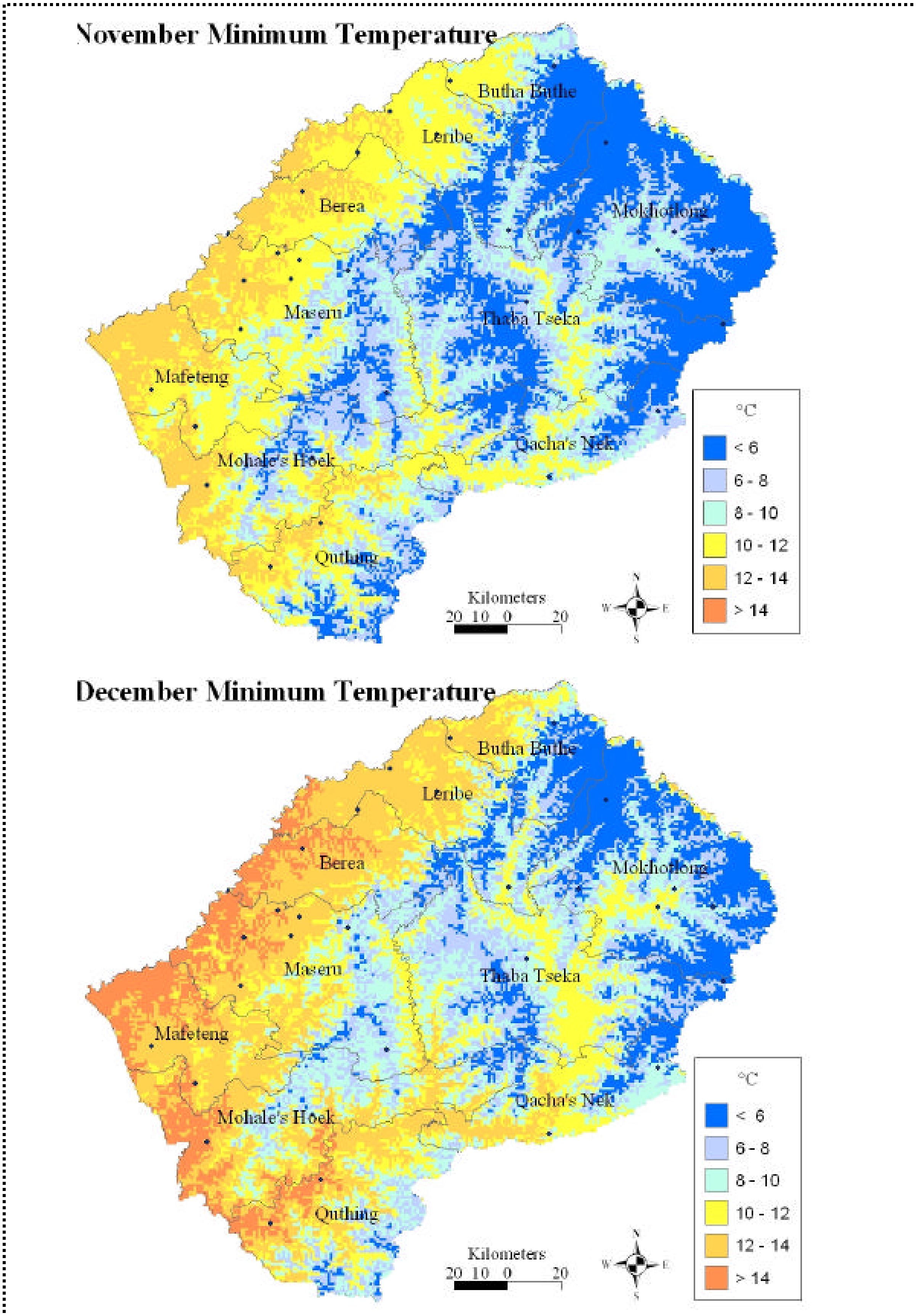


Fig 4.7 Maps of mean monthly minimum temperature for November and December

4.3.2 Maximum temperatures

Mean monthly maximum temperature for the month of January ranges from 16.5°C to 28.7°C being the hottest month of the year (Appendix 5.1). Just like in the mean monthly minimum temperatures, the high-lying areas over the northeastern and eastern parts of the country record relatively low temperatures with some places experiencing less than 18°C (Fig. 4.8). In the low-lying areas temperatures above 28°C are experienced over the western and southwestern parts of the country. In February the observed mean monthly maximum temperature starts from 15.8°C to 28.1°C slightly lower than January. Low monthly maximum temperatures are recorded in Lets'eng la Terai, Sani Pass and Oxbow with 15.8°C, 16.3°C and 17.9°C respectively (Appendix 5.1). High maximum temperatures are recorded in Mt Moorosi, Mejametalana and Mohale's Hoek with 28.1°C, 27.6° and 27.4°C respectively. The area with temperatures in excess of 28°C is only confined to few places (Fig. 4.8). In March the temperatures are starting to drop by around 2°C from the previous month. The lowest mean monthly maximum recorded is 13.9°C at Lets'eng la Terai with the highest value of 26.2°C at Mt Moorosi (Appendix 5.1). The central and eastern parts of the country are experiencing mean monthly maximum temperatures of lower than 20°C while the eastern and southeastern parts are having maximum temperatures of over 20°C (Fig. 4.9). Many districts with exception of Mokhotlong and Thaba Tseka are mostly experiencing temperatures greater than 20°C. April mean monthly maximum temperatures range from 11.2°C to 23.1°C (Appendix 5.2). Compared to March, April records lower maximum temperatures (Fig. 4.9).

May temperatures are low and the observed mean monthly maximum temperatures range from 8.7°C to 19.4°C (Appendix 5.2). The central, northeastern and eastern parts of the country receive temperatures of less than 14°C while the western lowlands and southwestern parts record high monthly maximum temperatures of greater than 18°C (Fig. 4.10). In June the monthly maximum temperatures are extremely low with the lowest of 6.1°C to 17°C (Fig. 4.10). July temperatures are also low with over 80% of the country experiencing less than 16°C mean monthly maximum temperature. The range is from 6.5°C to 16.9°C (Appendix 5.3). Therefore, June and July are the coldest months. In August the temperatures are starting to increase (Fig. 4.11). The mean monthly maximum temperature range from 8.6°C recorded over the high-lying areas to 19.8°C recorded in the low-lying areas.

September is marked by a further increase in temperatures, some places over the lowlands and the southern part of the Senqu River valley record mean monthly maximum temperatures greater than 22°C (Fig. 4.12). The temperature range is from 11.8°C to 23.3°C (Appendix 5.3). October mean monthly maximum temperatures are ranging from 13°C to 25.3°C (Appendix 5.4). The lowlands and Senqu river valley are having monthly maximum temperatures in the excess of 24°C. Temperatures less than 18°C are experienced at the high-lying areas with Thaba Tseka and Mokhotlong districts showing higher area of low temperature. In November there is a slight increase in the mean monthly maximum temperatures with the range of 14.3°C to 26.3°C. Few areas in the districts of Berea, Maseru, Mafeteng, Mohale's Hoek and Quthing are having temperatures greater than 26°C. The high-lying areas are still having less than 18°C (Fig. 4.13). Compared to November, December is slightly warmer with a few places experiencing over 28°C (Fig. 4.13). The temperature range from the observed data in this month is from 15.7°C to 28.2°C (Appendix 5.4).

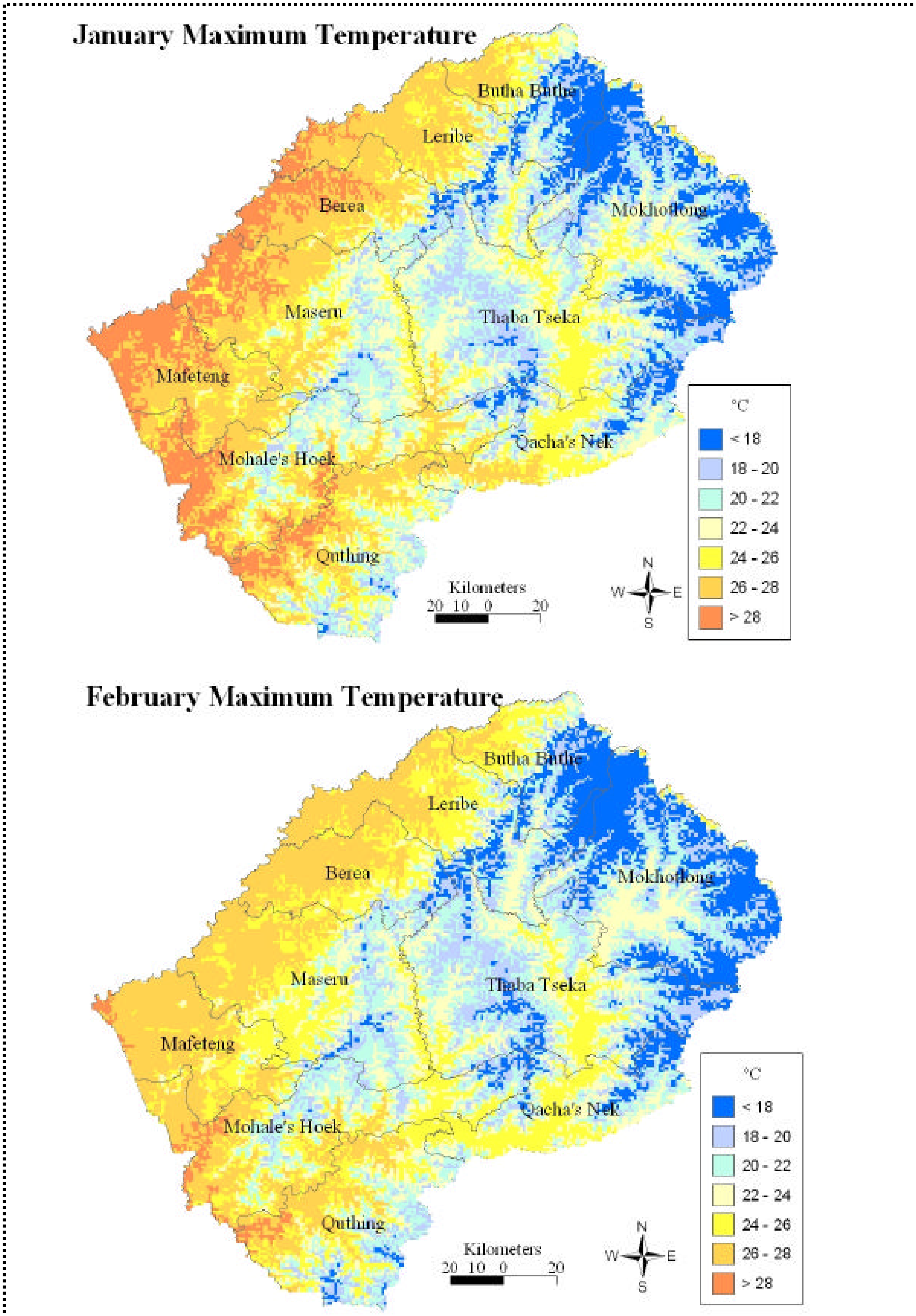


Fig 4.8 Maps of mean monthly maximum temperature for January and February

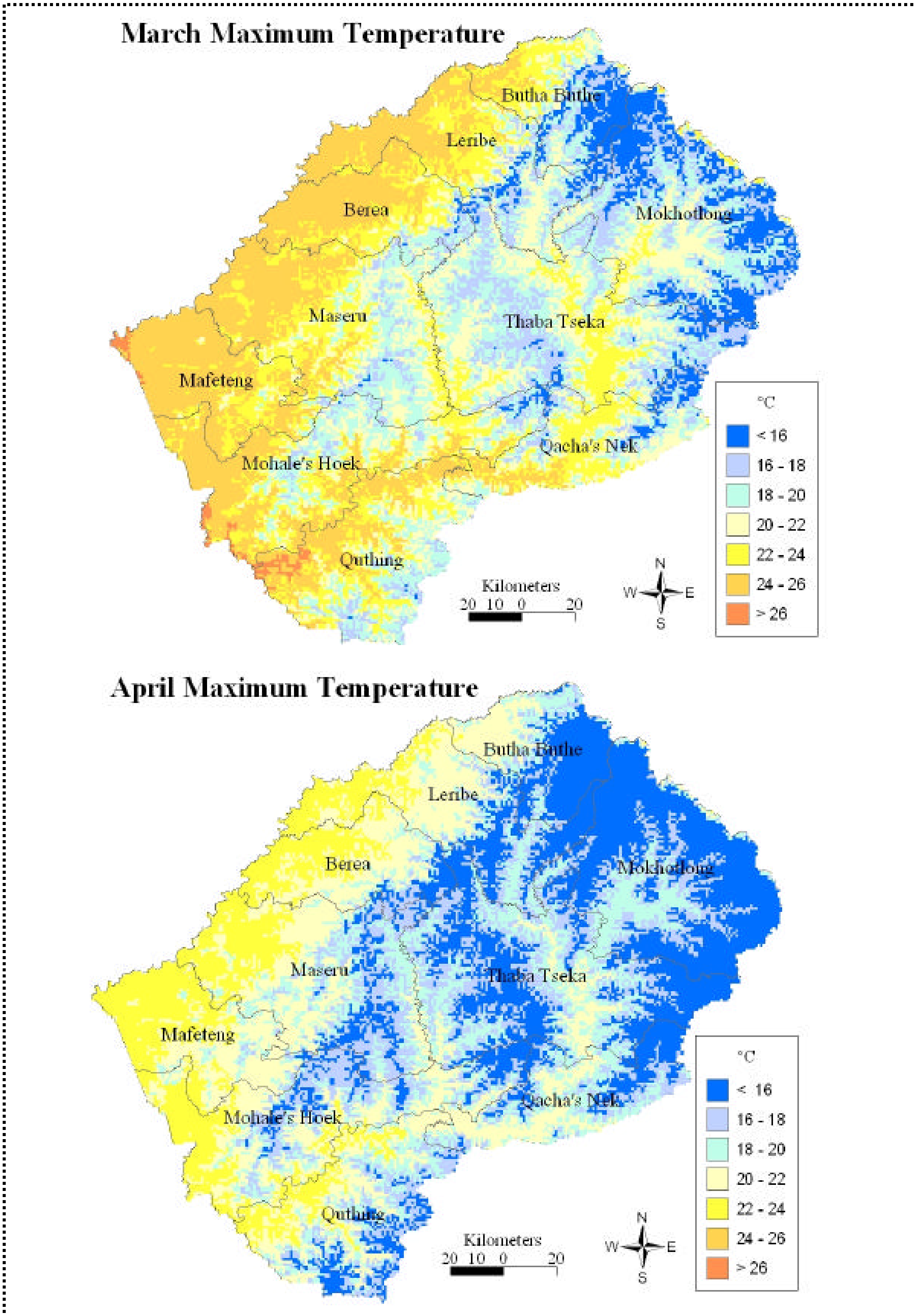


Fig 4.9 Maps of mean monthly maximum temperature for March and April

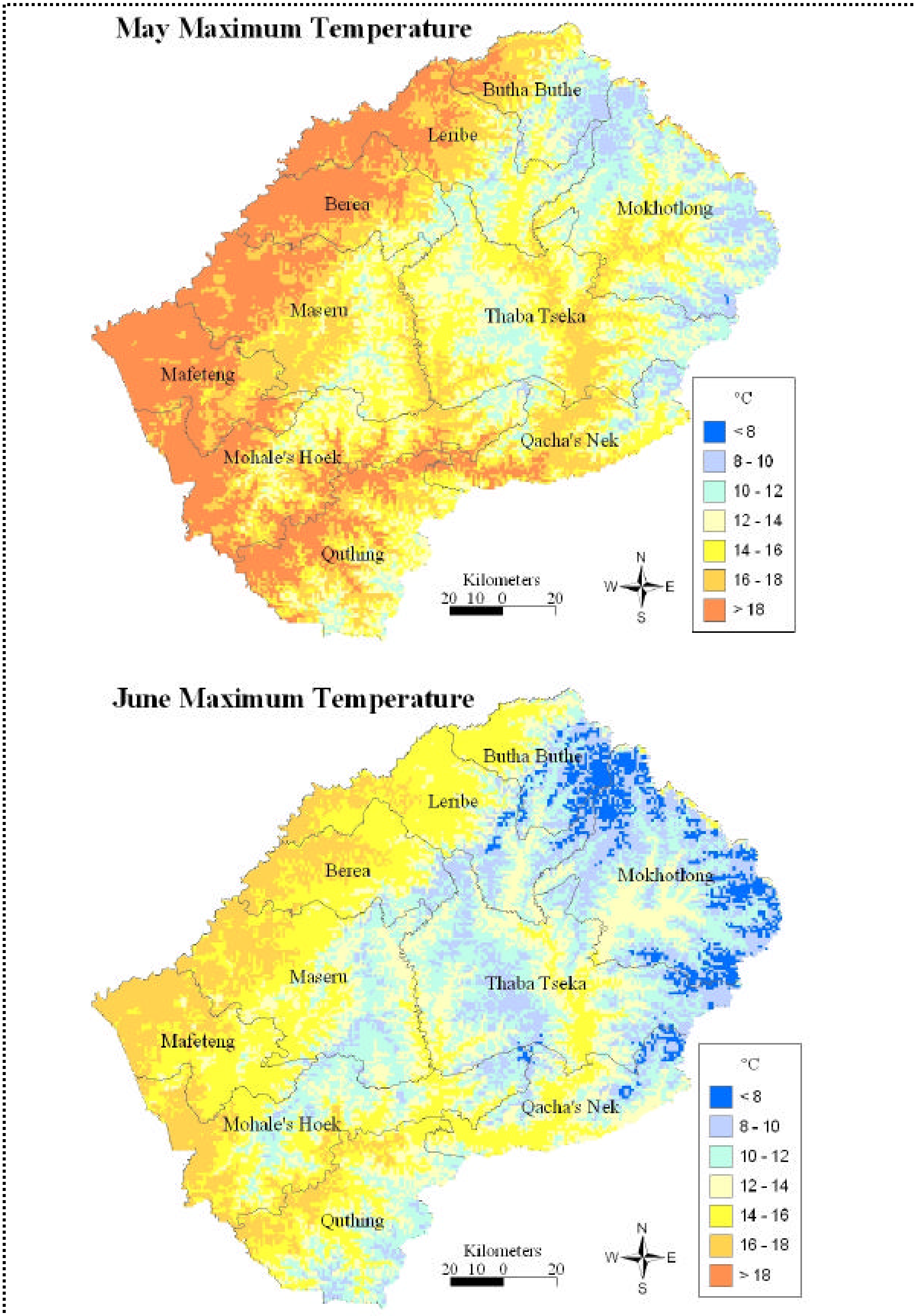


Fig 4.10 Maps of mean monthly maximum temperature for May and June

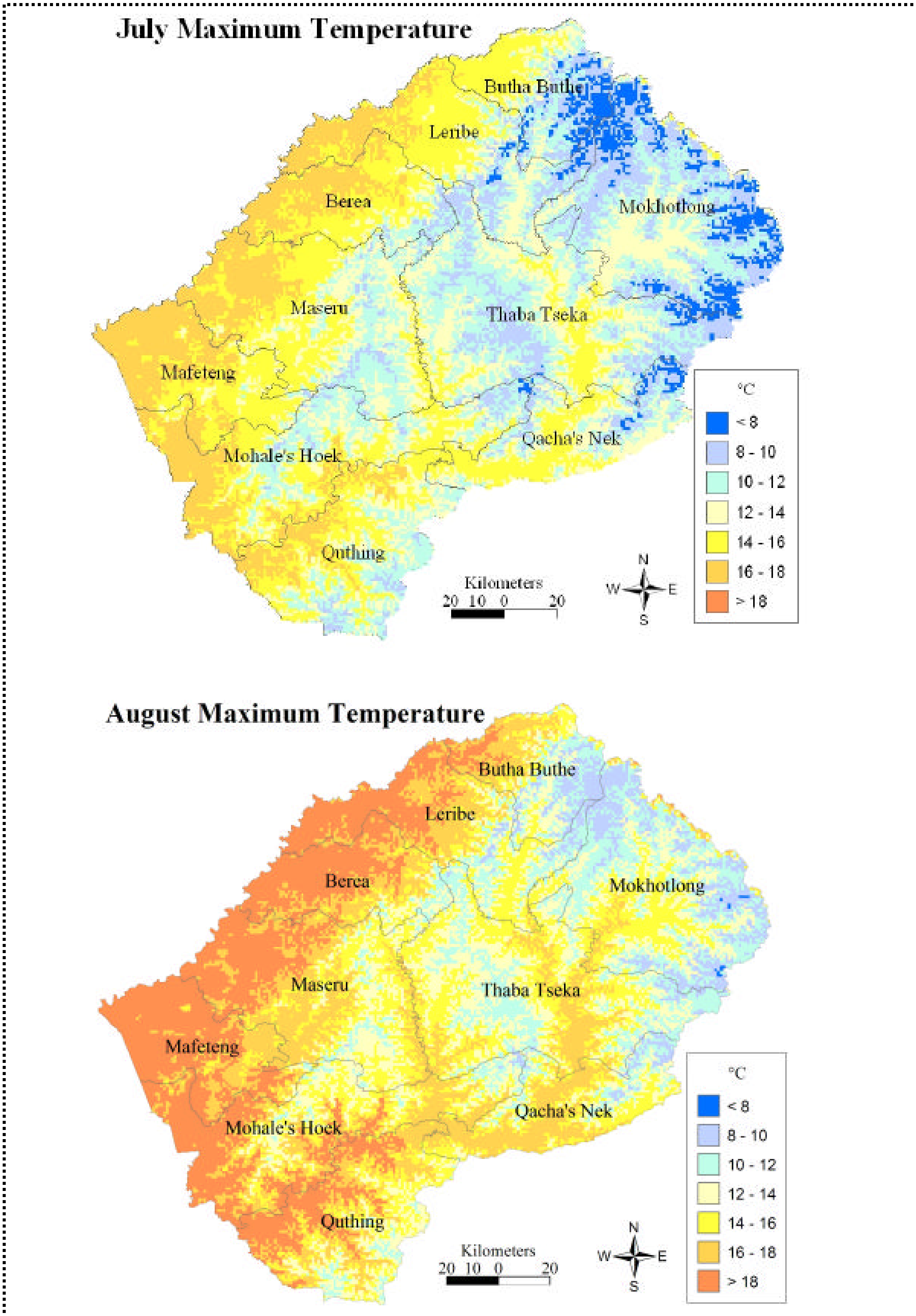


Fig 4.11 Maps of mean monthly maximum temperature for July and August

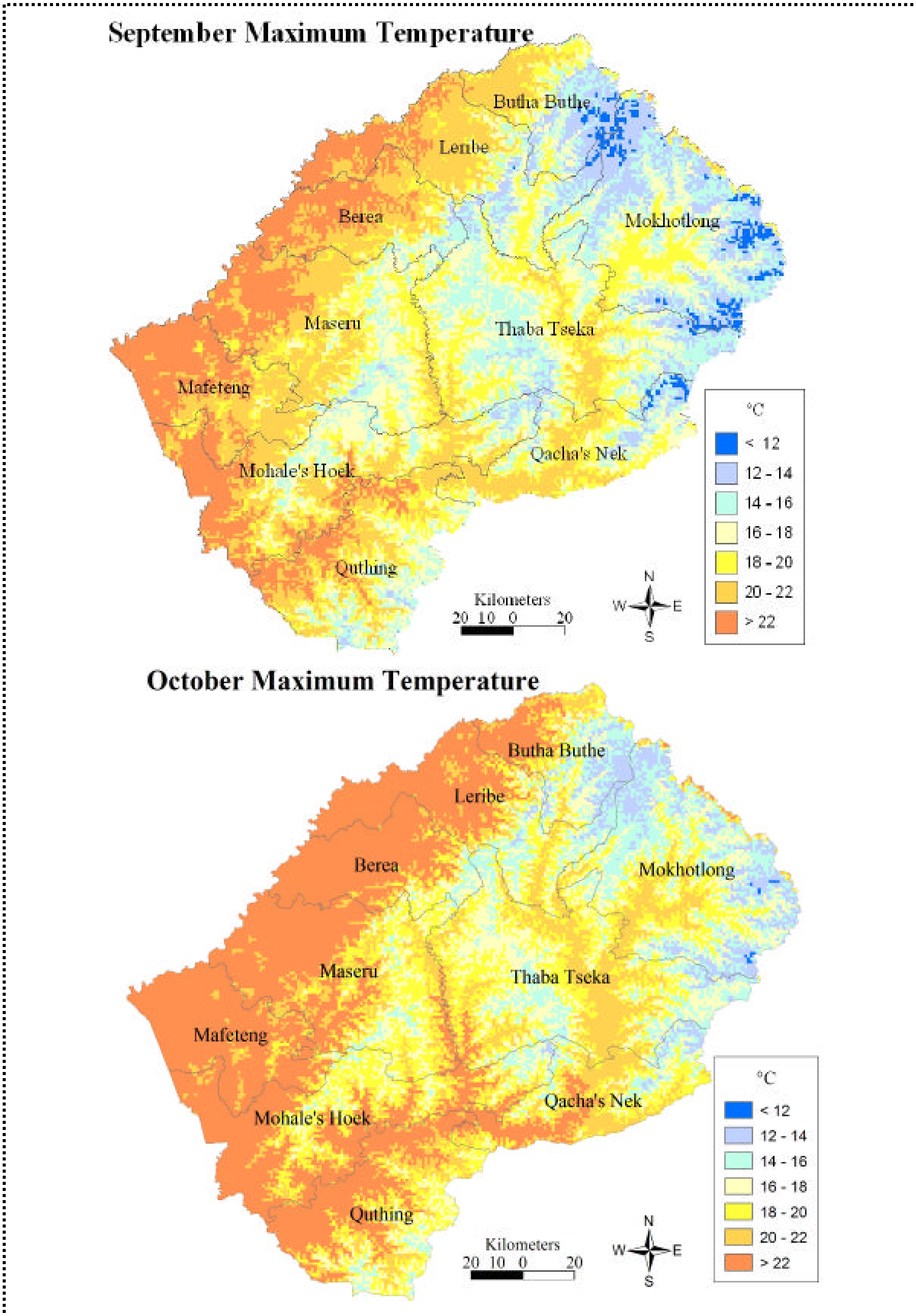


Fig 4.12 Maps of mean monthly maximum temperature for September and October

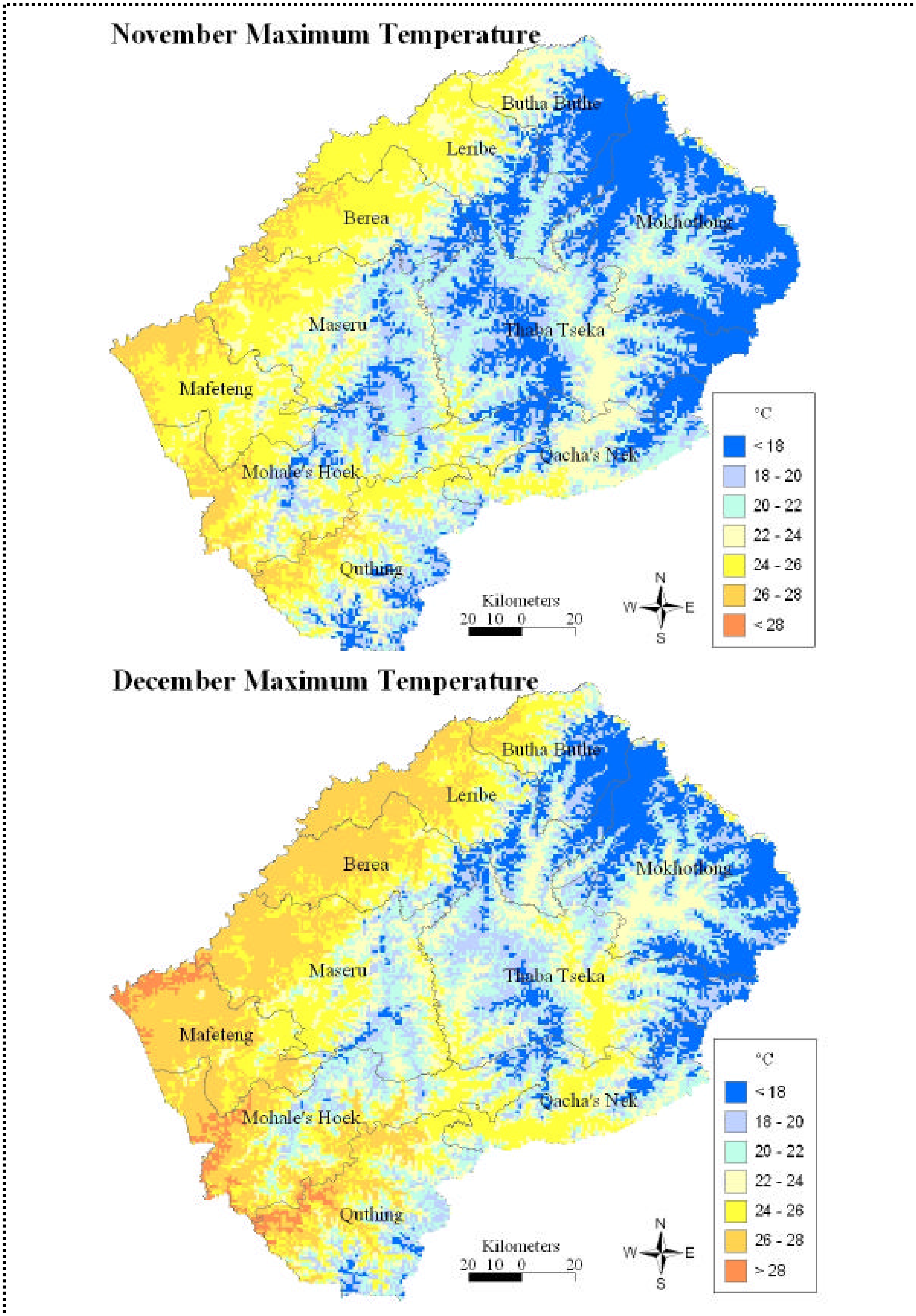


Fig 4.13 Maps of mean monthly maximum temperature for November and December

4.3.3 Growing degree days/Heat units

The January accumulated heat units with 10°C as the base temperature is spatial distributed like the mean monthly minimum and maximum temperatures. The heat units are higher over the lowlands and Senqu River valley and relatively less over the highlands (Fig. 4.14). They range from 45GDD to 363GDD (Appendix 6.1) with Mejametalana, Thaba Bosiu and Mt Moorosi recorded the highest values of 363GDD, 361GDD and 358GDD respectively. The values dropped slightly for February with the range of 31GDD to 326GDD. The low-lying areas record degree days greater than 300GDD while the highlands register monthly heat units of less than 100GDD. In March the growing degree range from 12GDD to 301GDD (Appendix 6.1), while April showed a great drop in the heat units with the amounts ranging from 1GDD to 196GDD (Appendix 6.2). This is attributed to the fall in both daily maximum and minimum temperatures during this month. Over 80% of the country experienced less than 150GDD (Fig. 4.15) but in some places over the low-lying the heat units are in the excess of 150GDD.

May also show very low heat units accumulation with the range of 0GDD to 92GDD (Appendix 6.2). On the whole, the Highlands record less than 10GDD with the exceptions of the lowlands and some parts of the Senqu River Valley which register more than 80GDD (Fig. 4.16). In June and July almost no heat units are accumulated over the country with few stations recording over 10GDD. In August there is a slight increase in the accumulated heat units with the range of 0GDD to 72GDD (Appendix 6.3). The western and southwestern receive over 60GDD in this month (Fig. 4.17).

In September the monthly heat units are slightly higher than the previous month. There are areas which are experiencing over 100GDD while over the highlands the values are lower than 50GDD (Appendix 6.3). October also shows an increase in the accumulated heat units with the minimum of 6GDD and the maximum of 251GDD (Appendix 6.4). The low-lying areas record heat units of over 200GDD in this month (Fig. 4.18). In November the observed heat units ranges from 11GDD to 281GDD. In December the observed heat units range from 24GDD to

338GDD. Higher accumulation of heat units are also seen over the western and southwestern parts with over 300GDD (Fig. 4.19).

October is the first month with relatively high degree days and corresponds to the beginning of rainfall over the country of Lesotho and thus it is considered as start of the growing season which extends to April. Seasonal heat units (accumulated from October to April) are in the range 132GDD to 2056GDD (Table 4.2). The heat units requirement for maize is the minimum of 1500GDD. As seen from Fig. 4.20, the highlands have less than 1000GDD so it is insufficient for a maize crop to grow to full maturity while the lowlands record over 1800GDD. Mt Moorosi, Mejametalana, Thaba Bosiu and Mapoteng recorded the highest seasonal heat units of 2056GDD, 1944GDD, 1942GDD and 1921GDD respectively. The lowest seasonal heat units are accumulated over Lets'eng la Terai, Sani Pass and Oxbow with 132GDD, 207GDD and 300GDD respectively.

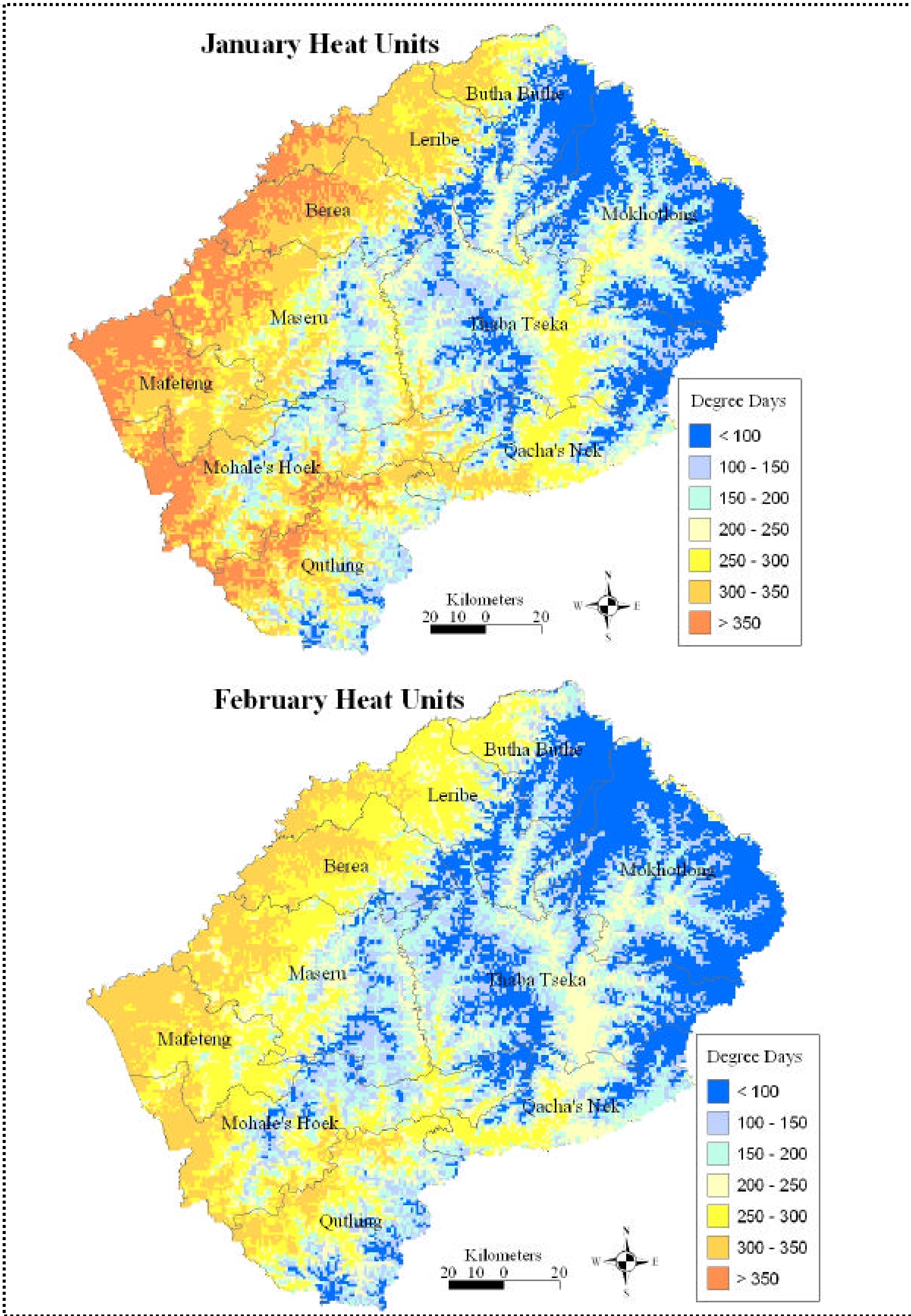


Fig 4.14 Maps of mean monthly heat units for January and February

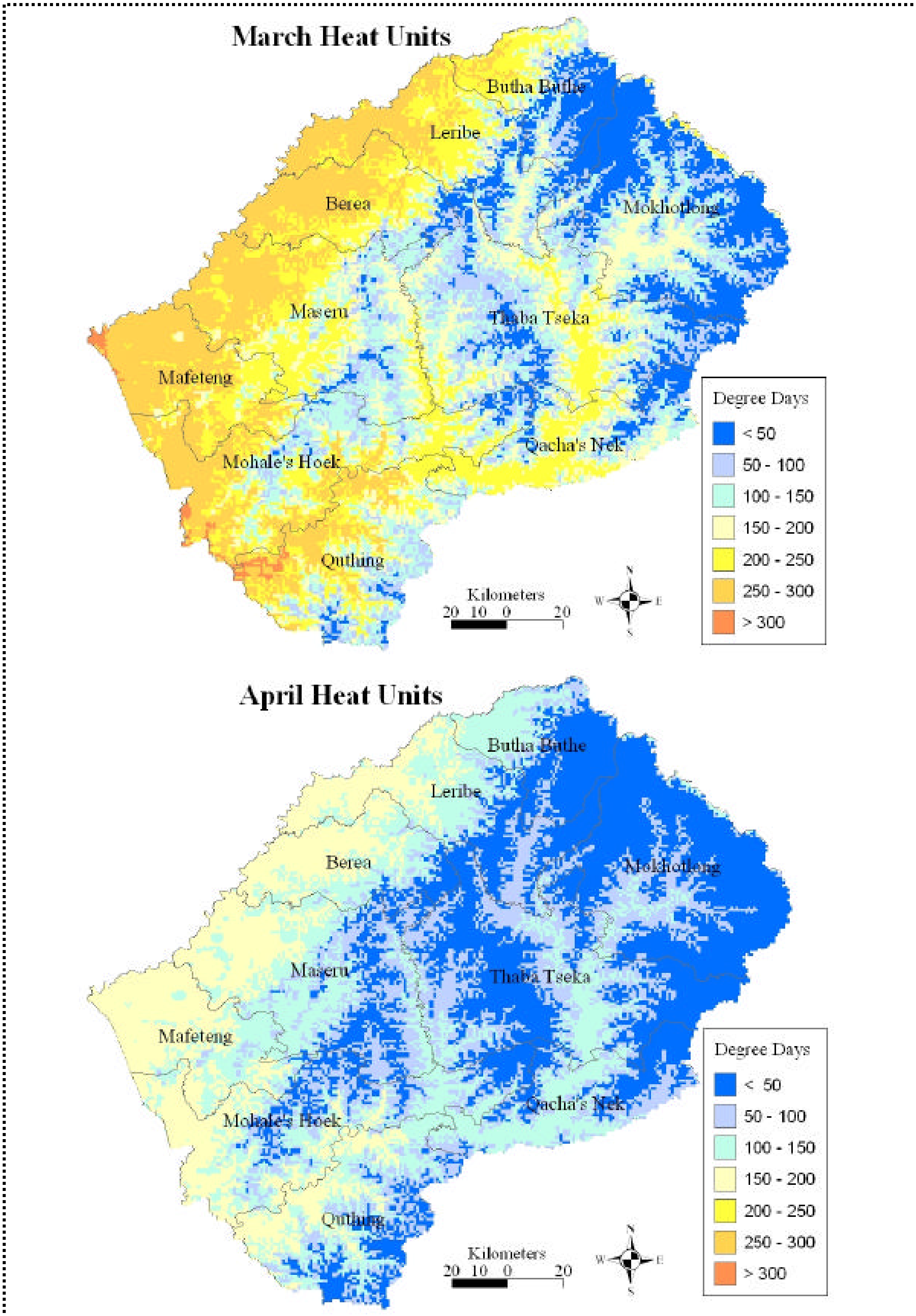


Fig 4.15 Maps of mean monthly heat units for March and April

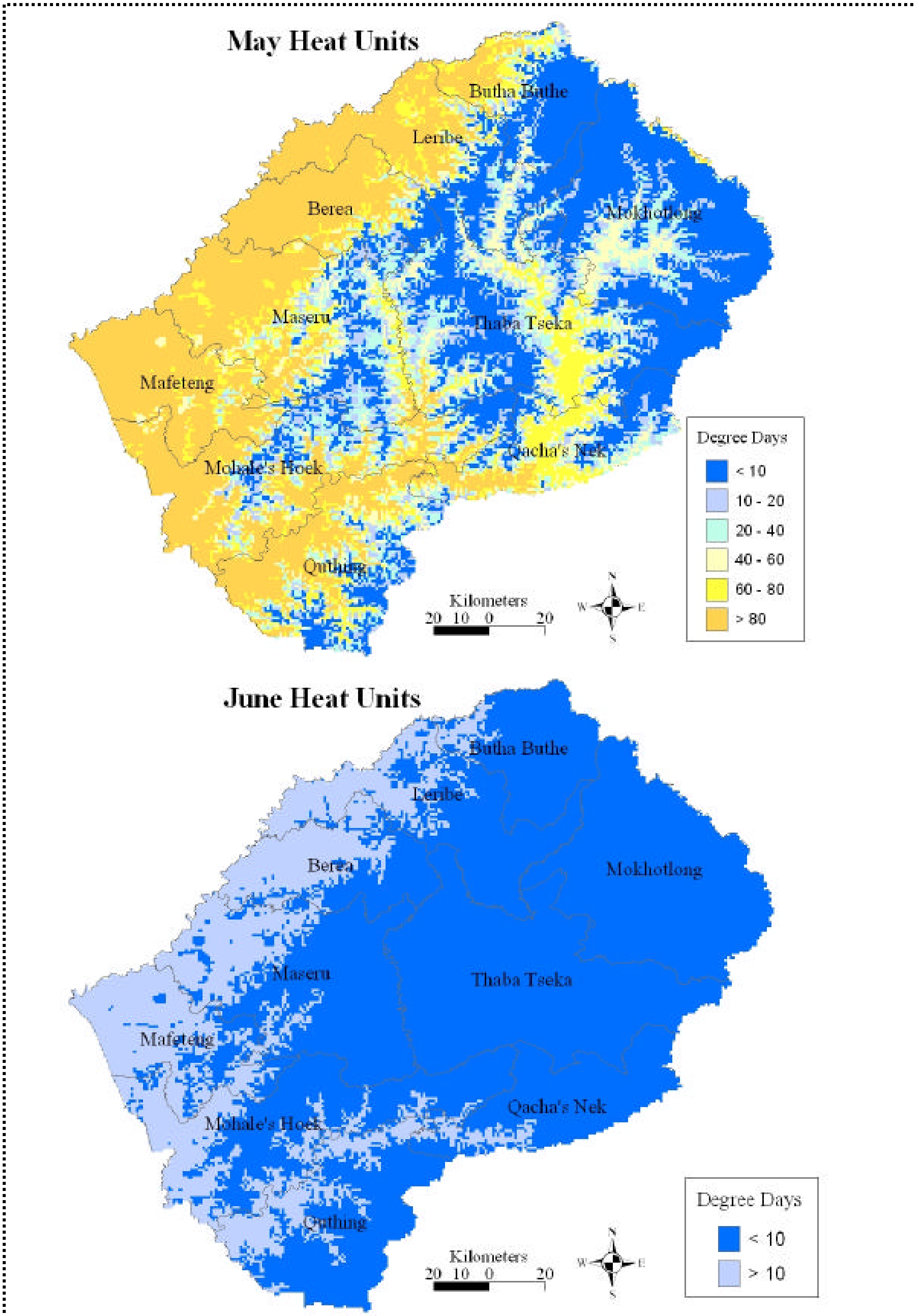
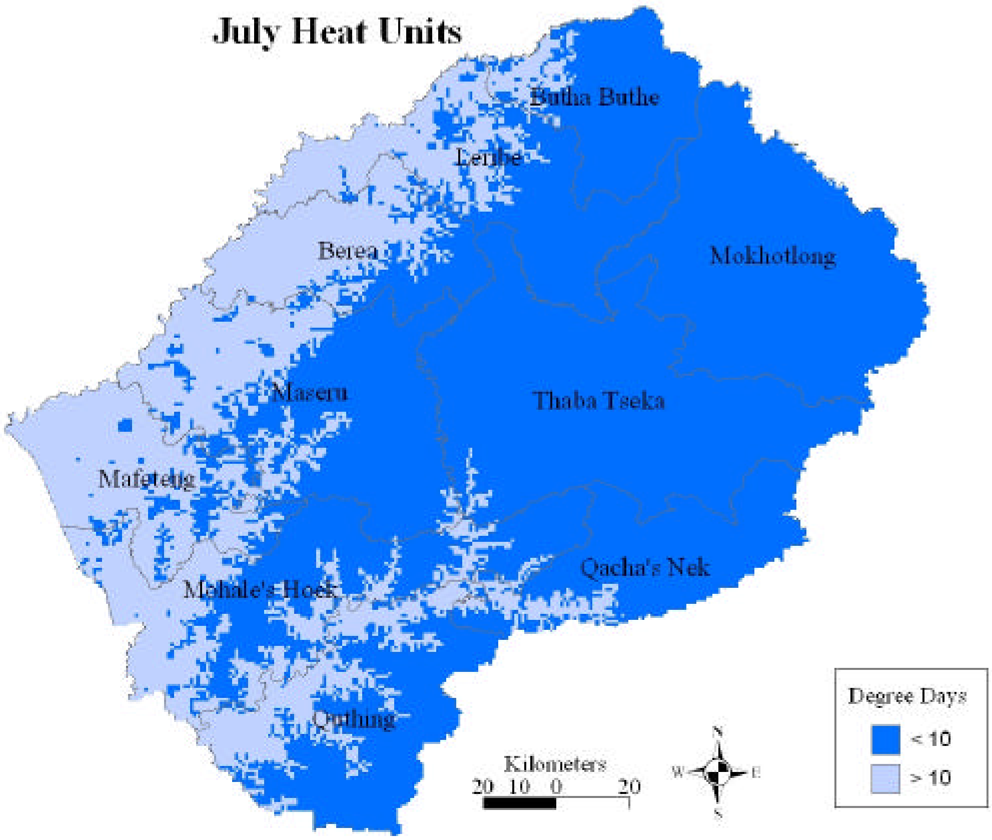


