Climate Change and Variability Effects on Malaria Prevalence in the Limpopo Province, South Africa

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DEDICATION

This work is dedicated to my parents; Patrick Rimwe and Gladys Sithole, to my wife, Pascar Maria-Rita Sithole and my two sons Patee & Travis, for their support and patience. Thank you for your love and encouragement. Without you I would not have made it.

I would also like to dedicate this work to all those that have suffered from malaria at some point in their lives, including myself. This study is part of the solution in trying to reduce malaria infections and possibly eradicating the disease in Southern Africa.

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ABSTRACT

As the world strives towards the elimination of the highest death causing vector-borne disease, namely malaria, research is needed in order to contribute towards this goal in South Africa. This study contributes towards the goal of eliminating malaria. The transmission of malaria is a complex biological process, which is associated with not only climate conditions but non-climate conditions like human behaviour, socio-economic, political situation and other environmental factors like ecology, hydrology and associated conditions. Research has shown that in malaria prone areas climatological elements have an effect on the propagation of malaria. However, the extent of the effect and the most influential climatological element vary from area to area when the local level is considered. This study sought to understand the strength of the relationship between malaria and climatological elements at the local level in Vhembe District, Limpopo Province, South Africa. The study analysed the climate elements rainfall, temperature and Relative Humidity, in terms of their effect and influence on malaria in Vhembe District.

Weather data from the network of weather stations in Vhembe District were obtained for the period 1981-2010, from the South African Weather Service in line with the 30-year period recommended by the World Meteorological Organisation (WMO). Data on malaria cases were obtained from the Regional Malaria Control Institute in Limpopo Province. The malaria data were only available in suitable form for a period from 1998-2010. The relationship between malaria and climate was, therefore, only analysed for the period 1998-2010. Climate normals for the area were obtained using the 1981-2010 data, per local municipality and then at the aggregated level of Vhembe District. Analysis of the data included the computation of anomalies (departures from the long-term mean), Mann-Kendall trend analysis, Pearson correlation coefficient (r) analysis, coefficient of determination (R^2) in assessing the variation in malaria cases as influenced by climate, lag-time analysis by cross-correlation to determine the lag between climate variable alteration and the onset of malaria, and mapping of malaria cases per given land demarcation unit in a Geographic Information System (GIS).

The results indicated that the climate of Vhembe District was quite variable in the analysis period, with very few significant trends established for the area. The association between malaria and climate varied for the four local municipalities in Vhembe District which are

Musina, Makhado, Thulamela and Mutale. The most influential climatological element on malaria was determined as the monthly minimum temperature if the existing Relative Humidity conditions are maintained. Statistical analysis showed that there was a statistically significant relationship between malaria and annual Relative Humidity (r = 0.709 at α = 0.05 level of significance) for Vhembe District.

It becomes important that the minimum temperatures in the district are monitored more closely since this can help in early detection and surveillance of malaria in the malaria prone areas. The only significant annual long term trends for the 30-year period 1981-2010 were a decreasing air temperature for Thulamela (Z-statistic = 1.67 at α = 0.1 level of significance), an increasing maximum temperature for Musina (Z-statistic = 1.93 at α = 0.1 level of significance) and Vhembe (Z-statistic = 1.71 at α = 0.1 level of significance), increasing minimum temperatures for Makhado (Z-statistic = 2.03 at α = 0.05 level of significance); increasing minimum temperatures for Vhembe (Z-statistic = 3.28 at α = 0.01 level of significance) and decreasing Relative Humidity for Mutale Local Municipality (Z-statistic = 1.71 at α = 0.1 level of significance). In terms of short term trends, i.e. between 1998 and 2010, the climate for the municipalities indicated mostly decreasing trends including in the number of malaria cases. The GIS-derived spatial distribution maps showed that there was a pocket nature in the distribution of malaria in Vhembe District, and that altitude somewhat influenced the spatial distribution. Most of the malaria cases were reported in areas below 700 meters above sea level (MASL), with very few and erratic cases between 701 and 1300 MASL.

Based on the results, a Malaria-Climate Management Framework (CliMM) was developed. The aim of the CliMM framework is to help in identifying malaria prone villages in Vhembe District. After identification, the CliMM framework then leads into the steps that may be taken to manage the particular area/village towards minimisation and possibly elimination of malaria. With the proposed CliMM framework, climate considerations can be brought into the management of malaria in Vhembe District.

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LIST OF ACRONYMS

ARIMA:	Auto-regression Integrated Moving Average
CDC:	Centre of Disease Control
CRU:	Climate Research Unit
DEM:	Digital Elevation Model
DDT:	Dichloro-diphenyl-trichloroethane
DEMETER:	Development of a European Multimodel Ensemble system for seasonal to inTERannual prediction
DoH:	Department of Health
ECMWF:	European Centre for Medium-Range Weather Forecasts
ENSO:	El Nino Southern Oscillation
EWS:	Early Warning System
GIS:	Geographic Information Systems
IDP:	Integrated Development Plan
IRS:	Indoor Residual Spray
KNP:	Kruger National Park
KZN:	KwaZulu Natal
MARA:	Mapping Malaria Risk in Africa
MALOF:	Malaria Outlook Forum
MASL:	Meters Above Sea Level
MEWS:	Malaria Early Warning System
MK:	Mann-Kendal
NGO:	Non-Governmental Organisation
NOAA:	National Oceanic and Atmospheric Administration
NSSA:	No Strong Significant Association
NSSR:	No Strong Significant Relationship
NSST:	No Significant Statistical Trend
NMCP:	National Malaria Control Programmes
NWU:	Northwest University
RCOFs:	Regional Climate Outlook Forums
RMCI:	Regional Malaria Control Institute

RH:	Relative Humidity
RF:	Rainfall
SA:	South Africa
SAWS:	South African Weather Services
SMCMF:	Strategic Malaria-Climate Management Framework
SST:	Strong Significant Trend
SSA:	Strong Significant Association
SSR:	Strong Significant Relationship
TAR:	Tibet Autonomous Region
Tp:	Temperature
Tpav:	Air Temperature
Tpmax:	Maximum Temperature
Tpmin:	Minimum Temperature
USA:	United States of America
UTM:	Universal Transverse Mercator
WCP:	World Climate Report
WGS:	World Geographic System
WHO:	World Health Organisation
WMO:	World Meteorological Organisation
WMR:	World Malaria Report

DEFINITION OF TERMS

Climate Change – refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate variability - refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Climatological Normal - refers to the 30-year average of a weather variable.

Early Warning System (EWS) - An Early Warning System is a disease surveillance and response system designed to detect, as early as possible, any change from the usual or normally-observed frequency or phenomenon.

El Niño/Southern Oscillation (ENSO) - *El Niño*, in its original sense, is a warm water current that periodically flows along the coast of Ecuador and Peru. This event is associated with a fluctuation of the intertropical surface pressure patterns and circulation in the Indian and Pacific Oceans, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is collectively known as the El Niño Southern Oscillation or ENSO. The opposite of an El Niño event is called *La Niña*.

Endemic - describes a species that is native only to a limited area, for example, a bird endemic to a particular island or a plant endemic to a mountain range.

Epidemic - An outbreak of a disease that affects a large number of individuals within a population or region at the same time.

Epidemiology - The study of epidemics and the diseases that cause them, especially the factors that influence the incidence, distribution and control of infectious diseases.

La Niña - is a weather condition which begins with the cooling of the waters in the western Pacific Ocean, eventually affecting global climate.

Long-term climate - For the purpose of this study, this is defined as a 30 year climate period. In this study the 30-year period was 1981 to 2010.

Medium-term climate - For the purpose of this study, this is defined as the 13 year climate period from 1998 to 2010, delimited by the availability of malaria data.

Tropical Cyclone – refers to a storm system characterized by a large low-pressure centre with strong winds and heavy rain. Tropical cyclones strengthen when water evaporated from the ocean is released as the saturated air rises, resulting in condensation of water vapour contained in the moist air. Tropical cyclones are typically generated in areas where the ocean surface temperature is greater than 27°C, and in a latitude band between 5-30°S. In the southern hemisphere they move SW from the equatorial region, in Africa specifically towards Mozambique and the Mozambique Channel. Approximately 10 cyclonic 'events' develop each year over the southern Indian Ocean and they normally travel in a westerly direction, then head southwards and eventually merge with the westerlies at approximately 35°S. Most events form east of Madagascar and travel towards Madagascar, often dissipating upon reaching the island, though some (40%) re-generate over the Mozambican Channel. Highest wind speeds tend to be over the south-eastern region of the 'eye' or centre with most cyclones developing wind speeds of up to 25 m/s. However, wind speeds of more than 50 m/s have been measured.

Chapter 1

INTRODUCTION

1.1 Background and Rationale

Globally, there are between 300 to 500 million cases of malaria, with 2 million deaths being reported each year (WCP, 2007b). In Africa alone, the number of malaria deaths has been estimated at 1 million (Baker *et al.*, 2009). In South Africa, the number of malaria cases averaged 17 000 per annum in the 20-year period 1990-2010 (Figure 1.1). An average of 106 deaths per annum due to malaria was reported for the country between 1990 and 2010 (WMR, 2011), with the highest number of deaths occurring in 1999 and 2000 (Figure 1.2).

As efforts geared towards the elimination of malaria by 2030 are gaining momentum, it is becoming increasingly apparent that South Africa needs to close all the necessary gaps in understanding malaria so as to know how to control the disease more effectively and efficiently. Malaria is a vector-borne disease whose transmission is a complex biological process that is associated with various climatic conditions and other non-climatic factors. The non-climatic factors that are associated with malaria include human behaviour, socio-economic situations and political situations. Other environmental factors like ecology, hydrology and associated conditions also influence malaria (Basurko *et al.*, 2011). Having analysed the influence of climate conditions on several diseases, Kuhn *et al.* (2005) suggested the need to include climate considerations in predicting epidemics and in disease surveillance early warning systems.

Since the prevalence of malaria is influenced by climatic conditions, it was important and necessary to understand the effect of the prevailing climate on malaria in the study area, Vhembe District. Vhembe District is located in the Limpopo Province of South Africa (Figure 1.3a), and is prone to malaria due to its tropical location. According to Birkholtz *et al.* (2012), a trans-disciplinary approach is required in the control and elimination of malaria. One aspect about malaria that needs to be fully understood is the effect of climate variability

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on its distribution. This study contributed to this trans-disciplinary approach by employing climatic and environmental variables in studying malaria in Vhembe District.