Fig 4.16 Maps of mean monthly heat units for May and June



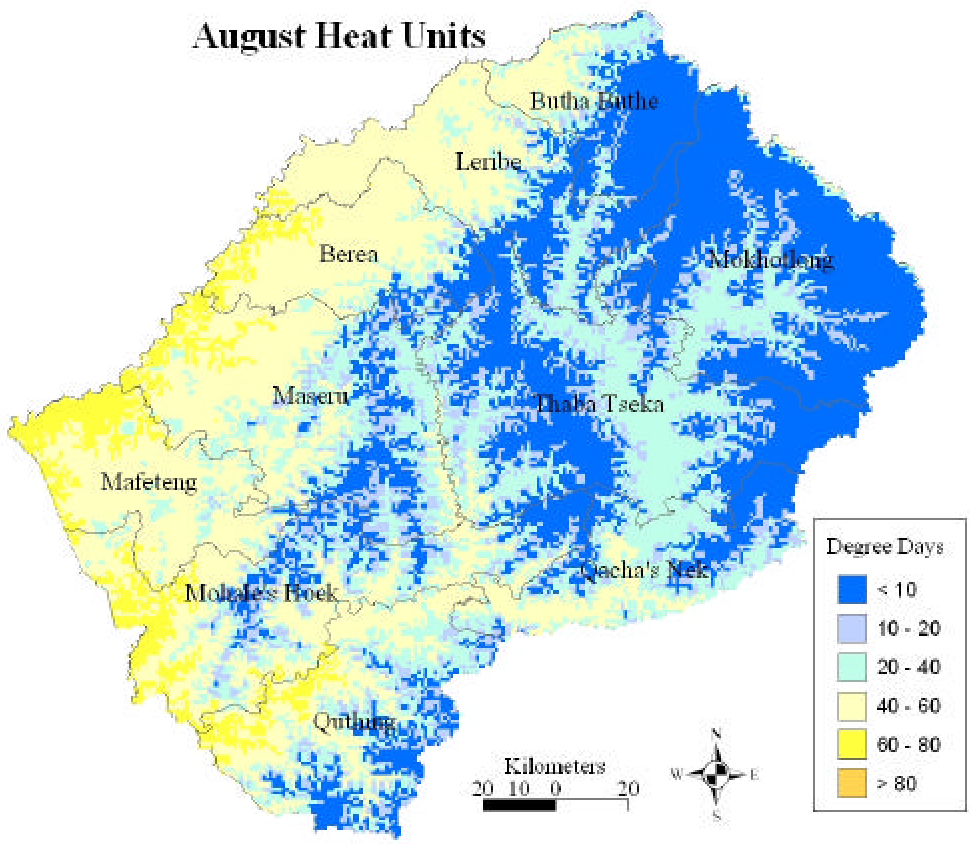


Fig 4.17 Maps of mean monthly heat units for July and August

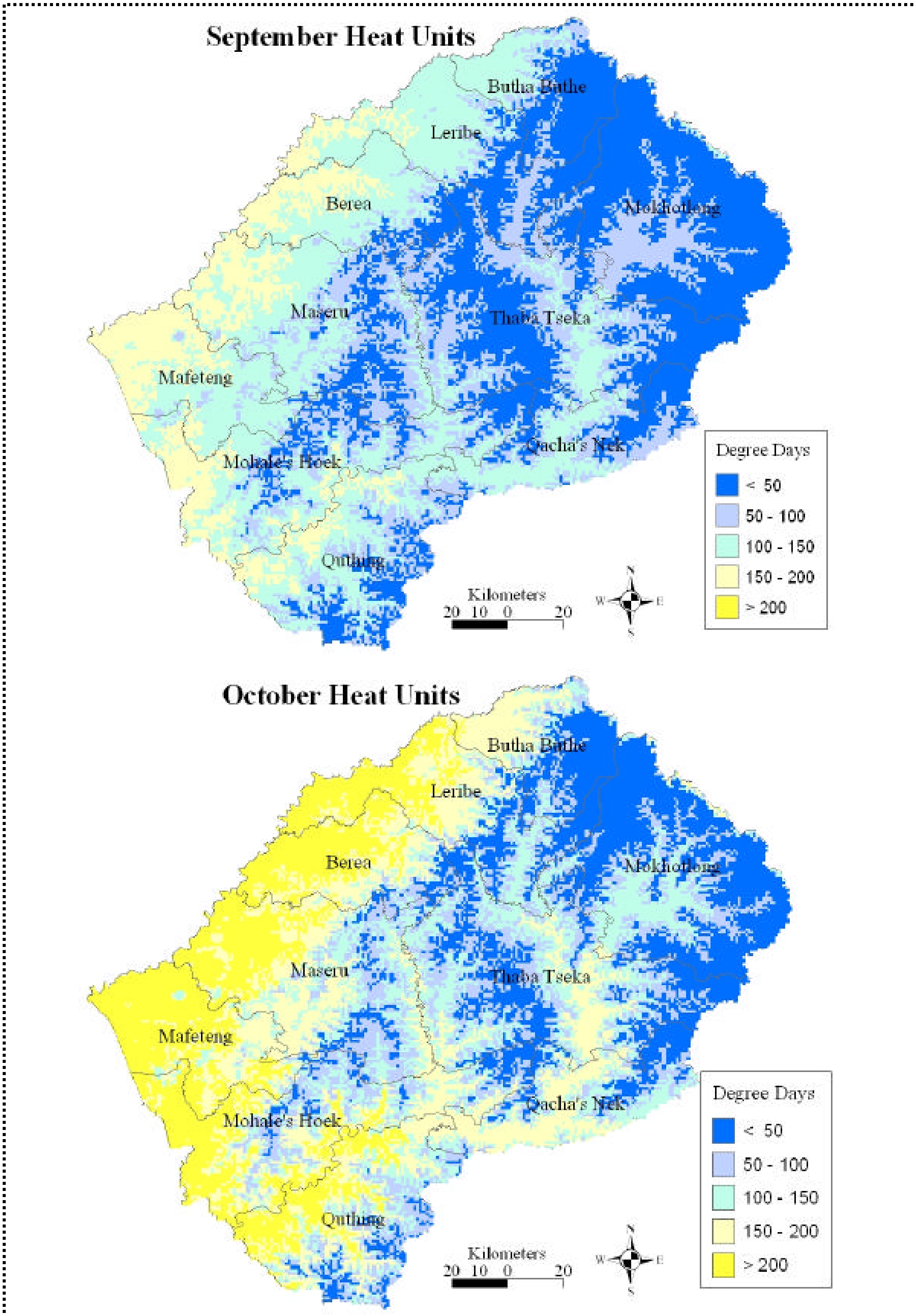


Fig 4.18 Maps of mean monthly heat units for September and October

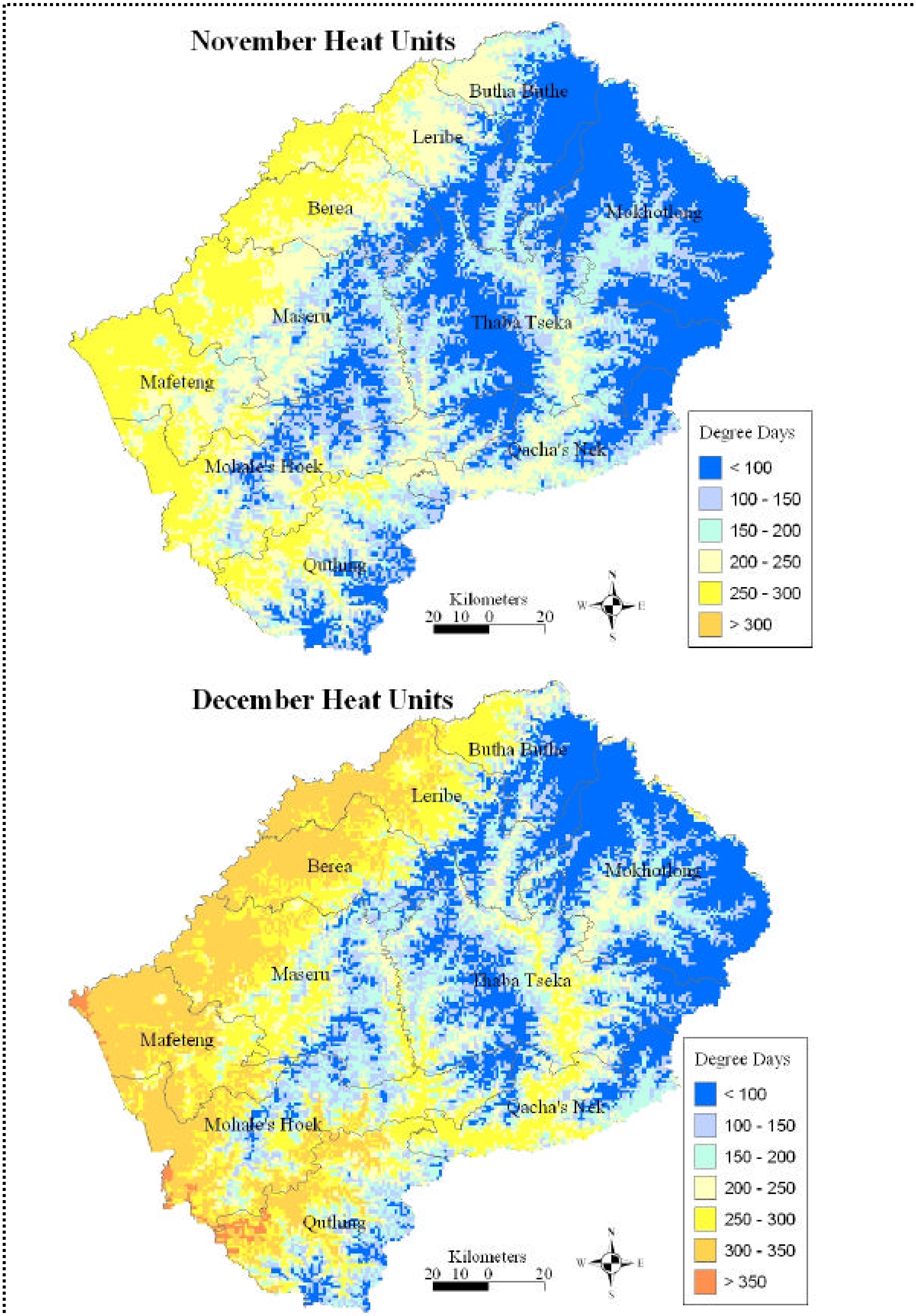


Fig 4.19 Maps of mean monthly heat units for November and December

Table 4.2 Mean seasonal heat units statistics (mean, 20th percentile, median, 80th percentile and standard deviation) for each station.

Station	Mean	20th Per	Median	80th Per	Std Dev
Butha Buthe	1684	1579	1751	1795	147
Kolbere	1214	1104	1243	1324	137
Lekubane	990	880	1006	1099	129
Leribe	1752	1653	1740	1850	118
Letseng la Terai	132	77	117	174	68
Mafeteng	1739	1615	1780	1827	137
Malefiloane	628	527	624	689	145
Mapoteng	1921	1811	1951	2055	146
Matela	1685	1582	1683	1790	130
Matsieng	1872	1764	1885	1977	122
Mejametalana	1944	1841	1957	2073	132
Mohales Hoek	1857	1733	1850	2005	154
Mokhotlong	1153	1057	1142	1281	150
Moshoeshoe I	1884	1771	1912	1993	130
Mt Moorosi	2056	1939	2082	2138	132
Nohana	1852	1791	1861	1934	98
Oxbow	300	253	291	360	64
Pitseng	1677	1589	1715	1780	142
Qachas Nek	1365	1247	1380	1502	159
Quthing	1801	1665	1787	1983	164
Roma NUL	1810	1705	1832	1911	140
Sani Pass	203	159	203	234	49
Sehlabathebe	632	547	621	709	100
Semonkong	814	720	840	877	100
St James	1066	951	1076	1204	149
St Martins	793	721	799	910	140
Teyateyaneng	1882	1736	1925	2002	149
Thaba Bosiu	1942	1843	1958	2053	130
Thaba Tseka	1112	1012	1129	1239	149
Thabana Morena	1919	1810	1908	2024	122

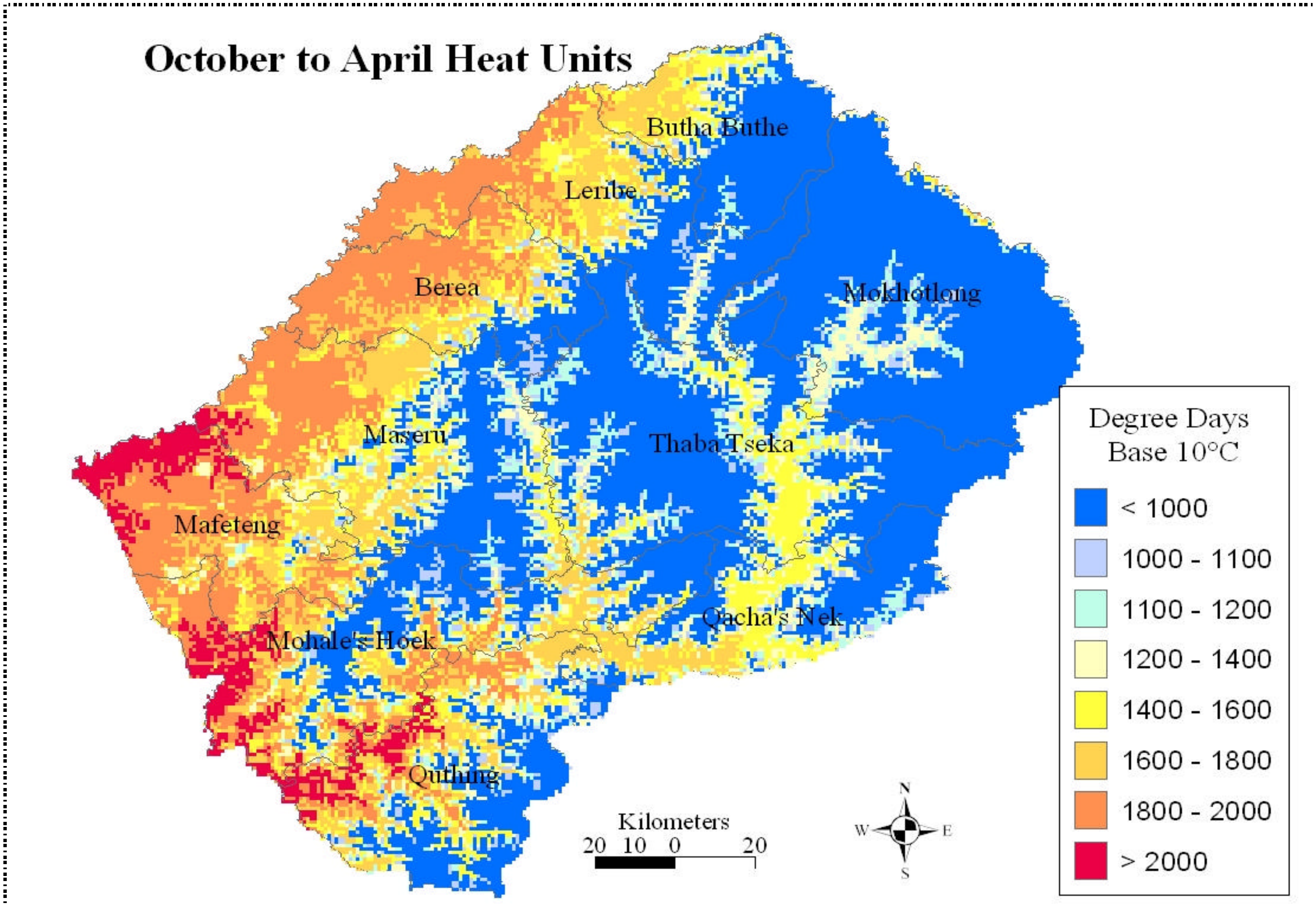


Fig 4.20 Map of seasonal (October to April) heat units for the country of Lesotho using the equation $GDD = \left[\frac{(T_{MAX} + T_{MIN})}{2} \right] - T_{BASE}$ **Where T_{MAX} and T_{MIN} are daily maximum temperatures and minimum temperatures respectively. T_{BASE} is the base threshold temperature = 10°C for maize.**

4.3.4 Frost occurrence

The first day of frost varies quite significantly over the country. A frost day is considered as the day in which the minimum temperature is equal or less than 0. For all the years on record the average first day and last day of frost was determined for all the stations. The observed average first frost starts as early as 1st March at Sani Pass station followed by Lets'eng la Terai on the 13th March and Oxbow on the 25th March (Table 4.3). Also seen in Fig. 4.21, the onset of frost in the high-lying areas is during the month of March. The first day of frost over the lowlands (Leribe, Berea, Maseru, Mafeteng, Mohale's Hoek and Quthing) is mostly between 16th May to 31st May. Also noted from Table 4.3 is the extreme latest dates of 20th June observed at Thabana-Morena station and that of the 12th June recorded at Mt Moorosi.

The last day of frost (cessation) is later over the highlands and early over the lowlands (Fig. 4.22). The observed earliest last days of frost are on 6th August, 10th August and 12th August observed at Thabana-Morena, Mapoteng and Teyateyaneng stations respectively (Table 4.3). Fig. 4.22 shows that the low-lying areas have the last days of frost not later than August. The latest dates are 2nd December, 28th November and 21st November at Lets'eng la Terai, Sani Pass and Oxbow stations. The highlands generally have the last days of frost after 15th October.

The recorded frost duration ranges from 47 days to 272 days (Table 4.3). The shortest durations are recorded at Thabana Morena, Teyateyaneng and Mt Moorosi with 47 days, 74 days and 81 days respectively. Fig. 4.23 shows that some parts of lowlands mostly towards the western border record frost duration of less than 90 days. The Highlands record frost duration of over 180 days with the highest duration recorded by Sani Pass, Lets'eng La Terai and Oxbow with 272 days, 264 days and 241 days respectively.

Appendix 7 shows the dates of the first day of frost, last day of frost and frost duration using the 20% occurrence criterion. On the whole the onset is later than when using the average first day while the last day is earlier in the 20% criterion. Thus, the frost duration is less when calculated using this method.

Table 4.3 First day of frost, last day of frost and duration of frost using the average of first day each year

Station	First day of frost				Last day of frost					Duration
	March	April	May	June	August	September	October	November	December	
Butha Buthe		8					12			187
Kolbere				6		22				140
Lekubane				8		17				132
Leribe		7				7				124
Lets'eng la Terai	13								2	264
Mafeteng			21		24					95
Malefiloane		3					17			197
Mapoteng			31		10					70
Matela			11		29					111
Matsieng			29		22					85
Mejametalana			17			1				108
Mohales Hoek			23			2				102
Mokhotlong		23					6			165
Moshoeshoe I			17		24					99
Mt Moorosi				12		1				81
Nohana		17			23					97
Oxbow	25							21		241
Pitseng			12		26					106
Qachas Nek			11			22				136
Quthing			25		26					96
Roma NUL			24		25					93
Sani Pass	1							28		272
Sehlabathebe		2						7		219
Semonkong	31							12		226
St James		22					7			168
St Martins		7					7			183
Teyateyaneng			30		12					74
Thaba Bosiu			26		18					84
Thaba Tseka			2			26				146
Thabana Morena				20	6					47

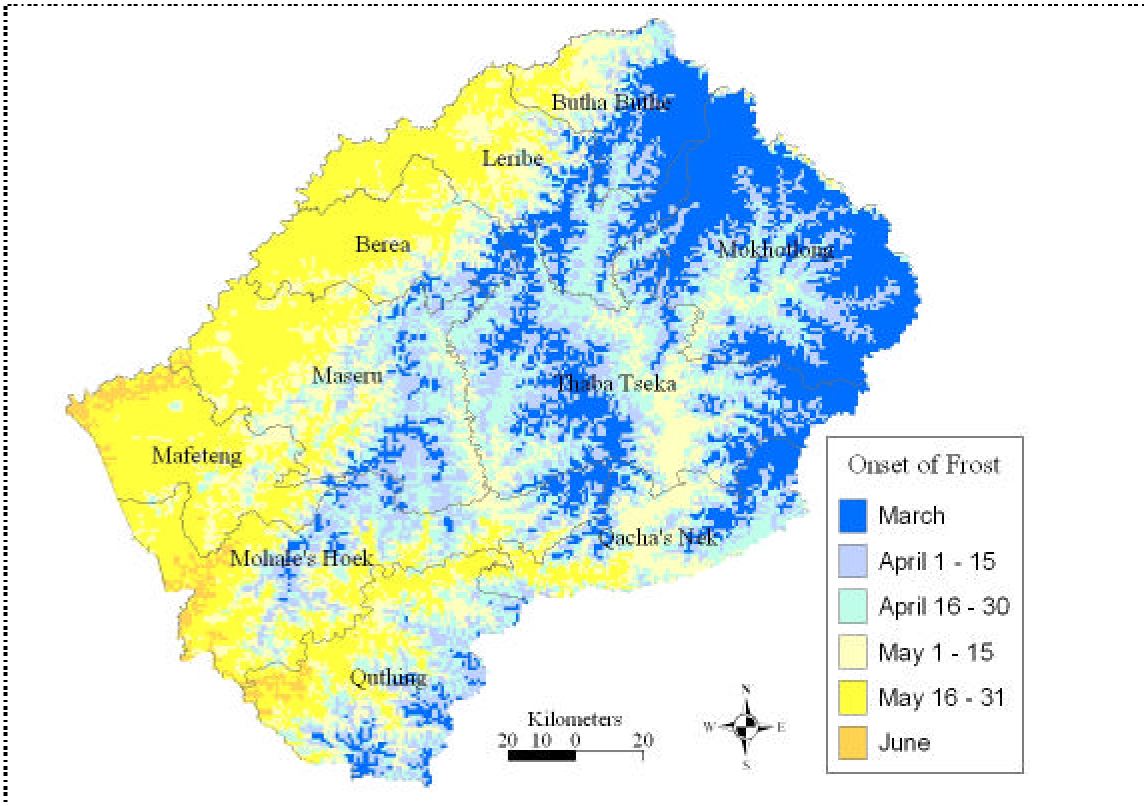


Fig 4.21Map of the average first day of frost for the country of Lesotho using the average of first day each year

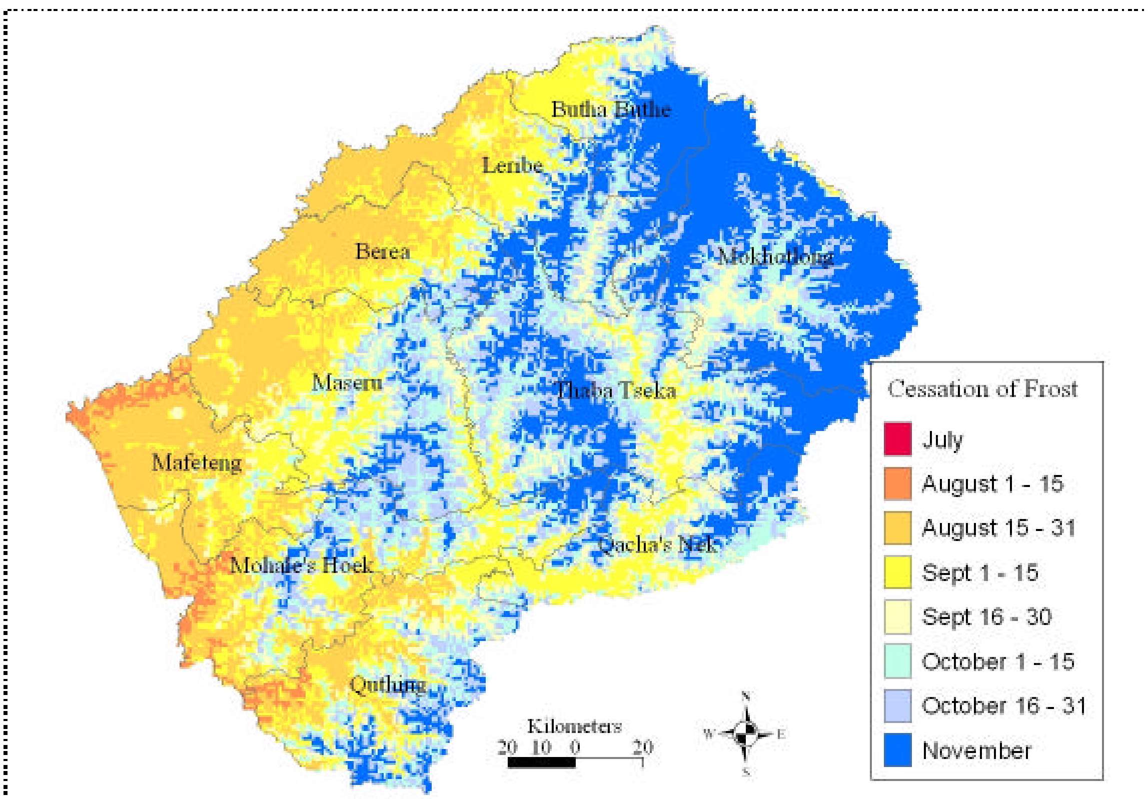


Fig 4.22 Map of the average last day of frost for the country of Lesotho using the average of first day each year

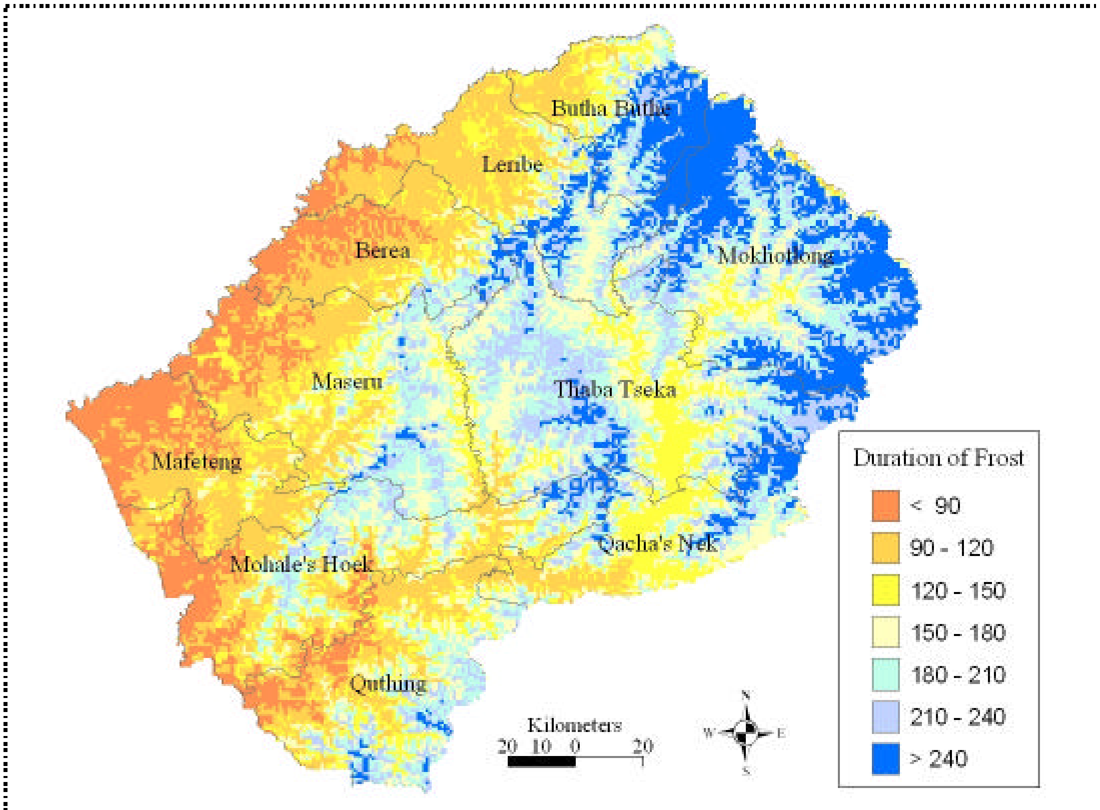


Fig 4.23 Map of the frost duration for the country of Lesotho using the average of first and last day each year

4.4 Conclusions

The main aim of this chapter was to investigate the temperature climatology of the country of Lesotho starting with the monthly means of both daily maximum and minimum temperatures. The accumulated heat units are also investigated and the frost occurrence was studied as these are important variables in the agricultural risk decision making. It is important also to study the spatial and temporal variation of these variables as they are important in the determining the timing of agricultural activities.

This study shows that the mean monthly minimum temperatures vary largely from one area to another due to the effect of change in altitude and topography. On the whole, the region from the northwestern part extending down to the southwestern part of the country experience higher mean monthly temperatures. These areas include the districts of Butha Buthe, Leribe, Berea, Maseru, Mafeteng, Mohale's Hoek and Quthing. Amongst the stations in these areas Thabana Morena, Mapoteng, Matsieng and Teyateyaneng recorded overall high mean minimum temperatures. The highest monthly minimum temperature of 15.6°C was recorded at Thabana-Morena for December. The highlands (altitude > 2000 m) which are mostly located over the central area as well as the region extending from the north to the eastern part of the country record very low mean monthly minimum temperatures. Lets'eng la Terai, Sani Pass and Oxbow are the stations in which the lowest minimum temperatures were observed. The lowest mean minimum temperature was recorded in Oxbow during July. On average the lowest minimum temperatures were recorded in the months of June and July while January and February recorded the highest minimum temperatures. The mean monthly minimum temperatures did not show much variability from year to year as the standard deviation mostly show values of less than 1.5 °C for all the observed values.

The maximum temperatures spatial variability was more or less similar to that of the minimum temperatures. The low-lying areas observed high maximum temperatures while the high-lying areas observed low maximum temperatures. December, January and February months showed the highest mean monthly maximum temperatures during summer. The highest mean monthly maximum of 28.7°C was recorded at Mejemetalana in January. In winter June and July are the coldest months with low maximum temperatures experienced in those months. The lowest monthly value recorded was 6.1°C during June at Lets'eng la Terai.

The accumulated heat units were high during the summer months with December and January showing the highest accumulated monthly values. During the winter months starting from May to August the heat units are at the lowest throughout the country with June and July showing the extremely low values. This is caused by negative minimum and low maximum temperatures during these months. Also noticed was spatial variance which depicted the western and southwestern as having the highest heat units while the northern, central and eastern parts of the country show low monthly values. The seasonal heat units take the same spatial shape as the monthly heat units and the above-mentioned parameters. The highlands record less than 600GDD while the low-lying areas seasonal heat units exceed 1800GDD for the summer growing season. Since, in the lowlands, foothills and the Senqu river valley areas receives seasonal heat units of more than 1400GDD, maize can grow to maturity at these places.

The frost occurrence is relatively extensive over the country of Lesotho with the high-lying areas (altitude > 2000m) experiencing more frost than the low-lying areas. The first day of frost comes as early as 1st March for the highlands and as late as 20th June for the Lowlands. The last day of frost is early over the low-lying areas and very late over the high-lying areas as a result the frost duration is relatively longer over the Highlands. In places where the frost period is over 180 days, it is considered not suitable for maize.

For further research, it will be good to include also the orientation of the slope in the algorithm which estimates the temperature indices in areas where there were no measurements. Factors like distance from the ocean should also be included to test their significance in the model which estimates non-observational areas.

In the next chapter, different precipitation indices will be discussed in full length. The monthly, seasonal both dry season and wet season and annual precipitation variation in space and time will be considered.

Chapter 5 –Precipitation Analysis

5.1 Introduction

The study of precipitation climate in any region is important from the view of agricultural production, drainage of urban and agricultural lands, erosion, flood, drought, water resources and civilization (Dinpashoh *et al.*, 2004). Precipitation is one of the most important factors in agricultural water management, especially in dryland farming. To do climatological analysis in a country like Lesotho, with its topographically influenced patterns of climate variables, is rather difficult especially in the case of precipitation. The interrelationship between the orographic features and the synoptic conditions in the mountainous regions usually produce a highly varying spatial structure which cannot be detected in detail using the data network of a relatively small number of observation sites available per surface area (Holawe and Dutter, 1999).

Precipitation occurs in association with some form of airflow disturbance causing air to rise. The resulting uplifting initiates adiabatic cooling and given suitable moisture conditions this leads to cloud formation (Buckle, 1996). Four main forms of uplifting provide the basis for a classification of precipitation types. Convectional precipitation is caused by the localized thermal heating and overheating of the ground surface causing the moisture laden air to rise resulting to cumuliform clouds (UK Met, undated). It is the most common type of precipitation in hot climates. Much of the rainfall received in summer over Southern Africa is of convective origin (Jayamaha, 1979; Tyson, 1986). Convergence precipitation is another type which is associated with low-level convergences in warm, moist air and is most common in the humid tropics (Buckle, 1996). Another type is the frontal or cyclonic precipitation which is associated with the passage of low-pressure systems. It develops ahead of and near the frontal zones that separate the warm and cold air masses (UK Met, undated; Buckle, 1996). Lastly, orographic or relief precipitation is associated with the passage of moist airstreams over mountain barriers (UK Met, undated). Precipitation describes the various forms of water droplet and ice that falls from the clouds. It can be in the form of rain, drizzle, hail, snow and sleet. The form and size of precipitation reaching the ground from the clouds depends on the humidity and temperature conditions beneath the cloud base and processes within the cloud (Buckle, 1996). Precipitation in Lesotho, which is the predominant meteorological parameter directly influencing nearly all agricultural activities is received mostly in the form of rain and occasional hail or snow (Jayamaha, 1979). Precipitation/rainfall is measured in millimetres and recorded as the depth of water that falls on $1m^2$ level area. The simplest recording instrument is the standard rain gauge and this is capable of measurements accurate to 0.1mm (Buckle, 1996).

Rainfall, whether it is annual, seasonal or daily, is the most changeable of the weather elements varying in distribution, duration and intensity (Tyson, 1986; Buckle, 1996). Understanding seasonal rainfall distribution is important for its influence on the economic activities of the population of Africa since agriculture is entirely dependant on rainfall and the economy of most African countries including Lesotho are driven by agricultural products (Buckle, 1996). The length of the rainy season including the time it starts and the time it ends are important. In Southern Africa, precipitation follows an annual cycle and is almost entirely received during summer (Tyson, 1986). More than 80% of the annual rainfall in Sourthen Africa occurs between October and March and the pronounced seasonality of rainfall in these region is illustrated by the monthly variation in rainfall (Wilken, 1978; Tyson, 1986). Seasonal rainfall patterns are mostly controlled by global factors related to the general circulation (Buckle, 1996; Hobbs *et al*., 1998). The rain is mostly dependent on location and behavior of the Inter-Tropical Convergence Zone (ITCZ), whose fluctuating boundaries are in turn influenced by changing pressure patterns (Buckle, 1996). In mid-latitude countries like Lesotho, pressure patterns are dominated by the subtropical high pressure belt. In summer, the high pressure belt shifts southwards, thus permitting the influx of moist air into the country and the convective, convergent and orographic lifting of these moist air masses result in rainfall. In winter the high pressures intensify over land inhibiting the entry of marine air and thus resulting to lack of rainfall (Wilken, 1978).

Inter-annual variability of rainfall is one of the factors which are important in the understanding of climate of an area. One of the factors which affect inter-annual fluctuation of rainfall is the El Niño Southern Oscillation (ENSO) phenomenon. The Southern Oscillation Index (SOI) and Sea Surface Temperature (SST) are the most common indicator of the status of ENSO (Hobbs *et al*., 1998, IRI, 1999). The SOI is calculated from the monthly or seasonal fluctuations in the surface pressure difference between Tahiti and Darwin. Sustained negative values of the SOI often indicate El Niño episodes. These negative values are usually accompanied by sustained warming of the central and eastern tropical Pacific Ocean and a decrease in the strength of the pacific trade winds (Aus BOM; Hobbs *et. al*., 1998). Positive values of the SOI are associated with stronger pacific trade winds and warmer sea temperatures to the north of Australia, popularly known as a La Nina episode. Waters in the central and eastern tropical Pacific Ocean become cooler during this time (Aus BOM). Hobbs *et al*. (1998) noted that research by Ogallo (1987), Nicholson (1988/9 and 1993) concluded that El Niño years are marked by drought in southern Africa. In contrast, La Nina years are accompanied by above average summer rainfall over much of southern Africa including Lesotho (Hobbs *et al*., 1998).

Precipitation in Lesotho is generally of high intensity especially in the summer months when there are frequent convective storms. Analysis of the characteristics of rainfall intensity is of importance to agriculture. According to Wilken (1978) Lesotho soils are mostly thin and underlain by impermeable rock and thus the threat of flooding and erosion are great during high intensity rainfalls. Heavy falls can lead to soil degradation processes whereby soil is eroded and valuable nutrients are washed away (Jayamaha, 1979, Ranatunge *et al*., 2003). According to Van Dijk *et al*. (2002) the amount of soil that is detached by a particular depth of rain is related to the intensity at which this rain falls and also that soil splash rate is a combined function of rainfall intensity and some measure of raindrop fall velocity. The higher the fall velocity the greater is the soil erosion. Thus moderate rainfall intensities could exceed the soil infiltration rates and storage capacities in Lesotho due to shallow soil and lead to water-logging in fields and local flooding of low-lying areas (Jayamaha, 1979 and Ranatunge *et al*., 2003). Standing water in fields are common sights following heavy falls, this can result in severe failure of crop yields (Wilken, 1978, Ranatunge *et al*., 2003).

5.2 Data and methods

5.2.1 Data

The precipitation analyses were done using daily rainfall from 62 stations distributed around the country. The data used was from 1960 to 2004 for all the stations with some stations data starting in 1970 while in other stations it started in 1980s (Table 5.1). The station with minimum number of years (19) is Moshoeshoe I which was installed in 1985. Four South African stations namely Wepener, Royal Natal Park, Cathedral Peak and Waterford were used in the generation of monthly, seasonal and annual rainfall.

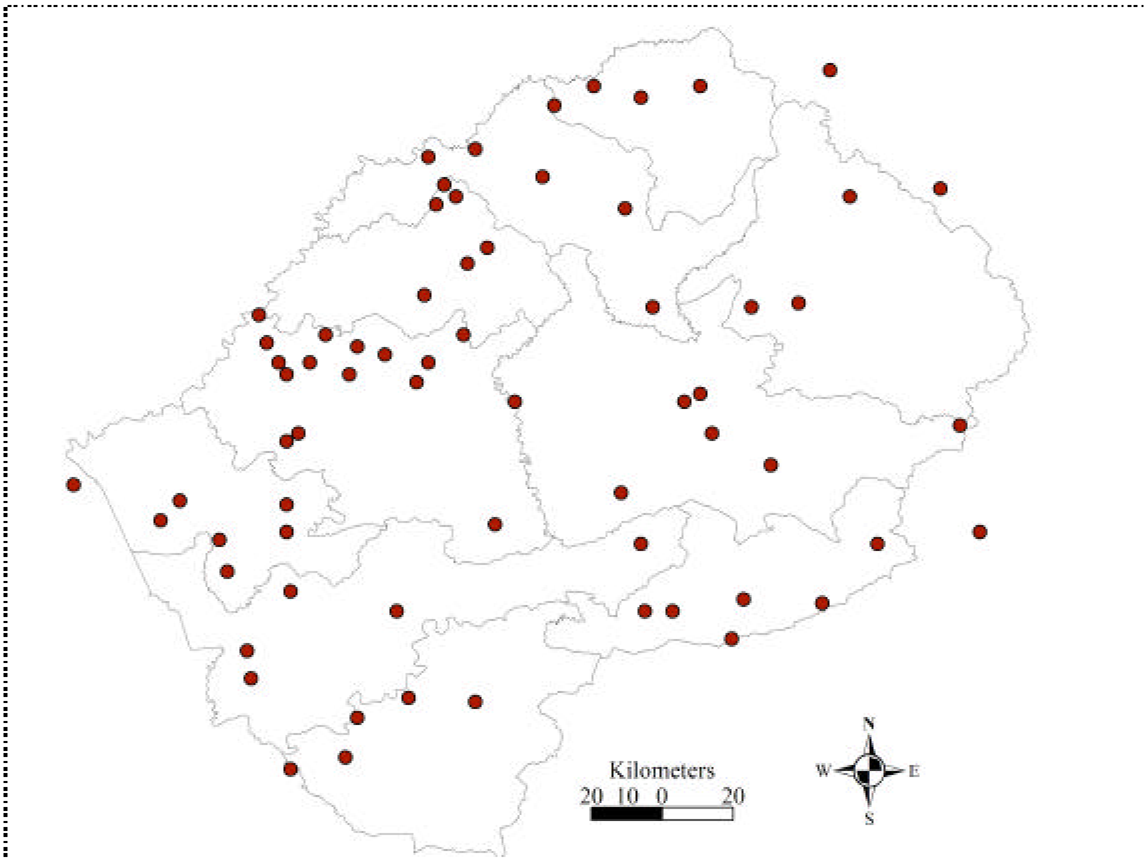


Fig 5.1 Observational network of rainfall stations used in the rainfall analysis

Table 5.1 Detailed information about rainfall stations in Lesotho to be used for rainfall analysis

Station	Latitude	Longitude	Elev.	Period	No. yrs	Station	Latitude	Longitude	Elev.	Period	No. yrs
Bots'abelo	-29.37	27.52	1575	1962 - 2004	42	**Mt Olivett**	-29.87	27.40	1623	1976 - 2004	28
Butha Buthe	-28.77	28.25	1770	1960 - 2004	44	**Nohana**	-30.05	27.85	1770	1979 - 2004	25
Fort-Hartley	-30.32	27.75	1490	1965- 2004	39	**Oxbow**	-28.72	28.62	2660	1960 - 2004	44
Hololo-Court	-28.72	28.35	1640	1965- 2004	39	**Paray**	-29.50	28.62	2160	1960 - 2004	44
Khoshane	-29.40	27.82	1900	1982 - 2004	22	**Pitseng**	-28.95	28.22	1780	1964 - 2004	40
Kolbere	-29.28	28.50	2650	1979 - 2004	25	**Pontseng**	-29.03	28.43	1875	1979 - 2004	25
Lekubane	-29.42	27.93	2360	1970 - 2004	34	**Pulane**	-29.25	27.92	1700	1971 - 2004	33
Lelingoana	-29.27	28.87	2100	1960 - 2004	44	**Qaba**	-29.78	27.57	1950	1978 - 2004	26
Leribe	-28.88	28.05	1740	1960 - 2004	44	**Qachas Nek**	-30.12	28.70	1970	1960 - 2004	44
Lesobeng	-29.75	28.42	2250	1979 - 2004	25	**Quthing**	-30.42	27.72	1740	1960 - 2004	44
Letseng la Terai	-29.00	29.00	3050	1963 - 1991	28	**Ramatseliso**	-29.03	28.93	2250	1979 - 2004	25
Mafeteng	-29.82	27.25	1610	1960 - 2004	44	**Rapase**	-30.05	28.55	1830	1960 - 2004	44
Makoae	-30.28	28.05	1800	1960 - 2004	44	**Roma NUL**	-29.45	27.73	1650	1962 - 2004	42
Malealea	-28.85	27.57	1970	1960 - 2004	44	**Samaria**	-29.77	27.30	1675	1969 - 2004	35
Maphutseng	-30.22	27.48	1560	1978 - 2004	26	**Sani Pass**	-29.58	29.28	2440	1975 - 2004	29
Mapoteng	-29.02	27.95	1725	1984 - 2004	20	**Seaka**	-30.45	27.58	1460	1978 - 2004	26
Maputsoe	-28.90	27.93	1620	1977 - 2004	27	**Sebedia**	-29.13	28.08	1725	1978 - 2004	26
Mashai	-29.68	28.80	1830	1960 - 2004	44	**Sehlabathebe**	-29.88	29.07	2320	1975 - 2004	29
Matela	-29.38	27.75	1775	1980 - 2004	24	**Semonkong**	-29.83	28.10	2458	1967 - 2004	34
Matelile	-29.88	28.47	1860	1978 - 2004	26	**St James**	-29.35	28.02	2250	1976 - 2004	28
Matsieng	-29.62	27.57	1800	1984 - 2004	20	**St Martins**	-29.28	28.75	2270	1972 - 2004	32
Mazenod	-29.42	27.55	1575	1976 - 2004	28	**St-John Marakabei**	-29.52	28.15	1980	1963 - 2004	41
Mejametalana	-29.30	27.50	1530	1960 - 2004	44	**St-Peters**	-28.75	28.47	1860	1965 - 2004	39
Mohales Hoek	-30.15	27.47	1620	1960 - 2004	44	**Teyateyaneng**	-29.00	28.00	1690	1960 - 1992	32
Mohlanapeng	-29.60	28.65	2250	1965 - 2004	39	**Thaba Bosiu**	-29.35	27.67	1600	1980 - 2004	24
Mokhotlong	-29.28	29.07	2230	1960 - 2004	44	**Thaba Tseka**	-29.93	27.40	2160	1976 - 2004	28
Moletsane	-29.17	28.03	1900	1977 - 2004	27	**Thaba-Khupa**	-29.42	27.63	1690	1974 - 2004	30
Molimo-Nthuse	-29.47	27.90	1900	1975 - 2004	29	**Thabana Morena**	-29.55	28.58	1680	1960 - 2004	44
Moshoeshoe I	-29.45	27.57	1628	1985 - 2004	19	**Ts'ilo**	-29.60	27.60	1775	1978 - 2004	26
Mt Moorosi	-30.27	27.88	1625	1978 - 2004	26	**Tsoelike**	-30.02	28.73	1770	1960 - 2004	44
Mt Carmel	-30.00	27.58	1750	1976 - 2004	28	**Whitehill**	-30.05	28.48	1680	1960 - 2004	44

5.2.2 Methodology

The monthly totals were computed using Microsft Excel and Instat+ softwares. The wet season, dry season and annual precipitation totals were also computed using Excel software. Different statistical parameters (mean, median, 20^{th} percentile, minimum, maximum, 80^{th} percentile and standard deviation) of monthly, seasonal and annual precipitation values were done using the Microsft Excel. The number of days with rainfall greater than 25mm a day per year was also determined using Microsft Excel software. The computed monthly, annual, seasonal and number of days receiving precipitation greater than 25mm were mapped using Arcview 8.3. The mean/average values at the stations were used in the interpolation using the ordinary kriging method to obtain a surface. Kriging method was chosen ahead of the other interpolation method because it tends to recognize the trend of the data to be interpolated.