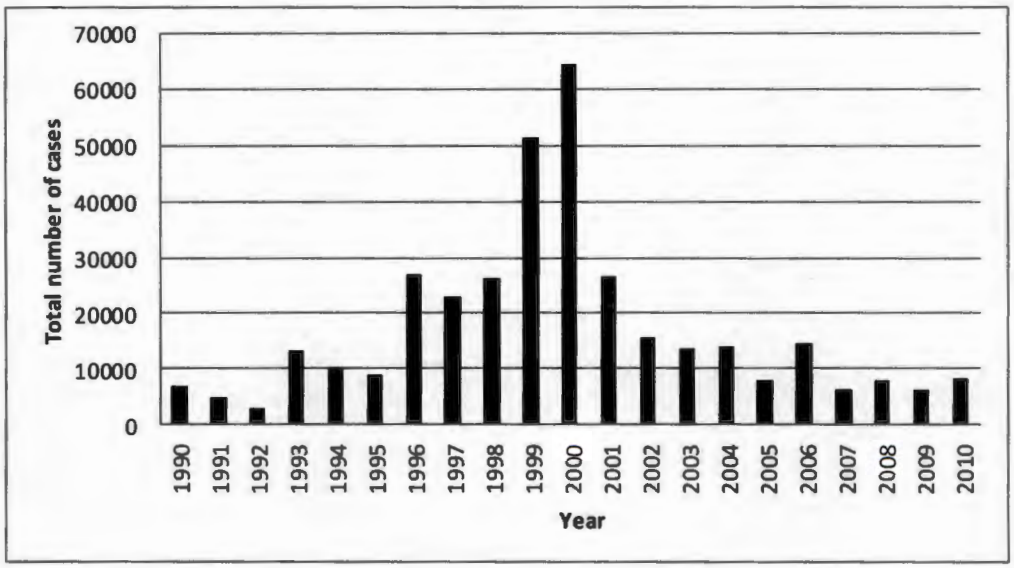


Figure 1.1: Reported total cases of malaria in South Africa, 1990-2010 (Data source: WMR, 2011).

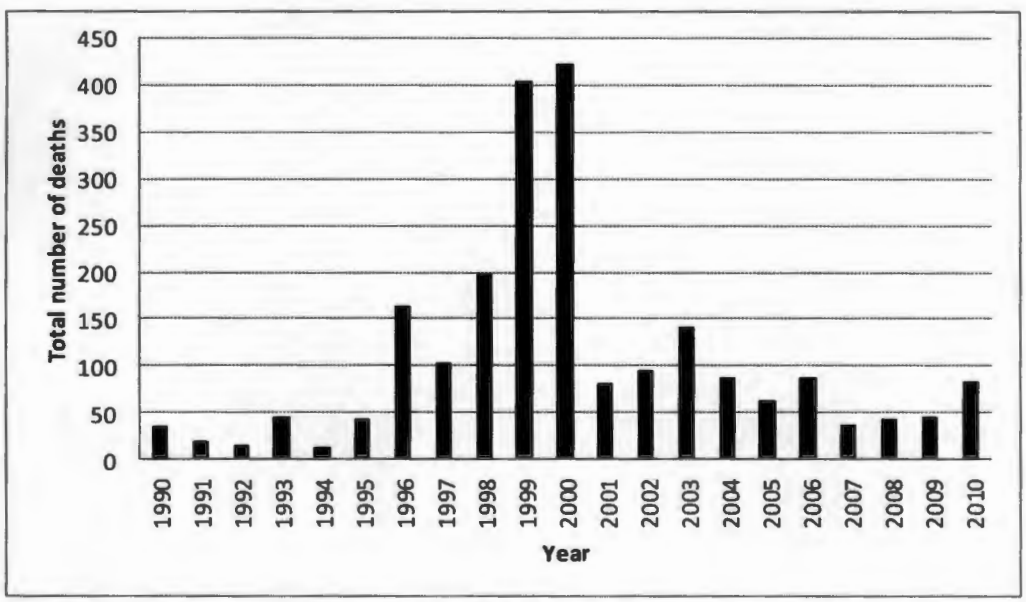


Figure 1.2: Reported total deaths due to malaria in South Africa, 1990-2010 (Data source: WMR, 2011).

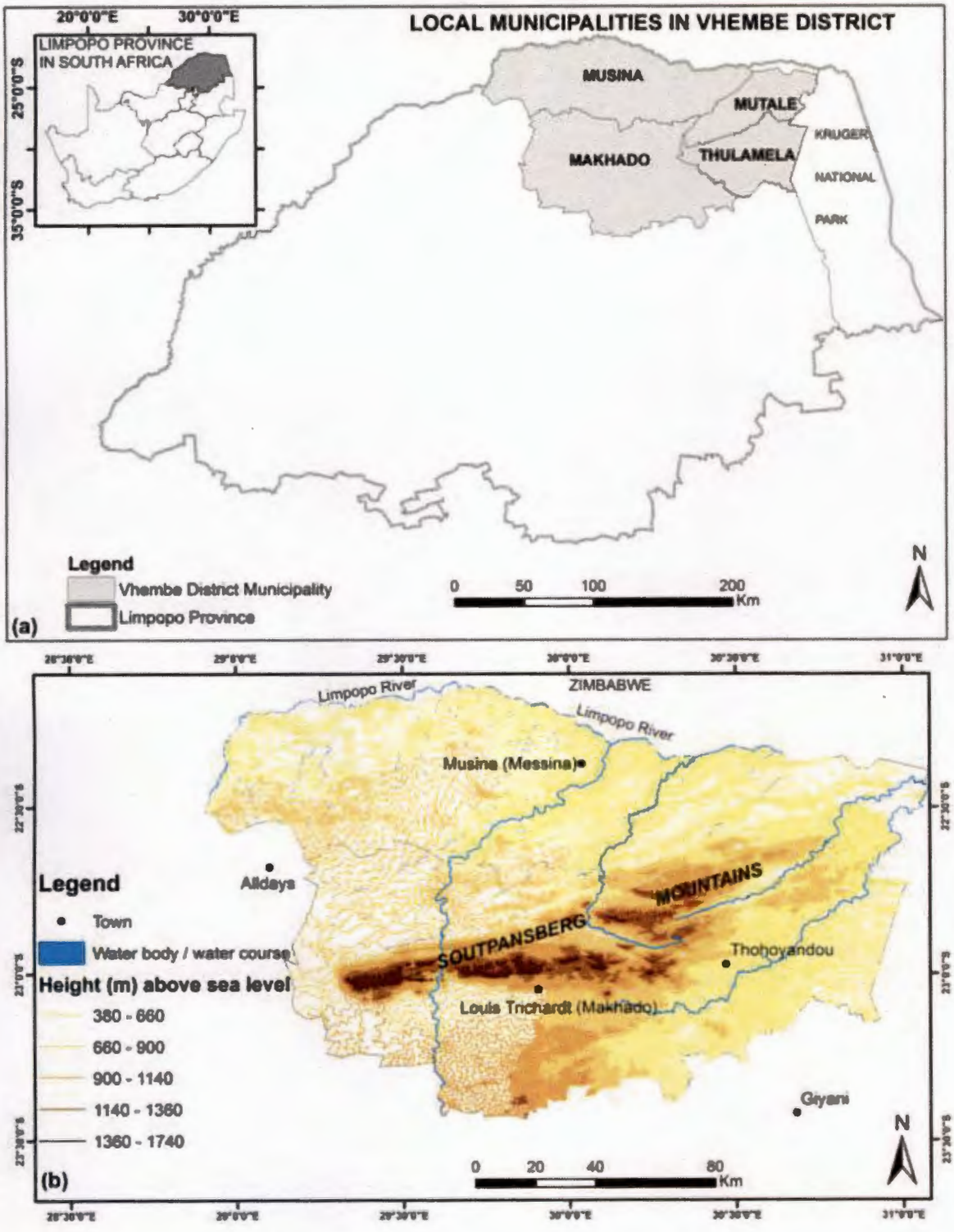


Figure 1.3: Location setting of Vhembe District in South Africa (a), and (b) topography of Vhembe District (spatial data source: National Geospatial Information directorate, Cape Town).

According to Desanker (2002), climate variability plays a crucial role in influencing the malaria spatial distribution patterns. Climate variability refers to the departure of the climatic parameter from the mean over a period (WMO, 2010). These departures are typically termed anomalies. An example on how climate has been variable in the study area is the pattern of rainfall and temperature in recent years. There have been incidents of flooding, drought and high temperatures in Vhembe District (Mpandeli, 2014). These climatic conditions do not only affect water supply, but the emergence and propagation of diseases like malaria, cholera and bilharzia.

Climate anomalies can be caused by a number of weather phenomena, which include the *El Niño* - Southern Oscillation (ENSO), among others. The climate anomalies associated with the ElNino Southern Oscillation phenomenon usually result in droughts and floods, and it is expected that these will increase in frequency and intensity (Githeko *et al.*, 2000). Rainfall anomalies affect the presence and absence of vector-borne and water-borne pathogens since these are linked to the climate behaviour (McCathy *et al.*, 2001). It has been established that small changes in temperature and precipitation tend to boost the population of mosquitoes, and extend the duration of the season in which mosquitoes are transmitting disease with several weeks (Takken *et al.*, 2005). This extended duration ultimately results in the infection of a larger population.

According to Desanker (2002), Africa is one of the most vulnerable regions to malaria in the world. This is due to the continent's limitations in adapting to climate variability that is associated with an average increase in temperature of approximately 0.7°C over the past century (Desanker, 2002). By 2100 it is estimated that the global temperature will have risen by between 1.0 – 3.5°C (Githeko, 2009). This will, therefore, increase the likelihood of vector borne diseases spreading to new areas and such increases in temperature may ultimately have a significant impact on the prevalence of malaria on the African continent.

A study by Omumbo *et al.* (2011) showed that under the most conservative estimates of climate variability, vector-borne diseases will shift their boundaries to higher latitudes and altitudes. This same scenario could affect the high altitude areas in southern Africa (and particularly in the East African highlands), which previously had a relatively cool climate. These areas are projected to observe increased latitudinal and altitudinal warming (Githeko, 2009). Vhembe District has a central zone of high altitude land on the Soutpansberg

Mountains (Figure 1.3b), and could experience these shifts. As the areas experience changes in climatic aspects such as rainfall patterns, vector-borne diseases will benefit from the changes; either by possibly increasing or decreasing in incidences (Takken *et al.*, 2005). It is, therefore, important that strategies which factor in the influence of climate variation as well as those that manage the spread and distribution of the disease be strategically adopted.