5.3 Results and Discussion

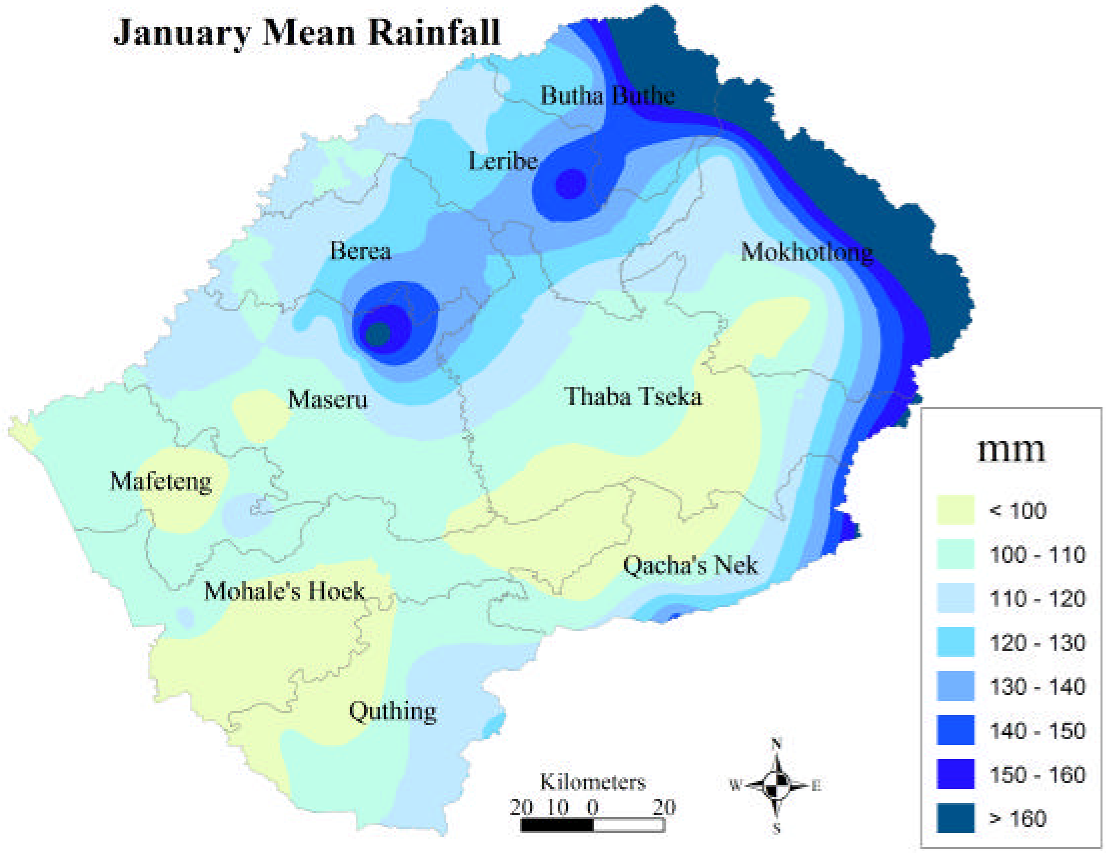
5.3.1 Monthly rainfall

Monthly rainfall varies with both space and time. Considering the month of January, around 80% of the country has a mean rainfall of over 100mm (Fig. 5.2) and 60% of the country has the median rainfall of greater than 100mm. Fort Hartley has the lowest mean monthly rainfall for January of 77.4mm and Oxbow has the highest of 182.2mm (Appendix 8.1). The spatial distribution shows high monthly rainfall over the north to northeastern parts of the country with over 160mm of rainfall (Fig. 5.2). The Senqu River Valley is the area with the lowest rainfall in January with mean monthly rainfall of less than 100mm. February rainfall is also high over the north to northeastern parts of the country with over 130mm and some parts of the foothills extending from northern Maseru to Butha Buthe also received high rainfall. The Senqu River Valley still has minimum rainfall with some places having less than 70mm of rainfall (Fig. 5.2). It can be noted from Appendix 8.1 that over than 50% of the stations has less than 100mm and the minimum mean monthly February rainfall of 57.2mm was received over Mashai. Ponts'eng station has the highest with 145.9mm for February. The area of low rainfall corresponds to the rainshadow area behind the Drakensberg ranges. The spatial distribution of rainfall in March takes the same shape as that of the previous months. In this month, the lowest 54mm was recorded at Mashai followed by St James with 63.4mm while Oxbow and Lekubane had the highest March mean monthly rainfall of 157.1mm and 126.3mm respectively (Appendix 8.1). The north to northeastern parts of the country record over 130mm of rainfall while some parts of the Senqu Valley received less than 70mm.

In April there is a sudden decrease in rainfall with the maximum of 88.4mm and over 80% of the country has less than 60mm of rainfall (Appendix 8.2 and Fig. 5.3). May marks the beginning of the dry-season as the whole country receives less than 50mm of rainfall. There is less spatial variability of rainfall over the country, but the eastern districts (Qacha's Nek, Thaba Tseka and Mokhotlong) show the least rainfall. Some parts of Maseru, Quthing and Butha Buthe district register more than 30mm of rainfall. In June and July rainfall ranged from 5.4mm to 24.8mm and 4mm to 20.4mm respectively (Appendix 8.2 & 8.3). These months record the lowest rainfall. Snowfalls are usually experienced during June and July months mostly over the highlands. In August the rainfall situation improves a little with the range from 14mm to 40.3mm (Appendix 8.3). On the whole the country register from 20mm to 30mm, but some parts of Maseru, Berea and Butha Buthe receive rainfall of over 30mm while the eastern part rainfall in August goes below 20mm (Fig. 5.5).

In September most of the places receive less than 40mm of rainfall but rainfall situation on the whole has improved compared to the previous winter months of June, July and August (Fig. 5.6). The western and eastern parts experienced less rainfall while the northern parts receive in excess of 40mm. The rainfall ranged from 21.4mm to 56 mm (Appendix 8.3). September marks the end of the dry season and the wet season starts in October as monthly rainfall at some places is in the excess of 100mm. Mean monthly rainfalls is more biased to the northern part while the Senqu valley and the western part of the country received less rainfall (Fig. 5.6). Appendix 8.4 shows that the monthly rainfall for October ranged from 46.2mm recorded at Seaka to 129.2mm observed at Oxbow station. In November the area extending from Mohale's Hoek to southern part of

Mokhotlong district receive less rainfall (< 80mm) while the northern region had the highest rainfall in excess of 100mm (Fig. 5.7). The area of high rainfall also is found over the foothills north of Maseru to Butha Buthe. The rainfall distribution of December is similar to that of November rainfall but a greater area of the country is receiving more rainfall. The mountains over Butha Buthe and Mokhotlong record rainfall of over 140mm. Maseru, Berea, Leribe and Quthing districts also received rainfall in the excess of 100mm. Less than 80mm of rainfall is found mainly in Mohale's Hoek and Thaba Tseka. The range stretches from 61mm to 169.7mm (Appendix 8.4).



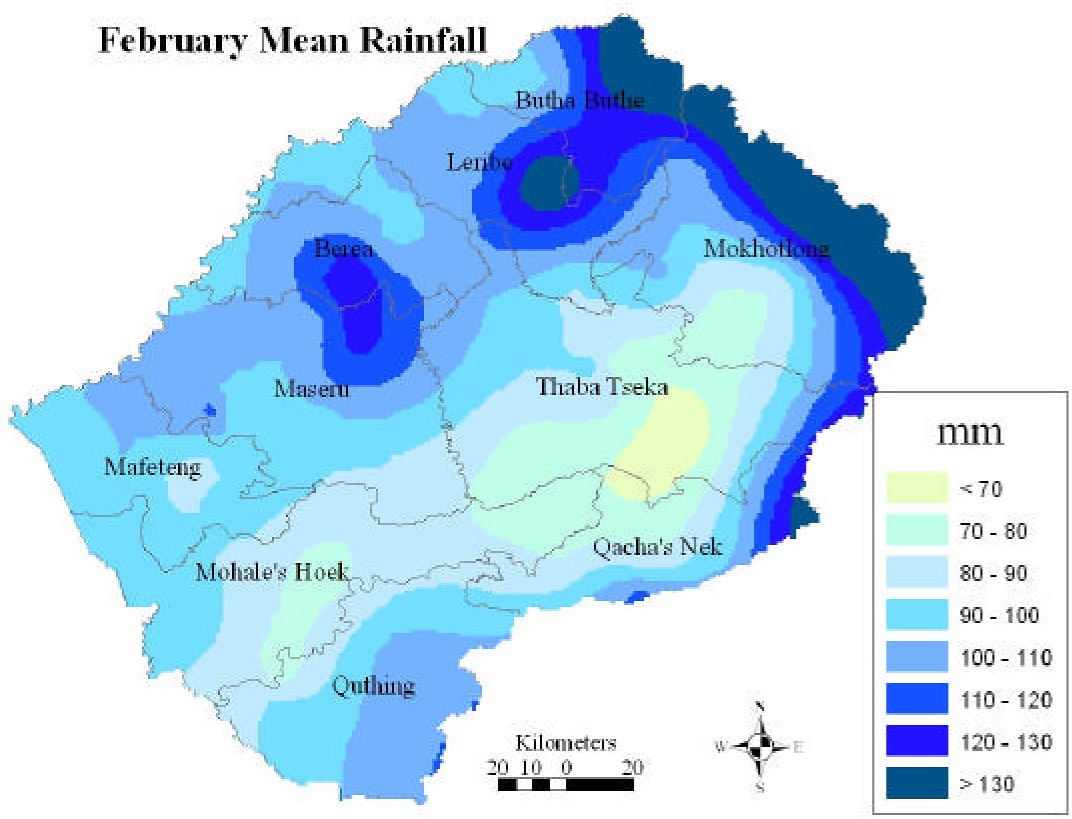


Fig 5.2 Maps of monthly rainfall for January and February

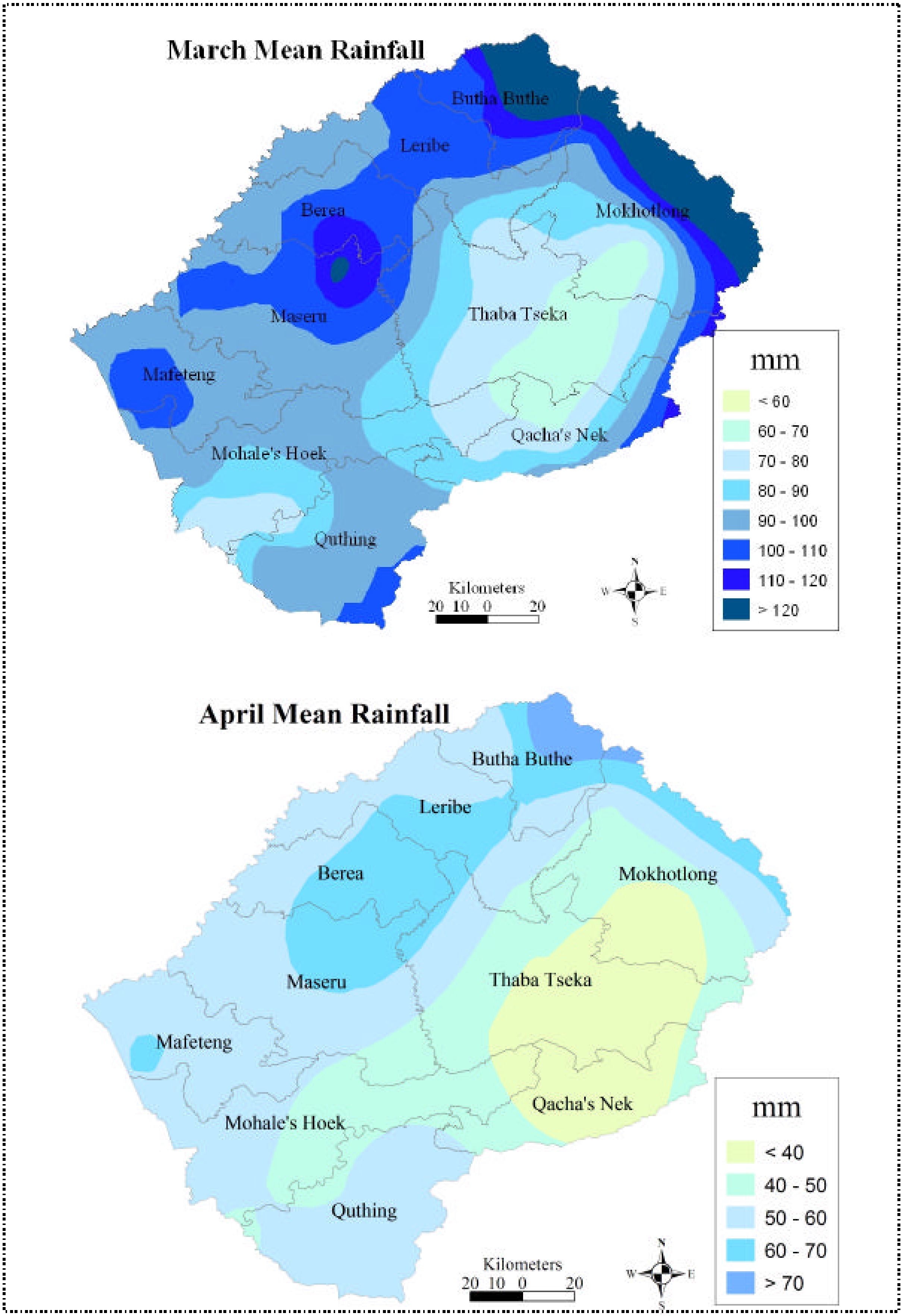


Fig 5.3 Maps of monthly rainfall for March and April

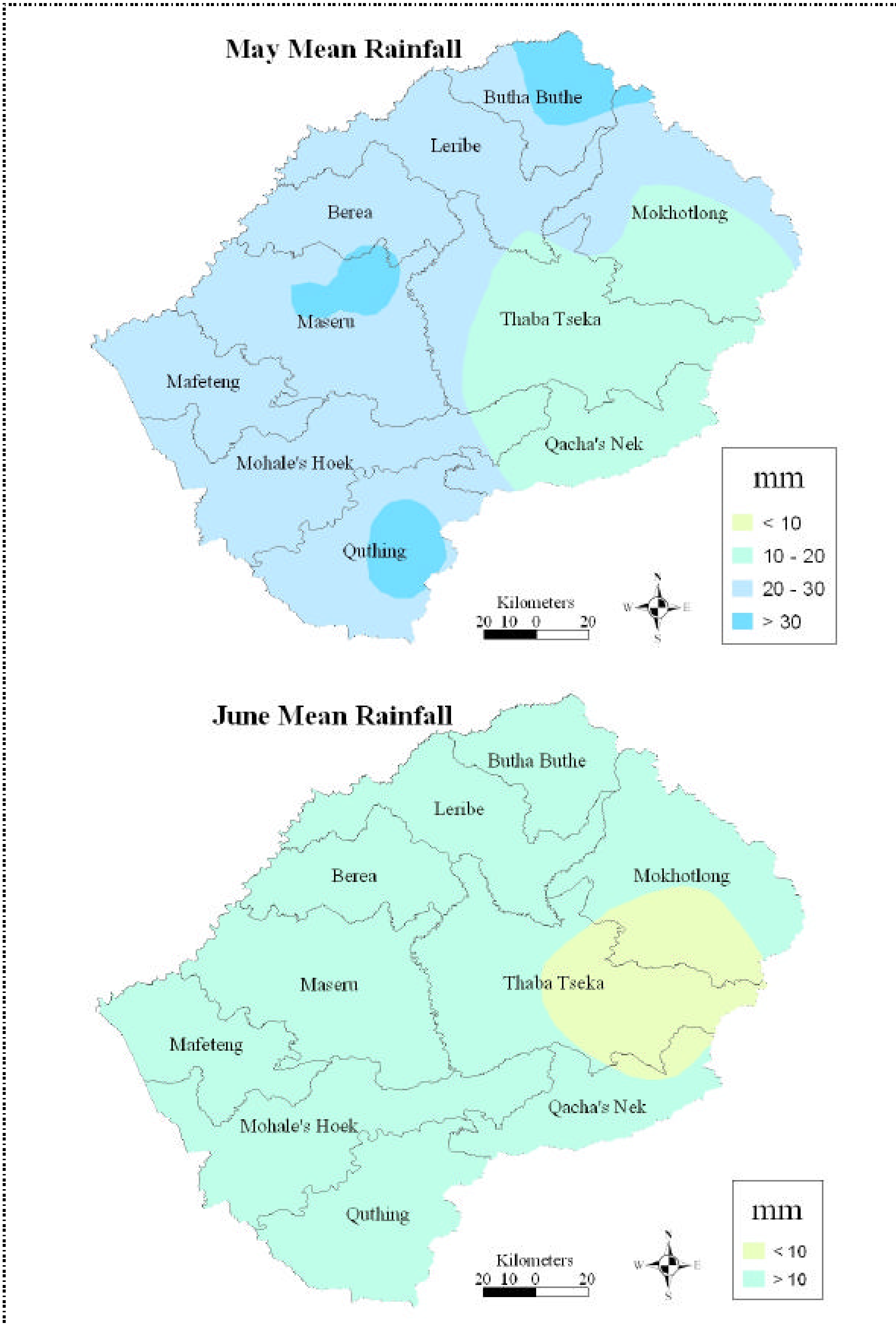


Fig 5.4 Maps of Monthly rainfall for May and June

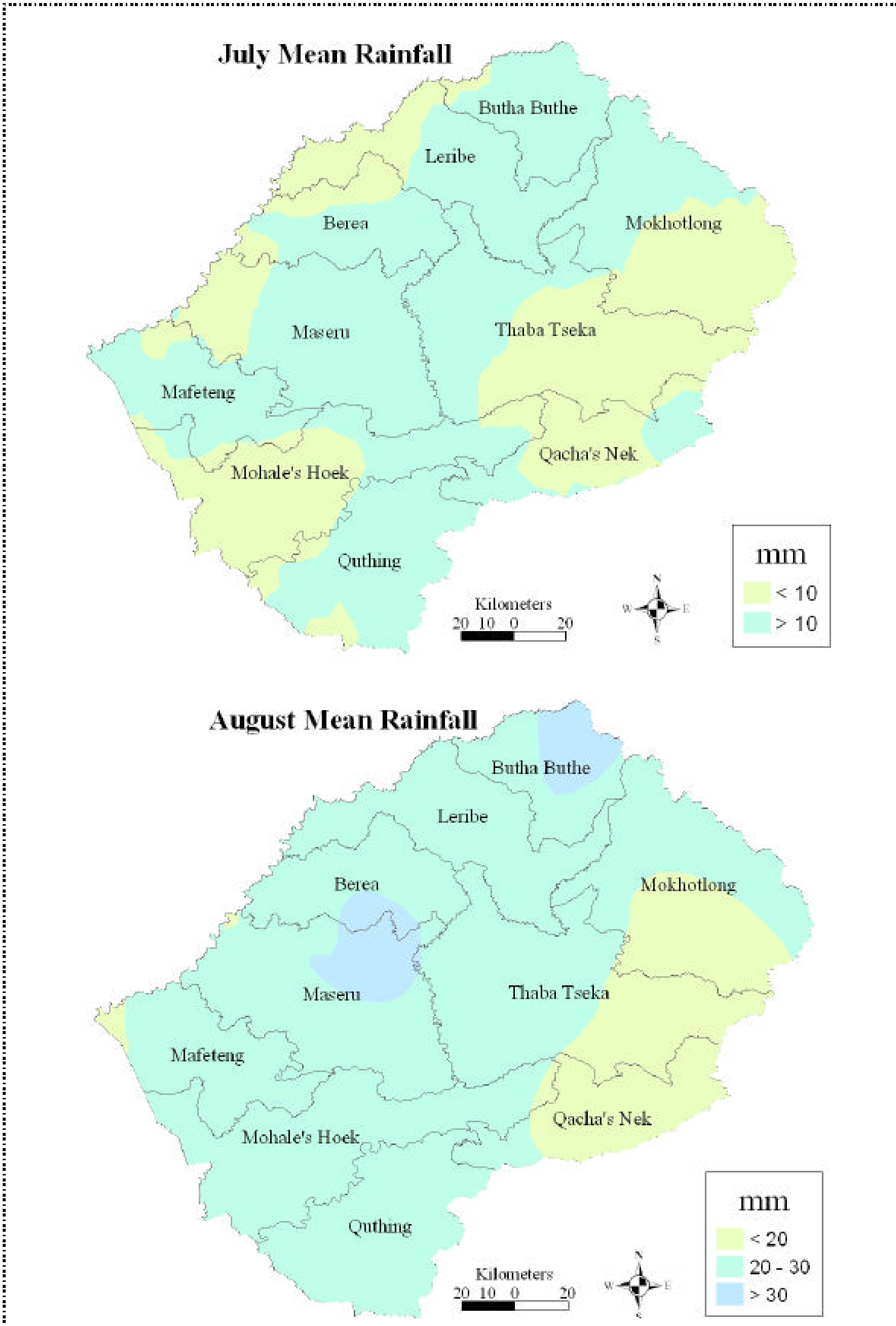


Fig 5.5 Maps of monthly rainfall for July and August

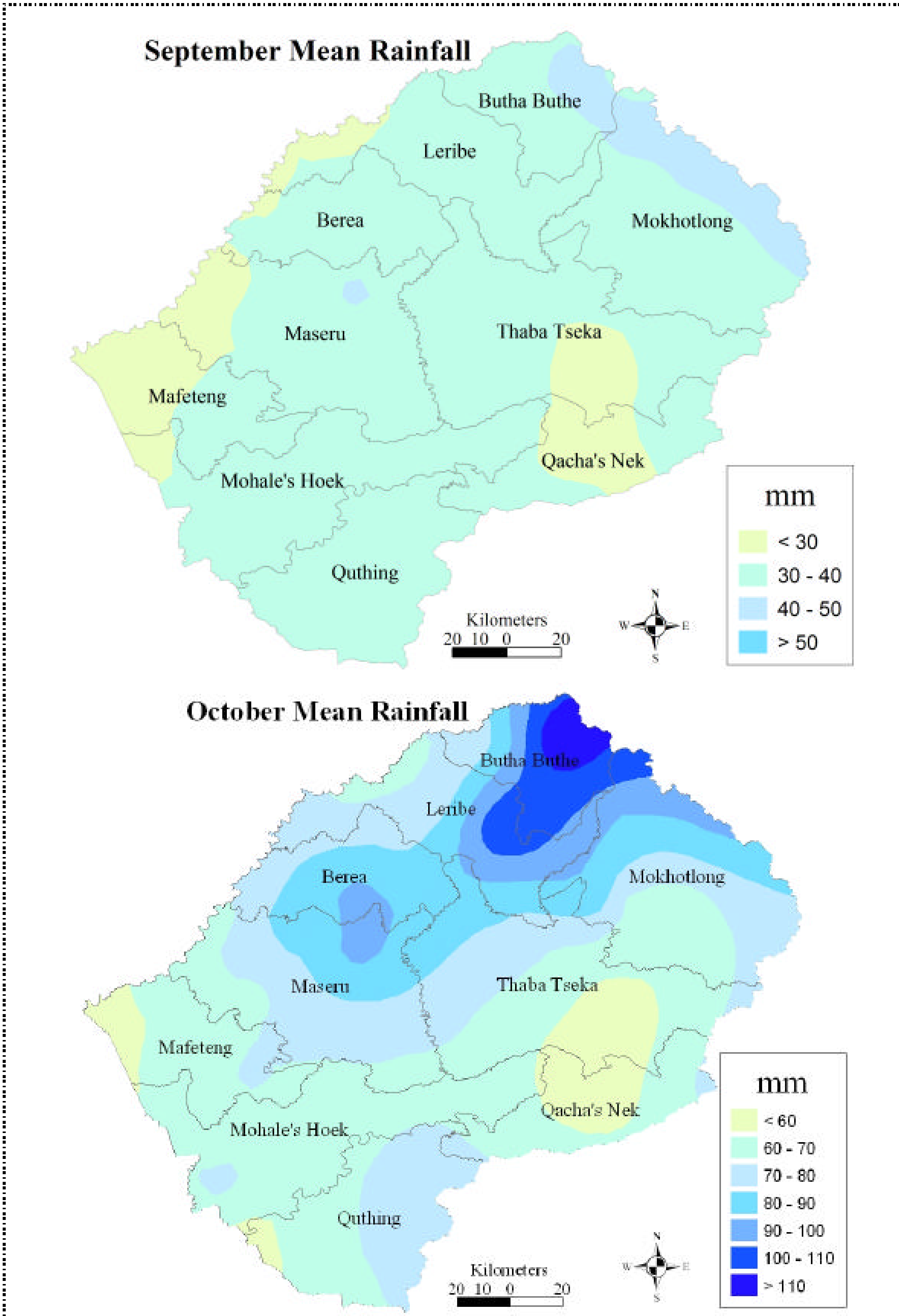


Fig 5.6 Maps of monthly rainfall for September and October

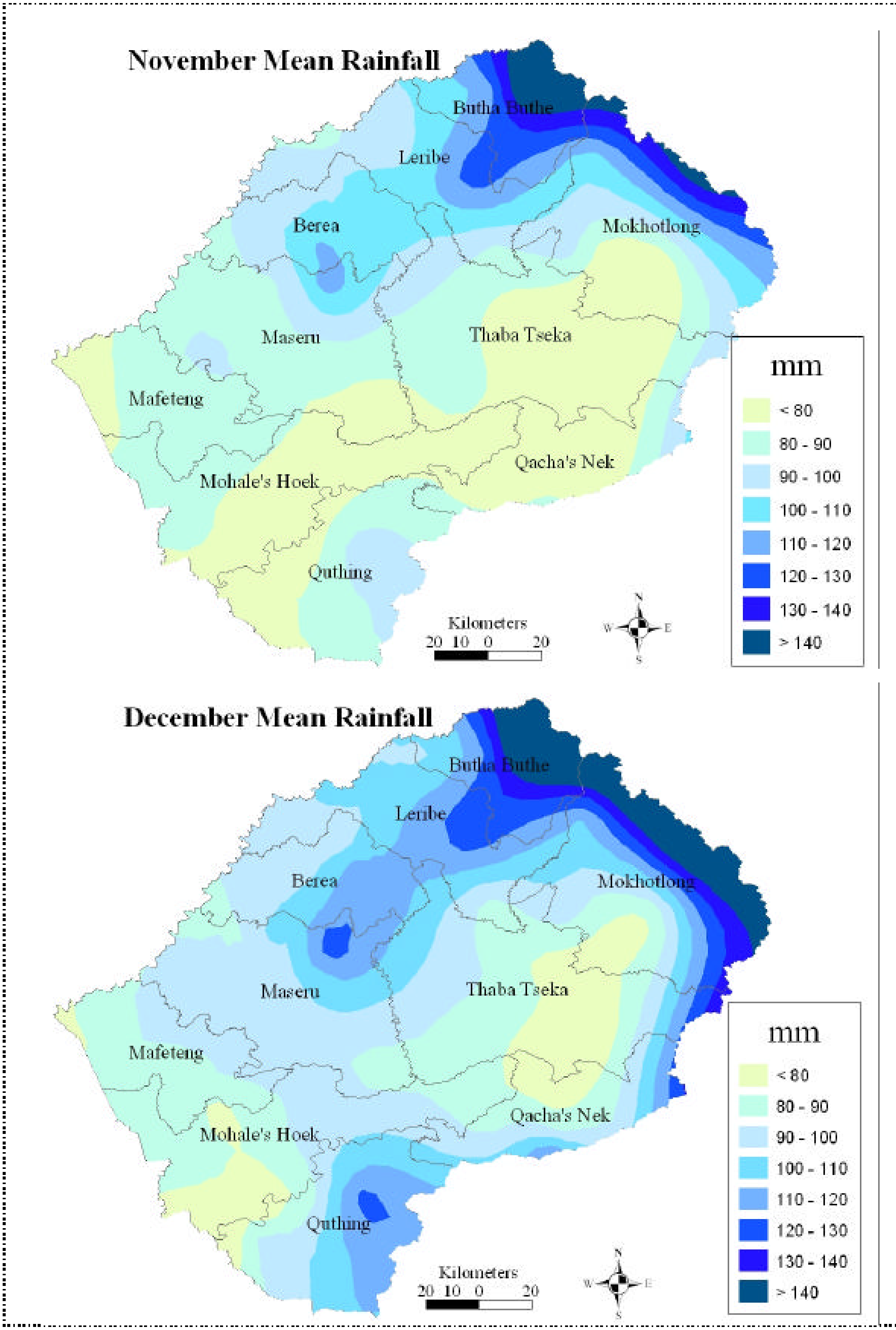


Fig 5.7 Maps of monthly rainfall for November to December

5.3.2 Annual rainfall

Mean annual precipitation over Lesotho ranges from 445mm to 1205mm (Appendix 9.1). Most of the rainfall received is from the months October to March. The lowest values are observed at Mashai, Seaka, Tsoelike and Fort Hartley with 445mm, 524mm, 546mm and 555mm respectively. As seen from Fig. 5.8, the area of low rainfall (< 600mm) is found in the boundary of Mohale's Hoek and Quthing district and Thaba Tseka district, the former falls within the Senqu River Valley while the later is mostly a rain-shadow area caused by the Drakensberg ranges on the eastern part of the country. Mohale's Hoek and Thaba Tseka districts have the greatest area with rainfall less than 700mm. The area extending from the western part of the country to the northern part including Maseru, Berea, Leribe and Butha Buthe receive more than 700mm of rainfall annually. Quthing and Mokhotlong districts also had areas of high annual rainfall. The region of highest rainfall is the north to northeastern escarpments with the excess of 1000mm. Oxbow, Lekubane, and Ponts'eng receive high annual precipitration of 1205mm, 1012mm and 984mm respectively.

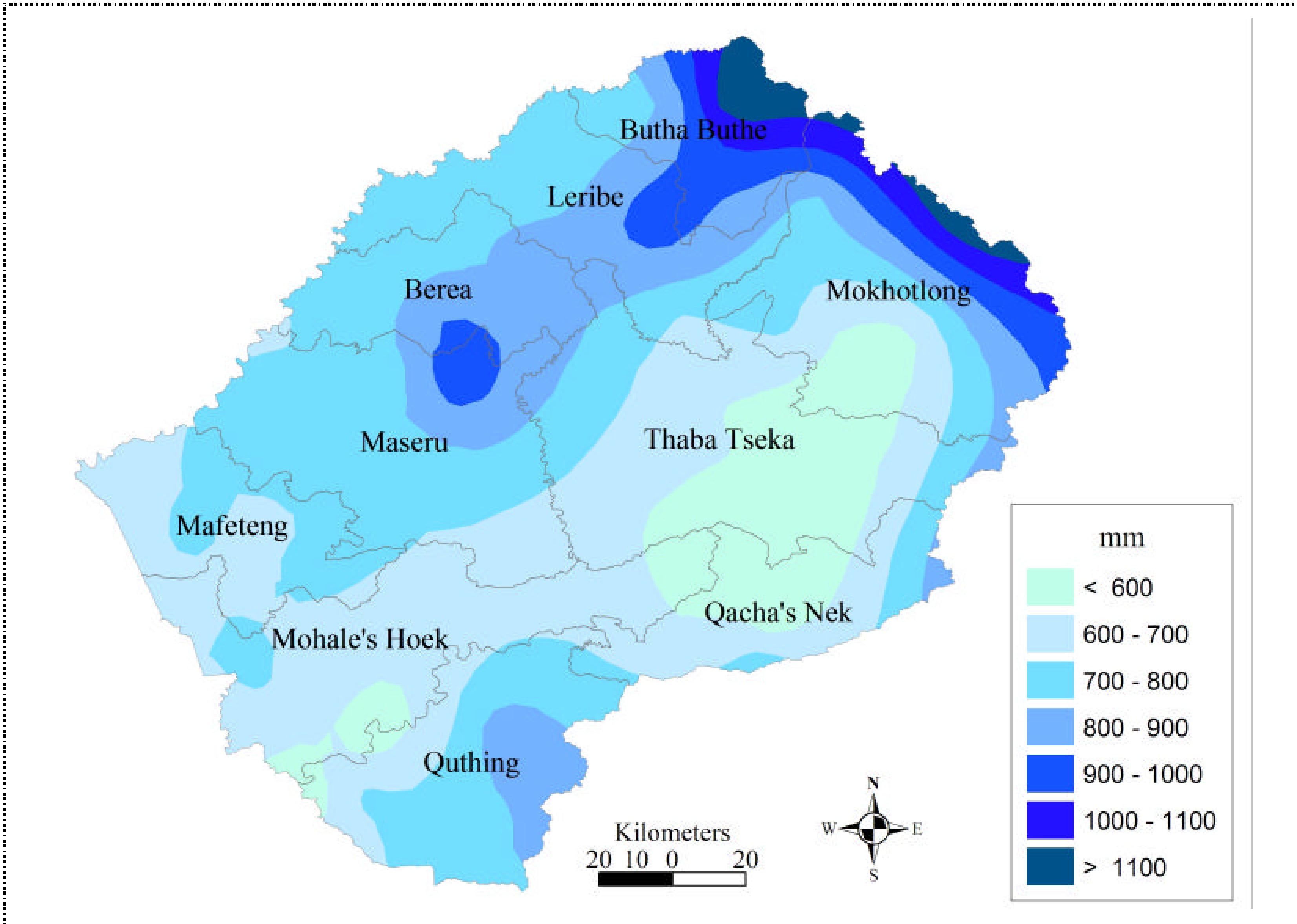


Fig 5.8 Average annual precipitation map of Lesotho obtained using kriging interpolation method (Data from Lesotho meteorological services)

5.3.3 Seasonal rainfall

5.3.3.1 Wet season (October to April)

Lesotho's wet season runs from October to March/April, this is also regarded as the main agricultural summer growing season. Over 90% of the maize is produced under the dryland farming in Lesotho and therefore this makes the rainfall amount and distribution very important to the country's crop farming. Most rainfall occurs in November, December, January and February. The least rainfall is in April when the summer agricultural crops are mostly at maturity stage. The mean seasonal rainfall varies quite a lot throughout the country with the minimum of 388mm recorded at Mashai, and the maximum of 1025mm registered at Oxbow (Appendix 9.2). Seasonal rainfall recorded at Seaka, Fort Hartley and St James with 435mm, 460mm and 464mm respectively is considerably low. At the other end of the scale, relatively high seasonal rainfall was recorded at Ponts'eng, Lekubane, Pulane and Sani Pass with 863mm, 855mm, 760mm and 756mm respectively. As seen from the seasonal map (Fig. 5.9), less than 500mm is recieved over the Senqu river valley (Mohale's Hoek, Quthing, Thaba Tseka and some parts of Qacha's Nek). The area of low rainfall especially over Qacha's Nek and Thaba Tseka is a result of rain-shadow area caused by the Drakensberg ranges with rainbearing winds from Indian Ocean. High seasonal rainfall (> 700mm) is observed over the northern to northeastern highlands and the foothills over the Butha Buthe, Leribe and northern Maseru.

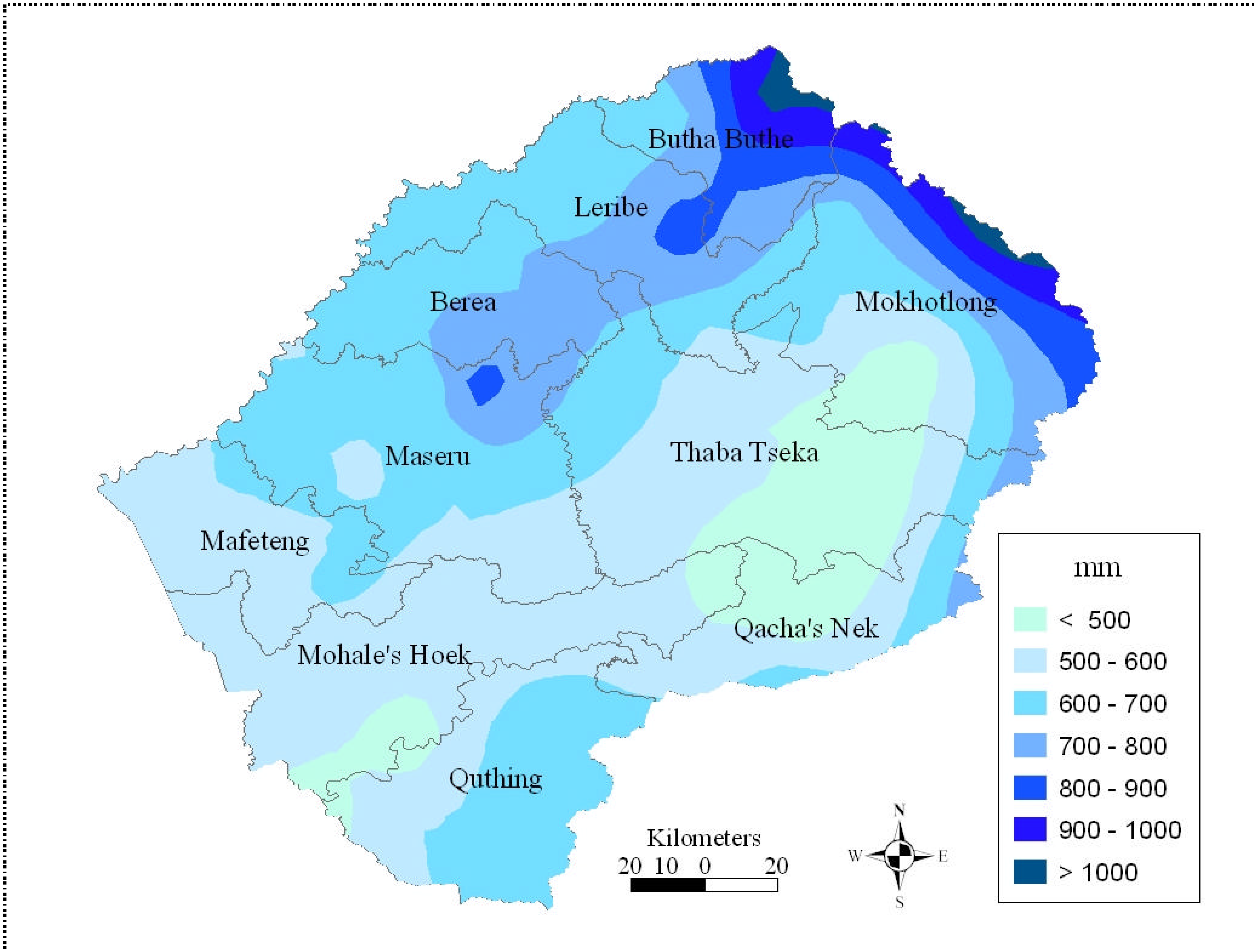


Fig 5.9 Average wet season (October to April) precipitation map of Lesotho obtained using kriging interpolation method (Data from Lesotho meteorological services)

5.3.3.2 Dry season (May to September)

In the dry season the country is dominated by the high pressure thus resulting in little rainfall. In the winter months May to July/August, some of the rainfall is in the form of snow especially over the central, Northern and eastern highlands resulting mostly from the passage of a cold front. The rainfall in the dry season makes around 15% of the total annual rainfall. The lowest mean seasonal amounts are at Mashai, Ramats'eliso, Mokhotlong and Tsoelike with 55mm, 66mm, 68mm and 71mm respectively (Appendix 9.3). In contrast, the highest seasonal amounts are recorded at Oxbow, Lekubane and Makoae with 176mm, 170mm and 166mm respectively. On average the country receives around 90mm of rainfall during this period. From Fig. 5.10, the higher rainfall amounts are evident over the northern (Leribe and Butha Buthe), central (Maseru) and southern (Quthing) parts of the country with over 130mm of dry season rainfall. The eastern part receive relatively low amount of dry season rainfall with less than 80mm of rainfall.

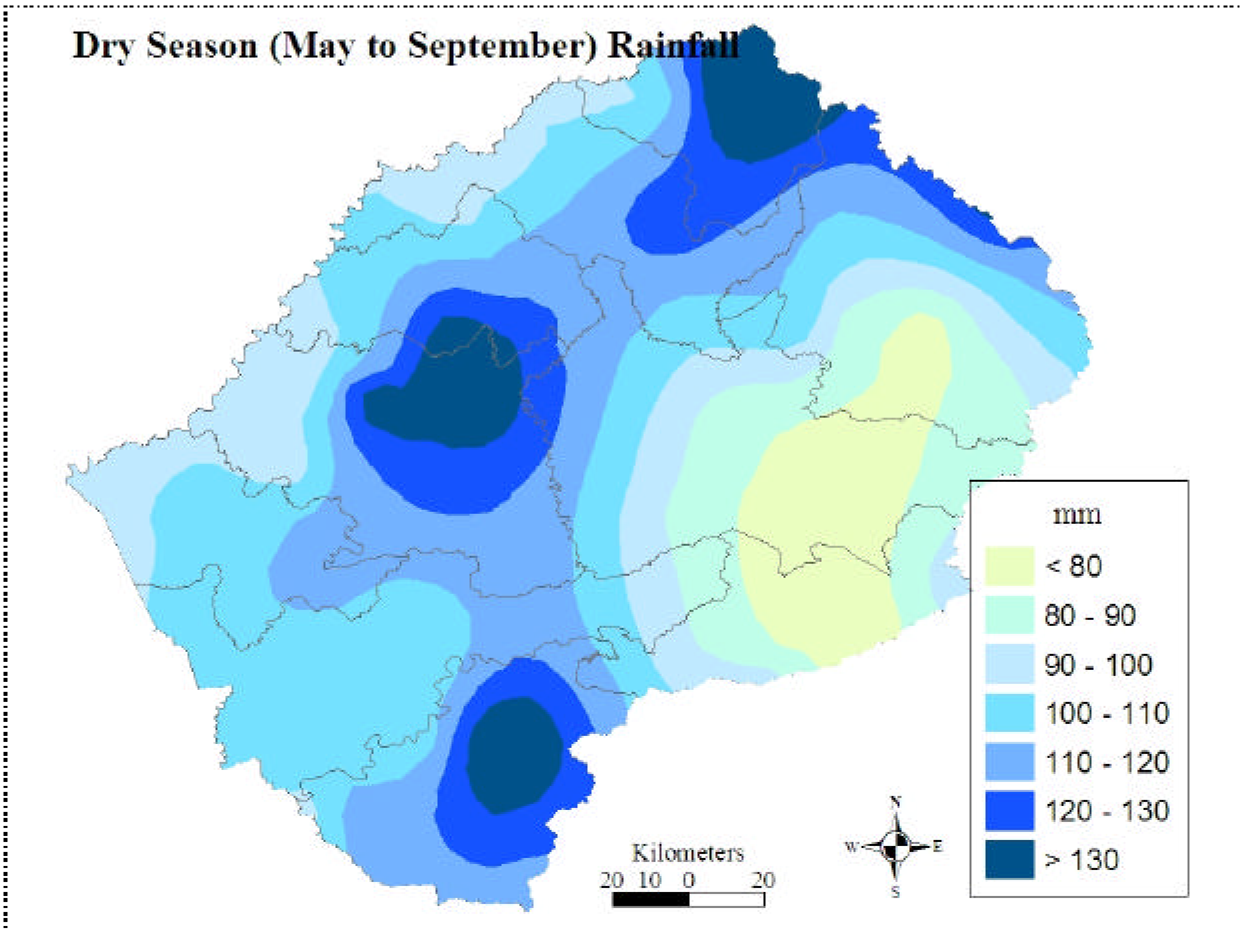


Fig 5.10 Average dry season (May to September) amount of precipitation map of Lesotho

5.3.4 High daily rainfalls

5.3.4.1 Number of days with daily rainfall exceeding 25mm

The increased number of days with rainfall greater than 25mm shows that an area is prone to flash flooding caused by convective type of rainfall. This high intensity rainfall occurs mainly in the months November to February. The number of rain days with 25mm or more ranges from 2 to 12 days with an average of 5 days per year (Table 5.2). The area which experience the most number of days with rainfall greater than 25mm is the northern part of the country where stations like Oxbow, Ponts'eng and Pulane recording an average of 12, 10 and 9 days respectively (Fig. 5.11).