Vhembe District normally experiences cold winters and warm summers with an average maximum summer temperature of 30°C. Such temperatures are very conducive for mosquito breeding (Craig *et al.*, 2004). The area experiences a mean annual rainfall of 632 mm, with an annual mean relative humidity just above 60%. Winds in Vhembe District are of relatively low speeds. All these climate characteristics are generally very conducive for mosquito breeding and movement (Craig *et al.*, 2004).

In areas that have complex mountainous terrain, the geographical distribution of malaria is typically very complex. This is due to the topographically induced 'regional pockets' with different climates (WCP, 2007a; Nenwiini and Kabanda 2013; Kabanda and Nenwiini 2015). This phenomenon normally results in malaria-prone and malaria-free areas being in close proximity. Hence, in order to control malaria more effectively and within sustainable budgets, the specific malaria-prone areas need to be identified. According to Kuhn *et al.* (2005), emphasis should be given to using climate factors to manage infectious disease epidemics. Such a move will ultimately result in the responsible public health departments becoming more prepared to undertake effective control measures in malaria-prone areas.

Since targeted malaria control interventions have borne results in countries like Kenya, Zambia, Malawi and China, the transmission of malaria in an area like Vhembe District of South Africa may also be effectively controlled through similar targeted interventions. However, targeted interventions require investment in research to map out the areas that are affected and, in doing so, identify the sources of vector breeding. In many cases, there would be no need for any blanket indoor residual spraying (IRS) which sometimes results in wasteful and unnecessary expenditures. Targeting the main and actual sources of vectors can make substantial savings and simplify logistics (Githeko, 2009).

1.2 Research Problem

Malaria is one of the main causes of death not only in the Limpopo Province or South Africa in general, but in the whole world. A lot of money has to date been invested towards the management and control of this disease in order to reduce and/or eventually eliminate its impacts. This has been, and continues to be, an elusive achievement which requires more and more funding every year. The elimination of malaria continues to be more and more elusive due to the complexity of the disease, and is supposedly hindered by both climatic and non-climatic conditions since these always vary continuously. Moreover, the disease creates "pockets" in the same geographical area as a result of the varying climate envelopes, altitudes and topographies.

Much of the work done hitherto has been done at a large spatial scale such as the regional level, for example southern Africa. Such initiatives and studies include the MARA and DEMETER projects (Palmer *et al.*, 2004), which are climate forecasting models used to predict peak times for malaria transmission. These projects have come up with malaria risk maps based on climate forecasting and modelling at a regional level. However, in these initiatives no detailed and specific studies which focus on the effect of climate variability and malaria have yet been done at a local level such as the district or local municipality levels. The biggest challenge is that, when large areas are considered at once, it results in ineffective and/or expensive control measures at the implementation level. Therefore, the influence of climate conditions at the local level has not yet been well understood, thereby hindering the progress that could have been made in controlling the epidemic.

In order for South Africa in general, and the Vhembe District in particular, to be able to deal with malaria more efficiently and effectively, the influence of localised climate conditions on malaria and its spatial distribution need to be closely and continuously studied. A general perception currently being peddled is that malaria epidemics, which have always been prevalent in the low lying areas below 1000 MASL, may be infesting the high altitude areas due to climate variability. If this is happening, then more climate-malaria studies and interventions are needed so as to curb the spread of the disease. This study, therefore, investigated the climate-malaria relationships and also the mapping of the spatial distribution of the disease in the Vhembe District of South Africa. On the basis of these investigations the study then proposes a management framework for improved control measures.

1.3 Theoretical Context

Climate change and variability have negatively impacted on the human race in many locations globally, and various environmental systems have to date been badly destabilised (Desanker, 2002). One typical negative consequence is the spatial distribution and prevalence of diseases like malaria. The changes in the climate patterns, coupled with changes in the environmental systems, may have resulted in changes in the spatial distribution of the *Anopheles* mosquito which is the malaria vector. This may have resulted in the spread of malaria to regions where it was not prevalent before.

In this study the climate elements rainfall, temperature and relative humidity were used in studying the climate-malaria relationship. These climate elements should never be dealt with in isolation of each other since one or two parameters can influence the other. For example, temperature and rainfall affect humidity, and in response the ground temperature gets affected or modified by humidity. The daily range of each parameter can, in some cases, become more significant than the daily mean. As such, brief periods of heat or cold can be more significant than long term temperature averages (Rieter, 2008). Heavy storms can have a different impact than light prolonged rainfall and one year's events may have a significant impact on the subsequent years to come. For example, heavy storms result in flash floods which cause soil erosion, thereby creating gullies and ponds for mosquito breeding. However, the intensity of the flood flow may result in the washing off of existing mosquito breeding areas, thereby possibly reducing vector populations in that particular area. On the other hand, light prolonged rainfall may minimise the formation of new breeding areas due to minimal flow as all the water is either deposited into existing ponds or completely infiltrate into the ground (Olivier and Grobler, 1992).

Figure 1.4 shows the conceptual framework of this study. The framework was based on the concept designed by the United States Agency for International Development (USAID) MEASURE Evaluation programme in 2010. As shown in Figure 1.4, a number of external factors (which include environmental, demographic and socio-economic issues) influence the risk of malaria infection. Even land use factors such as irrigation can have an influence on malaria, as has been shown in India (Lee *et al.*, 2016). Many countries have established programmes in their health care systems and introduced educational, treatment and prevention measures to control and manage malaria infection. The current study focussed on

climate, which is one of the environmental factors influencing malaria infection (under 'A' in Figure 1.4). The climate elements that were selected for this study are rainfall, temperature and relative humidity. The inclusion of relative humidity in the study was the fact that the two main climate elements that were under study, i.e. temperature and rainfall, should not analysed in isolation. Normally one or two climate parameters can influence the effect of another parameter. In this case, for example, temperature and rainfall affect relative humidity and in response the ground temperature gets affected or modified by humidity. The study also analysed the population demographics (under 'B' in Figure 1.4), and the demographic element that was selected for the study was the population density in Vhembe District, Limpopo Province, South Africa.

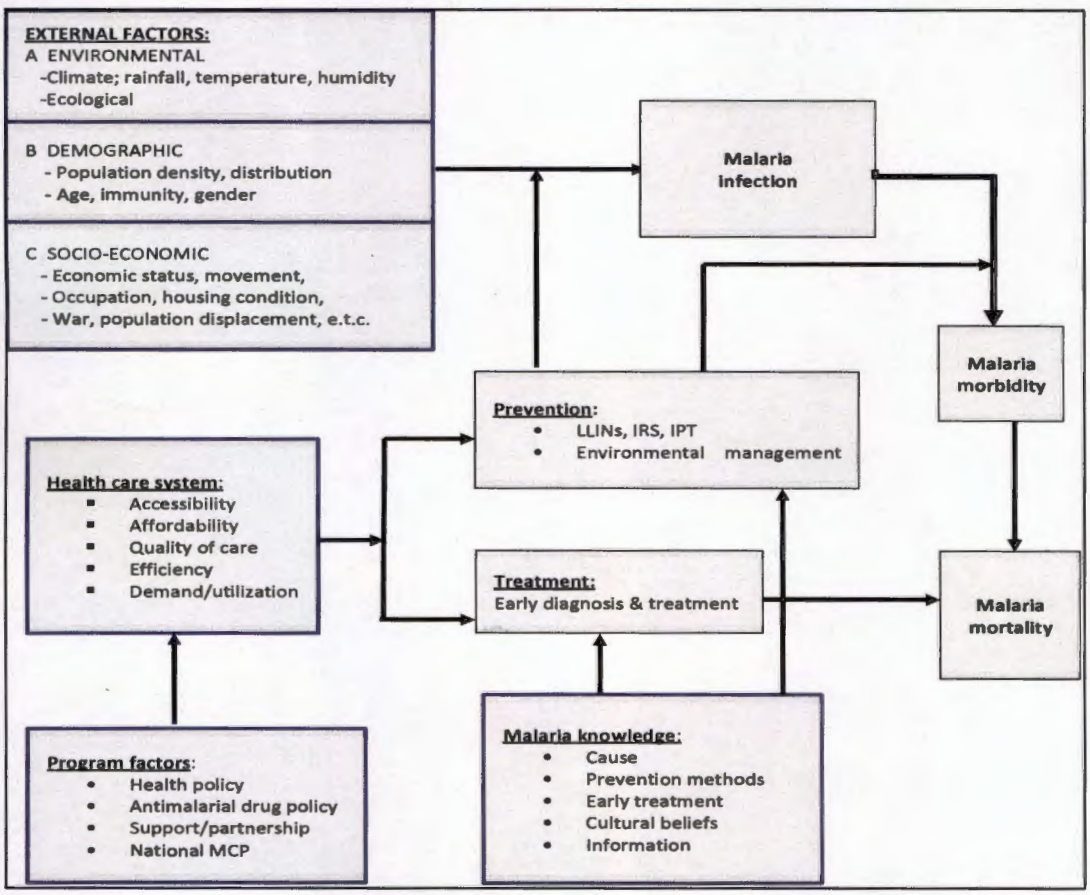


Figure 1.4: Contextual framework of the study (Source: MEASURE Evaluation USAID Programme, 2010).

1.4 Research Purpose

The aim of the study was to determine the variability of the climate in Vhembe District and the influence of the variability on the prevalence of malaria.

1.5 Research Objectives

In order to address the research aim, the following objectives were set:

1. To determine long-term (30 year, 1981-2010) climate trends in Vhembe District in terms of rainfall, temperature and relative humidity.
2. To analyse malaria and demographic trends in the Vhembe District between 1998 and 2010.
3. To determine the relationship between climate trends and malaria patterns in Vhembe District between 1998 and 2010.
4. To determine the spatial influence of the prevailing climate on the distribution of malaria in Vhembe District, between 1998 and 2010.
5. To develop an Early Warning System (EWS) management framework for malaria in Vhembe District based on observed climate-malaria spatial patterns.

1.6 Research Hypothesis

The following research hypothesis was formulated in order to address the set research objectives:

- There is spatial climate, topographic and land use variation which influences malaria and its distribution in Vhembe District

1.7 Justification of the Study

Climate variability and malaria have always been loosely associated by many scholars. However, the extent of the relationship between the two varies from one area to another and the main climate element drivers of malaria in each area also differ. This study was, therefore, very important within the South African context considering that it was the first comprehensive study to be undertaken at a local scale level looking at the malaria-prone (malaria hotspot) areas. A similar study by Thompson *et al.*, (2006) developed a malaria early warning system using leading global coupled ocean–atmosphere climate models developed in Europe. The forecast system that was developed was successfully applied to the prediction of malaria risk in Botswana where, according to the authors, links between malaria and climate variability were well established. The malaria forecast system developed by Thompson *et al.* (2006) was not tested in South Africa, where conditions differ from Botswana where it was successfully tested. This present study specifically sought to understand the intrinsic relationships between climate elements and malaria within Vhembe District and then, based

on this relationship, come up with a strategic malaria-climate management framework which could be used to detect early warning signs in identified malaria hotspot villages to enable effective control.

According to Morris *et al.* (2013), South Africa has actively controlled malaria since the 1940s using the WHO recommended strategies of vector control, case management, surveillance and information, education and communication. These interventions have helped the country in significantly reducing the number of malaria cases to such an extent that the Department of Health (DoH) has given itself a target date of 2018 by which to totally eliminate malaria (Morris et al., 2013). Notably, this latest report from a South African medical team did not include the aspect of climate effects on malaria. An understanding of the influence of climate conditions on malaria would enhance a further reduction and possibly the total elimination of malaria. This need to support the DoH ambition to eliminate malaria prompted this study.

1.8 The Study Area

Vhembe District in located in the Limpopo Province of South Africa (Figure 1.3a). It is the northern most district in South Africa (Figure 1.3a), bordering Zimbabwe. The Vhembe District exhibits hot and humid climatic conditions. The district was selected for this study since the available data showed that it is one of the most prone areas to malaria in the country (Morris et al., 2013). Administratively Vhembe District has four local municipalities namely, Musina, Makhado, Thulamela and Mutale (Figure 1.3a). Parts of Vhembe District encompass areas that were part of the Venda homeland ("Bantustan") until 1992. These areas are mostly in Thulamela and Mutale Local Municipalities which are predominantly rural and have a lot of villages.

Musina and Makhado Local Municipalities, on the other hand, were mostly outside of the Venda homeland and are mostly constituted of commercial farms, some of which combine rain-fed and irrigated arable farming. There are large dam reservoirs in the area, both for irrigation and for supply of water to the communities. Examples of such dams are Nzhelele, Luphephe, Vondo, Albasini and Nandoni Dams (Figure 1.5). Potentially mosquito harbouring crop plants are grown on the farms, including wheat, maize and bananas. Some of these crops are grown on fairly large farms. For example, between Louis Trichardt and Thohoyandou

(Figure 1.5) are large banana plantations, particularly in the Levubu area. There are also large forest plantations that grow exotic pine and eucalyptus trees for softwood timber. Around the Vondo Dam (see Figure 1.5) is a large tea plantation, the Tshivhase Tea Plantation which rely on both irrigation and rain-fed.

The main urban areas in Vhembe District are Louis Trichardt in Makhado Local Municipality, Thohoyandou in Thulamela Local Municipality, and Musina (previously called Mesina) in Musina Local Municipality (Figure 1.3b, Figure 1.5). The rest of the district consists of high population density villages, mainly in the district's eastern sector (Figure 1.5). The villages are located mainly on marginal (communal) land that is not suitable for farming, such as on rugged (mountainous or hilly) terrain. Much of the land in these communal areas is degraded; with its tree cover depleted (Figure 1.5, inset photograph).

Much of the rainfall received in Vhembe is of orographic origin. The central highland region (Figure 1.3b) consisting of the Soutpansberg Mountains which gives orographic lift to the winds that blow mainly from the south-east (Mucina and Rutherford, 2006), giving high rainfall to southern and eastern sections of Vhembe District as illustrated in Figure 1.6. In comparison there is relatively low rainfall westwards and towards the north in the Limpopo River valley (Figure 1.5). This high rainfall on the southern slopes has resulted in denser tree cover of indigenous species forest on the southern slopes of the Soutpansberg Mountains (Mucina and Rutherford, 2006).

1.9 Scope of the Study

The study specifically focused on Vhembe District, which falls within the high risk malaria zones in South Africa according to the regional maps of MARA, the 2003 Department of Health Maps of South Africa and Morris *et al.* (2013). A 30-year period is normally required for reliable trends to be established from climatic data.

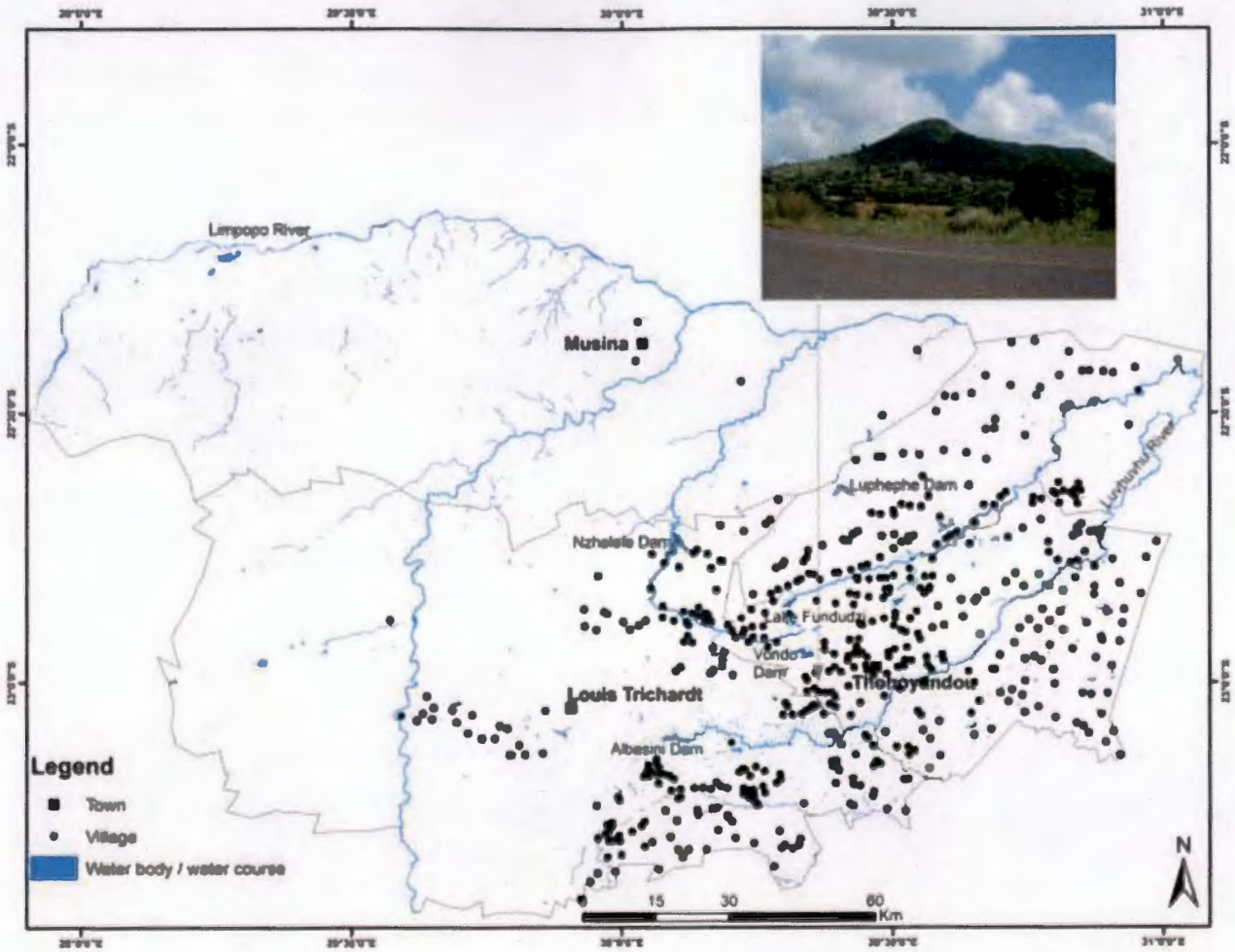


Figure 1.5: Distribution of human settlements in Vhembe District in relation to permanent and seasonal water bodies (spatial data source: National Geospatial Information directorate, Cape Town). The inset photo shows a typical village scene in the communal areas of the former Venda homeland, showing forest cover degradation on the Soutpansberg Mountains at Tshakhuma.

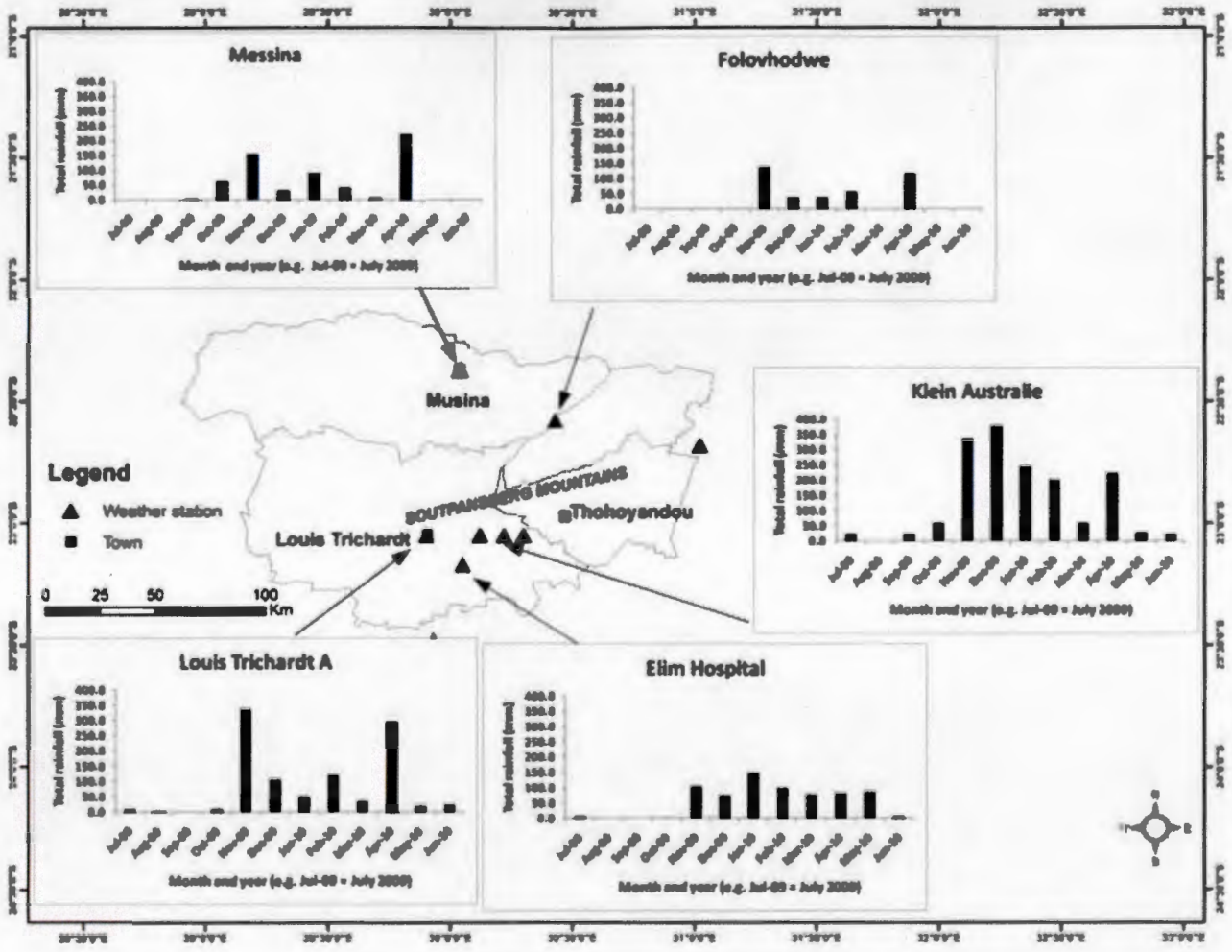


Figure 1.6: Illustration of the south-north reduction in amount of rainfall in Vhembe District due to orographic effects, using rainfall received in the 2009/2010 rain season (rainfall data: South African Weather Service).