Table 5.2 Average number of days with rainfall greater than 25mm

Station	No of days	Station	No of days	Station	No of days
Botsabelo	6	Matsieng	6	Quthing	8
Butha Buthe	8	Mazenod	7	Ramatseli	4
Fort Hartley	4	Mejametal	5	Rapase	4
Hololo Coourt	6	Mohales H	6	Roma NUL	6
Khoshane	6	Mohlanape	3	Samaria	6
Kolbere	3	Mokhotlon	3	Sani Pass	4
Lekubane	7	Moletsane	7	Seaka	4
Lelingoan	3	Molimo Nthuse	8	Sebedia	7
Leribe	6	Moshoesho	6	Sehlabathebe	5
Lesobeng	2	Mt Carmel	4	Semonkong	4
Letseng la Terai	3	Mt Moorosi	4	St James	3
Mafeteng	6	Mt Olivet	6	St Martins	4
Makoae	6	Nohana	3	St Peters	6
Malealea	8	Oxbow	12	Teyateyaneng	7
Maphutseng	4	Paray	3	Thaba Bosiu	7
Mapoteng	6	Peka	6	Thaba Khupa	5
Maputsoe	6	Pitseng	6	Thaba Tseka	3
St John Marakabei	5	Pontseng	10	Thabana Morena	5
Mashai	3	Pulane	9	Tsilo	5
Matela	6	Qaba	5	Tsoelike	2
Matelile	5	Qachas Nek	7	Whitehill	4

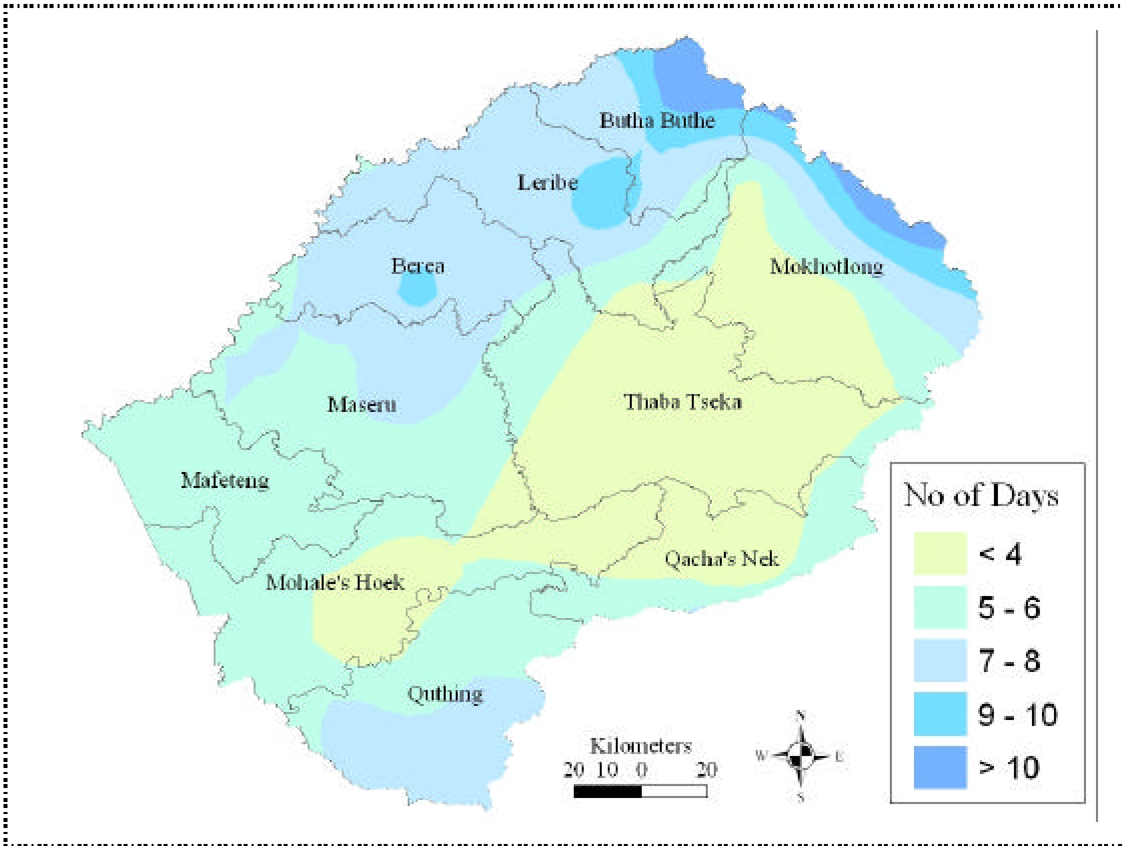


Fig 5.11 Map of average number of days with daily rainfall = 25mm per year for Lesotho

5.3.4.2 Highest daily rainfall on record

The highest daily rainfall was recorded at Sebedia, Butha Buthe and Maphutseng with 170.1mm, 142.2mm and 137.1 mm respectively. These rainfall amounts were observed on the 13th September 1998, 19th December 1960 and 14th February 1993 (Table 5.3). Over 65% of stations have highest falls in January to March and 28 stations out of 62 have highest daily rainfall of greater than 100mm.

Table 5.3 Highest daily rainfall and date of occurrence for all the rainfall stations

Station	Amount	Date	Station	Amount	Date
Bots'abelo	91.2	18 Feb 2001	**Mt Olivet**	115.4	20 Feb 1988
Butha Buthe	142.2	19 Dec 1960	**Nohana**	76.2	20 Feb 1988
Fort Hatley	97.0	31 Jan 1967	**Oxbow**	113.2	16 May 1967
Hololo Court	99.4	21 Mar 2001	**Paray**	92.5	6 Apr 2000
Khoshane	81.4	29 Jan 1999	**Pitseng**	113.0	20 Dec 1970
Kolbere	80.2	4 Mar 2000	**Ponts'eng**	99.0	4 Feb 1991
Makoae	93.0	3 Mar 2000	**Pulane**	121.0	29 Nov 1985
Lekubane	95.0	23 Dec 2002	**Qaba**	85.8	3 May 2001
Leribe	118.0	11 Feb 1983	**Qacha's Nek**	106.0	6 Jan 1965
Lesobeng	93.8	6 Dec 1980	**Quthing**	112.0	21 Feb 1988
Letseng la Terai	86.0	26 Sep 1980	**Ramats'eliso**	97.5	4 Feb 1994
Mafeteng	104.5	21 Jan 1966	**Rapase**	89.5	25 Dec 1985
Malealea	101.0	28 Jan 1977	**Roma NUL**	169.0	12 May 1966
Maphuts'eng	137.1	14 Feb 1993	**Samaria**	100.0	1 Jan 1995
Mapoteng	80.0	9 Feb 2004	**Sani Pass**	128.2	20 Mar 1976
Maputsoe	73.0	9 Dec 1977	**Seaka**	90.5	15 Mar 2000
Marakabei St John	131.1	11 Nov 1966	**Sebedia**	170.1	13 Sep 1998
Mashai	160.0	31 Jan 1967	**Sehlabathebe**	118.2	27 Sep 1987
Matela	87.2	20 Mar 2000	**Semonkong**	86.2	4 Mar 1977
Matelile	88.5	20 Feb 1998	**St James**	84.0	5 Jan 1984
Matsieng	102.0	23 Jan 1991	**St Martins**	94.5	5 Oct 1996
Mazenod	99.0	4 Feb 1991	**St Peters**	124.9	28 Mar 1974
Mejametalana	89.6	24 Feb 1972	**Teyateyaneng**	81.5	6 Mar 1961
Mohale's Hoek	107.7	21 Feb 1988	**Thaba Bosiu**	112.5	23 Aug 1981
Mohlanapeng	88.0	31 Jan 1967	**Thaba Khupa**	96.5	20 Mar 2000
Mokhotlong	76.8	28 Sep 1988	**Thaba Tseka**	93.1	26 Jan 2001
Moletsane	85.3	2 Mar 1994	**Thabana Morena**	112.0	22 Jan 1966
Molimo Nthuse	118.5	27 Mar 1998	**Ts'ilo**	85.5	28 Nov 1997
Moshoeshoe I	111.0	23 Jan 1991	**Tsoelike**	77.5	31 Jan 1967
Mt Carmel	130.0	4 Nov 1983	**Whitehill**	117	12 Mar 1963
Mt Moorosi	110.0	21 Feb 1988			

5.4 Conclusions

Monthly rainfall varies quite a lot from month to month with the summer months recording a relatively higher rainfall than the winter months. November to February is the period in which rainfall is highest (over 100mm per month) in most parts of the country. In contrast, May to September is the period of low rainfall with the monthly rainfall of less than 30mm being recorded in the majority of the rainfall stations. January is the wettest month while June and July are the driest months. The spatial distribution of rainfall is such that the northern to northeastern highlands together with some parts of the foothills in the northwestern to central parts of the country receive high rainfall amounts in almost all the months. The Senqu River Valley recorded the lowest rainfall. There is also a rainshadow area over the districts of Qacha's Nek, Thaba Tseka and southern Mokhotlong caused by the Drakensberg escarpments.

The mean annual rainfall varies from 445mm in the Senqu River Valley to 1205mm over the northern highlands. Over 80% of the rainfall falls in the wet season. Annual rainfall is highest over the northern highlands while the Senqu River valley and the southern lowlands receive less rainfall. Wet season (October to April) rainfall takes the same spatial distribution as that of the monthly and annual rainfall. The mean values started from 388mm with the average of 610mm and the maximum of 1025mm. The dry season (May to September) rainfall is high over the northern, central and southern parts of the country with over 100mm of rainfall. The dry season rainfall ranged from 55mm to 176mm. In Lesotho, rainfall (its spatial and temporal distribution and amount) is very important to the agricultural production because over 90% of the agricultural production comes from the dryland farming. In the next chapter the agro-climatic zoning of the maize crop using the indices derived from the temperature and precipitation parameters will be discussed.

.

High daily rainfalls occurrence is mostly high over the northern parts while the Senqu River Valley experiences relatively less frequent daily rainfall greater than 25mm and less than 50% of the stations have the highest rainfall of over 100mm. Most stations have their highest daily rainfall in the period from January to March while there are no stations recording highest rainfall during June/July months.

For further research, the relationship between elevation and precipitation for different parts of the country will help in understanding more the climate of Lesotho and interpolation of rainfall will maybe more accurate.

Chapter 6 – Agro-climatic Zoning of Maize crop

6.1 Introduction

Agro-climatological zoning is defined as the division of a certain area into several zones, according to the degree of favourability for growing a given crop using climate factors (Todorov, 1981). According to Bishnoi (1989), agro-climatological zoning is a useful tool for agricultural planning of new lands that need to be brought under cultivation and also for using old land resources more judiciously. Agro-climatic classifications have proved to be of great utility for planning and management of various agricultural and forestry activities (Yazdanpanah *et al.*, 2001). Agro-climatic zoning for specialised purposes like epidemic and spread of diseases, and agro-climatic zoning of particular crops, natural pastures etc are becoming important these days. This is because of the need for quantification of agro-climatic resources suitable for potential productivity in specific areas having optimum agro-climatic conditions (Bishnoi, 1989).

Comprehensive agro-climatic analyses may help to select the proper form of land exploitation, thus avoiding costly failures (Bishnoi, 1989). One typical example was a failure of the multimillion dollar peanut project near Tabora in Tanzania in the early 1950s, while another multi-million dollar failure occurred in 1980 in the Malaysian state of Negri Sembilan whereby a huge sugar cane plantation with all the infrastructure including the cane processing factory had to be abandoned (Todorov, 1981). During the first half of 20th century, climatologists and agroclimatologists tried to use well-known climatological classifications for agro-climatic zoning (Todorov, 1981). It was expected that a crop can be introduced into a new area if the climate of this area is the same or similar as the climate of the area of origin of the crop. Many of these attempts failed because the climatic comparisons between a location where the crop has been successfully grown and the proposed location cannot be based on means of climate parameters even if these refer to fairly short intervals of time like ten days (dekads) (Primault, 1977). The mean is never representative, in actual fact it may be composed of widely diverging values but calculations of the frequencies of occurrence of specific meteorological phenomenons should be used as a basis in determining suitable areas

(Primault, 1977). In order to obtain the desired result more quickly, it is preferable to make use of the crop itself in determining suitability rather than to undertake rigorous comparison of climatological data using the annual precipitation or mean monthly temperatures (Todorov, 1981).

To avoid a failure, before a crop (or a variety of a crop) is introduced into an area, the agro-climatic suitability of the area for growing the crop has to be known (Todorov, 1981). Primault (1977) emphasized the fact that introduction of a new crop or of a new variety is meaningful from an economic point of view if the crop can be grown fairly quickly, thus the farmer should be convinced that the crop in question will reach maturity in time to be harvested. Agro-climatological zoning of a crop is done separately for each crop because different crops have different agro-climatic requirements and different responses to climate. When varieties or cultivars of a given crop have different agro-climatic requirements or lengths of growing season, the zoning should be done separately for each variety (Todorov, 1981). In addition, suitable areas for agricultural use are determined by an evaluation of environment components (climate, soil, and relief), and the understanding of local biophysical restraints. In this kind of evaluation, many variables are involved and each one should be weighting according to their relative importance on the optimal growth conditions for the specific crops (Ceballos-Silva and Lopez-Blanco, 2003). The accurate identification and the characterization of current production areas and potential production areas are essential to successful agricultural research and development (Ceballos-Silva and Lopez-Blanco, 2003).

Applications of agro-climatic zoning techniques are so wide and varied, thus it is difficult to evolve a rational universal method for agro-climatic zoning (Bishnoi, 1989). For example, Yazdanpanah *et al.*, (2001) working with almonds used the climatic indices like probability of chilling occurrence on budding and flowering of almond and probablity of rainfall greater than 250mm. While Bazgeer (1993), used indices like annual precipitation of more than 300mm and ratio of autumn to annual precipitation in the zoning of wheat for dryland farming.

Geographic information systems (GIS) have been used for the site-selection of areas such as: recreational activities, crop suitability, hazardous waste disposal sites and critical areas for specific resource management and control practices (Ceballos-Silva and Lopez-Blanco, 2003). However, the GIS functionality in the management of the above areas has been limited by the restrictions inherent in overlaying of digital information maps (Ceballos-Silva and Lopez-Blanco, 2003). Some of these restrictions are: (1) overlays are difficult to use when there are many underlying variables (more than 4), (2) the overlay procedure does not enable one to take into account that the underlying variables are not of equal importance (Ceballos-Silva and Lopez-Blanco, 2003).

The objective of this chapter is to use GIS, temperature and rainfall data presented in the previous chapters to classify different regions of Lesotho according to their suitability for dryland maize farming. This would be done by combining a number of rasters, weighted by their significant impact on the growth and development of maize.

6.2 Data and Methods

6.2.1 Data

For this purpose, the temperature and precipitation paramameters of all the 30 climate stations and 62 rainfall stations of Lesotho were collected and analysed. The spatial distribution and period of observation for all the stations were showed in the previous chapters (4 and 5). The input data for determining suitable areas for maize production are the heat units, minimum temperatures, precipitation, and elevation.

6.2.2 Methodology

All geographic analysis was done in ArcGIS, ArcToolbox and ArcCatalog. The first step towards this objective was determining the indices that were to be used as the site selection for maize production. All the indices were mapped and the shape files were all converted to rasters. The rasters were all done at the resolution of the DEM of 1km x 1km resolution. The heat units and frost-free raster was done by merging the measured values with the raster obtained from the linear regression model which correlates the values at the stations to the elevation (Table 6.1). In order to combine the five datasets they must all have a common scale. The rasters were reclassified to transform them into 1 common scale. The common scale will show how suitable the particular location or each cell is for growing maize (Mc Coy and Johnston, 2001). The rasters were reclassified into four classes, a value of 1 would be given to factors that were unsuitable, a value of 2 to less suitable, 3 for suitable and 4 for more conducive places for growing of maize (McCardle, 2003). Table 6.2 shows classification for all the climatic indices. Then, all shape files were clipped to the Lesotho shapefile and also, all rasters were recalculated utilizing the Lesotho outline map.

The following suitability indices of climatic conditions were used for the selection of suitable areas in dryland farming for maize:

1) For proper maturity, on average maize cultivars need more than 1500GDD seasonally and thus the probability of growing degree days or heat units (POHU) being greater than 1500GDD were determined for each station. October was taken as the beginning of the season while April was taken as the end of the season. The results were correlated with the elevation to give the linear regression model for estimating areas where there were no data (Table 6.1). The areas in which POHU is less than 40 percent were considered undesirable for growing maize and were excluded in further investigation since heat units influence the rate at which crops progress through their development stages from planting to maturity.

2) Since maize seedlings are damaged by frost, it is one of the important requirements of maize to have a frost-free season. Thus the probability of a frost-free season (POFF) occurring in a season taken from October to April was determined for every station and the results were correlated once again with elevation to estimate the probability at unmeasured points. The areas where the probability of a frost-free agricultural season was less than 40% was considered

not suitable for growing maize and are excluded from the final map of suitable areas.

3) Seasonal precipitation of over 500mm is one of the requirements and the probabilities of seasonal rainfall (POSR) exceeding the 500mm mark were computed for all the stations. The season starts in October and ends in April. The areas where the probability of a seasonal rainfall was less than 40% were considered not suitable for dryland maize production.

4) The occurrence of drought during the flowering to grain-filling stages is critical. In Lesotho these stages roughly occur during the months of December for the early planted crops through to February. The probability of a 15-day dry spell (PODS) taking 1mm as the threshold was determined for all the stations. The places with 80% and more probability of dry spells during that period are considered unfavourable while those areas with less than 40% probability are considered more suitable.

5) The last criterion was chosen because of the nature of the country of Lesotho. The last index was the slope of a place due to the fact that maize production is preferable on relatively flat surfaces. The slope was calculated in degrees. All the areas of steep slopes (>12°) were also removed from further findings as it is impossible to plant on steep slopes.

Table 6.1 The regression model and square of correlation coefficient used for estimating probability of heat units equal to or greater than 1500GDD and probability of frost-free season (POHU=probability of seasonal heat units, POFF=probability of frost-free season, ELEV=elevation)

Parameter	Linear Regression Model	Square of Correlation coefficient (R^2)
Probability of heat units greater than 1500GDD	POHU = -0.00102 .ELEV + 2.61	0.8061
Probability of frost-free season	POFF = 7.429E-04 .ELEV - 1.04	0.7847

Table 6.2 The criteria used to determine the suitable areas to dryland maize production

Class	Parameter	POHU	POFF	POSR	PODS	Slope(°)
Not Suitable (1)		< 0.4	< 0.4	< 0.4	= 0.8	> 12
Less Suitable (2)		0.4 – 0.6	0.4 – 0.6	0.4 – 0.6	0.6 – 0.8	8 - 12
Suitable (3)		0.6 – 0.8	0.6 – 0.8	0.6 – 0.8	0.4 – 0.6	4 - 8
Most Suitable (4)		= 0.8	= 0.8	= 0.8	< 0.4	0 - 4

The above indices were chosen taking into consideration the critical requirements of maize. Once all the suitability indices were converted to raster and reclassified, a combined raster was calculated. Using the raster calculator, weights were given to each raster as shown in Table 6.3.

Table 6.3 Weights used in the calculation of suitable areas for dryland maize production in Lesotho.

Parameter	POHU	POFF	POSR	PODS	Slope(°)
Weights as a ratio	0.25	0.2	0.25	0.25	0.05

The accumulated heat units, seasonal rainfall and dry spell occurring at flowering are regarded as the most important parameters and thus are given more weight followed by frost-free growing season and lastly the slope of a place is given the lowest weight since it is the main contributor in the interpolation of both the heat units and frost period.

6.3 Results and Discussion

6.3.1 Probability of growing degree days = 1500GDD

The probability of receiving growing degree days of greater than or equal to 1500GDD were zero at some places over the highlands where the mean daily temperature are most often less than 10°C. Fig. 6.1 shows that the lowlands are conducive to planting maize since the probability of sufficient growing degree days to be 1500 is over 80%. Implying that 4 years out of five the growing degree days are more than 1500GDD. The southern part of Senqu River Valley which runs along the boundaries of Mohale's hoek and Quthing districts also show high probability of heat units. On average, the district of Mokhotlong shows the least probability with less than 10% of the area being in the second class category (40 to 60% class). The other district of low heat units is Thaba Tseka. The probability of high growing degree days is high in Mafeteng district.

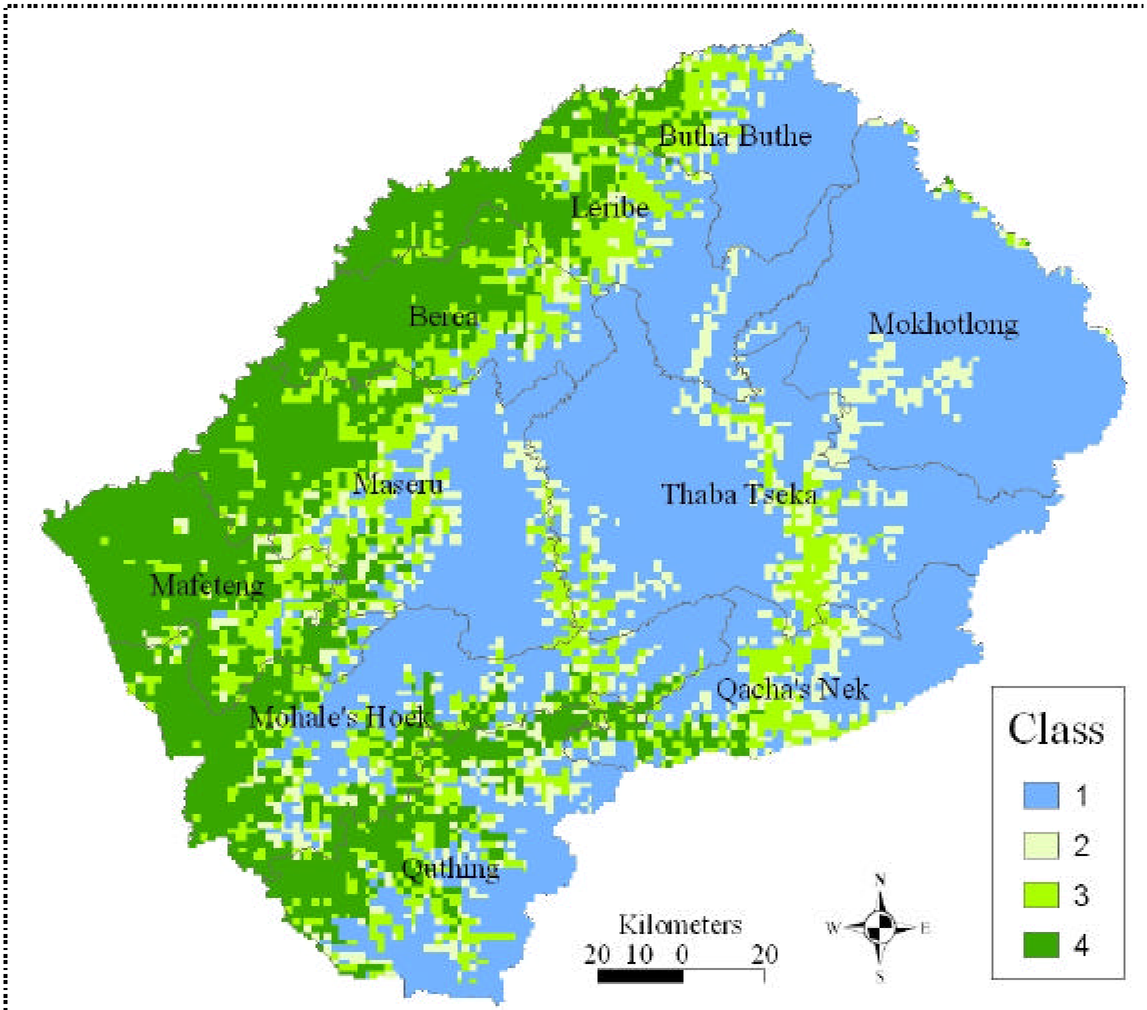


Fig 6.1 Suitability map showing the probability of obtaining 1500GDD growing degree days per season (1=less than 40%, 2=40 – 60%, 3=60 – 80% and 4=over 80%)

6.3.2 Probability of a frost-free season (October to April)

The areas of high frost occurrence show less probability of a frost-free season, these areas are mostly the high-lying areas. Thaba Tseka and Mokhotlong districts show the highest ratio of areas with low probability as compared to the area of the district (Fig. 6.2). When considering frost-free season index, the lowlands and some parts of the foothills and the Senqu River Valley are more suitable for maize. These regions show the probability of over 80% of the seasons (i.e. 4 out of 5 seasons) experiencing the frost-free agricultural season.

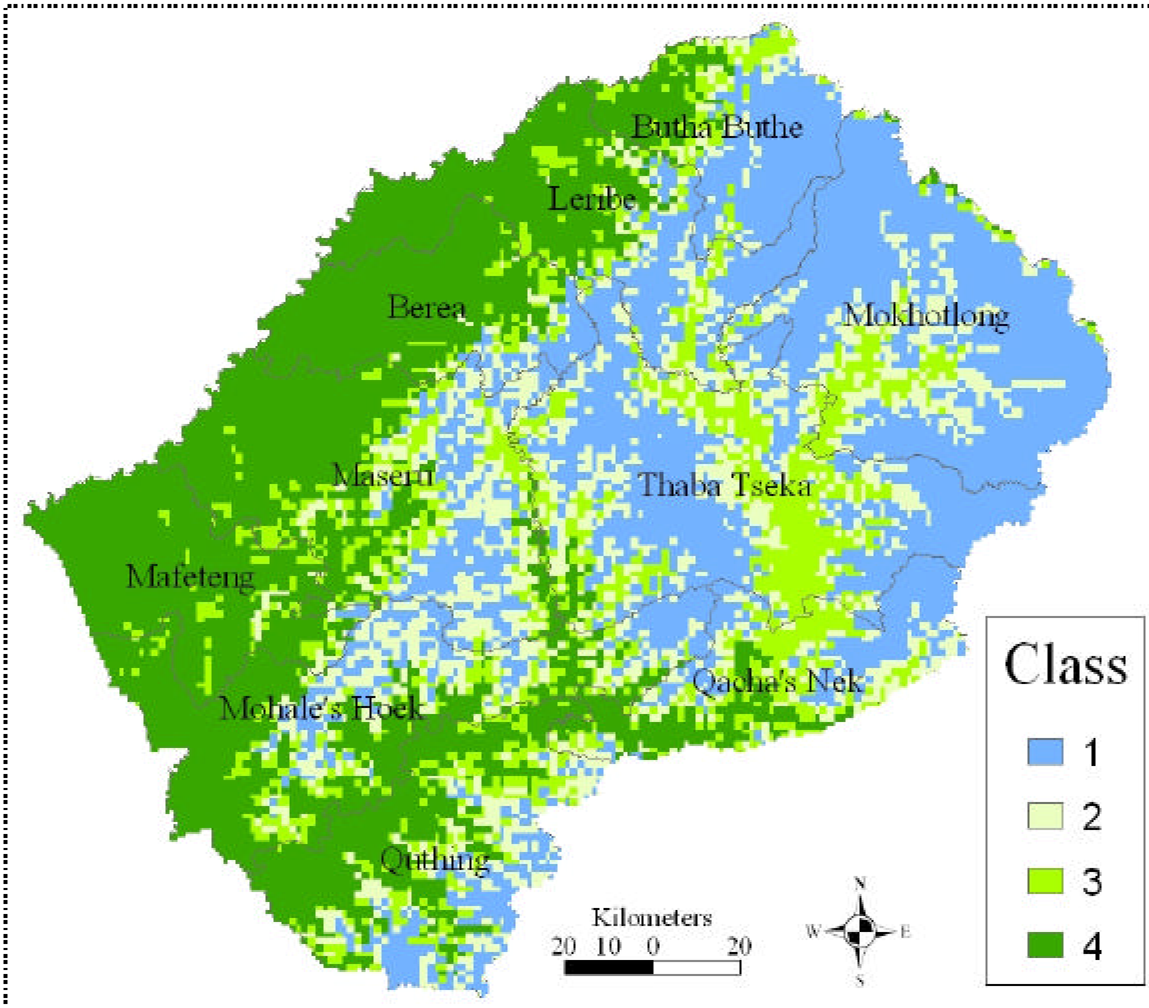


Fig 6.2 Suitability map showing the probability of a frost-free season (1=less than 40%, 2= 40 – 60%, 3=60 – 80% and 4=over 80%)

6.3.3 Probability of seasonal Precipitation of = 500mm

The map showing the probability of seasonal rainfall of greater than or equal to 500mm shows high probability over the northern districts (Butha Buthe, Leribe, Berea and northern Maseru). In these areas the probability is greater than 80% (4 out of 5 seasons cumulative rainfall is greater than 500mm) and thus showing more suitability for growing maize when considering seasonal rainfall as the only index for determination of growing regions (Fig. 6.3). The Senqu River Valley showed the lowest probability with some regions recording less than 40% (i.e. more than 3 out of 5 seasons the crop would fail). The region of class 1 includes some parts of Mohale's Hoek, Quthing and Thaba Tseka districts. Cumulative rainfall over these areas is not conducive for the planting of maize under dryland farming, but this can be compensated by applying different agricultural practices like in-field water harvesting. Some places like Mafeteng, most of Maseru and Mokhotlong districts fall under the 3rd class implying that their probability of obtaining sufficient rainfall is between 60 to 80% (i.e. 3 to 4 seasons out of 5 seasonal rainfall is sufficient). This distribution will be different from year to year and thus use of seasonal forecast to help determine the potential areas of high seasonal rainfall for a specific year.

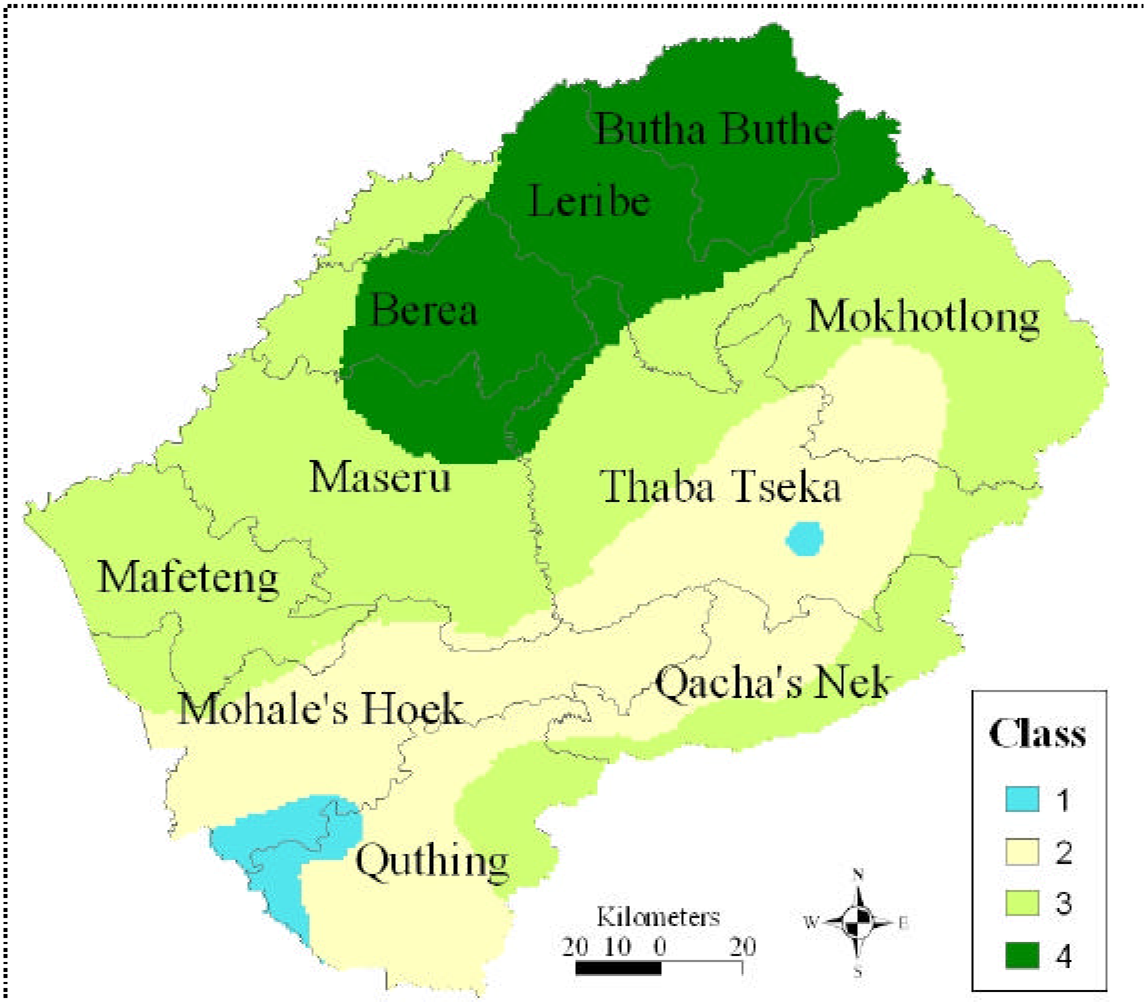


Fig 6.3 Suitability map showing the probability of recieving seasonal (October to April) cumulative rain of 500mm or more (1=less than 40%, 2=40 – 60%, 3= 60 – 80% & 4= over 80%)

6.3.4 Probability of 15-day dry spell in December to February

The occurrence of dry spells during the flowering to grain-filling stages impact both yield and the grain quality. Occurrence of a 15-day dry-spell with less than 1mm rainfall in a day shows that Mafeteng and Mohale's Hoek are the districts which are prone to mid-season drought. The western part of Quthing also experience frequent dry spells during

December to February. The overall probability in these areas is more than 80% (i.e. 4 out of 5 seasons crops can yield low due to drought) (Fig. 6.4). These areas are considered not suitable for maize due to the high frequency of dry spells. The northern districts of Butha Buthe, Leribe and Mokhotlong are less prone to drought with the probability in those areas being less than 40% (less than 2 out of 5 seasons). Some parts of Berea, Thaba Tseka, Qacha's Nek and Maseru fall into the 3rd class (60 to 80%), hence occurrence of dry-spells in the period from December to February is relatively low.

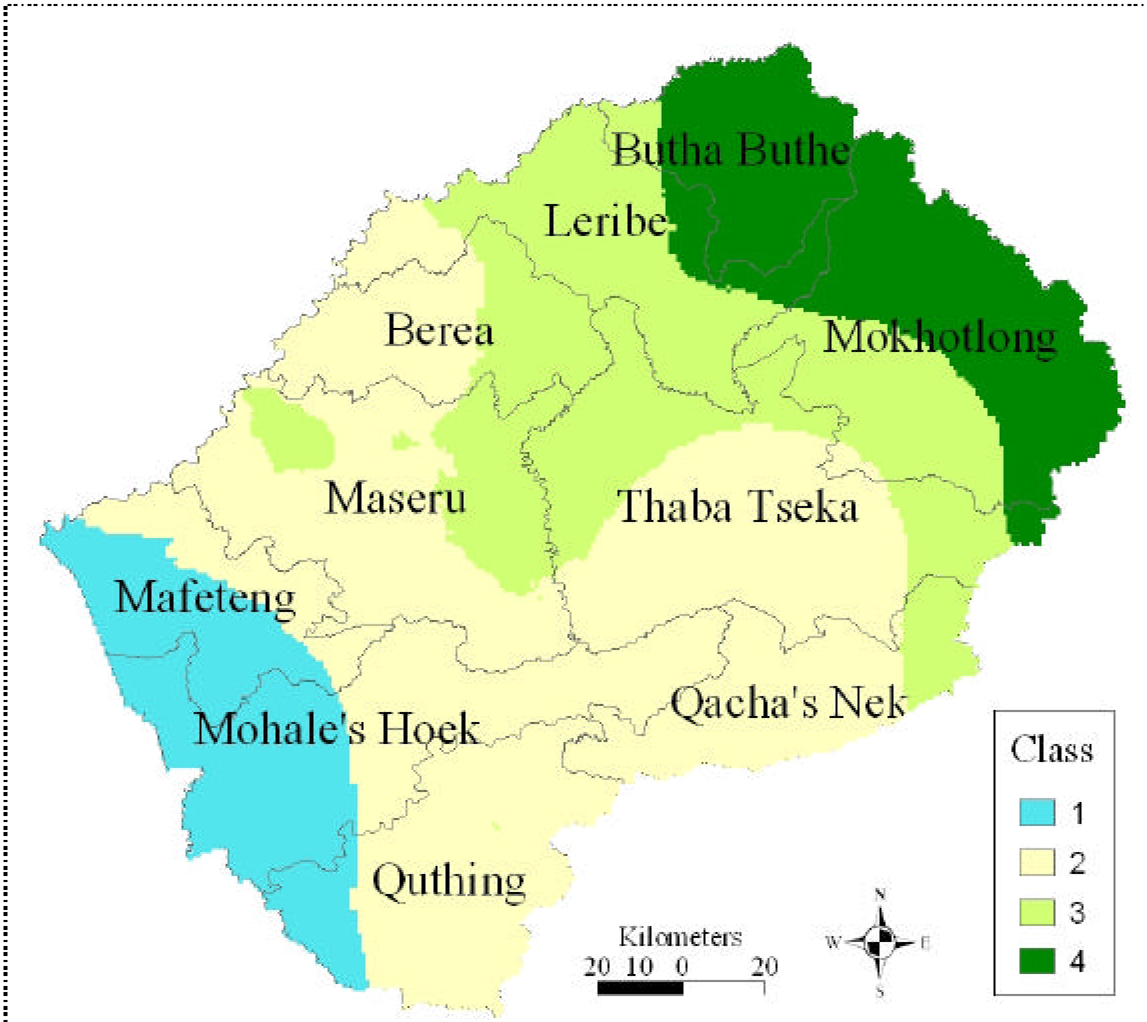


Fig 6.4 Suitability map showing the probability of a 15-day dry-spell during December to February (1= over 80%, 2=60 – 80%, 3= 40 – 60%, & 4= less than 40%).

6.3.5 Slope of an area

Since most of the country is mountainous, it is desirable to find places of relatively flat land for the cultivation of maize. Areas with steep slopes are considered not suitable for the planting of the maize crop; these areas are distributed all over the country. It is only in the lowlands where few steep slopes are found (i.e. relatively flat) (Fig. 6.5). These areas of relatively flat land are found mostly in the districts of Mafeteng, Mohale's Hoek, Maseru, Berea and Leribe towards the western border of the country.

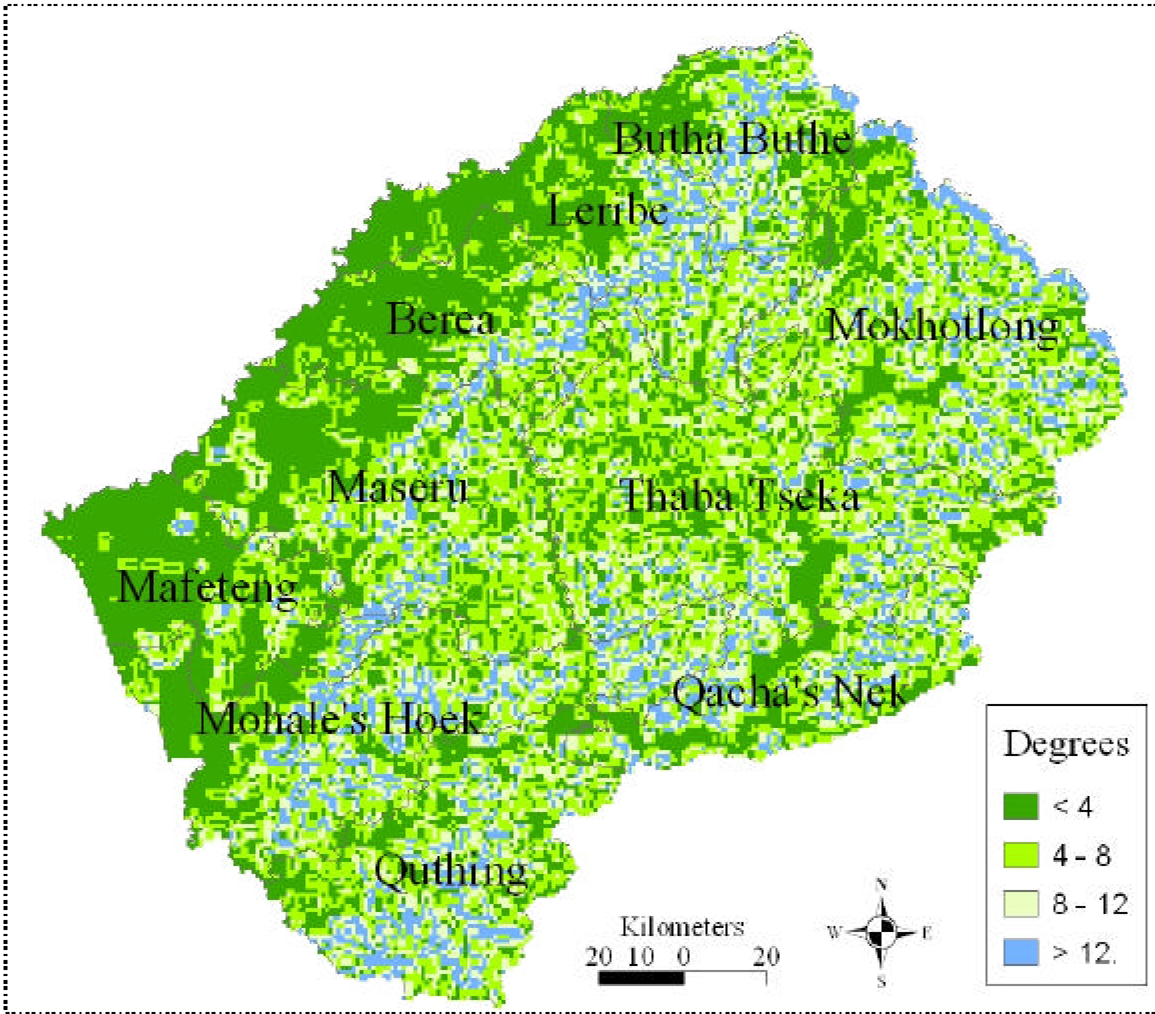


Fig 6.5 Suitability map showing the slope of an area

6.3.6 Agro-climatically zoned map for maize

The combined suitability map (Fig. 6.6) for growing maize under dryland farming over Lesotho developed using all the five suitability indices using the weights shown in Table 6.3. The most suitable areas for the maize production are mostly found in Butha Buthe, Leribe and Berea districts. The area extending from Berea to Mafeteng including Maseru is moderately suitable for maize production using all the five indices (Fig. 6.6). All other districts like Mohale's Hoek, Mafeteng, Quthing, Qacha's Nek, Thaba Tseka and

Mokhotlong are considered not suitable for maize production. Mafeteng district is greatly affected by mid-season dry-spells even though some of the other indices are satisfactory. Mohales's Hoek is unsuitable due to the coupled effect of high frequency of dry-spells and low seasonal rainfall. The districts of Mokhotlong and Thaba Tseka are not conducive for sustaining maize crop except a few patches of land falling under third class (Less Suitable). The main factors in these areas are low heat units and a short frost-free agricultural season. Qacha's Nek has areas under the second class and a few places in the third class category. The main deterent in this district is the low temperatures which give rise to less heat heat units and frost during the season and in some areas rainfall both the cumulative amount and the temporal distribution impact negatively on the maize crop.