This study commenced in 2010, hence the period of study was 1981 – 2010 (i.e. 30 years). However, for malaria prevalence the period was only 1998 – 2010. This period was used for malaria prevalence because it was the time frame in which the Institute of Malaria Control had captured malaria data in a format that could be used in this research (as explained in Chapter 3).

Although the study domain was the whole of Vhembe District, the villages within the district that were affected by malaria were also mapped so as to enable targeted interventions. A conceptual management framework which was specific to the Vhembe District and its local municipalities was then developed to be used for the effective management of the malaria prone areas and villages. The envisaged usefulness of this was in assisting the Department of Health (DoH) in South Africa to make progress towards further reduction and possibly eliminating malaria from this area by the year 2030, in line with the WHO goals.

1.10 Significance of the Study

This study was critical for planning purposes in terms of managing, controlling and probably eliminating malaria disease from the studied area by the year 2030. The study was set to provide some insight into the effect of climate change and variability on malaria at the local level and map the specific areas, thereby enhancing the efficient and effective management of the disease in Vhembe District. On the other hand, the study could also be strategically used in future research as a baseline for the study of other vector borne diseases occurring in the area and/or those which may later surface, for example cholera, bilharzia and tick-borne haemorrhagic fevers. The methodology used in this study could also be duplicated and employed in other areas with similar settings and/or needs.

According to the Institute of Malaria Control in the Limpopo Province, the methods that are currently employed in the control of malaria include Indoor Residual Spraying (IRS) using Dichlorodiphenyltrichloroethane (DDT) and synthetic pyrethoids, as well as the early diagnosis and prompt treatment using the artemisinin-based-combination therapy and, sometimes, spraying in areas that are likely to be mosquito breeding habitats. Unfortunately, all these programmes do carry a significantly huge burden on the public health system each year. Most of the management and control measures in use at the inception of this study were simply reactive since they were all mostly driven by the number of reported malaria cases in a particular area in the previous years or seasons. Hence, a better understanding of local

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conditions such as the spatial variation of climate at the local level could help identify the "hotspot" villages. Such information could then be used to achieve better management results in a more proactive and rather cost effective manner. This could in turn then further reduce the overall malaria treatment budget currently incurred by the South African government.

1.11 Structure of the Thesis

The thesis is divided into nine chapters. Chapter 1 introduces the study and places it in the context of contemporary ideas with regard to malaria, society and climate; and then the chapter states the scope of the study, its aim, objectives and research hypothesis. Chapter 2 then details the scientific context of malaria, climate and society by reviewing material from literature. In Chapter 3 the details of the methodology and data that were used in addressing the aim and objectives of the study are then laid out.

The ensuing chapters are then organised in a sequence that answers the objectives set out in Section 1.5. Chapter 4 details the observed climate trends in Vhembe district based on the long-term (1981-2010) data. Chapter 4, therefore, addresses *Objective 1* stated in Section 1.5. Chapter 5 presents demographic and malaria case issues in Vhembe District and, therefore, addresses *Objective 2* of the study. Chapter 6 links the climate trends established in Chapter 4 with the malaria and demographic aspects in Chapter 5. Therefore, Chapter 6 addresses *Objective 3* of the study as stated in Section 1.5. Chapter 7 details the spatial distribution of malaria in Vhembe District in answer to *Objective 4* of the study. Chapter 8 then presents a discussion to synthesise the results presented in Chapters 4, 5, 6 and 7. The final chapter (Chapter 9) then addresses *Objective 5* of the study in that it presents an Early Warning System (EWS) management framework for malaria in Vhembe District based on observed climate-malaria spatial patterns.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviewed studies conducted internationally, regionally, nationally and at local levels (including district municipality-wide boundaries) on climate variability, malaria and the likely relationships between climate and malaria. Some of the tools and techniques used elsewhere in carrying out similar studies were also studied. This knowledge was then applied in coming up with a specific approach and methodology for this study.

2.2 Climate Variability and Change

There are contrasting definitions of climate change and climate variability in the literature. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer" (IPCC, 2007). By this definition the IPCC recognises climate change as referring to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2007). The United Nations Framework Convention on Climate Change (UNFCCC), on the other hand, defines climate change as "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods" (WMO, 2010). The apparent difficulty in the UNFCCC definition of climate change is separating naturally caused change from the human induced change.

Climate variability, on the other hand, refers to the climatic parameter variation from the mean over a period of time. As indicated in the World Meteorological Organisation (WMO) Guideline to Climatological Practices (WMO, 2010), a 30-year period or more is ideal for dealing with climate data to enable the detection of climate variability and possibly climate change for an area. The 30-year period averages are used as the basis for determining the climate normals for a particular area.

2.2.1 Observed Global and African Continent Scale Climate Variability

According to the Intergovernmental Panel on Climate Change (IPCC) there is now unequivocal evidence of global warming based on global air and sea temperatures, with a marked accelerated rate in recent years (IPCC, 2007). The linear warming trend over the 50 year period 1956-2006, averaging 0.13°C per decade, was nearly twice that for the 100-year period 1906-2005 (IPCC, 2007). In a recent study on global climate variability with particular focus on temperature anomalies, Hansen *et al.* (2011) determined that the seasonal-mean temperature probability has shifted dramatically between 1981-2010 towards higher temperatures by more than one standard deviation with the shifting occurring on the maximum temperatures rather than the minimum temperatures. This shift will have a direct impact on biology and ecosystems in that the physiological and reproductive cycles of living organisms, especially smaller creatures, will be drastically affected. Boko *et al.* (2007), noted that a variety of ecosystems are already being affected, particularly in southern African, at a faster rate than anticipated due to changes in climate. Climate variability and change is also affecting the vast biodiversity in Africa, with areas outside formally conserved areas being more vulnerable (Boko et al., 2007). The study area, Vhembe District generally fits in this category.

Enfield *et al.* (1999), from a study on interannual-to-multidecadal climate variability, noted that climate shifts have occurred in terms of rainfall and temperature for the northern hemisphere extratropics in areas around central Europe and western North America; as a result of upstream fluctuations in the mid-westerly wind belts and features in atmospheric pressure patterns. The identification of such fluctuations and shifts around the globe indicate that similar shifts and fluctuations are occurring elsewhere, but the causes may be different. In Africa, increased interannual climate variability has, however, been observed in the post-1970 period, with higher rainfall anomalies and more intense and widespread droughts reported (Boko *et al.*, 2007). Furthermore, in different parts of southern Africa, a significant increase in heavy rainfall events has been observed, including evidence for changes in seasonality and weather extremes (Boko et al., 2007).

Thompson *et al.* (2009) also indicate that there is climate variability which is occurring as a result of natural causes and also anthropogenic activities. In their study, Thompson *et al.* (2009) analysed climate variability after removing natural climate variability signatures like

ENSO from the global-mean surface temperature. The results indicated a more refined understanding on the contribution of dynamically induced climate variability. This finding has implications on the current study in that a lot of anthropogenic activities have taken place in South Africa especially in Vhembe District. The study on the Africa region (Githeko *et al.*, 2000), show that changes in rainfall patterns and the seasonality of regular climate events that are taking place; may be caused by modification of local environmental conditions. These variations in climate patterns result in changes in the local ecosystems.

Direct effects of climate variability and change vary widely across the African continent, with some areas (e.g. eastern Africa) projected to get wetter, but much of southern Africa getting drier and hotter (Besada and Sewankambo, 2009). Many of the adverse consequences of climate change and variability are already apparent in Africa and in general, the drier subtropical regions will warm more than the moister tropics. It is also anticipated that northern and southern Africa will become much hotter (4°C or more) and drier (Collier, *et al.*, 2008). On the other hand, decadal climate variability has been found to be affecting climate conditions in the Mediterranean and South Europe regions (Mariotti, 2011). These changes have been found to be caused not only by the natural phenomenon of the North Atlantic Oscillation on precipitation and the Atlantic Multi-decadal Oscillation on temperature, but also an increase in greenhouse gasses (GHG).

Other studies on the African continent's climate have identified changes in climate conditions. For example a study in Nigeria yielded results that are in support of the Nigeria Meteorological Agency's determination that the onset of rains in the area had been pushed back and the cessation of the rainfall period pushed forward (Egbe *et al.*, 2014). In their study Egbe *et al.* (2014) identified a shortening of the rainfall season in the Cross River State of Nigeria. In the Sahel and in southern Africa it is anticipated that climate variability and change will result in a uniform decrease in rainfall that will hit the river flow extremely hard for example, in the basins of the Zambezi and the Limpopo (Collier, et al., 2008).

2.2.2 Observed Climate Variability in South Africa and Vhembe District

South Africa occupies the southernmost part of the African continent which also lies within a drought belt with fluctuating rainfall patterns and average rainfall of approximately 464 mm (DEAT, 2000). There is some evidence that rainfall change since 1950 has included both

drying trends (in parts of the summer rainfall region) and wetting trends (in parts of the winter rainfall region) (DEA 2011). The rainfall in South Africa is affected at various scales from interseasonal, to interannual, to decadal and multidecadal variability with interannual variability more pronounced in the drier parts (Kandji *et al.*, 2006). The rains vary in a cyclical pattern wet and dry phases of twenty year periodicities (Mason, 2001) under the influence of the El Niño – Southern Oscillation phenomenon (Mason, 2001; Fauchereau *et al.*, 2003). The mid-1980's for example were in a dry phase (Mason, 2001). A warming trend has been observed over southern Africa in the past few decades, a downward trend in rainfall with below normal rainfall years increasing in frequency (Kandji *et al.*, 2006). Most of these changes are a result of natural climate variability due to ENSO events and, to some extent, anthropogenic activities.