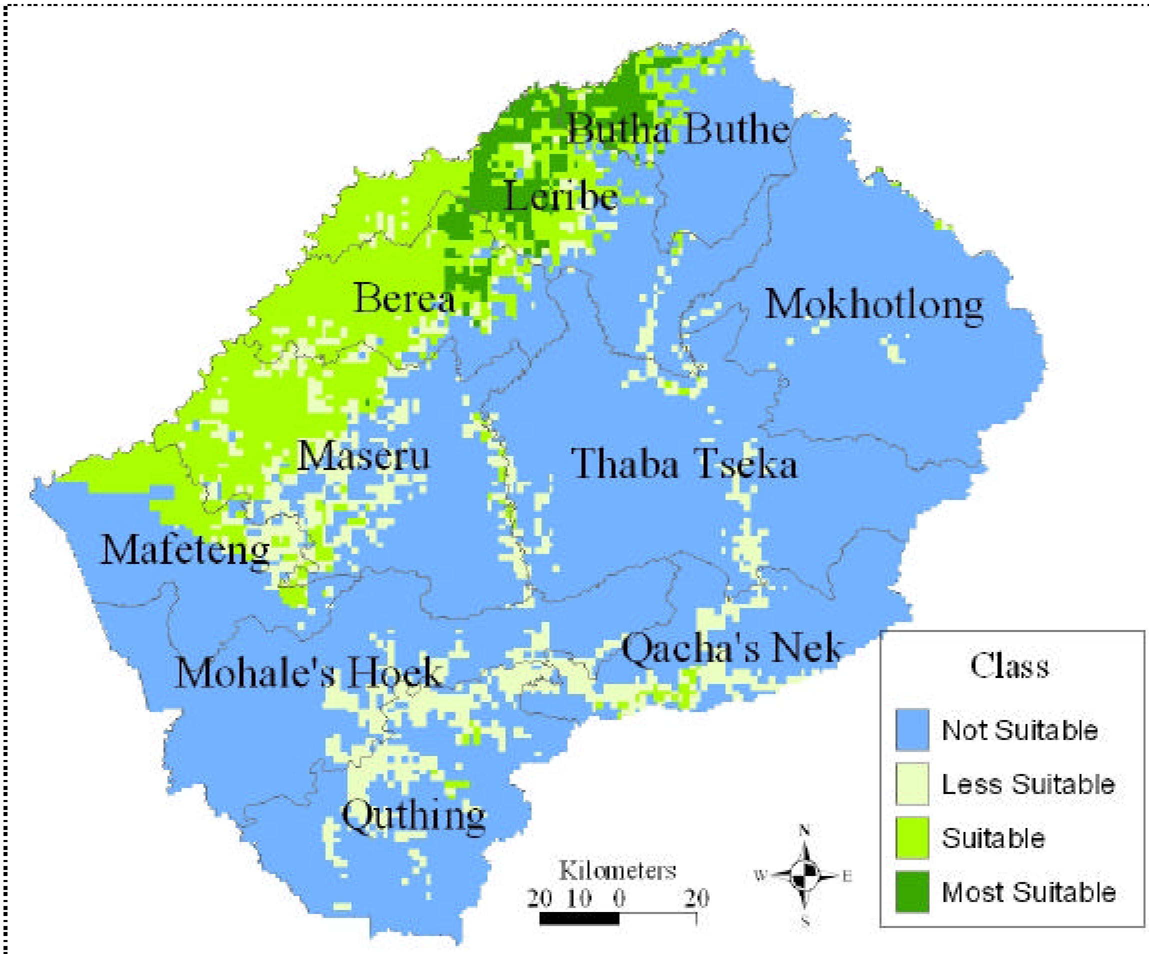


Fig 6.6 Final Suitability map for growing maize under dryland conditions in Lesotho, using the heat units(>1500GDD); frost-free season; slope; seasonal rainfall > 500mm and 15-day dry spell. (The raw data was supplied by Lesotho Meteorological Services)

6.4 Conclusions

The suitability map for growing maize under dryland farming using each of the five indices showed a lot of variation in suitable areas. The most important index which is that of probability of the heat units being greater than the basic requirement of 1500GDD showed the lowlands, some of the foothills and the Senqu River valley to be the most suitable areas. Frost-free season probability also showed the lowlands and the Senqu Valley as suitable areas. All the high-lying areas experienced high probability of frost during the season and thus are not suitable for planting maize.

Seasonal rainfall from October to April depicted the northern parts of the country a being suitable for the maize production. Leribe, Butha Buthe and Berea were the most suitable areas. Mohale's Hoek, Quthing, Qacha's nek and Thaba Tseka were less suitable for the growth and development of maize under dryland farming. The probability of dry-spells occurring during December to February is high over the southern lowlands districts of Mafeteng, Mohale's Hoek and Quthing. Other areas showed moderate dry-spell occurrence except the northern districts of Mokhotlong and Butha Buthe which experience less frequency of dry-spells during that period. The slope index only favoured the western parts of the country while other areas there are no clear pattern in the spatial distribution of steep slopes.

To find the suitable areas for the maize production under dryland farming, all the indices were overlaid using the weights shown in Table 6.3 whereby the probability of heat units, probability of seasonal rainfall and the probability of drought were given higher weight of 0.25 each while the frost-free season and slope were given 0.2 and 0.05 respectively. The resultant map shows that Butha Buthe, Leribe and Berea are the most suitable areas for the planting of the maize crop. Most of Maseru district is moderately suitable for maize except for the highlands towards the east. Some part of Mafeteng district is favourable for maize while most area is unfavourable due to the effects of drought. Thaba Tseka and Mokhotlong were the least suitable districts when using the above-mentioned model. Mohale's Hoek, Quthing and Qacha's Nek have small area which can be considered for planting maize under dryland farming. Places like Mafeteng, Mohale's Hoek, Quthing and Qacha's Nek fall under the less suitable to suitable class. Finally, it can be concluded that using the seasonal rainfall, occurrence of dry-spells during the flowering to grain-filling stage, seasonal growing degree days, frost- free season and the slope of an area as the indices for determining the degree of favourability of growing maize under dryland farming in Lesotho, Butha Buthe, Leribe and Berea are the most suitable areas. Mokhotlong and Thaba Tseka are the least suitable areas while other districts fall between less suitable to moderately suitable areas. Thus it can be concluded that maize can be successful in some areas but most parts of the country of Lesotho are not suitable for growing maize under dryland farming.

The generated maps will be different for cultivars that have shorter growing season to maturity (heat units requirements will be lower as well as the rainfall requirements) and thus in the future suitability maps can be generated using different culitivars to be used by the farming community.

For further research it will be important to incorporate factors like soils characteristics of areas, other climatic factor like evapotranspiration and landuse factor in the determination of the suitable areas for maize production. Incorporation of seasonal forecasts in the model for that particular season can be of help to the agricultural community in the determining the effect it will have in the degree of favourability. Finally, suitability maps of other crops should be investigated in order to maximise the agricultural production in the country.

Chapter 7 - Conclusions

The meteorological data of Lesotho including daily rainfall, daily maximum and minimum temperatures were used in the analysis of this study. The data was used in the determination of climatic indices which are important to crop farming especially that of maize. The monthly values were calculated to investigate both the spatial and temporal variations which is important in the determining the agricultural activities. Of great importance are the seasonal values of the heat units, rainfall and the frost occurrence.

These data had some missing daily values and these made the analysis difficult as some of the important climatic events will be over or underestimated. Patching of these temperature datasets was done using the UK method whereby the monthly means at the stations are compared with the neighbouring stations and a linear model is developed for a given month for maximum and minimum temperatures. Rainfall data was patched using the Inverse Distance (ID) method whereby the value at the station is estimated using nearby stations giving higher weights to the nearest station. The statistical evaluation using selected stations showed that both methods performed quite well. The average MAE for the stations was mostly below 1.8°C for daily minimum temperatures and 1.6°C for the daily maximum temperatures. The KS test also showed that the generated monthly values and the measured monthly temperatures difference were not statistically significant with the 5% confidence interval. The ID method of patching rainfall data gave a good estimate as evidenced by the selected stations which showed an average MAE of less than 2mm. The KS test showed the generated monthly values as being a good match to measured values with few exceptions especially in the dry months where small difference in the values were shown to be significant. On the whole the patching methods were good.

Minimum temperatures are one of the most important meteorological parameters to the agriculture sector in particular crop farming in Lesotho. This is caused by the high altitude of many areas in the country and thus low temperatures tend to be the decisive factor on which plants can be grown in the area. Maximum temperatures variability is important even though in Lesotho there is no great threat of extremely high temperatures as temperatures rarely exceeds 33°C. The results show high temperatures over the lowlands and extremely low temperatures over the high-lying areas. Heat units also biased towards low-lying areas with the highlands receiving relatively low accumulated heat units. Seasonal heat units over the highlands were less than 1000DD while the low-lying areas recorded over 1800DD. As for frost occurrence, its first day is as early as March over the highlands and in the lowlands it can set as late as June. The last day of frost is also late (November) over the high-lying areas while low-lying areas cessation of frost is early (August), thus making the duration of frost higher over the highlands with over 200 days at some places.

Rainfall variability over the country is one of the most critical meteorological parameter to dryland farming. Since over 90% of the maize is produced in the dryland farming in Lesotho, cumulative amount and the distribution of rainfall during the season is important for the success of the crops. Cumulative seasonal rainfall varies from season to season, some seasons are characterized by a lot of dryspells resulting in less than average rainfall while in other seasons is characterized by many rain-producing systems resulting to above average rainfall. On the whole high rainfall is obtained over the northern to northeastern parts of the country in the districts of Butha Buthe and Mokhotlong. In these areas monthly rainfall can go as high as 170mm during the December to February months while the wet season rainfall of over 900mm can be recieved. Also having high rainfall are the foothills of Maseru, Berea, Leribe and Butha Buthe, these areas are evident in all the rainfall maps forming a ‘tongue’ extending from Butha Buthe to northeastern Maseru. Areas of low rainfall are at the Senqu river valley at the boundary of Mohale’s Hoek and Quthing districts and also at Qacha’s Nek, Thaba Tseka and Mokhotlong which forms the rain-shadow area behind the Drakensberg escarpments. The highest rainfall is during the period of December to February while low rainfall is received in May to August.

Agro-climatical zoning of maize in Lesotho has to be performed due to the importance of maize as a staple food in the livelihood of the Basotho nation. Climatic indices calculated from the daily maximum, daily minimum and daily rainfall data were created. The suitability indices for determining the potential growing areas of maize under dryland farming in Lesotho were (1) the probability of the October to April heat units being greater than or equal to 1500GDD, (2) the probability of a frost-free growing season from October to April, (3) the probability of a cumulative rainfall from October to April being greater or equal to 500mm, (4) the probability of getting a mid-season 15-day dry-spell during December to February and (5) the slope of an area. The probability of heat units = 1500GDD was high over the low-lying areas and the mountain region had relatively low probability. More or less the same spatial distribution was obtained for the frost-free season probability. The probability of seasonal precipitation of greater than 500mm is low over the Senqu river valley and high over the northern districts of Butha Buthe, Leribe, Berea and northern Maseru. The probability of a 15-day dryspell was high over Mafeteng and Mohale's Hoek districts making less suitable for maize production while low probability of dry-spells is evident over Leribe, Butha Buthe and Mokhotlong. On average the districts of Mafeteng, Leribe, Butha Buthe, Maseru, Berea, Mohale's Hoek and Maseru relatively flat which make them conducive for crop farming. The combined suitability map for growing maize under dryland farming over Lesotho depicted Butha Buthe, Leribe and Berea districts as having areas where maize crop can perform using the above-mentioned climatic indices. Maseru, some parts of Berea and Mafeteng showed moderately suitable conditions while the other districts have less area in which maize can thrive. Hence, one can conclude that maize can be grown well in some areas over the country of Lesotho even though the total area of suitable places are less than 1/3 total size of the whole country.

References

Aldrich, S.R. and Leng, E.R., 1966. Modern Maize Production. *The Farm Quarterly*, Cincinnati, Ohio. p 17 – 23.

Aldrich, S.R., Scott, W.O. and Leng, E.R., 1978. Modern Maize Production. 2nd Edition. A & L Publications. p 1– 24.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and Drainage Paper #56. 300pp.

Antonie, J., 1996. Agro-ecological Zoning Guidelines. Food and Agricultural Organization (FAO) Soil Bulletin # 73, 78pp.

ACE (Atmosphere, Climate Environment Information Programme), undated. General Circulation. http://www.ace.mmu.ac.uk/eae/Climate/Older/General_Circulation.html 07/10/2004.

Aus BOM (Commonwealth of Australia, Bureau of Meteorology), undated. Climate Glossary. Available at http://www.bom.gov.au/climate/glossary/soi.shtml 26/10/2004.

Bazgeer, S., 1993. Agroclimatological zoning of wheat in dry land farming (A case study of Kurdistan province). M.Sc. thesis, Faculty of Agriculture, Department of Irrigation, Terhan University, Iran. Abstract available at http://www.agrometeorology.org/operational/bazgeer.pdf 20/11/2004.

Benoit, P., 1977. The start of the growing season in northern Nigeria. *Agricultural Meteorology* 18(2), 91-99.

Bishnoi, O. P., 1989. Agroclimatic Zoning. World Meteorological Publications (CAgM Report No. 30). 147pp.

Bloc, D. and Gouet, J.P., 1977. Influence of accumulated heat units on maturity in corn. World Meteorological Organization, *Agrometeorology of Maize, WMO-No 481.* ch 2, p 76 – 83.

Boer, E.P.J., de Beurs, K.M. and Hartkamp, A.D., 2001. Kriging and thin plate splines for mapping climate variables. *International Journal of Applied Earth Observation and Geoinformation*, 3(2), 146-154.

Bootsma, A., 1977. Maturity indices for corn in the low heat unit region of Eastern Canada. World Meteorological Organization, *Agrometeorology of Maize WMO-No 481.* ch 2, p 56 – 66.

Brown, D.M., 1997. Crop Heat Units for Corn and Other Warm Season Crops in Ontario. University of Guelph, Canada. Available at http://www.gov.on.ca/OMAFRA/english/crops/facts/93-119.htm#c1 11/05/2004.

Brown, D. M., 1977. Response of Maize to Environmental Temperatures: Review. World Meteorological Organization, *Agrometeorology of Maize, WMO-No 481.* ch 2, pp 15 – 26.

Browse, J. and Xin, Z., 2001. Temperature sensing and cold acclimation. *Current Opinion in Plant Biology* 4(3), 241-246.

Buckle, C., 1996. Weather and Climate in Africa. Addison Wesley, Longman Ltd, Essex, England. p 23 – 110.

Cakir, R., 2004. Effect of water stress at different development stages on vegetative and reproductive growth of corn. *Field Crops Research* 89(1), 1-16.

Caldiz, D.O., Gaspari, F.J., Haverkort, A.J. and Struik, P.C., 2001. Agro-ecological zoning and potential yield of single or double cropping of potato in Argentina, *Agricultural and Forest Meteorology* 109(4), 311-320.

California State Institute, undated. General circulation. Available at http://calspace.ucsd.edu/virtualmuseum/climatechange1/08_1.shtml 12/09/2004

Caruso, C., 1997. Interpolation Methods Comparison.. *Computers and Mathematics with Applications* 35(12), 109-126.

Ceballos-Silva, A. and López-Blanco, J., 2003. Delineation of suitable areas for crops using a Multi-Criteria Evaluation approach and land use/cover mapping: a case study in Central Mexico. *Agricultural Systems* 77(2), 117-136.

Chakela, Q.K., 1999. State of Environment in Lesotho 1997. National Environment Secretariat (NES), Ministry of Environment, Gender and Youth Affairs, Government of Lesotho. p 119 – 128.

Chapman, L. and Thorns, J.E., 2002. The use of geographical information systems in climatology and meteorology. Climate and Atmospheric Research Group, School of Geography and Environmental Science, University of Birmingham, Birmingham B15 2TT, UK. 24pp.

CSBSJ, undated. Statistics to use. Available at http://bardeen.physics.csbsju.edu/stats/ 21/09/2004

Collins, F.C. and Bolstad, P.V., 1996. A comparison of spatial interpolation techniques in temperature estimation. Available at http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/collins_fred/collins.html 07/05/2004

Crane, P.L., Goldsworthy, P.R., Cuany, R.L., Zuber, M.S. and Francis, C.A., 1977. The global characteristics of maize production: Review. World Meteorological Organization, *Agrometeorology of Maize WMO-No 481*. ch 1, p 4 – 11.

Critchfield, H.J., 1966. General Climatology, Second edition. Prentice-Hall, Englewood Cliffs, NJ. 453pp.

De Jager, J.M., Potgieter, A.B. and Van den Berg, W.J., 1998. Framework for forecasting the extent and severity of drought in maize in the Free State Province of South Africa. *Agricultural Systems* 57(3), 351-365.

De Jager, J.M. and Schulze, R.E., 1977. The broad geographic distribution in Natal of Climatological factors important to agricultural planning. *Agrochemophysica* 9, 81 – 91.

Denmead, O.T. and R.H. Shaw. 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. *Agronomy Journal 52*, 272–274.

Dinpashoh, Y., Fakheri-Fard, A., Moghaddam, M., Jahanbakhsh, S. and Mirnia, M., 2004. Selection of variables for the purpose of regionalization of Iran's precipitation climate using multivariate methods**.** *Journal of Hydrology* 297(1-4), 109-123.

Dirks, K.N., J.E. Hay, J.E., C.D. Stow, C.D. and Harris, D., 1998. High-resolution studies of rainfall on Norfolk Island Part II: Interpolation of rainfall data. *Journal of Hydrology* 208, 187–193.

Doorenbos, J. and Kassam, H.A, 1988. Yield response to water. Irrigation and Drainage Paper #33, 2nd edition. FAO, United Nations, Rome, p101 – 107, p 176.

Dubois, G., 1997. Spatial Interpolation Comparison 97: Foreword and Introduction. *Journal of Geographic Information and Decision Analysis* 2(2), 1-10. available at http://www.geo.sbg.ac.at/staff/lorup/lv/geostats2000s/downloads/SIC97/SIC97_Intro.pdf 07/05/2004

Du Plessis, J., 2003. Maize production. Department of Agriculture, South Africa. Available at www.nda.agric.za/docs/maizeproduction.pdf 21/09/2004

Floyd, N., Horst, W.J. and Riveill, N., 2002. Maize. Available at http://www.ienica.net/crops/maize.pdf 10/05/2004

Food and Agriculture Organization (FAO), 1978. Report on the Agro-ecological Zones project Vol.1 Methodology and Results for Africa. World Soil Resources Report no 48. 158pp.

FA0STAT, 2003. Food and Agricultural Organization Statistical Database. Available at http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0&subset=agriculture 16/04/2004

Frere, M., 1977. The global characteristics of Maize production:Review. World Meteorological Organization, *Agrometeorology of Maize, WMO-No 481*. ch 1, p 4 – 11.

Gardner, F.P., Pearce, R.B. and Mitchell, R.L., 1985. Physiology of Crop Plants. IOWA State University Press. Ch 12, p 296 – 318.

Goovaerts, P., 2000. Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall. *Journal of Hydrology* 228, 113–129.

GA, 2003. Agroclimatic Atlas of Alberta: Agricultural Climate Elements. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6301?OpenDocument#temp 10/05/2004.

Green, G.C., 1966. The Evaluation of Methods of Rainfall Analysis and the Application to the Rainfall Series of Nelspruit. M.Sc. Thesis, University of Free State, Bloemfontein. p 12 – 56.

Guenni, L., 1997. Spatial Interpolation of Stochastic Weather Model Parameters. *Journal of Environmental Management* 49, 31–42.

Hakanson, L. and Boulion, V.V., 2001. A practical approach to predict the duration of the growing season for European lakes, *Ecological Modelling* 140(3), 235-245.

Hall, J.P., 2004. Development of an implementation plan for a geographic information system: case of Lincoln County**.** *International Journal of Information Management* 24(3), 267-275.

Hatfield, J.L., 1977. Light Response in Maize: A Review. World Meteorological Organization, *Agrometeorology of Maize WMO-No 481*.Ch 5, p 199 – 206.

Herath, S. and Ratnayake, U., 2004. Monitoring rainfall trends to predict adverse impacts—a case study from Sri Lanka (1964–1993), *Global Environmental Change Part A* 14 (Supp.1), 71-79.

Hobbs, J.E., Lindesay, J.A. and Bridgman, H., A., 1998. Climates of the Southern Continents-Present, Past and Future. John Wiley and Sons. West Sussex, England. 318pp.

Hoeft, R.G., 1992. Maize. Department of Soil Fertility, University of Illinois, Urbana, IL, USA. Avalilable at www.fertilizer.org/ifa/publicat/html/pubman/ maize.pdf 16/05/2004

Holawe, F. and Dutter, R., 1999. Geostatistical study of precipitation series in Austria: Time and space. *Journal of Hydrology* 219, 70–82.

Holden, N.M. and Brereton, A.J., 2004. Definition of agroclimatic regions in Ireland using hydro-thermal and crop yield data. *Agricultural and Forest Meteorology* 122(3-4), 175-191.

Hoogenboom, G., 2000. Contribution of agrometeorology to the simulation of crop production and its applications. *Agricultural and Forest Meteorology* 103(1-2), 137-157.

Hutchinson, M.F., 1995. Stochastic space–time weather models from ground-based data. *Agricultural and Forest Meteorology* 73, 237–264.

Hyden, L., 1996. Meteorological droughts and rainfall variability in the Lesotho lowlands. Licentiate Thesis, Division of Hydraulic Engineering, Department of Civil and Environmental Engineering, Royal Institute of Technology. 140pp.

ICRISAT, 1980. Climatic classification: a consultant's meeting, 14-16 April 1980. Patancheru, Andhra Pradesh, India**.** p 1 – 149.

International Institute of Tropical Africa (IITA), 2002. Maize. Available at http://www.iita.org/crop/maize.htm 20/05/2004.

IRI, 1999. El Niño/La Niña Update, Available at http://www.wmo.ch/nino/updat.html#impact 10/10/2004.

Jayamaha, G.S., 1979. A contribution to the study of the Weather and Climate of Lesotho with Special Reference to the Agrometeorology in the Country. Lesotho Government Printer. 56pp.

Jeffrey, S.J., Carter, J.O, Moodie, K.B. and Beswick, A.R., 2001. Using spatial interpolation to construct a comprehensive archive of Australian climate data**.** *Environmental Modelling and Software* 16(4), 309-330.

Joerin, F., Thériault, M. and Musy, A., 2001. Using GIS and outranking multicriteria analysis for land-use suitability assessment. *International Journal of Geographical Information Science* 10(8), 321–339.

Johnston, K., Hoef, J.M.V., Krivoruchko, K. and Lucas, N., 2001. Using ArcGIS Geostatistical Analyst. ESRI Press. 300pp.

Jones, P.G. and Thornton, P.K., 2000. MarkSim Software to Generate Daily Weather Data for Latin America and Africa. *Agronomy Journal* 92, 445-453.

Kar, C. and Mohanty, A. R., 2004. Application of KS test in ball bearing fault diagnosis. *Journal of Sound and Vibration* 269(1-2), 439-454.

Kumudini, S. and Tollenaar, T., 1998. Corn Phenology. Available at http://www.plant.uoguelph.ca/research/homepages/ttollena/corn.htm 21/05/2004

Lacey,T. and Roe, A., 2001. Dryland maize growing in WA. Farmnote 95/2001. Department of Agriculture, Western Australia. 4pp.

Lauer, J., 1998. Weather impacts on corn yield**.** *Wisconsin Crop Manager* 4 (15), 82 -83. University of Wisconsin – Madison.

Lazaro, R., Rodrigo, F.S., Gutirrez, L., Domingo, F. and Puigdefafragas, J., 2001. Analysis of a 30-year rainfall record in semi-arid SE Spain for implications on vegetation. *Journal of Arid Environments* 48, 373–395.

LMS, 1999. Vulnerability Assessment Report- UNEP/GEF Climate Change Study in Lesotho. Project number GF/2200–96–16. 156pp.

LMS, 2000. Lesotho National Report on Climate Change. Ch.7, p 23-25.

Li, L. and Revesz, P., 2003. Interpolation methods for spatio-temporal geographic data. *Computers, Environment and Urban Systems* 28(3), 201-227.

Linacre, E. and Geerts, B., 1997. Climates and Weather explained. Routledge, London and New York. p 51 – 75.

Lindkvist, L., Gustavsson, T. and Bogren, J., 2000. A frost assessment method for mountainous areas. *Agricultural and Forest Meteorology* 102(1), 51-67.

Liu, M. and Samal, A., 2002. A fuzzy clustering approach to delineate agroecozones. *Ecological Modelling* 149(3), 215 – 228.

Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., 2001. Geographic Information Systems and Science. John Wiley & Sons, New York, 454pp.

Major, D.J., 1977. Corn maturity and weather in Alberta. World Meteorological Organization, *Agrometeorology of Maize, WMO No 481*. ch 2, p 67 – 75.

Martin, F.W., 1989. Maize-ECHO Technical Note**.** Available at http://www.echonet.org/tropicalag/technotes/Maize.pdf 10/02/2004.

Makhuvha, T., Pegram, G., Sparks, R. and Zucchini, W., 1997. Patching rainfall data using regression methods: 1. Best subset selection, EM and pseudo-EM methods: Theory. *Journal of Hydrology* 198(1-4), 289-307.

Mangelsdorf, P.C., 1974. Corn Its Origin Evolution and improvement**.** Harvard University Press Cambridge, Massachusetts. Ch 1&2, p 1 – 14.

McCardle, A., 2003. Land Use Suitability Analysis Surround the Fort Henry Development Complex Ohio County, West Virginia. Available at http://www.nrac.wvu.edu/rm493-591/fall2003/students/Mccardle/ 07/10 2004

McCoy, J. and Johnston, K., 2001. Using ArcGIS Spatial Analyst. ESRI Press. 232pp.

McMaster, G.S. and Wilhelm, W.W., 1997. Growing degree-days: one equation, two interpretations. *Agricultural and Forest Meteorology* 87(4), 291-300.

Mebrhatu, M.T., 2003. Rainfall Studies for the Highlands of Eritrea. MSc. Thesis University of Free State, Bloemfontein. 110pp.

Milbourn, G.M., 1968. Maize for grain. A grower's handbook. Department of Agriculture, Wye College, Ashford, Kent. p 3 – 10.

Milbourn, G.M. and Carr, M.K.U., 1977. The Importance of site selection for Maize in Great Britain. World Meteorological Organization, *Agrometeorology of Maize, WMO-No 481*. ch 1, p 45 – 48.

Moonen, A.C., Ercoli, L., Mariotti, M. and Masoni, A., 2002. Climate change in Italy indicated by agrometeorological indices over 122 years**.** *Agricultural and Forest Meteorology* 111(1), 13-27.

Mwangala, S., 2003. Wet-Spells in Namibia during the month of April with reference to the wet-spell of mid-April 2003. Namibia Climate Technical Publications- abstracts, April 2003. Avalilable at http://www.meteona.com/ 29/10/2004

Nalder, I.A. and Wein, R.W., 1998. Spatial interpolation of climatic Normals: Test of a new method in the Canadian boreal forest. *Agricultural and Forest Meteorology* 92, 211-225.

Neild, R.E. and Newman, J.E., 1990. Growing Season Characteristics and Requirements in the Maize Belt-National Maize Handbook US. Available at http://www.agcom.purdue.edu/AgCom/Pubs/NCH/NCH-40.html 18/11/2003

Oke, T.R., 1987. Boundary Layer Climates, Second edition, Routledge, London. 435pp.

Pannar Quality Seeds, 2002a. Heat Units - Fuel for the Maize plant. Pannar Seed Company, South Africa. p 1 – 3.

Pannar Quality Seeds, 2002b. Moisture Utilization. Pannar Seed Company, South Africa. p 1 – 2.

Pierre, W.H., Aldrich, S.R. and Martin, W.P., 1966. Advances in Corn Production: Principles and practices. Iowa State University Press. Iowa. 476pp.

Price, D.T., McKenney, D.W., Nalder, I.A., Hutchinson, M.F. and Kesteven. J.L., 2000. A comparison of two statistical methods for spatial interpolation of Canadian monthly mean climate data. *Agricultural and Forest Meteorology* 101(2-3), 81-94.

Primault, B., 1977. Zonation of the Maize crop using Biometeorological Indices. World Meteorological Organization, Agrometeorology of Maize, WMO-No 481. ch 1, p 40 – 44.

Quiring, M.S. and Papakryiakou, T.N., 2003. An evaluation of agricultural drought indices for the Canadian prairies**.** *Agricultural and Forest Meteorology* 118(1-2), 49-62.

Ranatunge, E., Malmgren, B.A., Hayashi, Y., Mikami, T., Morishima, W., Yokozawa, M. and Nishimori, M., 2003. Changes in the Southwest Monsoon mean daily rainfall intensity in Sri Lanka: relationship to the El Niño–Southern Oscillation**.** *Palaeogeography, Palaeoclimatology, Palaeoecology* 197(1-2), 1-14.

Ritchie, S.W., Hanway, J.J. and Benson, G.O., 1986. How a Corn plant develops. Cooperative Extension Services. Iowa State University, Ames. Available at http://maize.agron.iastate.edu/corngrows.html#stages 01/04/2004

Rosenberg, N.J., Blad, B.L. and Verma, S.B., 1983. The Biological Environment, Second edition. Wiley Interscience, New York. p 116 – 133.

Rouanet, G., 1987. The Tropical Agriculturalist-Maize**.** Macmillan Press Ltd London and Basingstoke. Ch1, p 1-4.

Sakata, S., Ashida, F and Zako, M., 2004. An efficient algorithm for Kriging approximation and optimization with large-scale sampling data. *Computer Methods in Applied Mechanics and Engineering* 193(3-5), 385-404.

Salih, I.M., Hakan, B.L.P., Sivertun, A. and Lund, E., 2003. Spatial correlation between radon (222Rn) in groundwater and bedrock Uranium (238U): GIS and geostatistical analyses. *Journal of Spatial Hydrology* 2(2), 10.

Saunders, A.R., 1930. Maize in South Africa. South African Agricultural Series No. 7. Central News Agency, Ltd. Ch 1 & 3, p 14 - 60.

Schulze, R.E., 1965. Climate of South Africa, Part 8 General Survey. South African Weather Bureau, Department of Transport. Republic of South Africa. p 1 – 25.

Schulze, R.E., Maharaj, M., Lynch, S.D., Howe, B.J. and Melvil-Thomson, B., 1997. South African Atlas of Agrohydrology and Climatology. Water Research Commision, Pretoria, Report TT82/96. 277pp.

Sharma, T.C., 1996. Simulation of the Kenyan longest dry and wet spells and the largest rainsums using a Markov model. *Journal of Hydrology* 178, 55–67.

Shaw, R.H., 1977. Water Use and Requirements- A Review. World Meteorological Organization, *Agrometeorology of Maize*, WMO-No 481. ch 4, p 119 – 134.

Shaw, R.H. and Newman, J.U., 1991. Weather Stress in the Maize Crop-National Maize Handbook US available at http://www.agcom.purdue.edu/AgCom/Pubs/NCH/NCH-18.html, 7/11/2003

Skirvin, S.M., Marsh, S.E., McClaranw, M.P. and Meko, D.M., 2003. Climate spatial variability and data resolution in a semi-arid watershed, south-eastern Arizona. *Journal of Arid Environments* 54, 667–686.

Sprague, G.F., 1955. Maize and Maize improvement. Academic Press INC., New York. Ch 7, p 315 – 339.

Sprague, G.F. and Dudley, J.W., 1988. Corn and Corn Improvement.3rd Edition. American Society of Agronomy, Inc. Madison, U.S. pp 578 – 638.

Stone, L.R., Schelgel, A.J., Gwin, R.E. and Khan, A.H., 1996. Response of corn, grain sorghum, and sunflower to irrigation in the High Plains of Kansas. *Agricultural Water Management* 30, 251–259.

Tang, W.Y., Kassim, A.H.M. and Abubakar, S.H., 1996. Comparative studies of various missing data treatment methods - Malaysian experience**.** *Atmospheric Research* 42(1-4), 247-262.

Taylor, S.P., Haywood, A.M., Valdes.P.J, and Sellwood. B.W, 2004. An evaluation of two spatial interpolation techniques in global sea-surface temperature reconstructions: Last Glacial Maximum and Pliocene case studies. *Quaternary Science Reviews* 23(9-10), 1041-1051.

Teitel, M., Peiper, U.M. and Zvieli, Y., 1996. Shading screens for frost protection. *Agricultural and Forest Meteorology* 81, 273-286.

Todorov, A.V., 1981. Agroclimatic Zoning of Agricultural Crops- 15th Conference Report of the Agrometeorological Division of the American Meteorological Society. LA. p 135 – 138.

Tyson, P.D., 1986. Climatic Change and Variability in Southern Africa. Oxford University Press, Cape Town, South Africa. p 1– 13.

Tyson, P.D. and Preston-Whyte, R.A., 2000. The Weather and Climate of Southern Africa. Oxford University Press, Cape Town, South Africa. 396pp.

UK Met, undated. http://www.ukmetoffice.com

V**an Dijk, A.I.J.M., Bruijnzeel, L.A. and Rosewell, C.J., 2002.** Rainfall intensity–kinetic energy relationships: a critical literature appraisal. *Journal of Hydrology* 261(1-4), 1-23.

Veenendaal, E.M., Ernst, W.H.O. and Modise, G.S., 1996. Effect of seasonal rainfall pattern on seedling emergence and establishment of grasses in a savanna in south-eastern Botswana. *Journal of Arid Environments* 32, 305–317.

Wallace, H.A. and Bressman, E.N., 1937. Corn and Corn Growing. John Wiley and Sons, New York.

Wang, Y., Yam, R.C.M. and Zuo, M.J., 2004. A multi-criterion evaluation approach to selection of the best statistical distribution. *Computers & Industrial Engineering* 47(2-3), 165-180.

White, D.H., Lubulwa, G., Menz, K., Zuo, H., Wint, W. and Slingenbergh, J., 2001. Agroclimatic classification systems for estimating the global distribution of livestock numbers and commodities. *Environment International* 27, 181–187.

Wilken, G.C., 1978. Agroclimatology of Lesotho. Discussion paper No.1, Lesotho Agricultural Sector Analysis Project, Ministry of Agriculture, Maseru and Economics Department, Colorado State University. pp 1 – 57.

Willmott, C. J., 1982. Some comments on the Evaluation of Model performance. *Bulletin American Meteorological Society* 63(11), 1309 – 1313.

Wokabi, S.M., After 1997(undated). Sustainability of Maize Production in Kenya. Kenya Agricultural Research Institute, Nairobi, Kenya. Available at http://144.16.93.203/energy/HC270799/LM/SUSLUP/Thema2/311/311.pdf 10/11/2004

Xia, Y., Fabian, P., Winterhalter, M., and Stohl, A., 1999. Forest climatology: estimation of missing values for Bavaria, Germany. *Agricultural and Forest Meteorology* 96(1-3), 131-144.

Xia, Y., Fabian, P., Winterhalter, M. and Zhao, M., 2001. Forest climatology: estimation and use of daily climatological data for Bavaria, Germany. *Agricultural and Forest Meteorology* 106(2), 87-103.

Yang, J., Greenwood, D.J., Rowell, D.L., Wadsworth, G.A. and Burns, I.G., 2000. Statistical methods for evaluating a crop nitrogen simulation model, N_ABLE. *Agricultural Systems* 64(1), 37-53.

Yazdanpanah, H., Hajam, S., Khalili, A. and Kamali, G., 2001. Agroclimatic zoning of Azarbayjan-Sharghi province for rainfed almond using GIS. 4pp Available online at http://www.gisdevelopment.net/application/agriculture/overview/agrio0006c.htm 09/11/2003.

Young, J.A., Vance, G.F. and Zhang, R., 2000.Climatic Patterns in the Big Horn Basin, Wyoming. University of Wyoming. Available at www.uwyo.edu/ces/PUBS/B-1089.pdf 05/03/2004.

Zaidi, P.H., Rafique, S., Rai, P.K., Singh, N.N., 2003. Response of maize (*Zea mays* L.) genotypes to excess soil water stress: Morpho-physiological effects and basis of tolerance. *European Journal of Agronomy* 19(3), 383-399.

Zaidi, P.H., Rafique, S., Rai, P.K., Singh, N.N. and Srinivasan, G., 2004. Tolerance to excess moisture in maize (*Zea mays* L.): Susceptible crop stages and identification of tolerant genotypes. *Field Crops Research* 90(2-3), 189-202.

APPENDICES

Appendix 1: Statistics (mean, median, skewness, 10th percentile, 20th percentile, 80th percentile and 90th percentile) for measured and generated monthly minimum temperatures

1.1 Leribe cctual and generated monthly minimum temperature (°C) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	13.8	13.8	13.2	13.3	11.0	11.2	7.2	7.3	2.4	2.5	-1.5	-1.8
Median	13.7	13.8	13.4	13.3	11.0	11.1	7.2	7.2	2.5	2.5	-1.7	-1.8
Skewness	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.2
10thperce.	12.6	12.5	11.4	12.0	9.2	10.0	5.0	5.7	0.8	1.4	-2.9	-2.8
20thperce.	13.3	13.0	12.3	12.6	10.1	10.5	5.8	6.3	1.3	1.8	-2.4	-2.4
80thperce.	14.5	14.6	14.3	14.1	12.0	11.9	8.3	8.5	3.4	3.3	-0.5	-1.2
90thperce.	14.8	14.8	15.1	14.8	12.5	12.5	8.6	8.7	4.2	3.5	-0.1	-0.7
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	-1.8	-1.6	1.4	0.9	5.8	5.8	9.1	9.1	10.9	10.7	12.6	12.5
Median	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.2
Skewness	0.5	0.6	0.7	0.2	-0.7	-0.5	-1.2	-1.4	0.4	0.6	-0.5	-0.5
10thperce.	-3.2	-3.0	0.0	-0.7	3.8	4.5	7.1	7.6	9.7	9.5	11.4	11.2
20thperce.	-2.7	-2.8	0.4	0.2	5.0	5.0	8.3	8.5	10.0	9.9	11.7	11.6
80thperce.	-0.6	-1.0	2.4	1.7	7.1	6.7	10.2	10.0	11.5	11.6	13.5	13.1
90thperce.	0.2	0.0	2.7	2.3	7.4	7.7	10.6	10.5	12.6	12.1	13.8	13.3

Jan = January
Jan* = Generated January Value

1.2 Mohale's Hoek actual and generated monthly minimum temperature (°C) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	14.3	14.2	14.1	13.8	11.8	11.9	8.4	8.6	4.6	4.8	1.2	1.6
Median	14.2	14.1	14.0	13.9	11.9	12.0	8.5	8.5	4.5	4.7	1.0	1.5
Skewness	0.3	0.6	1.0	-0.2	-0.5	-0.3	-0.3	-0.2	0.2	-0.6	0.7	-0.4
10thperce.	13.1	13.3	13.1	12.2	9.9	9.9	6.8	6.8	3.2	4.0	-0.1	-0.8
20thperce.	13.4	13.5	13.2	13.1	10.8	10.6	7.1	7.1	3.7	4.2	0.1	0.5
80thperce.	15.1	14.9	14.9	14.4	12.7	12.9	9.6	9.9	5.2	5.6	2.1	2.7
90thperce.	16.0	15.3	15.2	15.4	13.0	13.8	9.8	10.1	6.5	5.9	3.2	3.4
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	1.4	1.2	3.6	3.8	6.9	7.2	9.5	9.7	11.4	11.5	13.4	13.4
Median	1.2	1.3	3.5	3.7	6.8	7.4	9.8	9.9	11.6	11.5	13.3	13.4
Skewness	0.8	-1.4	0.2	-0.1	0.0	-0.7	-0.7	-1.2	-0.2	1.0	0.9	0.6
10thperce.	-0.1	-0.1	2.0	1.5	4.7	5.6	6.7	7.8	9.8	10.6	11.5	12.0
20thperce.	0.3	0.3	2.7	2.5	5.7	6.2	8.2	9.0	10.5	10.7	12.4	12.6
80thperce.	2.9	2.5	4.5	5.3	8.1	8.3	10.5	10.8	12.4	12.2	14.1	14.1
90thperce.	3.8	2.9	4.7	5.7	8.5	8.9	11.4	11.2	13.2	12.9	15.0	14.8

*** denotes Generated**

1.3 Mokhotlong actual and generated monthly minimum temperature (°C) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	10.9	11.0	10.5	10.3	9.1	8.8	4.7	4.8	0.5	0.6	-3.1	-2.9
Median	10.9	10.9	10.3	10.5	8.7	9.0	5.1	5.4	0.5	0.8	-3.1	-2.8
Skewness	0.1	-0.7	0.5	-0.8	3.3	-0.4	-0.6	-1.1	-0.3	-0.4	0.2	-0.4
10th perce.	9.5	9.7	8.4	8.2	6.7	6.6	2.5	2.5	-1.3	-1.1	-4.5	-5.5
20th perce.	9.9	10.1	9.6	8.8	7.6	7.8	3.5	3.4	-0.5	-0.7	-3.9	-4.2
80th perce.	11.6	12.1	11.5	11.7	9.8	10.1	5.9	5.8	1.7	1.6	-2.0	-1.6
90th perce.	12.4	12.2	12.1	12.4	10.5	10.7	6.4	6.0	2.0	1.9	-1.4	-0.9
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	-3.2	-2.8	-0.2	0.3	3.9	4.0	6.7	6.9	8.3	8.1	9.5	9.2
Median	-3.1	-2.6	-0.3	0.0	3.8	4.0	6.9	7.1	8.2	7.9	9.7	9.2
Skewness	-0.1	-0.3	0.9	0.7	0.3	0.1	-0.8	-0.9	-0.1	0.9	-1.0	-0.2
10th perce.	-5.1	-5.0	-1.7	-2.2	1.8	2.5	4.1	5.1	6.7	6.4	8.1	7.8
20th perce.	-4.2	-4.2	-0.7	-1.2	2.8	3.0	5.4	6.1	7.5	7.1	8.8	8.3
80th perce.	-2.0	-1.6	0.5	1.7	5.0	5.2	7.9	7.9	9.5	9.1	10.7	10.0
90th perce.	-1.4	-1.3	1.5	2.5	5.7	5.7	8.2	8.2	9.8	9.9	11.0	10.6

*** denotes Generated**

1.4 Moshoeshoe I actual and generated monthly minimum temperature (°C) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	14.9	14.7	14.4	14.1	12.7	12.5	9.0	8.9	4.4	4.2	1.0	1.2
Median	15.0	14.7	14.0	14.0	12.8	12.3	9.1	9.3	4.3	4.3	0.7	1.2
Skewness	0.1	-0.4	0.2	-0.3	1.4	0.2	-0.7	-0.5	0.0	-1.7	1.0	0.5
10th perce.	14.0	13.5	12.6	12.1	11.2	10.9	7.0	7.1	3.1	2.2	-0.1	-0.1
20th perce.	14.1	14.2	13.8	13.5	11.8	11.7	8.3	8.0	3.9	3.7	0.2	0.2
80th perce.	15.7	15.4	15.6	15.1	13.5	13.6	10.0	9.8	5.5	4.9	1.8	1.9
90th perce.	15.9	15.6	16.3	15.8	14.5	14.2	10.3	10.3	5.9	5.4	2.5	2.9
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	0.8	0.7	3.7	3.9	7.5	7.7	10.4	10.3	12.2	12.2	13.8	13.7
Medi an	0.6	0.6	3.6	3.8	7.7	7.6	10.5	10.3	11.9	12.3	13.8	13.8
Skewness	0.0	0.2	0.8	0.8	-0.1	0.3	-0.1	-0.3	0.8	0.4	-0.5	-0.4
10th perce.	-0.7	-1.0	2.6	2.5	6.2	6.2	9.1	8.8	10.9	11.0	12.4	12.0
20th perce.	0.1	-0.2	2.7	2.8	6.7	6.8	9.4	9.4	11.3	11.2	13.1	12.7
80th perce.	1.6	2.4	4.3	5.1	8.3	8.7	11.1	11.0	13.4	13.1	14.6	14.4
90th perce.	2.5	2.5	5.4	5.9	9.1	9.5	11.7	11.5	14.2	13.9	14.9	15.1