Analyses by Bellprat *et al.* (2015) have shown that, over southern Africa, unusually dry austral summers as occurred during 2002/2003 have become more likely, whereas unusually wet austral summers like that of 1999/2000 have become less likely due to anthropogenic climate change. According to Moyo and Nangombe (2015), global warming increases the atmospheric water vapour holding capacity (based on the Clausius-Clapeyron theory), but also provides energy which fuels violent storms such as those observed over southern Africa in the 2012/2013 rainy season. Moyo and Nangombe (2015) hypothesise that more intense storms are likely in southern Africa under a warmer climate. A long-term analysis of vegetation cover in the Limpopo valley by Ekblom *et al.* (2012) indicates that vegetation cover on the area's grassland-savanna has been resilient and can, therefore, be projected to be stable under the warmer and overall drier climate. However riverine forests are predicted to be more vulnerable especially as more extreme weather events are projected (Ekblom *et al.*, 2012).

Nenwiini (2011), from an analysis of rainfall zones and climate in Vhembe District, highlights changes in the rainfall pattern occurring after 1990 in the area. The rain season in Vhembe District appears to have shifted in terms of onset and cessation, and become shorter (Tshiala *et al.*, 2010; Nenwiini and Kabanda, 2013). Some studies have revealed that there has been a reduction and increase in the amount of rainfall in different zones within the study area, which has resulted in floods or droughts (Kabanda, 2011). The period of analysis of climate data in the current study encompasses periods which have been studied in some of

these previous works, and hence such studies give some background information and an insight on climate variability in the area.

In southern Africa, it was established that there was an increase in the number of warm spells and a decrease in the number of extremely cold days between 1961 and 2000 (Boko et al., 2007). In South Africa, the minimum temperatures have increased slightly faster than the maximum or mean temperatures (Boko et al., 2007). According to a report by DEAT (2000), the South African climate over the next 50 years is predicted to have a warming of between 1°C and 3°C; a possible reduction of 5 to 10 per cent current rainfall; increased daily maximum temperatures in summer and autumn in the western part of the country; increased incidents of flood and drought and enhanced temperature inversions. It has also been established that observed surface air temperature, and derived temperature measures relevant to impacts (e.g. frost days), have changed since 1950 across South Africa and these changes are in line with, and have sometimes surpassed, the rate of mean global temperature rise (DEA, 2011). It was also established that the averages of near surface daily maximum temperatures for January, peak at over 30°C in the north-western arid areas of the country and Limpopo province, while milder maximum temperatures are recorded over the east, south-east, and southern parts of the country (DEA, 2011).

2.3 The Life Cycle of Malaria

Malaria is a vector-borne disease which, under suitable climate conditions, is transmitted by different species of the female *Anopheles* mosquito. One of the malaria causing parasites *Plasmodium falciparum,* is thought to cause 90% of all malaria incidences in Southern Africa (Baker *et al.*, 2009). The other 10% are thought to be caused by other types of parasites such as *Plasmodium vivax* and *Plasmodium ovale* (Baker *et al.*, 2009).

Figure 2-1 shows the disease cycle of malaria, indicating that the lifecycle of the malaria parasite involves two hosts which are the human and the female *Anopheles* mosquito. Baker *et al.* (2009) summarise the stages in the lifecycle of malaria, stating that during a blood meal, a malaria infected female *Anopheles* mosquito inoculates sporozoites into the human host. Sporozoites infect liver cells and mature into schizonts, which rupture and release merozoites into the blood stream where they infect the red blood cells (Baker *et al.*, 2009). In malaria infections by *Plasmodium vivax* and *Plasmodium ovale*, a dormant stage

(hypnozoites) can persist in the liver and cause relapses by invading the blood stream weeks or even years later (Baker *et al.*, 2009). After the initial replication in the liver (exo-erythrocytic schizogony), the parasites undergo asexual multiplication in the erythrocytes (erythrocytic schizogony). The ring stage trophozoites mature into schizonts, which rupture, releasing merozoites. Some parasites differentiate into sexual erythroctic stages (gametocytes). Blood stage parasites are responsible for the manifestation of the disease. The male (microgametocytes) and female (macrogametocytes) gametocytes are ingested by an *Anopheles* mosquito during a blood meal (Baker *et al.*, 2009).

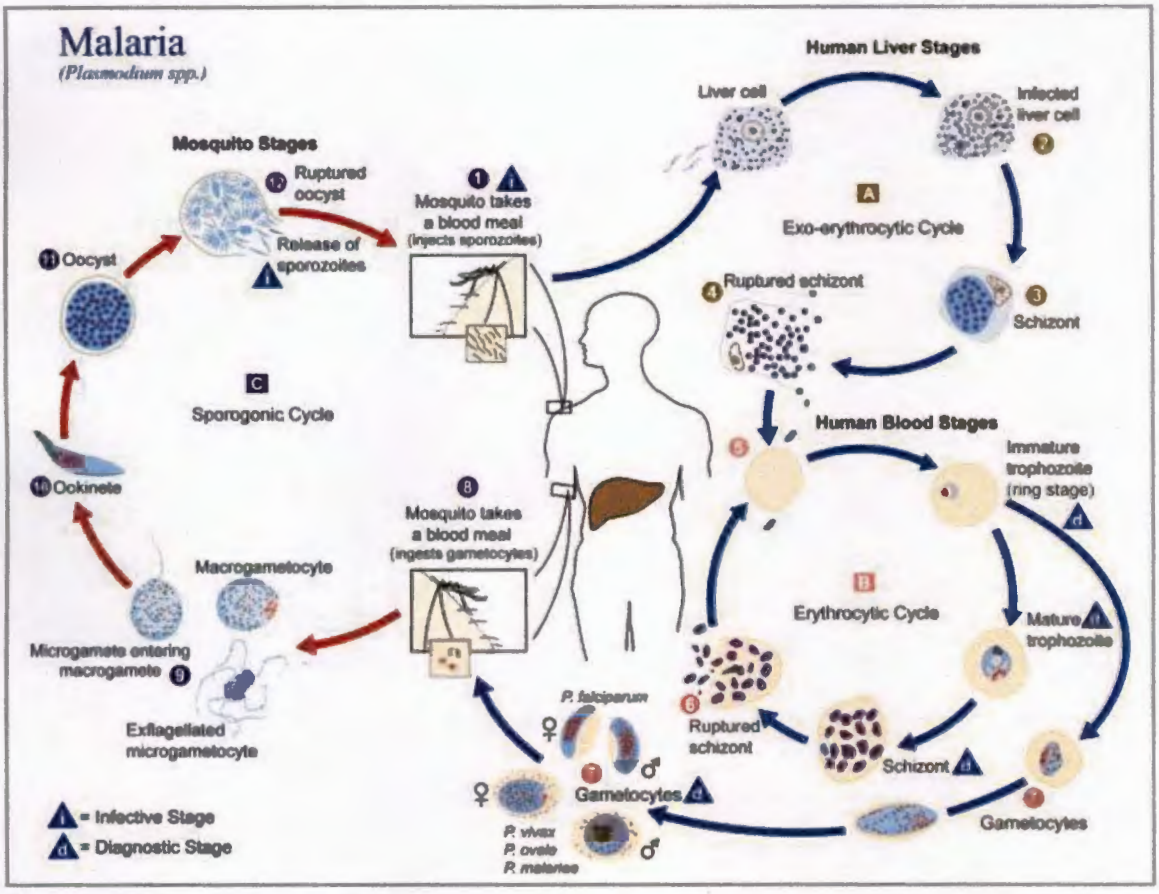


Figure 2.1: The malaria life cycle (source: US Centre for Disease Control [CDC] 2015).

The multiplication of the parasite in the mosquito is known as the sporogonic cycle, and sporozoites are released and make their way to the mosquito's salivary glands (Baker *et al.*, 2009). Inoculation of the sporozoites into a new human host perpetuates the malaria cycle (Baker *et al.*, 2009). The complete cycle for malaria from the larval stage until symptoms appear in people, therefore, ranges between 4-6 weeks. Symptoms of malaria infection (which include fever, headache, chills, muscular pain, nausea, vomiting and loss of appetite) normally develop 10-14 days after an infected mosquito bite; since they develop once the

parasite infect the red blood cells (Baker *et al.*, 2009). This period may be prolonged in individuals using prophylactic drugs.

The *Anopheles arabiensis* mosquitoes breed in warm sunlit pools, whereby the *Anopheles funestus* (another possible malaria vector that might be more abundant if we are affected by climate change) breeds in slow moving water with a larval stage of between 5-7 days and the adults can survive for 3-4 weeks (Baker *et al.*, 2009). If water temperature rises, the larvae take a shorter time to mature and, consequently, there is a greater capacity to produce more offspring. Coupled with this is the fact that in warmer climates, adult female mosquitoes digest blood faster and feed more frequently thereby increasing the number of bites which may lead to transmission of malaria (Githeko *et al.*, 2000).

As indicated in Figure 2.1, one of the most critical stages in the malaria cycle is the availability of a human host for the parasite to grow. This results in the infection of individuals as the mosquitoes feed. Because of the need for a human host to feed on, the *Anopheles* mosquito tends to reside in areas quite close to human settlements. From their study in Ethiopia, Abeku *et al.* (2004) point out that the levels of malaria transmission manifest significant spatial and temporal variability related to climate variability, altitude and human settlement patterns. In the long term however, individuals who have been repeatedly infected with malaria (i.e. "semi-immunes"), may develop a degree of immunity and tolerance to the infection, which may affect the number of cases reported. This normally occurs among residents of tropical countries where high levels of malaria transmission are present all year round. However, the intensity of malaria transmission and the duration of malaria season in South Africa is insufficient for the development of "semi immunity" (Baker *et al.*, 2009).

In South Africa, malaria was originally endemic in the low lying northern and eastern districts of the country which are below 1000 metres above sea level (MASL) especially during summer months of October-May and control measures have been in use since 1930 (Baker *et al.*, 2009). Resource intensive malaria control measures were put in place in the late 1940s, which resulted in previously endemic areas becoming largely malaria free (Craig *et al.*, 2004). The South African government has currently put in place prevention measures that focus on eliminating the mosquito and against the malaria parasite. The South African

reporting system captures every infection rather than clinical cases only, through both passive and active surveillance (Craig *et al.*, 2004).

2.4 Climate and Malaria Prevalence

Climatic conditions are related to the prevalence of malaria since both the disease agent (*Plasmodium*) and the vector (the *Anopheles* mosquito) are strongly affected by climate (Craig *et al.*, 2004). According to Craig *et al.* (2004) temperature affects the development of the parasite and the vector, rainfall provides breeding sites for the mosquitoes and relative humidity coupled with temperature affects mosquito survival. Therefore, climate data may prove useful in alerting malaria control officials to unexpected risk of epidemic conditions. Wangdi *et al.* (2010) established that temperature was an important predictor of malaria cases in some districts in Bhutan since it affects the mosquito bionomics through the time required for the development of the ookinete (the egg of the parasite in the mid-gut of the *Anopheles* mosquito). Rainfall, which provides the aquatic medium for the growth and development of mosquitoes, was also found to influence the prevalence of malaria in Bhutan especially when more variables were used (Wangdi *et al.*, 2010). Increase in temperature shortens the duration of the extrinsic cycle (Jackson *et al.*, 2010).

Malaria is prevalent in the tropical regions where the temperatures range between 16°C and 35°C. However, lower temperatures below 18°C affect the sporogonic cycle in Figure 2.1, and higher temperatures above 22°C begin to affect the behaviour and survival of the adult mosquito (Cox *et al.*, 1999; Yazoume *et al.*, 2007). Therefore, climate affects the incidence of malaria incidence mostly through its effects on both the mosquito vector and the development of the malaria parasite inside the mosquito vector (Huang *et al.*, 2011). In general, temperature suitability begins to decline at 31°C and reaches zero at 40°C. On the other hand, an average summer relative humidity of above 60% encourages the activity, feeding behaviour and increases the life-span of the mosquitoes and lower relative humidity affects the activity and survival of mosquitoes (Craig *et al.*, 2004; Martens *et al.*, 1995).

Evidence from the literature, therefore, indicates that there is a clear link between climate and malaria. Establishing the historical nature of the variations between the two requires historical data on climatic parameters. The measurement of climate measurement is unique in that climate is recorded according to globally acceptable standards at defined, regular time intervals. Climate is systematically analysed at the global or local scale, thereby allowing

comparison across geographical sites (Omumbo *et al.*, 2011). It was observed in a study by Craig *et al.* (2004) on malaria in South Africa's province of KwaZulu Natal (KZN) that the use of data from the weather stations in the specific area provides a better indication of local climate than use of regional data. If available, local climate data should, therefore, be used rather than interpolated data from institutions such as the global Climate Research Unit (CRU).

However, the transmission of malaria is generally known to be a complex biological process which is affected by many factors, not only the climatic conditions. Each area responds differently to prevailing climate conditions, behavioural issues, malaria management programmes, cultural issues and has a specific demographic mix. Hence, attempts to extrapolate the prevalence of malaria from averaged regional meteorological conditions have proven unsuccessful since this takes away the influence of the local climate and related local factors (Loha and Lindtjorn, 2010). Therefore, trying to establish relationships on malaria prevalence using regionally or nationally extrapolated data may bring in inaccuracies. This is the reason why this study focuses on specific data from weather stations in the area under study rather than regionally interpolated data since local climate variations may help in accurately predicting malaria prevalence in an area since the affected areas are at varying altitude.

There are causal relationships between meteorological variables and malaria incidence (Basurko *et al.*, 2011; Huang *et al.*, 2011; Loha and Lindtjorn, 2010; Omumbo *et al.*, 2011). However, the nature and strength of these relationships vary from one area to the other. For instance, the prevalence of malaria can be predicted based on the prevailing mean temperature, in other areas based on the mean maximum monthly temperature, but in other regions based on the relative humidity (Olivier and Grobler, 1992). In a study carried out in China between 1961 and 2000, it was observed that no malaria transmission occurred when the yearly average of relative humidity was less than 60% (Yang *et al.*, 2012). It has been observed that adult mosquitoes have a flying range radius of 7 km and prefer relative humidity above 60% (Ermert *et al.*, 2011). It is therefore, important to determine which meteorological variable gives the strongest correlation in the area under study so as to be able to manage malaria more effectively.

A study by Olwoch (2008) indicated that in malaria risk areas, an increase in rainfall normally results in an increase in the number of malaria cases. This occurs due the fact that an increase in the amount of rainfall tends to increase the number of water bodies, which are the breeding grounds for mosquitoes. When the number of mosquito population increases, the rate of biting the human host increases and hence the chances for infection increase as well. The availability of suitable mosquito habitats is, however, not a simple linear function of rainfall (Ermert *et al.*, 2011). Mosquitoes will prefer certain breeding sites to others and moreover, if there are floods, the rains end up washing away some of the breeding sites. In Chikhwawa district of Malawi malaria is one of the leading diseases suffered during and after floods (Kalinga-Chirwa *et al.*, 2011). The flood related upsurge in malaria incidence in this district of Malawi was attributed to the potential increase in the number of breeding areas of malaria vectors as a result of stagnant pools of water left by the flood events. Stagnant pools of water have also been noted to create suitable *Anopheles* larval habitats due to the availability of irrigation water puddles in the commercial farmlands of Motuo County in the Tibet autonomous region of China, where altitudes range between 700 and 2100m ASL (Huang *et al.*, 2011).

In their conclusion, Craig *et al.* (2004) could not explain the increase in malaria cases by climate, but the authors found that the inter-seasonal variability correlated with several climate variables. The main discrepancy noted in their study is that they only used three stations from their study area, which may not be a complete representation of the climate conditions for the area. This may have contributed to the sudden spikes and increases; the result of which was the lack of correlation between climate variables and malaria prevalence. Craig *et al.* (2004) go on to use the East African highlands (Kericho Tea Estates) example where previous studies did not attribute the increase in malaria to climate variables. This has been refuted by Omumbo *et al.* (2011), who examined the climate data used in the study and established that it was not properly quality controlled. In the present study on Vhembe District, all weather stations within the area of study were used so as to increase the representativeness of the data.

2.5 Climate Change and Malaria Prevalence

Current evidence suggests that inter-decadal climate variability has a direct influence on the epidemiology of vector borne diseases (Githeko *et al.*, 2000). Mosquitoes which spread

malaria thrive well in warmer areas than in relatively cool areas which are characteristic of higher ground. Due to the climate change phenomenon, chances are that high altitude areas are getting warmer a result, which will be conducive for attracting mosquito breeding ground (Takken *et al.*, 2005).

Studies in the Kericho tea estates area of Kenya (located at 1600-3000m ASL) have shown a gradual increase in temperature of 0.2°C per decade between 1979 and 2009 (Omumbo *et al.*, 2011). The Kericho area has seen an increase in malaria cases, and this change in climate conditions has been noted as one of the drivers. This has led to the general perception that climate change will lead to an increase in the intensity of malaria. On the other hand, some studies on climate and malaria have argued that long term climate changes do not necessarily influence malaria prevalence, but that brief periods of heat or cold can be more significant than long term averages (Rieter, 2008). Heavy storms can have a different impact than light prolonged rainfall and one year's events may have a significant impact on subsequent years to come.

Literature on the influence of climate on the prevalence of malaria (Adu-Prah and Tetteh, 2015; Basurko *et al.*, 2011; Huang *et al.*, 2011; Loha and Lindtjorn, 2010; Omumbo *et al.*, 2011) indicates that there is a statistical relationship between meteorological variables and malaria incidence. In Ghana Adu-Prah and Tetteh (2015) established that temperature and humidity have some association with malaria prevalence, but that although annual rainfall in the model that was used was found to be less significant, there was evidence of rainfall as a predictor of malaria in Ghana. From 1986 to 2009 data of the Tibet Autonomous Region (TAR) of China, Huang *et al.* (2011) demonstrated a strong correlation (Spearman correlation) between relative humidity and the incidence of malaria and strong positive cross-correlation between the meteorological variables on time lagging. The study also determined that there was an approximately one month lag time from the time an infectious mosquito bites a human and finally the human developing malaria symptoms. In a KwaZulu Natal provincial study in South Africa, Craig *et al.* (2004) determined a 3-4 months time lag period between malaria and climate variables. This indicates how lag times vary from region to region. Huang *et al.* (2011) could not propose any long term prediction method/equation in their study, since the lags of meteorological variables affecting malaria transmission were short.

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The quality of data to be used in determining the relationship between climate and malaria prevalence has to be of a high standard. If the data is not properly processed, different methods of analysis may produce conflicting conclusions. This is the case with the Kericho Tea Estates study where some authors have concluded that climate cannot be considered as an important factor in changes in malaria prevalence in the area, while some researchers argue the opposite. The malaria data that were used for the Tibet Autonomous Republic (TAR) study may not have been properly quality controlled since only 5.6 percent of the total population affected by malaria report the cases, and also because the area is inaccessible (Huang *et al.*, 2011). Moreover in the TAR, only symptoms rather than confirmation with smears were used to determine if someone had malaria or not. The current study considered all these factors and uses validated data only from the meteorological and malaria control institutions.

2.6 Malaria Early Warning Systems

WMO, working together with the World Bank, the National Oceanic and Atmospheric Administration (NOAA) of the USA, the IRI, the European Commission, and the NMHSs, develops seasonal climate prediction in Africa with the establishment of the Regional Climate Outlook Forums (RCOFs) since 1996. An integral part of the RCOF is that there have been sessions held since 2004 in the Southern Africa region and since 2007 in the East Africa-Greater Horn of Africa region to find an operational early warning system for malaria (WCP, 2007). A combination of the two regional groups forms what is called the Malaria Outlook Forum (MALOF).

Current projects, which include the DEMETER Project based in Botswana and some WMO projects, have been designed to predict the probability of climate scenarios in the region as a way of trying to predict malaria transmission. However, all these systems do not use specific data for specific areas. Resources were recently invested in a project led by the Tanzania Meteorological Agency to study the impacts of climate variability on malaria in Tanzania (WCP, 2007b). The main objective of the project was to further develop and apply the DEMETER methodology of integrating seasonal forecasts and malaria statistics into an end-to-end early warning system for malaria outbreaks. A new database of clinical cases was collected and made available for the wider scientific community, the seasonal cycle of malaria outbreaks determined and the high risk areas identified (WCP, 2007b). Using leading

global coupled ocean–atmosphere climate models developed in Europe, Thomson *et al.* (2006) developed a malaria early warning system based mainly on rainfall data. The system was successfully applied to the prediction of malaria risk in Botswana, adding up to four months lead time over malaria warnings issued with observed precipitation and having a comparably high level of probabilistic prediction skill. According to Thomson et al. (2006), the links between malaria and climate variability are well established in Botswana.