*** denotes Generated**

1.5 Qacha's Nek actual and generated monthly minimum temperature (°C) Statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	12.5	12.4	12.3	12.1	11.3	11.3	8.1	8.0	5.0	4.9	2.4	2.2
Median	12.5	12.5	12.3	12.2	11.0	11.1	8.1	7.8	4.9	4.8	2.5	2.2
Skewness	0.1	-0.7	0.1	-0.2	3.2	0.2	-0.1	0.2	0.1	-0.1	-0.2	0.1
10thperce.	11.5	11.4	10.8	10.7	9.8	9.8	6.8	6.4	3.8	3.7	1.0	1.0
20thperce.	11.8	11.6	11.3	10.8	10.1	10.5	7.0	6.7	4.3	4.3	1.3	1.2
80thperce.	13.0	13.2	13.4	13.4	11.6	12.2	9.2	9.3	5.8	5.6	3.4	3.0
90thperce.	13.6	13.3	13.7	13.6	12.1	12.5	9.6	9.6	6.3	6.2	3.6	3.7
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	2.1	1.9	4.2	4.0	6.9	7.0	8.5	8.2	9.9	9.8	11.6	11.6
Median	1.8	2.0	4.1	3.8	7.0	7.1	8.6	8.4	9.7	9.8	11.8	11.7
Skewness	0.5	-0.4	0.2	0.3	-0.5	-0.5	-0.8	-0.9	0.3	-1.4	-0.4	-0.3
10thperce.	0.5	0.1	2.8	2.4	5.0	4.9	7.1	6.9	8.4	8.5	10.3	10.4
20thperce.	1.0	1.0	3.1	3.3	5.8	6.3	8.0	7.3	9.1	9.0	10.8	10.8
80thperce.	3.1	2.8	5.1	4.9	7.8	8.1	9.4	9.0	10.8	10.9	12.2	12.3
90thperce.	3.8	3.4	5.8	6.1	8.0	8.4	9.9	9.7	11.4	11.4	12.8	12.7

*** denotes Generated**

Appendix 2: Statistics (mean, median, skewness, 10th percentile, 20th percentile, 80th percentile and 90th percentile) for measured and generated monthly maximum temperatures

2.1 Leribe actual and generated monthly maximum temperature (°C) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	27.7	27.6	27.0	26.8	24.4	25.2	22.5	22.3	19.5	19.4	16.4	16.3
Median	27.5	27.5	26.6	26.6	25.2	25.1	22.7	22.5	19.2	19.1	16.4	16.2
Skewness	0.2	0.2	0.7	0.2	-4.0	0.2	-0.3	-0.3	0.2	0.6	0.2	0.2
10th perce.	25.7	25.7	24.7	24.9	23.7	23.8	20.1	19.9	18.1	17.8	15.2	15.0
20th perce.	26.1	26.4	25.5	25.2	24.2	24.1	20.3	20.7	18.3	18.4	15.9	15.4
80th perce.	29.7	29.1	28.6	28.6	26.5	26.0	23.9	24.3	20.6	20.5	16.8	17.2
90th perce.	30.3	29.8	30.5	29.8	26.9	26.9	24.0	24.6	21.8	21.3	17.8	17.6
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	16.6	16.5	19.3	19.2	22.6	22.4	24.1	24.0	25.3	25.4	26.7	26.6
Median	17.0	16.5	19.2	19.4	22.4	22.5	24.1	24.2	24.8	25.0	26.7	26.5
Skewness	-1.9	-1.1	-0.2	-1.1	0.0	-0.3	-0.3	-0.5	0.7	1.0	0.2	0.2
10th perce.	15.2	15.6	16.9	17.0	20.3	20.1	22.2	22.2	23.4	23.8	24.6	24.8
20th perce.	16.0	15.7	18.7	18.4	21.0	21.0	23.1	23.1	24.1	24.0	25.2	25.2
80th perce.	17.6	17.4	20.1	20.0	24.7	24.0	25.2	25.0	26.8	26.5	28.2	28.2
90th perce.	18.0	17.8	21.3	20.5	24.9	24.6	25.8	25.5	28.0	27.6	29.0	28.9

*** denotes Generated**

2.3 Mohale's Hoek actual and generated monthly maximum temperature (°C) Statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	28.5	28.5	28.1	27.8	25.4	25.3	22.3	22.4	18.9	18.9	16.0	16.0
Median	28.2	28.5	27.8	27.4	25.1	24.9	21.5	21.7	18.9	18.8	15.6	15.8
Skewness	0.1	0.0	0.1	0.2	1.0	1.0	0.6	0.4	-0.5	0.6	0.5	0.6
10th perce.	25.9	25.8	25.5	25.4	23.1	23.7	19.7	20.2	17.2	17.8	14.3	14.9
20th perce.	26.6	26.9	26.5	26.1	24.0	24.1	20.7	20.8	18.3	18.1	14.8	15.2
80th perce.	30.3	30.3	29.8	29.9	26.9	26.4	24.6	24.4	20.0	19.6	17.7	16.7
90th perce.	30.9	30.7	30.9	31.0	28.8	28.4	25.4	25.1	20.3	20.3	18.2	17.5
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	16.2	16.3	18.6	18.6	22.2	22.4	24.5	24.5	25.8	25.8	27.6	27.7
Median	16.0	16.2	18.5	18.7	22.2	22.3	24.7	24.7	25.2	25.4	27.5	27.4
Skewness	0.7	0.2	-0.4	-1.0	0.0	0.0	-1.1	-0.6	1.1	1.2	0.0	0.0
10th perce.	14.8	15.0	16.4	16.5	20.2	20.4	22.0	22.0	23.8	24.2	25.1	25.3
20th perce.	14.9	15.3	17.6	17.5	20.4	20.6	23.7	23.8	24.5	24.7	26.0	26.2
80th perce.	17.9	17.7	19.6	19.8	23.9	24.1	25.7	25.4	27.3	27.1	29.4	29.2
90th perce.	18.5	17.8	20.3	20.2	24.4	24.3	26.3	26.4	28.4	28.1	30.5	30.4

*** denotes Generated**

2.4 Mokhotlong actual and generated monthly maximum temperature (°C) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	24.9	24.3	24.3	23.7	21.9	22.4	19.8	19.6	16.5	16.7	13.8	14.3
Median	24.7	24.1	24.4	23.5	22.3	22.6	19.6	19.4	16.6	16.6	13.8	14.3
Skewness	0.2	0.1	-0.2	-0.1	-4.0	-0.9	-0.6	-0.4	-0.5	0.1	0.5	0.6
10th perce.	23.2	22.7	22.6	21.5	20.9	21.4	17.2	18.1	14.8	15.5	12.3	13.0
20th perce.	23.6	23.5	22.8	22.4	22.0	21.7	18.7	18.5	15.8	16.0	13.0	13.2
80th perce.	26.4	25.6	26.1	25.6	23.6	23.0	21.3	21.0	17.4	17.5	14.7	15.4
90th perce.	26.9	26.3	26.3	25.8	23.7	23.2	21.9	21.2	17.8	17.7	15.2	15.8
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	14.2	14.5	16.6	16.3	19.9	19.3	21.4	21.0	22.4	21.9	23.3	23.4
Median	14.1	14.9	16.7	16.3	20.3	19.4	21.4	21.2	22.2	21.6	23.6	23.3
Skewness	0.2	-0.4	-0.5	-0.1	-0.7	-0.2	0.1	-0.4	0.7	-0.2	-3.1	-0.1
10th perce.	13.0	13.4	14.6	14.3	17.3	17.1	19.6	19.9	20.9	20.9	21.6	21.5
20th perce.	13.6	13.6	15.3	15.2	18.6	17.2	20.3	20.0	21.4	21.1	22.1	22.1
80th perce.	15.1	15.3	17.7	17.7	21.3	21.1	22.3	22.1	23.7	22.6	25.3	24.7
90th perce.	15.4	15.8	18.6	18.4	21.8	21.3	23.3	22.7	24.3	23.3	25.8	25.0

*** denotes Generated**

2.4 Moshoeshoe I actual and generated monthly maximum temperature (°C) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	27.7	27.4	26.6	26.5	24.9	25.0	22.1	22.0	19.0	19.1	15.5	15.8
Median	27.5	27.1	26.5	26.4	24.8	24.7	22.7	22.6	19.3	18.7	15.3	15.7
Skewness	0.1	0.1	0.1	0.1	0.6	0.3	-0.1	-0.1	0.3	0.7	0.6	0.5
10th perce.	25.6	25.2	24.0	24.2	23.0	23.2	19.5	19.5	17.7	17.8	14.2	14.3
20th perce.	26.0	25.7	24.9	24.6	24.1	23.5	20.2	20.1	17.9	18.1	14.5	14.9
80th perce.	29.8	29.5	28.4	28.2	25.6	26.3	24.1	23.8	20.4	20.1	16.4	16.6
90th perce.	30.0	29.6	30.0	29.7	27.0	27.1	24.4	24.2	20.7	21.3	17.4	17.5
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	15.9	16.2	18.6	18.5	21.9	21.7	23.9	23.8	25.3	25.0	26.7	26.4
Median	15.9	16.0	18.6	18.7	21.2	21.0	23.9	23.9	24.9	24.6	26.9	26.3
Skewness	0.6	0.2	-0.4	-0.7	0.1	0.2	0.0	-0.3	0.6	0.5	0.2	0.2
10th perce.	14.7	14.8	16.7	16.6	19.6	19.4	21.6	21.5	23.1	22.9	23.9	23.6
20th perce.	15.1	15.3	17.5	17.4	20.6	20.5	22.4	22.2	23.5	23.2	24.9	25.1
80th perce.	17.0	17.4	19.6	19.3	24.2	24.0	25.0	25.0	27.2	26.7	28.8	28.3
90th perce.	17.7	17.7	20.1	19.9	24.8	24.6	25.9	25.5	28.2	27.5	29.7	29.4

***denotes Generated**

2.5 Qacha's Nek actual and generated monthly maximum temperature (°C) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	25.0	24.6	24.3	23.9	22.8	22.8	20.6	20.2	17.4	17.6	14.2	14.9
Median	25.2	24.3	24.3	24.0	22.7	22.8	20.6	20.5	17.3	17.5	13.9	14.7
Skewness	0.1	0.1	-0.3	-0.3	0.1	0.5	-0.4	-0.2	0.8	0.3	0.2	0.8
10thperce.	23.4	22.8	22.2	21.8	21.2	21.6	17.8	17.9	15.8	15.5	12.7	13.4
20thperce.	23.6	23.6	23.1	22.6	21.8	22.2	18.8	18.3	16.1	16.3	13.1	13.8
80thperce.	25.9	25.9	25.8	25.3	24.0	23.3	22.1	21.9	18.4	18.5	15.4	16.3
90thperce.	27.6	27.0	26.9	25.4	24.2	24.0	22.4	22.4	19.3	19.4	16.0	16.5
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	14.6	14.5	17.0	17.2	20.1	20.2	21.2	21.2	22.4	22.1	24.4	23.8
Median	14.5	14.8	17.2	17.4	20.0	20.0	21.0	20.9	22.2	22.2	24.4	23.7
Skewness	-0.6	-2.1	-0.6	-0.6	0.2	0.3	0.1	-0.2	0.4	0.7	-0.2	0.2
10thperce.	12.8	12.7	14.4	14.7	18.3	18.2	19.3	20.1	21.0	20.7	21.8	22.2
20thperce.	13.9	14.0	15.8	15.6	19.1	18.7	20.2	20.3	21.1	21.2	23.0	22.6
80thperce.	15.8	15.7	18.5	18.6	21.4	21.5	22.0	22.4	23.6	23.1	26.3	25.0
90thperce.	16.3	16.0	19.3	19.5	22.0	22.0	23.5	23.0	24.3	23.8	26.5	26.2

*** denotes Generated**

Appendix 3: Statistics (mean, median, skewness, 10th percentile, 20th percentile, 80th percentile and 90th percentile) for measured and generated monthly rainfall

3.1 Leribe actual and generated monthly rainfall (mm) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	106.5	110.0	98.3	97.6	102.2	93.7	53.8	52.6	21.7	23.3	9.6	10.6
Median	98.6	89.9	93.0	103.7	82.1	91.1	46.7	45.6	11.9	19.9	5.0	5.7
Skewness	1.0	1.5	1.4	0.2	2.1	0.7	0.8	0.6	1.0	1.0	1.8	1.7
10th perce.	36.0	47.7	37.5	46.5	40.9	48.2	0.0	10.2	0.0	0.1	0.0	0.0
20th perce.	49.7	51.8	51.9	58.6	51.4	56.2	14.5	20.9	0.0	1.9	0.0	0.1
80th perce.	150.0	143.6	126.8	137.9	132.6	133.6	91.9	86.1	38.4	43.5	19.9	18.2
90th perce.	194.4	241.5	166.1	155.7	184.4	164.6	121.5	106.4	62.6	63.0	23.0	29.4
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	5.9	7.0	20.7	24.5	26.3	27.0	69.4	68.9	92.0	99.7	87.6	93.7
Median	1.3	3.5	4.7	10.1	14.2	15.9	63.7	71.2	88.1	98.1	82.2	97.8
Skewness	2.0	1.5	1.1	0.8	2.3	2.0	0.7	0.2	0.5	0.1	1.4	0.0
10th perce.	0.0	0.1	0.0	0.0	0.0	1.4	13.5	25.0	36.6	44.6	38.1	51.6
20th perce.	0.0	0.3	0.0	0.1	0.7	3.8	28.0	27.4	52.3	67.7	52.9	60.4
80th perce.	11.0	11.7	49.6	54.3	40.2	31.3	106.9	113.8	130.9	135.9	117.9	123.2
90th perce.	20.1	25.3	74.1	68.6	102.8	104.4	143.0	119.0	154.9	166.1	131.2	138.0

*** denotes Generated**

3.2 Mohale's Hoek actual and generated monthly rainfall (mm) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	111.1	94.3	93.5	87.3	97.0	83.6	60.9	58.0	21.6	32.2	20.5	19.6
Median	108.4	82.9	65.9	67.9	84.7	68.8	45.2	37.5	16.6	30.1	12.8	16.4
Skewness	0.4	0.7	1.3	0.7	1.7	1.0	1.0	2.0	1.7	1.4	0.9	0.4
10th perce.	34.3	43.9	31.1	24.4	45.5	44.6	3.7	9.1	0.0	0.5	0.0	0.0
20th perce.	47.4	52.8	40.7	31.3	56.7	55.8	12.2	20.4	0.3	4.2	1.8	3.1
80th perce.	168.9	146.2	154.5	149.7	135.6	119.6	99.0	78.9	36.6	50.0	40.7	34.5
90th perce.	198.1	167.4	206.7	165.8	158.7	147.0	164.4	180.3	60.8	56.0	55.2	42.3
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	10.8	9.0	28.4	22.6	41.6	45.0	64.7	82.4	83.2	101.1	104.9	86.6
Median	3.9	3.0	5.1	4.4	28.6	30.3	46.0	61.7	77.6	77.7	93.2	95.0
Skewness	2.1	1.7	1.4	1.1	1.2	0.8	1.0	1.1	1.4	1.3	0.8	0.1
10th perce.	0.0	0.0	0.0	0.0	0.1	1.4	3.5	5.8	20.9	24.7	26.3	30.2
20th perce.	0.0	0.4	0.0	0.1	3.7	16.3	19.5	15.3	36.7	49.3	42.8	40.4
80th perce.	18.3	17.5	72.7	52.1	79.2	89.9	124.7	122.8	109.6	153.3	160.2	124.6
90th perce.	37.1	29.6	91.7	79.5	122.4	102.5	154.5	213.0	189.5	246.3	215.8	147.0

*** denotes Generated**

3.3 Mokhotlong actual and generated monthly rainfall (mm) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	93.4	97.3	82.9	85.6	79.0	67.1	32.2	37.3	12.1	18.0	7.8	9.3
Median	90.0	90.8	69.3	76.0	65.2	58.5	33.7	34.9	7.3	14.0	4.3	3.7
Skewness	1.0	1.6	0.8	0.8	3.2	0.8	0.3	1.4	0.9	0.8	1.4	2.2
10thperce.	49.3	57.6	41.6	40.7	22.6	30.2	7.3	17.6	0.0	0.0	0.0	0.0
20thperce.	54.6	68.1	50.6	63.1	42.7	41.4	15.1	20.2	0.0	1.0	0.0	0.3
80thperce.	117.5	119.8	116.1	111.1	106.5	107.9	47.0	48.9	22.0	39.4	15.8	16.2
90thperce.	161.0	136.6	145.8	146.3	114.6	128.5	60.4	59.3	36.8	43.8	26.4	30.2
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	3.1	5.3	18.8	19.3	30.0	29.8	72.4	66.9	73.4	76.5	81.0	82.1
Median	0.0	1.6	13.3	10.7	11.3	13.4	59.2	63.2	80.0	80.1	70.8	72.5
Skewness	1.6	1.9	1.0	2.0	2.9	1.8	0.9	0.5	-0.6	0.0	0.3	1.0
10thperce.	0.0	0.0	0.0	0.1	0.5	2.8	24.5	15.0	27.4	22.8	46.7	53.3
20thperce.	0.0	0.0	0.2	0.7	3.4	6.9	27.9	22.6	43.3	36.0	55.0	59.6
80thperce.	8.3	10.8	45.1	32.3	45.0	52.1	102.2	86.4	94.7	106.3	120.2	101.6
90thperce.	12.0	16.3	59.4	63.3	86.2	103.2	153.6	131.5	110.2	124.2	137.0	136.7

*** denotes Generated**

3.3 Moshoeshoe I actual and generated monthly rainfall (mm) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	125.5	111.1	117.4	107.5	120.4	110.6	48.8	48.4	24.7	22.9	11.8	9.5
Median	114.1	96.0	88.3	84.6	97.9	82.6	40.8	39.1	12.2	13.4	7.4	5.6
Skewness	0.9	0.6	0.8	0.9	0.5	0.9	0.6	0.7	1.2	1.3	0.7	1.0
10thperce.	24.5	19.3	48.2	38.6	48.6	54.2	4.2	7.5	0.0	0.0	0.0	0.0
20thperce.	50.3	48.9	61.0	54.2	63.7	62.3	15.2	13.1	1.1	1.6	0.0	0.2
80thperce.	197.8	201.8	204.2	173.9	188.4	170.9	87.4	96.6	51.3	40.5	25.7	18.7
90thperce.	287.9	233.3	235.2	223.3	230.1	218.2	109.7	113.3	68.1	70.4	33.0	27.3
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	7.2	7.4	24.9	22.5	29.9	29.3	75.8	74.1	82.9	81.0	99.3	94.4
Median	2.5	3.2	17.8	12.9	17.4	17.5	73.6	79.1	79.6	79.0	105.2	93.5
Skewness	1.5	1.5	0.9	1.0	1.5	1.5	0.2	0.0	0.6	0.4	0.6	0.9
10thperce.	0.0	0.0	0.0	0.0	0.2	0.0	7.1	6.7	17.5	16.3	27.5	32.3
20thperce.	0.2	0.0	0.2	0.8	0.9	1.4	28.5	21.2	36.1	34.3	45.8	50.9
80thperce.	15.3	15.1	54.4	49.2	55.3	53.9	118.7	114.7	132.6	116.0	132.4	127.9
90thperce.	22.5	23.5	59.2	60.5	77.3	88.6	133.7	137.2	168.1	157.7	210.2	210.9

*** denotes Generated**

3.5 Qacha's Nek actual and generated monthly rainfall (mm) statistics

	Jan	Jan*	Feb	Feb*	Mar	Mar*	Apr	Apr*	May	May*	Jun	Jun*
Mean	146.2	154.9	125.9	118.0	96.0	94.3	40.2	49.9	12.1	15.5	14.8	15.8
Median	161.9	156.0	125.6	106.9	83.0	85.0	33.1	47.1	9.5	10.4	6.4	9.6
Skewness	0.1	-0.3	0.2	0.4	2.4	0.7	0.7	0.7	1.1	1.1	1.7	1.8
10thperce.	70.7	83.2	42.9	57.2	39.1	46.4	16.0	16.7	0.0	0.0	0.0	0.0
20thperce.	81.1	107.0	67.0	62.8	60.3	58.4	23.4	23.8	0.0	0.4	0.0	1.8
80thperce.	190.4	196.4	187.6	184.5	120.4	128.8	62.0	68.6	19.8	29.1	24.7	23.1
90thperce.	217.9	215.7	222.5	200.8	141.0	157.7	67.4	96.1	34.6	44.8	53.0	49.8
	Jul	**Jul***	**Aug**	**Aug***	**Sep**	**Sep***	**Oct**	**Oct***	**Nov**	**Nov***	**Dec**	**Dec***
Mean	9.5	9.5	23.0	26.0	39.7	36.9	70.0	82.0	81.8	99.1	125.9	116.9
Median	4.1	5.3	17.5	16.1	25.0	19.3	64.3	65.8	80.0	83.3	118.7	109.1
Skewness	1.5	2.5	1.1	1.0	3.2	2.4	0.6	1.0	0.6	0.9	0.3	0.1
10thperce.	0.0	0.0	0.0	0.1	2.9	3.8	17.6	27.8	36.4	30.9	30.2	37.5
20thperce.	0.0	0.4	0.8	1.2	4.9	6.5	44.8	39.1	54.4	53.3	75.2	79.1
80thperce.	17.7	17.0	43.2	56.7	50.2	58.5	102.4	136.4	108.8	156.3	197.8	174.0
90thperce.	35.2	21.8	68.9	76.9	83.7	88.5	120.8	165.5	121.0	198.2	212.0	198.6

*** denotes Generated**

Appendix 4: Monthly minimum temperature statistics (mean, 20th percentile, median, 80th percentile and standard deviation) from January to December.

4.1 January to March monthly minimum temperature (°C) statistics for all the climate stations

	January					February					March				
Station	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**
Butha Buthe	13.6	12.7	13.5	14.4	1.1	13.1	12.2	13.3	14.0	1.1	11.2	10.3	11.2	12.1	1.0
Kolbere	10.8	10.3	11.0	11.7	0.9	10.6	9.7	10.6	11.3	1.3	9.0	8.1	8.9	9.9	1.3
Lekubane	11.8	10.9	11.8	12.4	1.1	11.7	10.8	11.4	12.4	1.0	10.3	9.6	10.0	10.7	1.2
Leribe	13.9	13.0	14.1	14.7	0.8	13.4	12.8	13.6	14.2	1.2	11.4	10.5	11.4	12.5	1.2
Letseng la Terai	5.8	5.1	5.9	6.5	1.1	5.5	4.2	5.6	6.4	1.3	4.0	3.2	4.0	4.8	1.1
Mafeteng	13.7	12.9	13.7	14.7	0.9	13.7	12.9	13.7	14.5	1.2	12.0	11.2	11.9	12.5	1.2
Malefiloane	8.0	7.4	8.1	8.7	1.1	7.7	6.9	7.7	8.9	2.1	6.4	5.1	6.4	6.8	1.8
Mapoteng	15.5	15.0	15.6	16.0	0.6	15.0	14.2	15.0	15.8	0.9	13.4	12.7	13.3	13.8	1.0
Matela	13.5	12.9	13.4	14.2	0.8	12.9	12.3	12.7	13.8	1.0	11.3	10.7	11.2	11.8	1.2
Matsieng	14.9	14.3	15.0	15.4	0.7	14.7	14.0	14.8	15.7	1.1	12.9	12.2	13.0	14.0	1.0
Mejametalana	14.8	14.0	14.8	15.4	0.8	14.4	13.7	14.3	15.2	1.1	12.5	11.6	12.3	13.3	1.2
Mohales Hoek	14.2	13.3	14.3	15.1	1.1	14.0	13.2	14.0	14.8	1.0	12.0	11.2	12.0	12.7	1.1
Mokhotlong	10.7	10.0	10.7	11.5	0.9	10.2	9.4	10.2	11.3	1.3	8.7	7.8	8.7	9.5	1.4
Moshoeshoe I	14.9	14.1	15.0	15.5	0.7	14.5	13.9	14.2	15.3	1.1	12.7	11.8	12.6	13.2	1.3
Mt Moorosi	14.6	14.3	14.5	15.1	0.8	14.9	14.0	15.2	15.7	1.0	13.2	12.2	13.1	13.5	1.1
Nohana	14.3	13.2	14.2	15.2	0.9	13.8	13.1	13.4	14.6	1.0	12.2	11.5	12.1	12.8	1.0
Oxbow	7.0	6.5	7.0	7.3	0.8	6.6	5.8	6.6	7.5	1.1	4.7	3.7	4.6	5.6	1.1
Pitseng	13.3	12.6	13.4	13.9	0.8	12.9	12.3	13.0	13.6	1.0	11.3	10.4	11.3	12.0	1.3
Qachas Nek	12.2	11.6	12.4	12.9	1.0	11.9	10.9	12.1	12.9	1.5	10.8	10.1	11.0	11.6	0.9
Quthing	14.6	13.8	14.7	15.4	1.0	14.2	13.4	14.1	15.1	1.1	12.4	11.7	12.4	13.4	1.6
Roma NUL	14.4	13.8	14.5	15.3	0.8	14.0	13.0	14.1	15.0	1.1	12.3	11.6	12.3	13.4	2.0
Sani Pass	6.0	5.4	5.9	6.7	1.0	5.8	5.1	5.6	6.6	0.9	4.2	3.6	4.1	4.8	1.0
Sehlabathebe	8.0	6.9	8.1	8.9	1.1	8.0	7.3	8.0	8.7	0.9	6.7	5.6	6.8	7.5	1.2
Semonkong	8.8	7.9	9.1	9.6	1.1	8.4	7.1	8.5	9.6	1.4	6.5	5.3	6.5	7.4	1.2
St James	9.4	8.3	9.7	11.1	2.1	9.1	7.8	9.6	10.6	2.1	7.7	6.5	8.1	9.3	1.7
St Martins	9.1	8.3	9.5	10.1	1.3	8.7	7.6	9.2	9.8	1.6	7.6	6.7	7.8	8.7	1.3
Teyateyaneng	15.0	14.2	14.9	16.0	1.2	14.5	13.5	14.3	15.2	1.3	12.9	12.2	13.0	13.7	1.0
Thaba Bosiu	14.8	14.2	15.0	15.5	1.0	14.5	13.8	14.2	15.2	1.1	12.9	11.6	12.9	13.7	1.2
Thaba Tseka	10.8	9.8	10.9	11.7	1.1	10.3	9.3	10.4	11.4	1.4	8.8	7.7	8.8	9.8	1.3
Thabana Morena	15.6	14.8	15.6	16.3	0.8	15.5	14.6	15.4	16.6	1.1	13.6	12.9	13.4	14.0	1.1

4.2 April to June monthly minimum temperature (°C) statistics for all the climate stations

	April					May					June				
Station	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**
Butha Buthe	7.3	6.3	7.2	8.0	1.1	2.7	1.8	2.6	3.7	1.0	-0.6	-1.5	-0.6	0.5	1.3
Kolbere	5.9	4.7	5.8	7.4	1.7	2.2	1.5	2.5	3.4	2.0	-0.8	-2.2	-1.2	0.4	2.1
Lekubane	7.0	5.8	6.8	8.3	1.1	3.5	2.5	3.1	4.2	1.2	0.8	0.6	1.0	1.5	1.2
Leribe	7.5	6.5	7.5	8.5	1.2	2.7	1.5	2.7	3.6	1.2	-0.8	-2.2	-1.1	0.2	1.9
Letseng la Terai	0.6	-0.6	0.5	1.6	1.4	-2.8	-3.6	-3.1	-2.3	1.4	-6.1	-7.0	-6.1	-4.7	1.6
Mafeteng	8.6	8.0	8.7	9.5	1.1	4.7	4.1	4.8	5.4	1.1	1.4	0.8	1.6	1.9	0.8
Malefiloane	3.6	3.3	3.7	4.6	1.4	0.7	-0.9	0.7	1.6	1.7	-2.7	-3.5	-2.5	-1.3	3.0
Mapoteng	10.2	9.5	9.9	11.3	1.1	6.3	5.7	6.3	7.0	0.8	2.9	2.4	3.0	3.5	1.0
Matela	7.8	6.6	7.8	9.1	1.4	3.8	3.0	4.3	5.3	2.9	1.6	0.8	1.5	2.4	1.4
Matsieng	9.8	8.7	9.3	11.0	1.2	5.8	5.0	6.0	6.5	1.1	2.9	2.3	2.8	3.4	0.8
Mejametalana	8.3	7.3	8.2	9.4	1.1	3.5	2.8	3.6	4.5	1.6	-0.3	-1.0	0.1	0.9	1.7
Mohales Hoek	8.3	7.2	8.5	9.5	1.3	4.5	3.6	4.4	5.2	1.1	1.0	0.1	1.1	1.9	1.6
Mokhotlong	4.5	3.1	4.6	5.6	1.4	0.6	-0.4	0.5	1.5	1.4	-3.1	-3.9	-3.3	-2.1	1.4
Moshoeshoe I	9.0	8.3	8.9	9.8	1.0	4.4	4.0	4.3	5.1	1.0	1.1	0.3	1.2	1.8	1.0
Mt Moorosi	10.0	8.8	10.2	10.9	1.4	5.9	4.7	6.3	6.5	1.0	2.3	0.9	1.9	3.7	1.9
Nohana	8.9	8.0	8.4	9.9	1.7	4.9	3.9	5.0	5.9	1.3	2.2	1.4	2.2	2.7	0.9
Oxbow	1.3	0.0	1.1	2.3	2.3	-2.8	-3.8	-2.9	-1.7	1.1	-6.0	-7.2	-6.0	-5.2	1.3
Pitseng	8.5	6.9	8.9	9.6	1.5	4.6	3.7	4.7	5.3	1.1	1.2	0.4	1.4	2.0	0.9
Qachas Nek	7.7	6.8	7.5	9.0	1.2	4.4	3.6	4.4	5.4	1.2	1.7	0.8	1.9	2.9	1.3
Quthing	8.6	7.3	8.9	9.6	1.5	5.1	4.0	4.9	6.1	1.4	1.6	-0.1	2.0	3.1	1.9
Roma NUL	8.7	7.6	8.5	9.8	1.4	4.8	3.9	4.8	5.3	0.8	1.7	1.0	1.9	2.6	1.3
Sani Pass	1.3	0.6	1.1	2.2	1.2	-1.9	-2.9	-2.1	-1.2	1.2	-4.8	-5.6	-4.9	-4.2	1.5
Sehlaba thebe	4.0	2.9	3.7	5.0	1.4	0.7	-0.3	0.7	1.8	1.5	-2.1	-3.6	-2.1	-0.9	1.6
Semonkong	2.7	1.7	2.6	3.6	1.2	-1.5	-2.1	-1.4	-0.4	1.1	-4.9	-5.6	-5.0	-4.4	1.1
St James	4.8	3.5	5.0	6.0	1.5	0.7	-0.4	1.0	1.7	1.2	-2.6	-3.8	-2.6	-1.1	1.7
St Martins	4.3	3.0	4.8	5.5	1.5	1.2	0.2	1.3	2.0	1.1	-1.8	-2.9	-1.6	-0.7	1.4
Teyateyaneng	9.6	8.5	9.5	11.0	1.4	5.7	4.9	5.6	6.8	1.3	2.2	1.4	2.6	3.4	1.8
Thaba Bosiu	8.5	7.9	8.5	9.3	1.0	4.2	3.5	4.4	4.7	0.8	0.7	-0.2	0.8	1.4	1.3
Thaba Tseka	5.4	4.3	5.4	7.0	1.6	1.6	0.9	2.0	2.7	1.6	-1.8	-3.0	-1.7	-0.6	1.7
Thabana Morena	10.8	10.0	11.0	11.7	1.2	7.1	6.4	7.3	7.8	1.2	4.3	3.2	4.1	5.1	1.4

4.3 July to September monthly minimum temperature (°C) statistics for all the climate stations

	July					August					September				
Station	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**
Butha Buthe	-0.6	-1.9	-0.7	0.3	1.4	1.8	0.7	1.8	3.4	1.3	6.1	5.1	6.2	7.0	1.3
Kolbere	-1.4	-2.3	-1.4	0.0	1.8	1.5	0.3	1.5	2.9	1.9	5.0	4.4	5.2	6.2	1.4
Lekubane	0.5	-0.5	0.9	1.6	1.5	2.3	1.3	2.6	3.2	1.3	5.4	4.6	5.9	6.5	1.4
Leribe	-1.0	-2.5	-1.6	0.5	1.8	1.6	0.8	1.4	2.6	1.2	6.2	5.1	6.1	7.4	1.6
Letseng la Terai	-5.6	-6.5	-5.7	-4.3	1.3	-3.4	-4.3	-3.3	-2.6	1.3	-0.2	-1.3	-0.1	0.8	1.2
Mafeteng	1.2	-0.2	1.5	2.3	1.3	3.1	1.8	3.3	4.2	1.2	6.7	5.1	6.8	7.9	1.7
Malefiloane	-2.9	-4.7	-2.8	-1.5	2.6	-1.3	-3.0	-1.2	-0.1	1.6	2.8	1.8	3.0	4.1	1.4
Mapoteng	2.8	1.9	2.9	3.6	1.4	5.5	4.6	5.4	6.1	1.0	9.2	8.4	9.1	9.7	0.9
Matela	1.4	0.7	1.3	2.4	1.3	3.6	2.5	3.4	4.4	1.2	7.2	6.5	7.1	7.9	0.9
Matsieng	2.8	2.2	2.7	3.2	0.9	4.8	3.6	4.8	5.8	1.4	8.5	7.8	8.4	9.5	1.3
Mejametalana	-0.6	-1.5	-0.3	0.5	1.8	1.9	1.1	1.9	3.5	2.0	6.5	5.5	6.7	7.6	1.5
Mohales Hoek	1.2	0.3	1.3	2.1	1.5	3.5	2.3	3.5	4.7	1.4	7.1	6.0	7.2	8.1	1.4
Mokhotlong	-3.3	-4.2	-3.0	-2.6	1.2	-0.3	-1.4	-0.4	0.5	1.4	3.7	2.2	3.6	4.9	1.5
Moshoeshoe I	0.8	0.2	0.6	1.6	1.0	3.7	2.7	3.6	4.4	0.9	7.6	6.8	7.7	8.2	0.8
Mt Moorosi	1.7	0.1	1.9	2.9	1.6	4.4	3.6	4.4	4.8	0.8	7.9	6.8	8.3	8.8	1.4
Nohana	2.0	1.0	1.7	3.1	1.3	4.1	3.3	3.8	4.8	1.2	8.0	6.7	8.0	8.8	1.6
Oxbow	-6.5	-7.7	-6.4	-5.1	1.4	-3.8	-4.5	-4.0	-3.2	1.4	0.2	-0.5	0.1	1.4	1.4
Pitseng	1.2	0.4	1.2	2.5	1.8	3.8	2.9	3.7	5.2	1.6	7.2	6.5	7.2	8.0	1.1
Qachas Nek	1.6	0.6	1.6	2.6	1.2	3.6	2.5	3.8	5.0	1.5	6.5	5.2	6.6	7.7	1.2
Quthing	1.8	0.6	1.8	2.9	1.7	3.9	2.3	4.0	5.2	1.8	7.6	6.2	7.5	9.0	1.5
Roma NUL	1.2	0.7	1.2	2.3	1.5	3.6	2.7	3.7	4.8	1.3	7.6	6.2	7.6	8.8	1.4
Sani Pass	-5.5	-6.8	-5.3	-4.1	1.7	-2.5	-4.2	-3.5	-1.5	2.4	0.7	-0.2	1.1	1.6	1.2
Sehlabathebe	-2.6	-4.2	-2.2	-1.8	1.7	-0.1	-1.3	-0.3	1.6	1.9	2.8	1.9	2.7	3.8	1.1
Semonkong	-5.1	-5.8	-5.1	-4.3	1.1	-2.6	-4.0	-2.4	-1.5	1.5	1.3	0.5	1.5	2.3	1.2
St James	-2.7	-4.0	-2.4	-1.9	1.6	0.3	-1.4	0.2	1.4	1.9	3.8	1.8	3.9	5.5	1.7
St Martins	-2.3	-3.2	-2.4	-1.2	1.5	0.6	-0.5	0.1	1.4	2.1	3.3	2.5	3.4	4.4	1.3
Teyateyaneng	2.6	2.0	2.8	3.4	1.4	4.7	3.8	4.6	6.1	1.5	8.6	7.3	8.9	9.7	1.3
Thaba Bosiu	0.4	-1.1	0.5	1.9	1.5	3.8	2.4	3.5	4.6	2.1	7.5	6.7	7.5	8.3	1.6
Thaba Tseka	-1.9	-2.9	-1.8	-0.5	1.6	1.1	-0.2	1.4	2.1	1.8	4.6	3.2	5.0	5.9	1.5
Thabana Morena	3.6	2.5	3.5	4.5	1.4	6.1	5.3	6.2	7.2	1.6	9.4	8.6	9.2	10.3	1.2

4.4 October to December monthly minimum temperature (°C) statistics for all the climate stations

	October					November					December				
Station	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev
Butha Buthe	9.0	8.2	9.1	10.1	1.3	10.9	10.1	10.8	11.5	1.0	12.6	11.7	12.7	13.5	1.0
Kolbere	6.9	6.3	7.2	7.8	1.5	8.4	7.7	8.3	9.0	1.0	9.9	9.1	10.3	10.7	1.0
Lekubane	7.8	7.1	8.1	8.7	1.2	9.3	8.0	9.1	10.0	1.4	10.8	9.6	10.6	11.3	1.3
Leribe	9.1	8.6	9.4	9.8	1.1	10.9	10.3	11.0	11.3	0.9	12.6	11.7	12.7	13.5	1.0
Letseng la Terai	1.5	0.9	1.6	2.3	1.1	3.1	2.2	3.1	3.8	1.1	4.5	3.7	4.4	5.0	1.0
Mafeteng	9.0	8.0	8.9	9.9	1.2	10.9	10.1	10.9	11.8	1.0	12.6	11.8	12.5	13.5	1.1
Malefiloane	5.0	4.7	5.3	5.9	1.6	6.5	5.0	5.9	7.6	2.4	7.3	6.3	7.3	7.9	1.6
Mapoteng	11.5	11.0	11.5	12.2	0.7	12.8	12.0	12.8	13.3	0.9	14.3	13.7	14.4	15.0	0.8
Matela	9.5	8.7	9.7	10.3	1.2	11.1	10.4	11.1	11.8	1.0	12.7	11.8	12.8	13.2	1.0
Matsieng	10.8	10.2	10.9	11.5	1.0	12.5	11.6	12.6	13.3	0.9	14.1	13.2	14.1	15.0	1.0
Mejametalana	9.7	8.7	9.8	10.7	1.2	11.6	10.9	11.6	12.2	1.0	13.5	12.6	13.6	14.3	0.9
Mohales Hoek	9.5	8.5	9.6	10.4	1.3	11.3	10.5	11.4	12.3	1.1	13.2	12.1	13.2	14.0	1.2
Mokhotlong	6.2	5.3	6.7	7.4	1.8	7.9	7.2	8.0	9.1	1.4	9.3	8.8	9.4	10.5	1.6
Moshoeshoe I	10.5	9.6	10.7	11.2	0.9	12.1	11.3	11.9	13.1	1.1	13.8	13.3	13.8	14.5	0.8
Mt Moorosi	10.8	10.0	11.0	11.7	1.0	12.5	11.9	12.3	13.3	1.0	14.0	13.1	14.0	14.6	1.3
Nohana	10.6	9.6	10.5	11.3	1.6	12.4	11.0	12.2	13.2	1.3	13.9	13.3	13.7	14.2	1.4
Oxbow	2.7	1.9	2.9	3.8	1.3	4.3	3.7	4.3	5.0	0.8	5.8	5.1	5.9	6.4	0.8
Pitseng	9.3	8.5	9.5	10.3	1.2	10.7	9.9	10.6	11.7	1.1	12.6	11.5	12.7	13.5	1.2
Qachas Nek	8.3	7.5	8.4	9.3	1.3	9.6	8.7	9.6	10.8	1.3	11.2	10.7	11.5	12.2	1.4
Quthing	9.8	8.5	9.9	11.0	1.5	11.3	10.4	11.2	12.0	1.2	13.3	12.3	13.6	14.2	1.1
Roma NUL	9.9	9.1	10.2	10.9	1.2	11.9	11.0	11.8	12.7	1.2	13.5	12.5	13.5	14.2	1.3
Sani Pass	2.8	2.1	2.6	3.6	1.4	3.5	2.8	3.5	4.6	1.2	4.9	3.4	5.3	6.1	1.4
Sehlabathebe	4.3	3.2	4.2	5.4	1.3	5.7	5.0	5.7	6.5	1.7	7.2	6.4	7.3	7.9	1.0
Semonkong	4.2	2.9	4.8	5.6	1.6	6.2	5.5	6.1	7.2	1.1	8.1	7.4	8.1	8.7	1.0
St James	5.9	4.7	6.0	7.5	1.7	7.2	6.0	7.4	8.8	1.8	8.5	7.3	8.7	9.8	1.7
St Martins	5.5	4.8	5.6	6.4	1.5	6.4	6.0	6.8	7.7	2.0	7.8	7.3	8.3	8.8	1.9
Teyateyaneng	10.6	9.9	10.8	11.5	1.1	12.3	11.4	12.3	13.4	1.1	14.1	13.1	14.1	15.0	1.2
Thaba Bosiu	10.2	8.6	10.3	11.0	1.8	12.0	11.2	12.0	12.9	1.1	13.7	13.3	13.7	14.3	0.7
Thaba Tseka	6.8	6.1	7.1	8.0	1.5	8.1	7.4	8.1	9.2	1.6	9.7	8.8	10.3	10.8	1.4
Thabana Morena	11.6	10.3	11.7	12.5	1.1	13.0	12.3	13.0	13.6	0.9	14.9	14.1	14.8	15.7	1.0

Appendix 5: Monthly maximum temperature statistics (mean, 20th percentile, median, 80th percentile and standard deviation) from January to December.

5.1 January to March monthly maximum temperature (°C) statistics for all the climate stations

	January					February					March				
Station	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**
Butha Buthe	26.7	25.2	26.7	28.6	1.8	25.9	24.7	25.8	27.2	1.5	24.5	23.1	24.9	25.5	1.4
Kolbere	24.5	23.1	24.6	26.2	1.5	23.8	22.8	23.5	25.7	1.7	22.5	22.0	22.6	23.2	0.8
Lekubane	21.3	20.5	21.5	22.3	1.3	20.7	19.4	20.9	21.3	1.3	19.5	17.9	20.0	20.7	1.5
Leribe	27.4	25.8	27.2	29.2	1.8	26.7	25.3	26.4	27.7	1.6	24.9	23.6	24.9	26.3	1.4
Letseng la Terai	16.5	15.7	16.5	17.4	1.4	15.8	15.1	15.8	16.5	1.2	13.9	12.8	14.4	15.2	2.2
Mafeteng	27.5	26.3	27.1	28.9	1.5	26.7	25.3	26.3	27.8	1.9	23.4	23.5	24.0	25.6	4.5
Malefiloane	20.6	19.6	20.7	21.6	1.1	20.1	18.9	20.0	21.0	1.3	19.2	18.4	19.1	19.8	0.8
Mapoteng	27.1	25.9	27.1	28.2	1.4	26.3	24.8	26.2	28.0	2.1	24.4	22.8	24.1	25.7	1.5
Matela	26.9	25.6	26.8	28.4	1.5	25.9	24.1	26.0	27.4	2.0	24.4	23.0	24.6	25.5	1.5
Matsieng	26.9	25.3	26.9	28.4	1.5	25.9	24.1	25.9	27.3	1.8	24.1	22.8	23.9	25.2	1.5
Mejametalana	28.7	26.9	28.5	30.6	2.0	27.6	26.0	27.5	29.4	1.9	25.6	24.0	25.7	27.0	1.6
Mohales Hoek	28.2	26.7	28.0	29.9	1.7	27.4	25.7	27.5	28.8	1.9	24.8	23.3	24.9	26.4	3.3
Mokhotlong	24.7	23.5	24.7	26.4	1.5	24.0	22.8	24.1	25.2	1.5	22.4	21.6	22.3	23.5	1.1
Moshoeshoe I	27.6	26.4	27.8	29.0	1.5	26.5	25.0	26.5	27.7	1.9	24.8	24.1	24.6	25.5	1.2
Mt Moorosi	28.4	27.4	28.1	30.2	1.5	28.1	26.3	28.3	29.4	1.8	26.2	24.5	25.7	27.8	1.8
Nohana	26.8	25.7	26.6	27.6	1.4	26.7	25.4	26.5	28.3	1.8	24.7	23.8	24.5	25.6	1.2
Oxbow	18.4	17.3	18.3	19.4	1.2	17.9	16.9	17.9	18.7	1.2	16.3	15.1	16.5	17.2	1.2
Pitseng	26.5	25.2	26.5	27.5	1.7	26.0	24.7	25.8	27.5	1.8	24.1	22.6	24.2	25.3	1.6
Qachas Nek	24.5	23.3	24.6	25.7	1.9	23.6	22.3	23.7	24.9	1.7	22.1	20.9	22.2	23.1	1.5
Quthing	27.6	26.3	27.4	29.4	1.9	26.6	25.2	26.3	28.2	1.9	24.3	22.6	24.2	25.8	1.7
Roma NUL	27.4	25.6	27.3	29.2	1.9	26.4	24.8	26.3	27.9	1.7	24.7	23.3	24.6	25.9	1.7
Sani Pass	17.1	16.2	17.0	17.7	1.0	16.1	14.2	16.8	17.7	1.8	14.6	13.4	14.6	15.9	1.3
Sehlabathebe	20.7	20.0	20.7	21.9	1.8	20.0	18.8	19.7	21.5	1.5	18.9	17.9	19.0	19.9	1.2
Semonkong	23.0	22.0	22.5	24.2	1.4	22.4	21.3	22.2	23.9	1.5	20.7	19.8	20.5	21.6	1.1
St James	24.2	23.2	24.3	25.1	1.4	23.8	22.6	23.5	25.3	1.5	22.3	21.4	22.4	23.0	1.1
St Martins	21.9	21.1	21.8	22.3	1.2	21.4	20.6	21.4	22.5	1.9	20.0	19.1	20.1	20.9	1.6
Teyateyaneng	27.4	25.8	27.3	29.6	2.5	26.3	24.8	26.3	27.8	1.8	24.5	22.9	24.2	26.1	1.8
Thaba Bosiu	28.5	27.2	28.4	30.3	1.8	27.8	26.2	27.6	29.1	1.8	25.8	24.7	25.7	26.4	1.5
Thaba Tseka	23.6	22.7	23.5	24.5	1.4	23.1	21.8	22.9	24.5	1.4	21.6	20.7	21.7	22.4	1.1
Thabana Morena	26.7	25.7	26.6	28.5	1.5	25.9	24.6	25.7	27.4	1.9	23.9	22.9	23.8	24.4	1.4

5.2 April to June monthly maximum temperature (°C) statistics for all the climate stations

	April					May					June				
Station	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**
Butha Buthe	21.7	19.9	21.9	23.5	1.9	18.8	17.6	18.6	19.8	1.6	16.0	15.0	16.3	17.1	1.4
Kolbere	19.6	18.6	19.6	20.8	1.4	17.1	16.2	16.7	18.0	1.5	14.6	13.1	14.4	15.5	2.2
Lekubane	16.6	15.4	16.7	18.1	1.6	13.7	12.3	13.4	15.1	1.4	11.3	10.5	11.4	12.0	1.2
Leribe	21.9	20.2	22.1	23.8	1.8	18.8	17.5	18.5	20.1	1.6	15.8	15.0	16.0	16.6	1.3
Letseng la Terai	11.2	10.1	11.0	12.3	1.3	8.7	7.6	8.7	9.3	1.2	6.1	5.3	6.4	7.2	1.5
Mafeteng	21.6	20.1	21.2	23.4	1.6	18.0	17.1	17.9	18.2	1.2	14.8	13.8	14.5	16.1	1.3
Malefiloane	16.7	15.5	16.7	18.0	1.5	13.6	12.8	13.8	14.5	1.2	11.7	10.7	11.3	12.5	1.3
Mapoteng	21.5	19.8	21.5	23.6	1.9	18.3	17.0	18.2	18.9	1.5	15.4	14.5	15.3	16.5	1.1
Matela	21.4	19.8	21.6	22.7	1.6	18.3	17.5	18.2	19.4	1.3	15.3	14.4	15.1	16.3	1.1
Matsieng	21.2	19.4	21.1	22.9	1.7	17.8	16.8	17.7	19.0	1.3	14.8	13.9	14.6	15.6	1.0
Mejametalana	22.5	21.2	22.6	24.8	1.9	19.3	18.0	19.2	20.4	1.4	16.5	15.8	16.6	17.2	1.2
Mohales Hoek	22.3	20.6	21.6	24.3	2.2	18.8	17.6	18.7	19.9	1.3	15.8	14.8	15.6	16.9	1.3
Mokhotlong	19.5	18.5	19.5	21.0	1.5	16.3	15.2	16.3	17.4	1.5	13.8	13.0	13.8	14.7	1.0
Moshoeshoe I	22.0	20.3	21.9	23.7	1.7	18.8	17.9	18.7	19.6	1.2	15.7	14.7	15.7	16.7	1.2
Mt Moorosi	23.0	21.3	23.1	24.6	1.8	19.4	18.4	18.8	21.0	1.3	17.0	15.9	17.1	18.2	1.3
Nohana	21.9	20.2	22.4	23.6	1.7	17.9	17.2	18.0	18.8	1.2	15.6	14.8	15.7	16.3	1.0
Oxbow	13.4	11.9	13.0	14.8	1.6	10.8	9.9	10.6	11.8	1.2	8.4	7.5	8.5	9.4	1.4
Pitseng	21.6	19.9	21.4	23.3	1.7	18.5	17.4	18.7	19.7	1.4	15.6	14.6	15.7	16.5	1.1
Qachas Nek	19.7	18.5	19.6	21.3	1.7	17.0	15.8	16.8	18.0	1.6	14.2	13.3	14.3	15.2	1.4
Quthing	21.3	19.8	20.6	23.3	1.8	17.8	16.7	17.7	18.7	1.2	14.8	13.8	14.6	16.1	1.2
Roma NUL	21.4	19.9	21.3	23.1	1.8	18.3	17.2	18.1	19.7	1.3	15.5	14.7	15.5	16.5	1.3
Sani Pass	12.3	10.8	12.8	14.1	1.8	9.6	8.5	9.8	10.6	1.2	8.3	7.3	8.0	9.4	1.2
Sehlabathebe	16.5	15.2	16.2	18.0	1.5	14.2	13.0	14.1	15.2	1.3	11.7	10.6	11.4	12.7	1.3
Semonkong	17.6	16.1	17.7	19.3	1.7	14.4	13.6	14.6	15.3	1.8	11.4	10.5	11.2	12.6	1.1
St James	19.5	18.0	19.8	20.8	1.5	16.5	15.5	16.4	17.6	1.3	13.9	12.9	13.8	14.9	1.2
St Martins	17.1	16.2	17.3	18.2	1.5	14.3	13.5	14.3	15.0	1.0	12.1	10.7	11.5	13.4	1.7
Teyateyaneng	21.5	20.0	21.4	23.0	1.8	18.6	17.3	18.4	19.9	1.4	15.4	14.8	15.3	16.6	1.2
Thaba Bosiu	23.1	21.8	23.2	24.3	1.4	19.4	18.5	19.0	20.4	1.4	17.0	15.9	16.6	18.2	1.3
Thaba Tseka	18.8	17.2	18.5	20.6	1.8	15.5	14.6	15.7	16.6	1.7	13.1	12.2	13.1	13.9	1.1
Thabana Morena	21.2	19.7	21.0	22.8	1.8	18.1	17.2	17.8	19.2	1.3	15.1	14.1	15.2	15.8	1.1

5.3 July to September monthly maximum temperature (°C) statistics for all the climate stations

	July					August					September				
Station	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**
Butha Buthe	16.3	15.6	16.4	17.0	1.3	18.8	17.5	18.8	19.8	1.5	22.1	20.9	22.1	23.4	1.6
Kolbere	14.5	13.6	14.8	15.6	1.5	16.7	15.6	16.9	18.2	1.6	19.8	19.2	19.7	21.6	1.6
Lekubane	11.3	10.7	11.3	12.3	1.3	13.0	12.3	13.0	13.8	1.2	16.0	14.9	16.1	17.0	1.1
Leribe	16.3	15.6	16.4	17.4	1.3	18.9	17.7	18.9	19.8	1.3	22.4	21.1	22.4	23.5	1.5
Letseng la Terai	6.5	5.2	6.4	7.9	1.9	8.6	7.5	8.7	9.7	1.6	11.8	10.9	11.8	12.7	1.2
Mafeteng	15.1	14.3	15.1	16.2	1.1	17.7	17.0	17.8	18.8	1.4	21.5	20.1	21.2	23.0	1.7
Malefiloane	11.7	11.1	12.2	12.6	1.7	13.1	12.3	13.1	13.8	0.9	16.8	15.9	16.4	18.5	1.6
Mapoteng	15.8	15.1	15.7	17.1	1.2	18.3	17.4	18.5	19.1	1.2	21.7	20.6	21.5	23.3	1.6
Matela	15.5	14.7	15.4	16.4	1.2	17.9	16.8	18.1	19.0	1.3	21.1	19.7	21.0	22.6	1.7
Matsieng	15.0	14.2	15.0	15.8	1.0	17.5	16.2	17.8	18.5	1.4	21.0	19.7	21.1	22.4	1.7
Mejametalana	16.8	15.9	16.8	17.9	1.0	19.4	18.6	19.6	20.5	1.4	23.0	21.7	22.9	24.2	1.5
Mohales Hoek	16.0	15.1	16.0	16.7	1.1	18.7	17.8	18.8	19.7	1.5	22.0	20.9	22.1	23.4	1.6
Mokhotlong	14.1	13.2	14.1	15.1	1.3	16.5	15.5	16.7	17.7	1.5	19.9	19.1	20.3	21.1	1.3
Moshoeshoe I	15.8	15.1	15.8	16.6	1.1	18.6	17.6	18.6	19.7	1.2	22.0	20.7	22.1	23.4	1.7
Mt Moorosi	16.7	16.0	16.5	17.5	0.9	19.2	18.4	19.6	20.4	1.5	23.3	21.8	23.8	24.5	1.4
Nohana	15.6	14.5	15.7	16.6	1.3	18.2	17.4	18.1	19.1	1.1	21.8	20.3	21.9	23.0	1.4
Oxbow	8.7	8.0	8.8	9.7	1.3	10.6	9.6	10.8	11.8	1.3	13.9	13.1	13.6	14.8	1.3
Pitseng	15.9	15.1	16.2	16.9	1.3	18.6	17.5	18.7	19.5	1.4	21.7	20.0	22.2	23.0	1.8
Qachas Nek	14.8	14.0	14.5	15.8	1.8	17.1	15.5	17.0	18.5	1.9	20.0	18.9	19.9	21.0	1.3
Quthing	15.3	14.4	15.3	16.3	1.0	17.8	16.9	17.8	18.7	1.4	21.2	20.0	21.4	22.3	1.4
Roma NUL	15.9	15.2	15.8	16.8	1.2	18.2	17.3	18.6	19.2	1.3	21.8	20.4	21.8	23.1	1.6
Sani Pass	8.4	7.9	8.6	9.6	1.6	10.5	8.9	10.4	11.5	1.9	13.8	12.5	14.3	14.5	1.3
Sehlabathebe	11.4	10.8	11.8	13.2	3.1	13.9	12.4	14.1	15.3	1.8	16.3	15.1	16.9	18.1	3.0
Semonkong	11.6	10.9	11.6	12.5	1.3	14.4	13.6	14.6	15.5	1.4	17.3	16.0	17.2	18.7	1.6
St James	14.0	13.2	14.2	15.1	1.7	16.1	14.8	16.2	17.3	1.4	19.2	17.6	19.5	20.3	1.5
St Martins	12.2	11.4	12.0	12.8	1.7	14.1	12.6	14.3	15.2	1.7	16.9	15.2	16.9	18.6	2.2
Teyateyaneng	16.0	15.4	16.3	16.8	0.9	18.3	17.5	18.6	19.2	1.3	21.7	20.5	22.3	23.2	1.5
Thaba Bosiu	16.9	16.3	16.8	17.8	1.1	19.8	19.1	20.1	20.7	1.7	22.9	21.8	22.4	24.0	1.4
Thaba Tseka	13.1	12.3	13.3	14.2	1.4	15.6	14.5	16.0	16.8	2.0	18.9	17.4	18.9	20.4	1.8
Thabana Morena	15.0	14.2	15.1	15.6	1.2	17.9	16.7	18.1	19.2	1.3	21.2	19.8	21.3	22.9	1.7

5.4 October to December monthly maximum temperature (°C) statistics for all the climate stations

	October					November					December				
Station	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**
Butha Buthe	23.5	22.3	23.7	24.4	1.3	24.7	23.7	24.4	25.9	1.6	25.9	24.6	25.8	27.3	1.7
Kolbere	21.4	20.3	21.5	22.2	1.1	22.5	21.8	22.4	23.5	1.2	23.7	22.4	23.4	25.1	1.4
Lekubane	18.2	17.1	18.3	19.6	1.4	19.2	18.1	19.0	20.4	1.3	20.5	19.7	20.5	21.1	1.2
Leribe	23.9	23.0	24.0	24.8	1.3	25.2	24.2	24.9	26.4	1.3	26.7	25.6	26.6	27.5	1.4
Letseng la Terai	13.0	11.9	13.2	14.1	1.2	14.3	13.3	14.1	15.1	1.1	15.7	14.8	15.5	16.4	1.1
Mafeteng	23.4	23.1	23.5	24.1	1.2	25.1	24.2	24.7	25.8	1.4	26.6	25.1	26.2	28.1	2.0
Malefiloane	18.2	17.4	18.2	19.1	0.9	18.6	17.6	18.6	19.7	1.4	19.8	18.7	19.8	21.6	1.8
Mapoteng	23.8	22.8	23.8	24.8	1.6	24.8	23.7	24.4	25.6	1.5	24.8	23.7	24.4	25.6	1.5
Matela	23.1	21.8	23.2	24.2	1.3	24.5	23.3	24.3	25.8	1.5	26.0	25.1	26.0	27.5	1.6
Matsieng	23.0	22.0	22.9	24.4	1.4	24.4	23.4	24.0	25.8	1.6	25.8	24.5	25.7	27.3	1.7
Mejametalana	24.7	23.6	24.8	25.9	1.4	26.3	25.0	26.0	27.6	1.5	27.9	26.5	27.6	29.5	1.8
Mohales Hoek	24.0	23.0	24.2	25.1	1.4	25.8	24.6	25.6	27.0	1.6	27.4	26.2	27.3	29.0	1.8
Mokhotlong	21.3	20.5	21.4	22.3	1.2	22.4	21.3	22.1	23.7	1.3	23.9	22.7	23.7	25.3	1.4
Moshoeshoe I	23.8	23.0	23.8	24.9	1.4	25.2	23.9	24.8	26.8	1.7	26.7	25.1	26.3	28.5	1.9
Mt Moorosi	25.3	24.2	24.9	26.5	1.8	26.2	24.8	25.8	27.3	2.0	27.8	25.7	27.5	29.8	2.1
Nohana	23.7	22.9	23.7	24.2	1.0	24.8	23.9	24.4	25.8	1.6	26.4	25.3	26.1	28.0	1.6
Oxbow	15.2	14.0	15.3	16.1	1.2	16.1	15.1	15.9	17.1	1.2	17.5	16.7	17.6	18.5	1.1
Pitseng	23.2	21.8	23.4	24.4	1.5	24.5	23.5	24.3	25.6	1.6	25.7	24.5	25.3	27.2	1.6
Qachas Nek	21.0	20.2	20.9	22.0	1.2	22.2	21.1	21.8	23.4	1.2	23.9	22.6	23.8	25.3	1.6
Quthing	23.1	22.5	23.2	24.1	1.3	24.9	23.7	24.7	26.0	1.5	26.6	25.3	26.5	28.5	1.7
Roma NUL	23.4	22.5	23.5	24.3	1.5	24.9	23.4	24.6	26.2	1.5	26.4	25.4	26.1	27.8	1.6
Sani Pass	14.7	13.9	14.7	15.4	0.8	15.3	14.2	14.9	16.2	1.2	16.7	16.0	16.8	17.6	1.2
Sehlabathebe	17.6	16.8	17.4	18.8	1.3	18.7	17.8	18.7	19.6	1.1	20.0	18.9	19.9	21.1	1.5
Semonkong	19.2	18.5	19.1	20.2	1.1	20.4	19.4	20.0	21.7	1.3	22.0	20.9	21.7	23.5	1.4
St James	20.9	19.7	21.0	22.0	1.3	22.0	20.8	21.8	23.1	1.4	23.4	21.9	23.5	24.5	1.5
St Martins	18.3	17.5	18.4	19.6	1.5	19.7	18.8	19.7	20.6	1.6	21.3	20.2	20.9	22.8	1.4
Teyateyaneng	23.4	22.3	23.7	24.4	1.4	25.3	24.1	25.2	26.5	1.4	26.6	25.4	26.6	27.5	1.7
Thaba Bosiu	24.5	23.4	24.6	25.1	1.1	26.3	25.0	25.7	27.3	1.7	28.2	26.9	28.2	29.8	1.7
Thaba Tseka	20.3	19.0	20.7	21.3	1.4	21.7	20.3	21.6	22.6	1.4	22.9	21.8	22.7	24.4	1.4
Thabana Morena	23.1	22.1	23.5	24.1	1.4	24.4	23.1	24.3	25.1	1.5	25.8	24.5	25.4	27.4	1.8

Appendix 6: Monthly heat units statistics (mean, 20th percentile, median, 80th percentile and standard deviation) from January to December.

6.1 January to March monthly heat units statistics for all the climate stations

	January					February					March				
Station	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**
Butha Buthe	314.9	279.8	323.1	343.5	33.2	270.7	252.1	272.0	290.2	30.4	243.7	221.3	250.6	265.6	28.6
Kolbere	236.7	217.5	234.8	263.6	27.6	202.8	178.8	198.1	231.1	33.7	178.4	157.6	179.2	197.4	23.8
Lekubane	202.6	179.0	210.0	223.4	31.1	173.4	163.1	170.2	189.7	23.2	150.9	117.2	164.0	174.5	31.6
Leribe	329.4	297.2	321.9	365.9	35.0	283.4	257.2	282.8	308.4	33.5	252.0	228.8	252.1	270.4	26.8
Letseng la Terai	44.6	22.8	37.8	64.9	25.6	30.9	15.2	25.7	43.1	20.0	11.8	3.1	10.6	17.6	9.3
Mafeteng	328.7	312.4	325.6	355.8	26.9	287.8	261.2	288.0	314.1	40.2	243.9	225.7	253.2	268.7	53.0
Malefiloane	134.2	126.5	141.1	149.7	25.2	110.5	87.3	101.0	136.4	37.2	89.1	72.6	80.2	100.0	27.8
Mapoteng	349.8	330.3	351.7	369.7	27.6	301.0	273.3	294.6	342.1	39.8	275.3	243.1	269.3	302.6	31.9
Matela	315.2	291.3	311.2	344.7	28.7	265.8	230.8	267.6	293.2	36.9	243.0	216.0	248.4	268.9	31.9
Matsieng	333.6	301.6	337.3	357.5	31.5	294.7	259.9	297.9	329.5	38.6	266.5	242.2	264.0	293.2	31.4
Mejametalana	362.6	333.8	364.0	388.1	33.4	310.3	281.8	312.1	336.0	33.3	279.9	249.9	281.1	303.5	31.1
Mohales Hoek	347.1	322.1	335.9	370.7	35.9	302.7	272.3	297.4	327.1	34.1	265.4	233.8	262.6	293.8	38.5
Mokhotlong	238.1	208.7	239.5	265.9	29.8	199.7	167.3	197.3	227.1	31.8	171.9	147.7	173.6	187.4	29.9
Moshoeshoe I	349.7	320.8	352.0	369.1	29.3	295.9	263.6	295.3	327.5	35.6	270.9	247.0	268.0	284.5	29.2
Mt Moorosi	357.7	341.9	348.6	389.6	32.4	325.9	289.1	324.3	353.7	38.1	300.6	267.3	286.1	331.8	35.9
Nohana	327.5	296.7	329.4	351.6	31.7	292.6	273.6	284.6	313.7	29.5	264.4	246.2	261.3	289.2	25.3
Oxbow	84.3	63.4	83.7	104.6	20.6	65.7	48.2	66.8	83.4	20.0	33.7	22.1	31.2	46.3	14.2
Pitseng	307.4	285.1	307.8	334.0	31.7	267.4	243.7	262.4	289.5	34.7	239.3	209.1	252.4	266.5	35.3
Qachas Nek	260.0	238.2	261.3	286.8	37.5	219.5	196.0	218.3	248.3	41.0	200.7	181.7	200.9	226.4	30.0
Quthing	343.7	314.8	348.0	376.5	36.2	294.0	263.4	290.2	314.5	35.9	259.7	230.7	257.6	298.4	40.9
Roma NUL	337.7	311.6	332.0	370.0	32.6	284.0	256.3	284.5	319.6	41.3	260.8	236.5	261.5	296.0	42.8
Sani Pass	57.0	40.5	60.1	71.8	17.4	40.6	20.4	29.9	63.0	23.0	18.5	7.6	13.6	29.2	11.9
Sehlabathebe	136.9	120.9	142.0	158.0	29.7	114.7	87.3	115.1	138.3	25.7	93.3	71.3	91.2	108.5	25.7
Semonkong	183.7	163.6	182.5	214.5	26.9	153.3	130.5	152.2	172.3	28.0	111.4	89.8	106.5	134.7	26.5
St James	211.5	183.1	219.3	237.8	36.6	183.6	152.6	189.1	212.5	40.3	156.6	142.2	157.4	175.1	29.3
St Martins	171.1	151.1	170.0	187.5	30.3	143.9	124.5	147.4	172.3	38.9	119.2	97.4	118.6	138.9	32.5
Teyateyaneng	347.6	321.6	347.1	387.9	46.9	293.9	276.9	293.2	316.8	33.3	270.2	237.0	268.1	298.5	36.5
Thaba Bosiu	360.7	332.6	352.1	397.1	32.8	310.3	284.1	310.7	333.5	35.1	283.2	255.9	283.3	302.5	33.2
Thaba Tseka	222.4	197.5	227.1	251.3	32.2	186.7	160.0	191.8	213.1	36.2	161.8	142.3	162.0	187.2	30.1
Thabana Morena	348.6	327.0	341.3	376.7	33.1	307.8	278.0	306.1	336.3	37.0	273.9	252.0	271.7	301.7	34.6

6.2 April to June monthly heat units statistics for all the climate stations

	April					May					June				
Station	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**
Butha Buthe	136.8	112.0	144.2	167.7	35.9	41.7	20.1	49.5	61.0	21.5	5.7	0.2	5.7	10.6	5.2
Kolbere	88.0	59.6	82.7	124.2	34.0	25.4	4.9	19.4	35.2	24.9	7.9	0.0	0.8	4.3	26.9
Lekubane	64.9	39.3	59.9	98.8	30.9	12.3	3.0	8.3	22.1	11.1	0.2	0.0	0.0	0.1	0.5
Leribe	142.1	118.6	138.6	177.2	34.3	41.6	26.6	40.9	54.8	16.8	6.4	1.0	4.1	8.3	8.1
Letseng la Terai	0.8	0.0	0.0	0.7	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mafeteng	153.8	131.8	143.8	189.3	34.0	59.4	43.8	55.9	69.6	21.4	7.9	2.6	5.9	14.8	6.7
Malefiloane	27.9	17.5	23.4	39.4	13.0	6.0	0.0	1.8	9.1	9.3	0.2	0.0	0.0	0.0	0.6
Mapoteng	175.9	149.8	161.6	222.6	40.8	82.3	62.5	81.4	97.3	24.5	16.3	8.7	16.9	20.9	8.5
Matela	142.1	114.1	136.2	173.3	37.4						8.8	3.9	7.9	12.8	6.0
Matsieng	171.3	140.3	160.2	210.9	39.4	55.8	36.0	60.9	72.7	24.8	15.1	5.6	12.8	24.1	11.3
Mejametalana	164.6	139.7	159.7	202.0	37.5	67.9	51.6	68.9	88.6	22.1	8.4	3.0	7.2	12.6	7.2
Mohales Hoek	160.4	122.4	157.4	202.9	43.5	58.8	40.2	61.6	74.9	20.6	11.9	4.3	9.3	19.0	9.4
Mokhotlong	69.4	45.4	66.9	98.8	28.9	64.8	42.8	67.1	83.3	22.4	2.2	0.0	0.0	0.5	10.9
Moshoeshoe I	165.2	135.1	156.0	199.7	35.0	14.1	2.2	8.6	17.2	24.5	9.7	5.4	7.3	13.0	6.6
Mt Moorosi	195.9	172.2	194.0	230.7	41.1	65.1	53.3	68.5	72.1	15.0	22.9	8.4	18.0	41.7	19.7
Nohana	165.7	131.9	168.4	198.1	45.0	92.0	72.2	87.8	116.2	24.1	13.0	5.5	13.0	18.4	8.6
Oxbow	2.9	0.0	1.6	4.8	3.7	61.0	43.5	67.4	73.5	23.1	0.0	0.0	0.0	0.0	0.0
Pitseng	152.6	124.4	152.7	197.1	35.1	0.2	0.0	0.0	0.0	0.7	8.2	3.9	8.2	11.6	4.8
Qachas Nek	115.8	83.3	115.3	145.6	37.5	61.7	42.8	66.4	80.9	23.5	9.9	2.1	7.0	17.8	8.1
Quthing	150.6	114.5	147.2	191.6	42.8	47.6	25.0	48.8	67.6	25.4	10.3	2.9	8.1	17.4	8.7
Roma NUL	154.7	125.5	143.2	195.6	41.3	59.2	35.1	61.7	80.3	25.0	0.2	0.0	0.0	0.0	0.6
Sani Pass	2.2	0.0	0.9	2.3	3.6	62.2	41.8	61.7	78.8	22.2	0.0	0.0	0.0	0.0	0.0
Sehlabathebe	33.0	16.8	29.4	47.6	23.8	0.4	0.0	0.0	0.6	0.7	0.9	0.0	0.0	1.8	1.7
Semonkong	32.7	14.6	31.4	49.3	19.2	7.5	1.3	5.0	9.2	10.5	0.2	0.0	0.0	0.0	0.8
St James	73.5	46.3	67.9	104.1	29.8	3.0	0.0	2.2	5.0	3.4	0.7	0.0	0.0	0.8	1.4
St Martins	41.7	24.0	42.6	62.9	21.0	12.2	5.3	10.0	16.5	9.8	0.5	0.0	0.0	0.6	1.2
Teyateyaneng	168.3	134.9	166.3	217.4	42.6	6.0	1.1	4.0	9.2	6.4	14.6	8.5	14.5	18.6	8.4
Thaba Bosiu	169.9	149.7	167.0	202.4	32.9	74.9	50.8	67.1	91.7	29.7	9.8	4.4	8.0	11.5	7.4
Thaba Tseka	73.4	50.0	71.8	108.4	35.6	70.5	55.3	67.8	79.9	19.5	1.2	0.0	0.0	2.9	2.0
Thabana Morena	179.5	147.0	175.7	224.3	41.1	14.0	1.1	12.2	26.5	12.3	23.1	9.6	17.5	35.8	17.0

6.3 July to September monthly heat units statistics for all the climate stations

	July					August					September				
Station	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev
Butha Buthe	6.5	0.9	4.0	8.4	8.5	38.0	21.7	49.5	57.2	19.3	129.1	108.6	130.0	151.1	30.9
Kolbere	2.7	0.0	0.7	2.0	6.9	22.2	10.4	15.6	32.4	17.5	85.6	57.7	93.1	117.0	28.6
Lekubane	0.6	0.0	0.0	0.5	1.3	8.4	4.3	7.2	11.5	6.2	54.2	29.8	63.9	72.8	21.3
Leribe	5.5	1.0	3.5	7.3	6.7	35.9	24.7	31.8	47.6	14.3	134.6	103.7	135.7	162.3	34.4
Letseng la Terai	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.5	0.0	0.0	2.7	2.5
Mafeteng	8.3	2.1	7.3	12.2	6.4	41.1	24.5	43.4	50.9	17.1	127.3	97.6	131.0	156.4	38.2
Malefiloane	0.3	0.0	0.0	0.1	0.8	1.5	0.0	0.5	2.0	2.1	32.2	15.4	23.4	50.8	20.4
Mapoteng	20.0	9.8	15.1	29.2	11.9	72.2	57.8	69.4	91.3	22.0	166.0	144.1	159.3	194.0	32.5
Matela	10.0	3.4	7.7	16.0	7.7	45.4	30.3	46.5	59.9	19.9	130.5	103.6	128.0	162.7	32.0
Matsieng	16.5	6.0	16.6	26.6	10.2	60.4	40.9	57.7	78.2	23.2	156.3	129.8	158.0	187.5	37.9
Mejametalana	9.2	4.3	6.5	15.4	7.0	49.0	31.7	40.5	69.3	22.1	148.8	119.3	149.0	180.9	32.8
Mohales Hoek	13.1	4.5	9.1	16.9	11.7	56.4	33.2	51.9	79.8	22.3	141.7	114.5	141.3	170.8	34.0
Mokhotlong	0.8	0.0	0.0	1.2	2.2	11.4	2.4	10.1	18.5	10.0	70.2	51.0	68.1	88.9	24.2
Moshoeshoe I	9.7	3.3	6.4	14.6	7.7	55.8	40.9	54.1	72.3	18.7	147.7	122.8	140.5	173.8	31.3
Mt Moorosi	18.7	10.3	15.5	28.9	13.8	69.5	53.1	68.0	88.7	20.4	170.6	147.9	169.8	193.0	29.7
Nohana	15.1	6.0	11.6	21.2	12.4	52.0	35.7	49.1	64.3	21.1	153.6	118.2	152.4	187.1	36.5
Oxbow	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.7	7.4	3.0	6.5	11.3	4.9
Pitseng	13.2	3.6	8.1	22.1	11.4	58.2	34.7	54.4	77.3	25.4	139.9	113.0	142.1	162.6	32.3
Qachas Nek	13.8	4.1	9.9	18.6	15.2	47.7	27.6	44.6	64.2	24.0	114.4	91.8	110.6	134.0	25.4
Quthing	12.5	4.0	8.4	21.4	11.2	52.6	27.6	45.9	67.2	25.9	139.4	112.1	136.2	164.0	30.4
Roma NUL	11.1	3.5	7.2	16.6	10.2	51.1	34.3	50.3	71.1	19.1	146.3	113.1	139.9	178.2	35.1
Sani Pass	0.1	0.0	0.0	0.0	0.2	4.4	0.0	0.0	0.0	12.7	9.9	4.5	9.4	12.9	7.0
Sehlabathebe	0.6	0.0	0.0	0.9	1.2	8.3	3.2	5.8	12.2	6.8	38.0	25.3	35.2	54.3	16.9
Semonkong	0.2	0.0	0.0	0.0	0.6	3.6	0.0	1.7	6.0	4.7	30.9	19.4	30.0	42.3	13.7
St James	0.7	0.0	0.0	0.8	1.8	12.9	3.5	9.3	18.3	13.8	65.3	38.7	63.4	93.0	27.3
St Martins	0.1	0.0	0.0	0.0	0.4	6.9	0.7	3.6	6.1	12.7	38.6	18.3	37.7	58.3	22.2
Teyateyaneng	16.7	9.0	17.3	24.1	8.4	63.2	45.8	60.9	76.5	21.8	159.0	131.5	159.7	187.8	33.2
Thaba Bosiu	12.4	4.1	10.3	21.1	9.8	66.3	39.7	62.8	89.6	36.8	151.9	126.3	147.9	186.4	33.7
Thaba Tseka	0.5	0.0	0.0	0.6	1.1	16.3	6.5	13.2	22.0	13.3	74.0	45.4	72.7	99.2	28.7
Thabana Morena	19.4	8.4	16.2	27.0	13.0	72.8	46.3	68.9	96.2	31.5	157.2	124.4	157.9	191.1	36.7

6.4 October to December monthly heat units statistics for all the climate stations

	October					November					December				
Station	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**	**Mean**	**20th Per**	**Median**	**80th Per**	**Std Dev**
Butha Buthe	194.7	170.3	206.3	226.4	33.5	234.0	207.2	232.9	259.9	34.2	286.8	248.3	289.9	325.5	37.8
Kolbere	129.2	116.4	138.7	147.2	32.4	165.2	146.5	161.9	185.5	31.4	211.0	185.2	209.1	243.2	30.7
Lekubane	99.7	73.0	101.9	122.9	29.4	128.4	94.1	131.6	157.0	34.5	174.3	145.5	167.1	209.5	32.1
Leribe	202.3	183.0	206.6	227.3	30.0	242.7	217.0	238.1	269.4	29.6	299.8	274.1	301.1	322.6	32.9
Letseng la Terai	5.5	1.5	4.4	9.8	4.7	11.4	3.5	7.9	19.1	9.8	24.4	10.8	19.6	36.7	17.7
Mafeteng	192.9	178.7	191.4	209.9	21.7	240.5	216.5	227.3	274.0	32.2	298.4	280.2	294.2	323.5	39.9
Malefiloane	61.8	38.8	64.7	80.9	26.4	85.8	56.8	76.8	105.5	45.5	114.0	100.5	109.8	144.9	31.1
Mapoteng	237.2	214.2	235.7	266.2	29.9	264.1	235.2	261.4	277.8	32.6	320.6	304.9	317.2	353.3	31.5
Matela	195.4	178.7	195.2	217.5	33.6	234.1	208.1	232.3	261.2	31.0	290.0	263.2	293.3	320.6	35.8
Matsieng	224.9	210.6	220.6	241.2	22.1	259.9	235.5	253.9	283.8	34.8	310.9	272.9	307.9	353.7	41.2
Mejametalana	224.2	200.2	226.1	251.9	32.3	269.6	245.2	270.4	293.2	29.7	329.8	305.0	328.0	358.8	37.4
Mohales Hoek	209.4	190.1	212.3	237.4	35.0	256.9	224.5	258.5	285.8	33.8	318.9	289.7	314.2	347.4	41.9
Mokhotlong	120.1	94.4	131.9	143.6	34.4	149.4	129.2	145.8	175.7	39.9	203.0	179.9	206.6	232.8	37.6
Moshoeshoe I	223.2	206.4	223.9	246.0	27.8	260.2	231.8	249.3	287.1	37.0	317.2	289.0	309.8	356.4	38.5
Mt Moorosi	250.8	232.7	254.6	270.9	32.9	280.6	248.8	274.8	307.0	40.6	337.7	300.2	336.6	373.5	49.4
Nohana	222.3	201.5	217.6	246.3	30.8	261.7	236.9	255.0	283.1	33.5	315.5	286.1	309.1	347.7	41.8
Oxbow	20.7	11.9	21.1	27.0	11.8	31.5	17.1	31.0	41.4	15.2	59.2	38.7	58.7	75.7	20.8
Pitseng	193.0	171.3	200.8	215.9	37.2	228.1	209.7	224.8	254.3	35.2	282.7	256.8	285.2	317.4	36.3
Qachas Nek	150.9	128.1	152.5	175.7	32.0	179.6	155.7	174.5	213.1	31.6	234.6	209.1	243.3	264.7	40.3
Quthing	201.6	174.8	209.6	232.7	34.8	242.4	216.0	239.5	271.2	37.0	308.6	281.2	303.0	336.2	38.0
Roma NUL	208.0	190.4	210.7	228.8	29.8	250.7	220.0	244.4	277.8	37.4	309.6	279.5	312.5	338.3	36.5
Sani Pass	20.5	11.3	16.6	33.8	13.0	25.0	17.1	24.1	31.5	10.6	44.8	33.2	44.8	57.8	17.1
Sehlabathebe	56.6	38.7	53.8	75.2	20.2	80.0	63.6	76.6	92.5	29.6	114.5	96.5	111.2	134.6	29.1
Semonkong	69.5	59.8	69.3	86.3	22.5	105.5	85.2	100.1	121.5	27.3	156.5	138.8	150.4	186.3	31.6
St James	110.1	87.8	109.9	132.4	30.5	141.2	114.1	141.8	169.8	36.6	186.2	154.4	186.0	221.9	36.7
St Martins	71.9	49.9	70.2	91.8	28.4	99.6	81.3	100.4	127.2	35.6	146.1	115.1	144.7	174.9	32.1
Teyateyaneng	217.8	197.1	220.1	238.9	32.7	263.9	228.8	272.8	291.4	32.2	321.0	291.5	320.9	345.7	38.3
Thaba Bosiu	219.5	202.1	215.9	244.6	33.2	268.0	241.4	265.7	292.3	32.6	330.7	310.9	330.2	352.3	34.1
Thaba Tseka	115.5	94.4	122.4	142.2	34.3	148.3	123.9	145.0	178.1	38.9	195.9	172.9	196.8	227.0	36.3
Thabana Morena	224.8	204.7	226.5	248.2	30.6	261.5	234.1	255.9	278.0	29.8	324.1	303.5	318.1	362.9	37.6

Appendix 7: Onset of frost, last day of frost and duration of frost for all the climate stations using 20% probability as the criteria.

Station	First day of frost				Last day of frost					Duration
	March	April	May	June	July	August	September	October	November	
Butha Buthe			14			27				105
Kolbere			10				5			118
Lekubane			8				8			123
Leribe			15			28				105
Letseng la Terai		3							15	226
Mafeteng			27			26				91
Malefiloane		13						14		184
Mapoteng				7	28					51
Matela			9			23				106
Matsieng				6		24				79
Mejametalana			18			25				99
Mohales Hoek			31			26				87
Mokhotlong		28					12			137
Moshoeshoe I			29			26				89
Mt Moorosi				8	19					41
Nohana			14			22				100
Oxbow	30							25		209
Pitseng			15			16				93
Qachas Nek			28			22				86
Quthing				3		12				70
Roma NUL			30				2			95
Sani Pass	25								29	249
Sehlabathebe		29					30			154
Semonkong		18						27		192
St James		29					11			135
St Martins		29					19			143
Teyateyaneng				5		23				79
Thaba Bosiu			28			22				86
Thaba Tseka			7				19			135
Thabana Morena				23	29					36

Appendix 8: Monthly rainfall statistics (mean, 20th percentile, median, 80th percentile and standard deviation) from January to December.

8.1 January to March monthly rainfall (mm) statistics for all the rainfall stations

	January					February					March				
Station	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev
Botsabelo	116.2	49.8	105.5	172.5	66.2	103.3	49.5	91.0	156.0	55.2	97.3	47.4	95.9	143.6	51.1
Butha Buthe	119.0	64.7	103.9	165.6	65.2	96.0	64.1	91.3	137.7	43.6	109.8	64.7	105.6	134.4	63.7
Fort Hatley	77.4	45.0	65.0	109.9	44.6	74.3	33.9	69.6	107.2	47.4	72.2	32.2	69.1	104.9	45.0
Hololo Court	123.3	68.9	103.9	186.9	68.2	123.3	68.9	103.9	186.9	68.2	99.6	46.1	105.5	129.7	53.4
Khoshane	109.0	53.9	88.4	152.9	61.4	100.8	58.1	99.1	139.6	46.8	95.5	51.7	96.0	144.9	46.2
Kolbere	110.6	77.0	116.3	137.7	36.8	88.7	46.0	85.0	125.9	42.2	71.6	38.1	66.5	115.5	35.8
Lekubane	172.8	91.8	174.5	237.5	89.7	124.1	71.6	134.5	181.7	63.4	126.3	55.9	115.5	191.0	81.4
Lelingoana	104.3	64.7	106.7	137.2	44.2	82.0	45.1	84.2	103.3	36.5	78.2	44.9	66.3	111.9	41.5
Leribe	120.7	55.3	103.7	149.4	84.8	108.2	50.2	99.6	139.6	68.7	96.3	47.9	102.8	137.4	47.3
Lesobeng	96.0	74.2	103.9	134.7	44.8	70.0	27.6	64.6	100.5	41.8	71.5	39.2	61.2	116.8	39.5
Letseng la Terai	112.6	72.4	105.2	145.7	51.0	102.9	57.0	109.0	143.0	55.4	95.0	61.7	83.3	119.7	39.4
Mafeteng	112.1	49.5	92.6	156.7	78.0	94.5	42.7	74.3	140.0	65.7	102.2	51.7	103.2	138.5	62.0
Makoae	115.9	69.0	120.0	167.4	52.1	108.4	59.4	101.1	161.4	55.4	101.2	54.5	103.0	148.3	55.3
Malealea	120.3	57.0	103.2	175.4	72.2	107.2	55.0	104.8	140.9	57.7	100.9	48.6	92.1	151.9	57.3
Maphutseng	79.0	45.0	65.1	113.9	45.3	97.2	32.4	73.4	139.6	85.1	76.7	39.8	59.2	126.6	43.3
Mapoteng	112.0	59.1	100.8	143.0	77.0	95.9	49.4	86.4	130.5	55.7	89.4	57.5	82.6	120.4	42.8
Maputsoe	112.6	70.1	96.9	139.0	65.0	96.2	61.9	92.5	125.4	41.2	98.8	51.7	93.5	138.3	50.9
Marakabei St	121.6	74.1	116.6	161.9	57.4	103.5	62.1	86.9	155.1	54.9	103.2	56.2	86.9	141.0	53.9
Mashai	83.5	31.4	72.0	130.1	56.9	57.2	28.8	54.1	82.8	31.8	54.0	31.2	50.0	76.0	32.4
Matela	125.9	62.5	116.2	186.0	65.6	106.6	65.7	103.3	140.2	52.6	101.7	54.2	81.1	172.6	61.1
Matelile	86.4	48.6	78.3	111.0	53.1	73.9	31.0	55.5	111.1	58.5	87.2	35.3	72.7	137.1	59.4
Matsieng	108.8	38.2	87.5	153.5	79.4	114.9	54.2	89.2	193.5	71.0	92.6	37.3	78.0	151.0	55.6
Mazenod	119.0	57.7	91.5	214.6	80.9	106.9	53.8	84.8	149.2	64.7	105.7	54.4	89.3	155.4	62.9
Mejametalana	111.9	50.0	107.7	177.0	60.9	92.6	50.7	80.9	137.9	54.3	94.9	56.1	88.9	137.9	49.8
Mohales Hoek	112.7	54.4	94.3	160.5	69.8	102.6	44.2	75.4	151.1	69.1	95.2	55.7	90.7	127.7	47.6
Mohlanapeng	113.3	68.2	119.7	142.6	42.3	80.6	46.0	71.0	116.5	37.1	72.3	44.7	68.0	91.0	34.9
Mokhotlong	112.3	62.1	105.9	151.8	50.8	83.2	50.4	81.0	110.6	37.8	81.7	44.0	70.7	105.8	58.1
Moletsane	126.9	63.6	111.2	165.6	75.1	96.4	58.3	91.4	129.3	42.8	104.6	50.1	90.2	162.0	59.0
Molimo Nthuse	120.2	62.0	109.3	170.9	72.2	122.2	54.4	129.1	177.8	68.6	111.3	75.7	96.4	160.9	53.7
Moshoeshoe I	120.6	59.6	103.6	183.8	85.3	111.9	63.8	81.5	170.2	67.1	113.2	66.1	93.4	179.2	64.4

8.1 continues...

	January					February					March				
Station	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev
Mt Carmel	101.2	54.1	80.5	153.6	61.8	87.9	38.5	80.4	136.3	54.1	90.8	39.9	84.8	142.3	57.3
Mt Moorosi	82.3	55.4	77.7	118.8	38.6	88.8	39.8	78.1	121.7	63.8	82.5	47.5	72.3	105.0	46.8
Mt Olivet	96.6	48.2	91.1	131.5	59.0	95.4	54.3	82.5	117.7	66.4	107.5	48.1	104.5	152.3	55.9
Nohana	96.8	66.5	80.2	138.2	51.2	74.1	31.6	62.0	96.5	54.7	93.7	63.0	82.7	133.3	47.6
Oxbow	182.2	126.2	156.2	245.3	78.6	139.3	91.0	136.7	182.2	50.6	157.1	98.3	154.2	200.9	69.0
Paray	100.7	58.9	100.8	141.7	48.8	74.5	43.3	65.4	100.1	34.0	73.1	42.3	63.5	102.1	41.5
Pitseng	119.3	65.5	118.2	173.8	65.7	100.7	56.5	102.6	139.5	53.9	101.2	40.8	98.2	146.3	54.7
Pontseng	157.2	83.8	111.6	248.9	106.8	145.9	75.1	113.9	178.5	115.7	106.0	71.8	100.8	133.4	41.4
Pulane	132.3	57.6	117.2	208.6	88.4	132.5	74.6	118.0	178.5	69.3	115.1	58.9	105.0	173.7	64.7
Qaba	100.3	58.4	90.3	130.8	57.1	87.7	51.1	72.0	130.6	47.4	89.4	40.6	78.5	143.4	53.1
Qachas Nek	144.1	81.1	147.9	194.4	61.9	120.3	73.5	113.5	161.5	53.1	97.9	62.9	94.2	123.8	49.4
Quthing	104.4	54.9	100.5	135.9	55.6	96.8	48.2	94.1	129.3	54.7	104.4	62.0	95.3	141.1	56.7
Ramatseliso	119.7	67.6	127.9	158.5	56.0	99.5	50.2	87.7	129.0	68.0	98.6	43.0	79.9	144.7	74.4
Rapase	103.4	53.4	103.0	141.2	47.1	90.2	60.5	85.7	120.5	36.1	81.1	41.2	74.8	110.2	44.8
Roma NUL	111.5	48.3	110.6	175.2	63.0	100.9	55.5	81.0	151.2	59.3	103.8	39.5	84.6	160.9	68.7
Samaria	101.5	54.9	84.8	159.3	62.3	100.9	40.2	106.3	140.9	66.5	102.6	41.2	83.2	157.7	81.1
Sani Pass	157.5	98.9	131.9	237.0	78.6	122.3	75.6	113.7	154.4	56.9	111.8	71.4	94.3	124.7	63.7
Seaka	79.8	30.8	58.9	123.8	66.0	77.9	32.9	68.1	119.3	48.2	76.1	35.4	58.5	114.0	51.5
Sebedia	130.7	62.4	107.5	172.5	89.6	97.4	52.3	88.6	127.4	57.4	104.8	48.9	87.4	158.1	67.1
Sehlabathebe	135.0	86.2	133.4	169.3	51.7	126.5	76.6	105.6	176.2	66.1	102.0	60.2	85.8	145.8	56.7
Semonkong	100.5	58.7	93.5	139.3	49.2	82.4	43.4	80.4	109.1	46.5	86.7	47.2	81.0	119.3	42.6
St James	97.9	52.4	87.2	120.0	69.9	78.6	39.3	74.6	113.3	51.7	63.4	28.5	59.5	106.2	40.6
St Martins	112.1	82.0	107.0	154.6	35.5	101.4	60.4	97.9	137.1	55.4	82.9	49.9	70.6	119.0	39.0
St Peters	122.3	74.2	112.6	149.6	56.3	100.7	62.1	92.7	141.3	40.7	107.1	66.3	96.1	132.8	57.3
Teyateyaneng	128.2	55.1	95.7	194.9	88.6	101.1	48.2	80.0	157.9	62.7	98.1	46.7	92.9	147.5	55.2
Thaba Bosiu	103.3	38.6	101.2	148.3	71.2	100.7	46.1	84.2	151.2	63.9	95.3	57.8	83.4	117.8	48.2
Thaba Khupa	110.6	49.4	93.4	177.4	64.9	107.4	58.3	105.8	158.3	55.2	98.3	55.5	74.2	154.3	56.8
Thaba Tseka	102.8	59.8	103.9	140.5	47.0	93.5	58.7	94.4	128.1	39.3	76.0	45.8	63.7	110.5	38.8
Thabana Morena	104.7	49.0	95.3	161.9	66.9	97.4	52.1	95.6	132.6	51.3	97.6	46.2	87.3	140.9	68.5
Tsilo	90.6	31.8	86.9	127.2	66.9	86.2	38.7	77.7	120.2	50.0	91.9	36.7	86.1	131.9	61.0
Tsoelike	101.7	53.7	115.3	140.1	47.5	79.2	45.1	79.7	113.2	38.1	70.5	44.4	73.0	88.7	33.9
Whitehill	95.6	61.6	84.2	131.2	43.7	81.5	48.6	80.5	106.1	40.5	75.7	43.8	59.3	108.4	45.7

8.2 April to June monthly rainfall (mm) statistics for all the rainfall stations

	April					May					June				
Station	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev
Botsabelo	55.4	24.7	43.3	93.0	37.8	26.2	4.0	14.0	48.3	28.5	12.4	0.0	9.0	21.9	13.5
Butha Buthe	53.7	21.7	55.9	80.7	34.0	25.2	5.4	16.2	46.1	23.7	11.9	0.0	6.6	21.1	13.5
Fort Hatley	42.6	16.7	37.6	61.6	31.6	21.3	0.0	18.8	42.2	24.2	14.2	0.0	11.2	26.0	12.7
Hololo Court	43.7	18.2	40.8	64.1	30.3	21.6	4.8	13.4	37.7	21.1	10.3	0.0	4.7	16.3	13.6
Khoshane	58.0	19.9	55.9	90.4	34.0	27.2	3.3	15.3	47.3	30.9	17.4	1.8	14.8	23.3	23.8
Kolbere	46.5	18.4	44.0	66.2	34.2	18.6	1.5	10.9	41.9	20.6	14.8	0.0	4.2	31.9	20.1
Lekubane	75.8	36.1	64.8	122.2	44.3	39.5	13.6	25.8	52.2	33.2	14.4	0.7	8.2	23.1	16.6
Lelingoana	38.3	20.4	36.4	50.3	26.4	19.2	2.3	11.5	26.0	33.7	10.4	0.3	2.1	14.0	24.5
Leribe	59.5	22.5	50.2	99.4	40.4	23.6	3.3	13.2	37.4	23.9	12.2	0.0	7.5	19.6	18.7
Lesobeng	38.9	20.5	40.8	54.7	20.9	14.5	0.0	11.1	23.2	17.3	9.8	0.0	6.7	17.4	11.6
Letseng la Terai	43.3	23.4	44.3	62.4	20.9	19.9	4.5	11.3	30.8	21.0	11.8	2.8	5.1	21.0	12.8
Mafeteng	64.7	28.5	47.8	97.0	48.1	26.9	1.6	17.2	51.7	27.3	13.9	1.8	10.0	23.9	15.9
Makoae	72.0	25.8	59.0	108.5	51.8	37.4	3.0	29.1	70.9	41.8	24.8	8.0	19.1	37.5	25.2
Malealea	66.2	29.1	54.9	93.1	49.3	31.8	7.1	23.4	53.1	31.0	22.7	0.5	20.3	38.7	22.1
Maphutseng	57.3	24.1	34.2	74.7	53.6	25.1	0.0	16.2	42.6	30.2	16.0	1.5	12.8	27.2	13.8
Mapoteng	53.0	13.0	38.6	91.4	43.2	23.9	0.0	12.7	38.9	29.0	11.3	0.0	3.7	20.6	14.7
Maputsoe	50.2	12.7	45.9	79.8	40.2	25.0	1.7	9.5	51.6	32.0	11.3	0.0	4.8	21.9	14.2
Marakabei St	58.5	26.2	56.5	75.7	35.9	25.9	6.2	17.4	42.0	24.8	17.0	2.5	12.7	32.9	17.7
Mashai	27.0	9.4	26.0	46.5	19.7	7.8	0.0	1.8	18.0	10.8	6.2	0.0	0.2	12.1	10.9
Matela	67.1	25.4	53.7	105.0	45.2	24.3	1.5	11.3	46.8	25.4	11.9	0.0	6.0	20.6	14.4
Matelile	54.2	17.9	45.7	70.9	43.2	22.4	1.6	15.7	40.1	21.1	12.8	0.0	7.3	29.5	15.2
Matsieng	58.0	22.3	38.8	67.5	67.5	20.4	0.0	16.2	41.7	21.1	12.6	0.0	3.4	22.7	14.5
Mazenod	51.5	16.5	42.1	89.1	40.9	21.7	2.1	13.6	37.2	23.7	9.2	0.1	6.0	16.8	10.3
Mejametalana	56.6	22.3	50.1	81.7	35.8	25.7	2.7	12.0	44.7	28.7	11.6	0.9	8.2	20.7	11.7
Mohales Hoek	63.0	28.4	59.5	89.4	43.3	23.7	1.5	19.2	36.9	23.8	18.1	3.2	10.2	30.5	17.6
Mohlanapeng	35.3	17.4	31.8	54.6	20.7	14.9	0.0	9.5	29.9	15.3	8.8	0.0	3.7	16.8	11.0
Mokhotlong	34.5	17.9	34.1	47.3	18.7	12.4	0.4	11.0	19.6	11.4	7.6	0.0	4.3	14.7	9.7
Moletsane	63.1	26.0	67.0	95.6	38.4	25.8	1.9	18.9	45.5	27.6	15.1	3.0	10.0	24.8	15.5
Molimo Nthuse	68.3	31.5	59.9	102.7	45.8	28.9	6.1	20.0	43.5	31.0	18.8	3.6	14.5	26.1	20.2
Moshoeshoe I	48.2	17.0	47.4	71.4	35.3	24.4	3.1	16.0	46.7	26.9	11.9	0.2	7.8	22.9	12.1

8.2 continues...

	April					May					June				
Station	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev
Mt Carmel	61.6	10.1	49.6	82.0	62.0	26.4	0.4	20.1	30.5	37.3	16.6	0.6	11.4	28.3	16.7
Mt Moorosi	41.7	9.0	36.0	68.8	35.7	22.8	1.7	19.9	35.7	25.7	12.5	0.0	8.9	20.7	13.0
Mt Olivet	53.1	25.8	49.1	66.0	38.9	21.8	0.0	19.1	40.9	22.7	16.5	0.0	7.0	26.4	23.2
Nohana	36.0	9.6	35.2	51.7	26.6	18.6	2.2	12.6	25.6	24.6	16.7	0.0	6.1	33.1	22.2
Oxbow	87.6	34.6	79.9	132.9	53.8	45.0	13.4	32.3	73.5	41.3	20.3	3.9	11.1	37.7	23.3
Paray	41.7	20.5	40.4	57.2	25.7	16.1	1.3	11.7	27.6	16.3	8.7	0.0	3.6	16.3	12.2
Pitseng	57.3	25.6	48.5	79.5	49.1	25.5	4.3	15.1	54.0	25.9	13.4	0.0	10.1	25.8	14.8
Pontseng	65.6	35.4	54.4	90.1	41.3	27.2	0.0	10.0	46.1	38.3	18.2	0.0	9.8	36.1	19.7
Pulane	66.3	32.0	53.5	94.4	48.6	26.7	1.4	18.5	49.7	28.4	18.1	0.0	10.3	25.9	27.7
Qaba	63.1	16.8	48.0	82.4	61.6	28.0	0.0	12.9	49.8	32.3	12.5	0.0	9.0	19.4	12.2
Qachas Nek	41.1	24.8	37.7	58.1	19.6	15.2	2.5	11.6	24.6	13.5	15.8	0.0	6.3	22.6	24.6
Quthing	66.7	31.6	60.7	99.9	41.9	30.5	5.1	26.0	51.2	30.7	19.9	5.4	14.3	34.2	16.0
Ramatseliso	34.9	9.5	35.9	54.8	23.6	11.3	0.7	6.0	18.3	13.6	9.0	0.0	4.3	15.8	13.8
Rapase	39.5	23.2	34.7	59.5	20.9	16.7	3.5	13.5	32.2	14.9	14.4	0.1	6.5	18.8	22.4
Roma NUL	63.7	27.3	54.3	89.7	48.3	34.6	2.2	19.4	49.9	46.3	24.3	2.0	14.8	32.7	31.8
Samaria	59.4	19.8	51.1	96.9	44.7	24.9	1.3	13.9	42.0	30.2	15.0	0.0	6.3	28.8	23.1
Sani Pass	42.9	14.5	47.7	61.7	29.0	11.4	0.1	8.6	23.7	12.1	5.4	0.0	0.0	13.6	8.7
Seaka	40.9	10.6	30.7	72.5	32.9	18.9	0.0	10.2	35.7	20.9	12.5	0.0	10.9	21.7	12.1
Sebedia	88.4	17.5	49.1	86.8	185.2	29.2	2.2	16.0	47.0	35.4	12.4	0.0	6.9	19.7	15.0
Sehlabathebe	40.1	18.4	42.2	54.9	24.4	13.7	1.4	8.8	29.1	13.4	9.6	0.0	3.4	15.2	13.4
Semonkong	45.5	21.6	40.5	64.6	30.5	25.9	4.2	21.3	40.3	24.4	13.1	2.0	9.0	18.7	14.2
St James	33.0	13.3	33.2	44.6	27.9	12.2	0.1	10.8	21.0	11.9	7.8	0.0	3.3	11.3	11.6
St Martins	44.7	22.3	40.1	68.7	29.3	23.8	5.0	20.1	39.4	21.7	9.3	0.0	3.3	20.1	13.6
St Peters	52.8	26.6	48.1	75.7	29.9	25.7	5.9	15.8	37.6	26.3	10.6	0.4	7.4	20.1	12.1
Teyateyaneng	63.3	29.9	55.5	97.5	36.2	24.1	0.2	13.5	45.9	27.6	15.7	1.8	10.4	25.1	16.3
Thaba Bosiu	54.9	24.8	45.0	78.6	40.8	24.0	2.5	15.5	46.1	25.6	11.6	0.0	6.5	20.8	13.2
Thaba Khupa	49.7	18.8	43.7	74.9	36.6	25.8	4.2	16.9	38.8	27.8	11.8	0.0	7.6	20.8	13.5
Thaba Tseka	35.9	15.9	28.5	59.8	24.0	13.4	0.5	10.0	26.4	13.0	7.6	0.0	3.0	14.6	9.3
Thabana Morena	54.6	26.7	43.4	74.3	43.3	24.5	3.8	16.5	40.7	25.9	15.5	1.9	9.5	24.8	15.8
Tsilo	50.1	22.5	40.6	56.3	47.6	26.5	2.7	17.8	44.5	29.3	11.8	3.0	9.4	19.4	11.5
Tsoelike	30.5	16.0	30.0	45.2	19.0	11.5	0.0	9.8	21.2	11.3	11.4	0.0	4.3	14.6	20.2
Whitehill	42.4	23.2	36.4	65.0	24.3	16.9	1.0	10.4	33.3	16.5	16.5	1.2	9.2	20.7	23.3

8.3 July to September monthly rainfall (mm) statistics for all the rainfall stations

	July					August					September				
Station	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev
Botsabelo	10.4	0.0	2.4	23.1	15.7	20.6	0.0	13.5	36.2	24.7	27.4	3.8	15.8	48.4	31.7
Butha Buthe	9.6	0.0	2.8	17.6	12.2	23.6	0.0	9.7	52.0	30.7	27.6	5.5	15.1	40.5	33.1
Fort Hatley	8.6	0.0	4.5	14.0	10.8	22.3	0.7	15.2	39.6	24.1	27.9	1.4	16.8	58.0	29.6
Hololo Court	9.5	0.0	1.7	15.9	17.2	23.4	1.1	9.5	45.9	30.2	28.7	3.8	18.4	45.6	28
Khoshane	12.2	0.0	6.6	23.7	14.6	26.6	1.9	13.5	46.0	32.5	35.8	6.6	15.7	64.8	36.7
Kolbere	13.5	0.0	5.3	31.2	18.6	23.3	0.0	15.4	44.2	28.5	32.1	4.4	15.0	42.2	44.4
Lekubane	16.3	0.0	4.5	31.5	25.8	40.1	7.7	20.5	79.4	42.9	56.0	17.0	47.7	97.3	43.1
Lelingoana	10.7	0.0	2.8	11.5	25.4	16.1	1.2	10.6	26.9	17.6	26.3	7.6	16.6	38.8	26.8
Leribe	7.9	0.0	2.8	12.4	12.5	19.5	0.4	7.8	25.6	27.5	29.3	3.0	16.5	48.3	33.2
Lesobeng	8.8	0.0	4.4	19.1	9.7	22.4	0.0	14.4	46.1	26.9	32.4	4.5	14.9	47.6	40.4
Letseng la Terai	10.9	0.6	4.4	17.7	13.6	22.1	1.3	13.3	37.6	26.0	44.6	8.8	29.6	66.9	54.8
Mafeteng	9.7	0.0	3.8	15.3	13.9	22.4	0.0	13.1	35.2	27.9	25.3	2.5	10.4	42.2	34.3
Makoae	20.4	3.5	12.3	26.5	27.1	36.2	8.0	27.6	68.5	32.3	47.4	14.9	24.8	76.0	50.3
Malealea	16.2	0.0	8.5	25.4	21.0	29.3	4.5	16.8	63.4	29.9	36.9	4.1	20.1	64.9	39.9
Maphutseng	9.9	0.0	1.4	17.3	13.5	26.8	0.0	19.7	46.3	31.2	34.1	1.8	21.2	57.1	34.4
Mapoteng	7.7	0.0	2.5	10.9	12.6	23.8	0.5	13.0	48.4	28.4	24.2	3.0	15.3	43.1	25.9
Maputsoe	6.9	0.0	0.8	9.4	13.9	24.1	0.0	7.6	47.6	31.4	28.4	1.5	20.7	36.4	37.9
Marakabei St	14.1	0.5	11.0	21.4	18.6	29.1	2.8	24.0	51.7	28.6	38.3	8.8	26.1	68.2	35.2
Mashai	4.0	0.0	0.0	8.7	6.1	15.7	0.0	9.9	22.1	21.1	21.4	0.9	11.0	36.2	27.1
Matela	10.7	0.0	3.2	19.7	16.0	27.1	0.0	21.9	53.6	28.4	32.2	5.7	16.4	64.0	34.9
Matelile	11.5	0.0	2.1	15.4	19.7	28.6	0.0	17.5	52.5	31.6	25.7	4.0	18.1	41.2	30
Matsieng	6.8	0.0	1.0	15.8	9.4	21.9	0.0	9.8	42.6	29.9	27.3	2.2	16.8	38.6	39.7
Mazenod	9.7	0.0	0.8	17.2	16.5	22.1	0.2	10.3	42.8	26.0	33.3	2.6	18.6	61.4	38.3
Mejametalana	8.6	0.0	2.1	16.6	12.8	18.4	0.2	11.1	34.8	21.2	27.4	3.2	15.6	43.9	33.3
Mohales Hoek	10.1	0.0	4.1	16.9	15.0	26.3	0.5	11.2	50.8	31.5	30.5	1.0	20.8	53.3	34.9
Mohlanapeng	9.1	0.0	5.4	18.0	11.3	23.9	1.0	15.0	37.1	28.1	28.3	4.9	13.2	48.7	32.5
Mokhotlong	5.5	0.0	1.6	8.5	9.7	14.4	0.8	8.4	14.1	21.4	27.9	4.2	12.4	39.1	40.2
Moletsane	11.5	0.7	4.7	16.1	15.8	26.9	0.4	12.0	54.4	33.6	30.8	5.1	22.3	58.5	31.3
Molimo Nthuse	13.9	0.0	6.3	18.4	20.4	31.0	0.1	23.8	54.8	34.8	39.9	0.4	26.8	66.0	46.7
Moshoeshoe I	6.9	0.1	2.4	13.4	9.2	23.6	0.1	16.2	50.9	25.2	27.8	2.1	16.2	51.6	33.3

8.3 continues...

	July					August					September				
Station	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev
Mt Carmel	6.6	0.0	1.4	10.0	13.1	21.5	0.0	8.1	41.6	26.8	33.5	1.6	21.6	55.1	39.3
Mt Moorosi	9.8	0.0	5.5	16.2	14.4	25.3	0.2	10.4	46.0	27.9	31.5	8.8	21.2	44.8	32.6
Mt Olivet	9.9	0.0	1.3	12.0	20.2	30.5	0.0	16.9	66.4	37.1	37.4	6.8	23.7	63.4	39.1
Nohana	6.3	0.0	1.6	10.4	9.7	24.0	2.8	15.5	39.9	26.0	23.1	7.2	13.7	37.4	23.8
Oxbow	15.4	0.1	8.3	33.6	17.2	40.3	6.5	30.1	65.9	40.8	54.4	13.1	43.5	92.4	50.3
Paray	7.1	0.0	4.3	12.6	9.4	20.4	0.0	10.5	33.5	24.8	27.4	4.6	13.0	38.8	35.9
Pitseng	11.8	0.0	3.8	19.2	16.9	24.0	0.0	10.8	44.8	33.1	34.0	8.3	26.0	48.2	37.6
Pontseng	16.6	0.0	0.4	26.8	27.8	32.8	0.0	16.2	52.2	47.4	38.0	4.1	28.8	78.2	35.8
Pulane	11.5	0.0	4.0	22.3	15.9	32.8	0.9	15.0	62.8	38.3	43.0	5.6	20.5	90.7	49.9
Qaba	11.9	0.0	1.1	15.0	20.2	27.1	0.0	18.0	37.9	32.0	34.2	6.0	24.4	47.0	33.2
Qachas Nek	11.2	0.0	3.3	23.5	16.2	20.3	1.9	17.4	34.0	20.7	35.0	10.7	24.4	50.8	42.0
Quthing	12.1	0.1	8.1	19.5	13.8	26.8	2.8	16.6	44.6	30.4	37.6	6.3	20.3	74.1	40.5
Ramatseliso	9.4	0.0	0.0	9.3	17.2	14.9	0.1	5.8	28.2	16.4	21.7	5.6	17.5	39.4	18.0
Rapase	9.1	0.0	4.5	15.5	12.0	17.5	0.6	14.0	26.5	18.2	29.6	5.9	14.7	46.7	32.8
Roma NUL	20.2	0.0	7.7	31.3	30.2	34.2	2.2	11.8	55.3	46.3	45.1	6.5	27.9	79.0	44.8
Samaria	10.7	0.0	2.2	21.4	16.4	27.2	0.0	22.6	51.9	30.7	31.3	4.1	23.4	54.3	35.1
Sani Pass	5.6	0.0	0.0	9.6	8.6	15.3	0.6	9.3	23.7	19.9	42.7	6.2	32.1	63.4	43.0
Seaka	7.4	0.0	2.1	14.8	9.6	19.8	0.0	15.8	31.6	21.6	28.9	6.2	13.8	38.5	35.8
Sebedia	8.9	0.0	5.5	14.0	10.4	25.2	0.5	14.8	40.4	31.8	37.3	6.0	14.5	58.3	45.1
Sehlabathebe	13.7	0.0	3.5	23.5	21.2	16.3	0.1	10.8	32.2	17.8	42.0	9.5	28.0	63.5	48.3
Semonkong	12.3	1.5	5.5	21.4	15.1	26.8	0.8	15.3	42.1	31.7	40.0	8.7	22.0	68.1	41.3
St James	8.1	0.0	0.9	15.7	12.2	15.4	0.0	8.4	33.3	19.3	31.6	5.1	13.1	45.4	55.6
St Martins	13.6	0.0	6.5	20.6	21.1	26.8	0.0	17.1	47.3	29.2	41.9	6.9	30.2	59.8	48.9
St Peters	8.8	0.0	2.4	19.7	10.9	24.8	4.6	14.0	39.4	31.8	34.1	7.0	21.6	56.0	36.9
Teyateyaneng	7.5	0.0	5.0	12.6	9.7	21.2	1.7	10.5	38.9	25.3	31.1	2.5	16.0	46.3	38.7
Thaba Bosiu	9.6	0.0	4.7	14.6	15.3	25.3	0.0	8.4	48.3	34.4	26.1	4.2	14.8	47.3	28.7
Thaba Khupa	8.8	0.0	2.3	14.6	13.6	22.5	0.0	12.6	43.3	24.4	27.5	5.6	16.4	48.6	26.7
Thaba Tseka	6.9	0.0	3.8	12.1	9.9	21.3	0.2	11.3	46.0	24.4	30.2	3.3	14.5	47.6	37.0
Thabana Morena	10.2	0.0	2.6	16.4	14.7	21.1	0.0	9.8	31.3	26.9	26.1	3.8	16.4	41.0	29.3
Tsilo	13.0	0.0	4.1	24.7	19.7	24.2	0.0	18.1	37.6	29.2	26.3	3.5	20.3	44.2	23.5
Tsoelike	9.2	0.0	3.0	17.0	14.1	14.6	0.0	9.2	25.6	17.5	23.9	4.5	14.8	40.7	26.0
Whitehill	9.4	0.0	3.7	15.4	13.1	20.3	1.1	16.3	33.8	20.8	27.8	5.9	17.8	47.3	31.1

8.4 October to December monthly rainfall (mm) statistics for all the rainfall stations

	October					November					December				
Station	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev
Botsabelo	66.3	26.0	60.3	106.6	42.2	82.8	44.5	67.4	130.9	46.4	87.0	42.7	76.0	119.0	51.3
Butha Buthe	71.0	40.9	66.8	101.0	35.6	101.3	60.4	101.2	136.9	51.1	98.0	66.7	94.4	137.8	43.2
Fort Hatley	57.1	21.3	44.5	92.0	42.5	61.7	30.8	54.5	77.3	36.8	74.5	30.7	67.9	115.6	44.2
Hololo Court	67.7	23.7	62.6	102.3	40.9	107.6	55.0	95.7	160.5	60.6	102.0	53.2	90.6	141.1	70.0
Khoshane	74.5	31.4	64.2	131.6	48.2	93.4	49.0	84.5	132.4	55.2	97.0	55.0	96.8	120.1	45.8
Kolbere	79.3	27.2	62.0	122.6	54.9	87.1	57.2	91.5	119.7	35.9	84.5	50.6	80.1	123.9	42.9
Lekubane	98.3	56.9	83.5	155.8	61.2	115.9	65.7	101.5	164.7	53.5	129.3	73.0	107.6	188.9	72.6
Lelingoana	64.8	32.3	60.9	90.8	36.2	76.4	44.2	71.3	105.5	36.9	85.5	52.6	81.9	111.5	40.4
Leribe	67.8	35.3	60.0	102.6	39.2	92.4	46.0	77.1	128.1	61.7	100.8	56.2	93.9	129.9	50.6
Lesobeng	65.0	40.3	60.1	91.2	36.6	84.1	38.4	69.8	94.9	64.5	83.8	35.5	87.6	112.8	55.9
Letseng la Terai	88.3	52.7	76.5	111.3	39.7	103.0	60.2	105.7	130.4	40.9	109.6	79.9	109.5	136.3	38.7
Mafeteng	62.0	22.4	58.5	101.2	47.6	80.5	40.4	69.1	124.9	52.3	85.4	34.3	78.5	126.1	60.1
Makoae	85.4	29.9	79.2	143.0	52.1	96.9	52.8	83.3	143.7	64.0	124.9	58.0	103.5	197.2	80.7
Malealea	74.6	30.2	73.3	115.0	52.4	104.7	51.2	95.8	157.5	61.4	89.3	45.4	87.3	128.0	51.6
Maphutseng	81.4	16.5	58.5	121.3	72.9	89.5	49.7	64.7	131.9	73.8	77.9	38.5	79.1	128.1	47.8
Mapoteng	74.2	34.7	81.1	109.2	41.1	97.5	55.2	110.6	127.2	48.1	87.0	48.3	92.8	119.3	48.8
Maputsoe	65.3	27.6	65.7	106.8	40.7	87.9	67.4	83.5	129.9	40.4	101.5	76.0	105.5	132.5	35.4
Marakabei St	81.5	40.6	71.1	117.6	48.0	88.6	55.0	82.8	129.3	48.4	105.1	66.5	106.4	147.4	48.2
Mashai	47.7	18.2	40.1	81.4	35.5	59.3	26.5	57.0	88.3	33.3	61.0	34.1	61.8	87.2	29.7
Matela	85.1	46.2	84.8	123.1	51.5	88.1	51.3	80.9	138.8	44.4	105.3	56.9	96.7	141.8	55.1
Matelile	68.3	25.0	52.5	111.6	53.3	78.7	46.0	72.4	115.0	48.8	80.7	32.0	83.1	119.5	49.6
Matsieng	71.7	31.4	69.5	110.2	50.3	99.9	44.6	97.6	148.8	60.2	109.0	81.5	103.7	128.9	64.0
Mazenod	78.1	29.0	79.1	121.2	47.4	87.7	47.3	82.8	113.9	51.2	94.9	51.9	92.9	125.3	50.8
Mejametalana	66.6	22.7	62.8	105.8	43.5	83.2	38.7	66.1	132.8	46.9	85.9	44.4	83.3	119.8	49.0
Mohales Hoek	64.5	18.8	53.3	119.7	52.8	80.5	37.6	71.3	110.8	52.5	95.6	40.3	91.7	141.9	60.9
Mohlanapeng	64.8	37.2	55.0	101.6	38.6	74.7	39.7	69.0	102.4	36.6	83.6	46.5	85.2	109.0	40.6
Mokhotlong	63.4	28.8	57.2	88.3	39.2	79.7	47.8	84.0	112.0	35.0	88.7	61.0	88.3	118.4	32.1
Moletsane	88.4	47.1	87.0	144.3	49.7	95.8	54.8	96.9	137.2	45.6	118.1	62.1	125.6	155.5	49.5
Molimo Nthuse	93.5	32.1	90.1	155.8	60.5	97.4	46.3	75.7	158.4	63.2	108.4	56.7	108.1	137.0	67.2
Moshoeshoe I	78.1	33.9	74.3	117.7	46.3	83.9	39.6	79.8	112.2	48.7	100.1	58.1	104.5	129.5	53.0

8.4 continues...

Station	October					November					December				
	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev	Mean	20th Per	Median	80th Per	Std Dev
Mt Carmel	69.8	24.8	65.1	105.7	57.9	85.0	32.0	75.4	99.1	97.7	75.1	21.4	74.3	106.8	59.5
Mt Moorosi	59.7	18.7	50.4	94.8	45.9	74.6	29.0	67.2	104.5	46.2	83.3	36.8	75.0	128.7	48.8
Mt Olivet	61.3	21.7	59.1	93.2	45.1	78.7	33.9	78.4	113.0	47.1	77.6	37.8	84.2	110.0	42.7
Nohana	58.7	8.1	53.7	90.8	58.5	68.3	23.1	54.3	86.3	67.0	93.4	39.2	87.3	142.6	57.5
Oxbow	129.2	71.8	119.6	179.3	63.0	161.6	105.5	147.6	205.9	79.7	169.7	114.6	169.1	225.5	61.8
Paray	60.5	31.0	50.4	86.9	34.7	73.3	44.5	68.8	103.6	35.8	77.4	42.7	83.7	103.4	38.0
Pitseng	72.1	32.1	66.9	114.3	42.5	98.4	53.5	97.2	148.1	48.7	110.1	69.6	104.8	156.9	50.1
Pontseng	119.9	47.5	102.5	163.1	102.7	127.2	98.3	127.5	162.9	43.9	130.3	80.0	120.5	176.9	54.7
Pulane	95.7	49.7	90.1	139.8	56.8	112.6	48.3	98.0	183.2	72.4	105.0	39.2	95.2	154.3	72.2
Qaba	69.6	26.5	52.5	96.1	57.3	83.8	35.0	77.6	118.8	57.1	99.1	55.0	99.8	151.0	50.5
Qachas Nek	71.1	46.7	64.5	102.5	38.2	85.3	53.4	79.1	114.3	37.7	121.0	72.3	119.0	171.5	58.8
Quthing	67.7	22.4	52.8	109.0	48.9	81.8	36.5	72.7	121.1	52.7	96.2	61.8	100.9	125.5	51.1
Ramatseliso	61.4	28.8	49.0	102.4	38.5	77.8	32.2	66.2	105.9	47.4	91.4	50.1	88.5	139.5	48.4
Rapase	61.4	26.4	51.3	89.0	40.2	73.6	40.6	63.4	94.6	45.4	92.7	56.7	85.4	129.2	44.3
Roma NUL	82.3	30.9	70.0	132.7	53.6	87.9	42.3	76.8	139.0	53.3	94.5	56.2	91.8	123.8	51.8
Samaria	62.6	4.5	52.9	120.0	53.7	86.5	31.5	81.3	115.7	66.9	89.6	33.6	76.5	122.4	73.7
Sani Pass	73.0	38.1	71.8	106.8	34.4	95.6	48.6	104.4	124.2	48.1	134.7	85.1	118.8	163.3	77.7
Seaka	46.9	13.2	36.5	74.8	45.1	50.9	19.9	34.9	65.8	52.0	64.1	17.6	62.6	109.5	47.2
Sebedia	77.4	34.4	77.3	124.2	46.0	104.9	61.9	108.2	140.0	41.5	110.6	71.0	111.7	153.9	57.0
Sehlabathebe	71.1	39.4	59.5	102.5	37.0	89.5	51.6	87.4	126.4	42.0	112.3	77.3	112.1	139.0	42.8
Semonkong	68.1	31.6	64.6	115.1	45.3	73.3	46.0	68.7	103.8	38.6	86.3	55.2	69.7	124.8	41.3
St James	59.5	24.1	58.0	91.7	38.2	66.3	30.6	68.1	92.5	41.3	75.0	40.1	72.8	108.7	47.6
St Martins	92.4	40.9	80.5	138.2	73.0	94.6	42.8	103.8	132.0	44.9	99.1	65.5	94.8	125.7	43.1
St Peters	86.5	53.8	79.4	126.8	44.7	111.6	59.0	108.0	165.7	56.9	117.0	82.9	114.0	167.8	49.8
Teyateyaneng	77.3	29.2	69.5	118.9	58.3	100.5	49.9	97.3	154.0	56.1	92.7	48.7	95.0	125.1	44.3
Thaba Bosiu	86.2	24.1	97.4	124.6	57.5	90.9	42.8	81.0	136.9	54.1	92.4	47.7	89.4	138.4	47.9
Thaba Khupa	73.6	25.7	75.1	110.4	51.4	77.5	34.3	78.5	111.6	44.0	85.2	47.2	75.8	111.0	51.8
Thaba Tseka	70.1	41.6	64.7	101.4	36.6	73.1	40.9	72.5	99.7	31.2	89.7	56.5	86.3	109.3	39.1
Thabana Morena	64.7	21.2	63.3	92.4	45.4	94.9	43.8	80.0	139.0	77.8	85.5	41.5	83.4	119.9	47.0
Tsilo	61.1	16.7	60.7	93.5	44.8	85.5	38.0	76.6	113.0	52.1	92.0	33.5	89.0	133.0	62.2
Tsoelike	49.7	24.0	41.4	68.5	34.5	59.6	38.0	53.6	85.3	32.9	82.5	55.0	80.8	110.0	37.2
Whitehill	65.6	32.0	59.2	96.4	42.2	72.7	36.2	71.8	96.0	39.4	87.9	60.2	82.7	123.2	40.1

Appendix 9: Annual, wet season and dry season rainfall statistics (mean, minimum, 20th percentile, median, 80th percentile, maximum and standard deviation

9.1 Annual rainfall statistics for all the rainfall stations

Station	Mean	Min	20th Perc	Median	80th Perc	Max	Std Dev	Station	Mean	Min	20th Perc	Median	80th Perc	Max	Std Dev
Botsabelo	707	416	585	691	848	1003	149	**Mt Moorosi**	612	283	450	572	735	1326	217
Butha Buthe	745	348	609	727	917	1188	167	**Mt Olivet**	686	215	533	704	815	981	185
Fort Hatley	555	253	416	538	655	987	162	**Nohana**	608	307	424	642	700	1035	184
Hololo Court	732	423	573	711	877	1282	182	**Oxbow**	1205	872	1017	1174	1374	1664	201
Khoshane	750	482	579	745	900	1017	164	**Paray**	580	256	492	577	679	887	125
Kolbere	670	334	568	650	766	994	153	**Pitseng**	767	488	631	748	895	1245	172
Lekubane	1012	539	759	1050	1205	1452	266	**Pontseng**	984	655	770	921	1060	2367	345
Lelingoana	612	382	478	596	730	1065	147	**Pulane**	906	367	714	893	1152	1317	246
Leribe	739	408	568	685	866	1488	220	**Qaba**	712	401	531	697	842	1261	211
Lesobeng	596	268	423	614	744	998	186	**Qachas Nek**	777	401	619	801	925	1079	164
Letseng la Terai	764	535	631	779	871	1086	136	**Quthing**	744	460	552	715	894	1292	196
Mafeteng	703	327	544	680	888	1160	192	**Ramatseliso**	654	364	439	571	852	1232	223
Makoae	869	445	659	800	987	1829	285	**Rapase**	626	364	489	615	754	1002	145
Malealea	800	369	659	803	988	1135	189	**Roma NUL**	809	440	614	822	988	1412	218
Maphutseng	669	353	444	630	821	1378	241	**Samaria**	720	215	538	678	918	1149	241
Mapoteng	695	325	529	687	861	1100	193	**Sani Pass**	826	494	629	823	1018	1188	209
Maputsoe	705	453	619	719	783	964	130	**Seaka**	524	224	362	522	745	915	208
Marakabei St John	785	425	630	770	916	1315	184	**Sebedia**	855	406	653	822	981	1659	276
Mashai	445	109	352	469	537	737	132	**Sehlabathebe**	772	413	682	771	884	1061	135
Matela	786	413	674	787	922	1106	172	**Semonkong**	659	255	523	638	779	1183	189
Matelile	629	339	501	665	787	859	162	**St James**	550	183	393	576	678	1006	193
Matsieng	745	365	587	734	870	1148	196	**St Martins**	740	369	618	742	872	1122	151
Mazenod	741	352	544	728	904	1275	227	**St Peters**	805	520	695	811	934	1107	140
Mejametalana	684	401	582	667	778	1033	146	**Teyateyaneng**	761	500	614	694	945	1193	186
Mohales Hoek	723	292	555	714	865	1284	205	**Thaba Bosiu**	722	291	617	734	849	1113	188
Mohlanapeng	609	352	520	600	705	887	126	**Thaba Khupa**	702	334	609	684	860	1061	184
Mokhotlong	612	380	469	624	711	875	126	**Thaba Tseka**	620	391	521	615	721	850	115
Moletsane	803	447	673	812	954	1121	182	**Thabana Morena**	696	390	571	694	809	1185	168
Molimo Nthuse	852	207	710	858	1087	1278	238	**Tsilo**	657	281	409	629	857	1131	249
Moshoeshoe I	752	359	584	739	964	1233	213	**Tsoelike**	546	305	444	565	653	870	130
Mt Carmel	676	217	424	711	845	1193	258	**Whitehill**	613	385	482	604	738	946	141

9.2 Wet season (October to April) rainfall (mm) statistics for all the rainfall stations

Station	Mean	Min	20th Perc	Median	80th Perc	Max	Std Dev	Station	Mean	Min	20th Perc	Median	80th Perc	Max	Std Dev
Botsabelo	608	340	463	638	720	964	145	Mt Moorosi	513	243	424	491	591	968	149
Butha Buthe	647	262	535	654	748	1056	141	Mt Olivet	561	369	437	553	661	821	126
Fort Hatley	460	261	333	449	616	732	129	Nohana	514	288	402	499	605	887	151
Hololo Court	633	338	498	613	741	1214	169	Oxbow	1025	668	858	1048	1171	1374	170
Khoshane	635	324	509	680	740	845	145	Paray	503	229	398	502	602	814	122
Kolbere	575	340	432	537	702	923	152	Pitseng	658	277	490	638	814	992	179
Lekubane	855	444	653	903	1001	1290	212	Pontseng	863	435	673	817	1011	1684	293
Lelingoana	528	301	441	480	599	1147	138	Pulane	760	164	576	792	951	1253	248
Leribe	642	359	503	588	755	1436	214	Qaba	590	344	479	563	738	944	155
Lesobeng	513	198	379	491	651	988	180	Qachas Nek	681	295	561	693	779	1089	153
Letseng la Terai	641	236	563	627	769	1006	149	Quthing	617	328	519	602	733	929	145
Mafeteng	604	307	438	605	749	970	173	Ramatseliso	585	164	416	530	744	1030	221
Makoae	706	450	536	647	893	1207	198	Rapase	541	286	428	520	640	835	129
Malealea	661	368	559	686	760	951	141	Roma NUL	661	386	481	666	803	1120	177
Maphutseng	553	310	410	496	658	1115	181	Samaria	593	141	456	584	750	1168	229
Mapoteng	613	158	480	635	725	1036	176	Sani Pass	756	297	561	748	913	1385	259
Maputsoe	610	406	473	593	738	976	142	Seaka	435	171	293	456	548	808	165
Marakabei St John	659	321	565	619	773	1203	170	Sebedia	740	529	566	690	846	1651	242
Mashai	388	150	299	389	459	733	118	Sehlabathebe	678	408	566	660	747	1177	147
Matela	674	315	530	704	813	912	152	Semonkong	538	283	408	527	672	1090	160
Matelile	524	169	421	513	624	828	140	St James	464	72	318	469	578	977	178
Matsieng	661	399	544	626	815	925	146	St Martins	624	323	538	618	719	1018	146
Mazenod	630	313	457	635	784	987	179	St Peters	697	365	582	715	815	1038	137
Mejametalana	592	333	453	595	729	870	139	Teyateyaneng	649	341	517	666	776	1073	165
Mohales Hoek	612	239	489	604	715	1066	155	Thaba Bosiu	630	323	482	583	753	1095	184
Mohlanapeng	527	305	427	517	625	805	115	Thaba Khupa	599	225	458	598	753	863	169
Mokhotlong	541	336	445	537	626	833	113	Thaba Tseka	536	380	454	512	627	743	93
Moletsane	687	444	531	679	843	1003	162	Thabana Morena	599	310	459	592	707	1008	158
Molimo Nthuse	719	311	526	741	854	1195	213	Tsilo	552	189	354	507	765	898	208
Moshoeshoe I	667	434	503	694	761	1017	155	Tsoelike	472	221	360	468	580	691	116
Mt Carmel	561	229	425	533	692	918	184	Whitehill	520	291	429	504	634	781	115

9.3 Dry season (May to September) rainfall (mm) statistics for all the rainfall stations

Station	Mean	Min	20th Perc	Median	80th Perc	Max	Std Dev	Station	Mean	Min	20th Perc	Median	80th Perc	Max	Std Dev
Botsabelo	97.0	7.7	61.1	97.4	130.4	239.0	48.9	**Mt Moorosi**	103.2	25.6	66.1	78.2	156.0	304.8	61.7
Butha Buthe	97.8	2.5	52.0	89.8	127.3	297.1	59.1	**Mt Olivet**	116.8	0.5	65.5	103.7	168.7	296.9	76.4
Fort Hatley	94.9	19.8	56.5	82.5	134.8	288.4	54.5	**Nohana**	88.7	24.7	44.1	62.2	132.1	243.2	61.2
Hololo Court	93.6	2.0	44.2	89.7	120.1	265.0	54.9	**Oxbow**	176.4	21.3	101.2	163.2	243.4	410.6	89.3
Khoshane	120.3	27.2	62.9	104.1	170.1	259.1	61.0	**Paray**	79.7	0.0	36.9	71.1	116.2	228.9	50.2
Kolbere	102.3	2.9	46.1	103.1	158.0	284.6	64.1	**Pitseng**	108.7	0.0	52.8	108.7	138.4	328.9	65.7
Lekubane	170.3	100.5	110.1	149.8	198.6	412.5	78.7	**Pontseng**	133.8	11.0	51.4	121.3	216.5	343.4	90.3
Lelingoana	82.8	6.6	38.2	66.2	106.7	504.1	78.1	**Pulane**	134.2	19.8	73.4	129.6	205.4	264.2	70.8
Leribe	92.9	1.2	46.6	83.2	116.6	285.4	60.8	**Qaba**	114.7	2.6	72.7	97.4	152.2	279.1	66.8
Lesobeng	88.3	0.0	39.0	66.5	125.3	282.0	65.5	**Qachas Nek**	97.6	6.2	53.2	87.2	136.9	372.1	62.8
Letseng la Terai	109.4	12.0	63.9	95.2	139.5	292.5	66.1	**Quthing**	126.8	20.3	75.8	116.1	160.5	401.5	72.3
Mafeteng	98.2	4.5	52.2	96.2	139.9	248.0	54.6	**Ramatseliso**	66.2	9.9	39.0	55.8	100.9	159.9	36.9
Makoae	166.3	58.3	90.5	132.7	204.9	494.4	107.4	**Rapase**	87.3	6.4	53.1	76.8	115.0	226.0	46.9
Malealea	137.0	14.8	88.8	131.1	183.1	327.8	66.4	**Roma NUL**	144.9	7.2	77.7	113.8	174.7	560.7	112.9
Maphutseng	112.8	18.1	70.2	91.9	150.8	359.4	71.0	**Samaria**	109.8	16.5	52.4	86.9	164.1	243.6	60.6
Mapoteng	91.0	9.1	62.3	89.9	115.3	230.5	48.7	**Sani Pass**	80.5	0.0	36.0	69.3	137.3	198.9	56.7
Maputsoe	95.7	3.2	54.5	83.8	130.2	262.1	62.4	**Seaka**	87.9	23.4	43.3	73.7	133.8	202.0	52.3
Marakabei St John	124.4	24.3	68.5	123.7	162.9	346.6	62.5	**Sebedia**	117.1	0.0	70.6	103.3	171.0	265.2	65.6
Mashai	55.3	0.0	20.8	46.8	90.2	192.8	40.2	**Sehlabathebe**	95.2	22.5	41.5	93.5	121.2	342.4	65.0
Matela	106.2	25.6	62.6	103.0	141.5	237.8	55.1	**Semonkong**	118.8	18.9	59.8	119.7	159.8	308.8	65.0
Matelile	101.0	6.5	56.2	86.2	171.3	213.5	58.1	**St James**	75.2	6.0	26.9	60.6	100.9	388.8	72.7
Matsieng	89.0	0.0	45.2	87.8	119.6	251.2	59.7	**St Martins**	115.5	7.7	67.3	102.4	158.2	369.4	75.7
Mazenod	95.9	12.1	44.7	84.0	140.5	245.0	58.9	**St Peters**	104.0	9.6	59.6	99.7	134.7	298.0	58.7
Mejametalana	92.4	12.1	56.7	93.4	123.8	226.5	45.3	**Teyateyaneng**	99.6	15.2	60.7	101.4	141.0	219.6	50.8
Mohales Hoek	108.6	12.0	61.5	98.6	140.0	295.9	60.4	**Thaba Bosiu**	96.7	24.2	36.9	89.6	138.9	210.9	59.8
Mohlanapeng	85.5	6.0	40.4	76.0	122.0	272.5	53.2	**Thaba Khupa**	96.3	19.3	52.3	87.1	136.9	252.8	52.3
Mokhotlong	68.0	5.4	34.9	52.7	104.8	266.2	49.6	**Thaba Tseka**	79.8	0.3	32.2	63.3	130.6	233.2	56.1
Moletsane	110.1	13.3	65.0	105.1	138.3	261.0	60.4	**Thabana Morena**	98.0	15.4	51.9	94.2	141.2	205.0	50.5
Molimo Nthuse	132.5	24.7	66.4	118.2	194.8	320.5	77.4	**Tsilo**	101.7	15.5	57.5	85.6	119.2	343.6	68.8
Moshoeshoe I	94.5	2.7	49.6	86.0	134.5	268.4	63.5	**Tsoelike**	70.7	2.6	36.4	62.7	86.5	224.0	44.0
Mt Carmel	104.6	0.0	43.3	96.8	165.6	250.5	64.3	**Whitehill**	91.3	15.6	55.0	75.0	119.2	270.7	53.0