A malaria early warning technique proposed by the European Centre for Medium-Range Weather Forecasts (ECMWF), the IRI and the Ministry of Health in Botswana incorporates climate forecasts from multi-model ensembles to predict when malaria risk will be at its peak, by examining climatic variables which influence the proliferation of mosquitoes. The team successfully deployed the technique in Botswana and was able to give policy-makers and health programme officers up to four months of advance notice (WCP, 2007a).

There is need to distinguish between long-term epidemic forecasting and early warning epidemic surveillance systems. Long-term epidemic forecasting is based on climate forecasting and relies on such data sets as the El Niño Southern Oscillation indices in order to predict epidemic risk months in advance over a large geographic area (Loha and Lindtjorn, 2010). Models like DEMETER are based on long term climate forecasting, which is of a regional setting. The forecasting allows officials to prepare well in advance the upcoming malaria season. This, however, is not specific enough for an area and tends to waste resources. The current study seeks to develop the early warning epidemic surveillance system which has a shorter lead time of several weeks to months, based on abnormal or above average climate conditions as a result of climate variability.

The incidence of malaria in Ethiopia shows that the prevalence varied from location to location, and the time lags differed from area to area; hence the models for predicting malaria prevalence would be different (Loha and Lindtjorn, 2010). The oversight in most studies is to try and blanket a region under the same climate envelope. This current study considered the differences in climate envelopes per local municipality and the overall district climate and sought to determine the various malaria pockets, using GIS. In order to cater for this climate and malaria behaviour Wangdi *et al.* (2010) proposed various application models for each of the endemic districts of Bhutan near India.

Some approaches (e.g. Omumbo *et al.*, 2011, Barsuko *et al.*, 2011) focus on one particular variable in trying to explain findings. However, the present study focuses on the three climate parameters temperature, relative humidity, and rainfall. Temperature is split further into air, minimum and maximum temperature to bring the total number of variables to five. These five variables were used in trying to determine which climatic parameter was strongly associated with malaria in Vhembe District. Other factors such as the vector (mosquito) species and abundance, human behaviour, population immunity, social and economic status and control measures, are known to have a significant influence on malaria prevalence (Huang *et al.*, 2011).

A number of statistical techniques have been used in studying the relationship between climate variability and the prevalence of malaria. In a climate variability trend analysis, Omumbo *et al.* (2011) used least squares regression analysis and the nonparametric Mann-Kendal (MK) test to identify significant trends. Craig *et al.* (2004) used linear regression in studying malaria prevalence in the Kwazulu Natal Province of South Africa.

2.7 Mapping Malaria Distribution

GIS is a general purpose computer based technology for handling geographical data in digital form in order to capture, store, manipulate, analyse and display sets of spatial or geo-referenced data (Burrough and McDonnell, 1998). It was, therefore, critical in this study to be able to visualise the occurrence of malaria within the Vhembe District using GIS. An example of the use of GIS in malaria assessment is in disease surveillance and the identification of high risk areas and population at risk in India, thereby enhancing targeted interventions (Gupta *et al.*, 2003). A number of studies have utilised GIS as a tool in understanding malaria. These studies include maps of India plotted by Srivastava *et al.* (2009), Sipe and Dale (2003) in Indonesia, Johnson and Johnson (2001) in India, and Kuhn *et al.* (2005). Mapping is critical since it helps in targeted intervention due to the behaviour of malaria infection, which creates zones that are always potentially prone to malaria outbreaks (Chanda *et al.*, 2012).

Available malaria risk maps which were generated by projects like MARA, and DEMETER interpolation of climate data, have been generated using regional data modelling and so they do not represent the local scale data. Use of regional data reduces the accuracy and precision

of the maps; hence they cannot be used for effective management and control. The use of interpolated data has resulted in controversy on the Kericho Tea Estates in Omumbo *et al.* (2011). The current study uses actual data obtained from weather stations within the study area, in order to maximise accuracies and localise the climate factor. This approach acknowledges the concern by Wangdi *et al.* (2010), who observed that significant relationships between some climatic factors and malaria in Bhutan could not be established in some of the areas because the meteorological stations collecting the climatic data were not from the same area as the occurrence of malaria. Therefore, in this study only South African Weather Service (SAWS) managed stations within Vhembe District were used to create the climate envelop, since the data is reputable and checked.

Mapping of some mosquito species has been successfully done in Africa using meteorological data. Gimnig *et al.* (2005) mapped mosquito vectors that are related to three climatic conditions in southern Africa. Martens *et al.* (2005) indicated changes in areas suitable for mosquitoes in Southern Africa, with a net increase in area covered by the *Anopheles gambiae* species. In another study, grid surface interpolation was used as a base for determining links and relationships between vectors/disease and climatic factors (Takken *et al.*, 2005) although coverage was relatively sparse and inappropriate, making the use of modelled map a challenge in use for accurate management and control.

2.8 The Orographic Effect and Malaria

Mosquito vectors prefer warmer climates which are typical in low lying altitude areas below 1000 MASL (Cox *et al.*, 1999; Moss *et al.*, 2011). A warmer climate in a region can result in increase in temperature in higher altitude areas above 1000 MASL. This can then result in the area being conducive to mosquito breeding; hence in this study a change in temperature had to be studied.

A study carried out in Zambia using Digital Elevation Modelling (DEM) revealed that lower elevation areas had more malaria cases in comparison with areas in higher altitudes (Moss, *et al.*, 2011). Nmor *et al.* (2013) used a DEM to map mosquito habitats in Kenya, and observed an absence of mosquitoes in higher altitudes compared to the lower altitudes. One of the shortcomings of the use of DEM currently is that only the height above sea level is being considered and not issues like hydrology, soil type and texture, slopes (whether V or U

shape) and ecology. According to Githeko *et al.* (2000), the transmission of malaria in southern Africa occurs intensely even at altitudes around 1200 m and below. A number of areas in Vhembe District (in northern, eastern and southern sections; Figure 1.3b) are at low altitude, lower than 400 MASL. Given the observations by Githeko *et al.* (2000), such areas are susceptible to malaria epidemics. Current malaria risk maps for South Africa indicate that malaria is not found in regions at 1000 MASL and above. However, the Kericho Tea Estates area in Kenya has already started to experience malaria transmission at altitudes around 2000 m (Omumbo *et al.*, 2011). This is a cause for concern in South Africa since there are areas above 2000 MASL which are currently mapped as malaria free.

2.9 Summary

This chapter looked at literature material on climate variability and its effects on malaria, which is a vector-borne disease. The literature review looked at the phenomenon of climate variability at a global, regional and local scale. It has been observed in many studies that global climate variability is occurring. However, of particular importance is that the causes of the variability, the frequency, duration and impact vary from region to region. On the basis of this, it is important to understand climate variability in the area of study and be able to determine the key climate trends in Vhembe District.

The life cycle of malaria and related favourable conditions for infections was also outlined in this chapter. Studies on the relationships between malaria and climate that were established in other areas were reviewed. It was deduced from this review that the extent of the effect of climate on the prevalence of malaria varies from area to area and also that the determinant climate variable differs from region to region. Further to this, the effect of climate on vector diseases like malaria varies from year to year and from region to region as a result of varying climatological conditions. This then results in changes in the behaviour of vectors like the female *Anopheles* mosquito which transmits malaria, and in turn, the number of infections that ultimately occur in a particular area. Finally a review of information on malaria spatial and temporal distribution was conducted in this chapter. It was noted from previous studies that most malaria maps are drawn at a regional level using, in most cases, interpolated data. A number of statistical tools which include Pearson correlation, Mann-Kendal analysis, linear regression and cross correlation, have been used in studying the relationship between malaria prevalence and climate variability. The literature review also showed the importance of using

data that has been properly checked. The use of data with errors has resulted in inaccurate observations in other studies.

On the other hand, a number of gaps have been identified in the literature. These gaps include limited local level research on climate variability for the 30 year period 1981-2010, and malaria-climate linkages for the study area. Localised maps on the spatial and temporal distribution of malaria that can be used for the effective management of the disease are not available. There are no area specific management models that include climate as a consideration for malaria control in Vhembe District. The current study, therefore, focuses on understanding the 30 year climate variations in Vhembe District province from 1981–2010 and the 13 year period from 1998 to 2010 for which there was malaria data. Long-term epidemic forecasting has been identified as one of the weaknesses in the current system by MARA and DEMETER, due to interpolation.

This study will work on understanding the short-term behaviour in climate-malaria relationships in order to address gaps identified. The influence of climate conditions on the spatial distribution of malaria will be analysed, and their effect on malaria discussed. Malaria maps will be drawn for the different municipalities. The knowledge gained will be used to contribute towards the establishment of a management framework that can be used as a tool in the reduction or elimination of malaria from the study area by 2030 (in line with the World Health Organisation goals) or by 2018 (in line with the South African agenda; Morris *et al.*, 2013).

Chapter 3

DATA AND METHODS

3.1 Introduction

In Chapters 1 (Introduction) and 2 (Literature Review) the background of the study, research problem, context, and annotated findings from relevant literature related to factors that affect malaria prevalence were presented. This chapter details the data and methods that were used in this research, in addressing the research objectives that are stated in Section 1.5.

Climatological information can be used and applied in various fields of study which include, among others, agriculture, ecosystems, forestry, water resources and human well-being (Kuhn *et al.*, 2005; WMO, 2011). In this research, climatological data was used to establish the relationship with malaria. This was because it has been noted that the ambient temperature drives the malaria vector and parasite reproduction stages, especially with the availability of water or rainfall and high relative humidity levels which enhance the survival of the adult mosquitoes (Palmer *et al.*, 2004; Eckhoff, 2011).

Using statistical analysis, several studies (Huang *et al.*, 2011; Olwoch, 2008; Omumbo *et al.*, 2011) have shown that the climatological factor that influences malaria prevalence the strongest varies from area to area. Hence this research sought to establish the climate factors which drive malaria in the Vhembe District. Using various statistical tools an analysis of long-term (30-year) climate data was done, in order to determine the presence or absence of variability. Understanding the variability of climate in Vhembe District would give insight on how to respond effectively to malaria epidemics based on the prevailing climate conditions. The data obtained on malaria prevalence was then related to population demographics in order to understand the influence of population dynamics on malaria prevalence. This is because in malaria prone areas, areas with high population density areas tend to favour malaria transmission than sparsely populated ones (Deresa *et al.*, 2006). In order to depict the relationships among the three variables of malaria epidemics, climate and population dynamics, these variables in the study area were mapped using Arc-GIS 10.1. This enhanced an understanding of the spatial distribution of malaria based on the prevailing climate conditions and population dynamics. The use of GIS not only highlight the affected areas but

also gave a visual representation of the information, thereby helping in noting trends occurring in different areas at once.

3.2 Data and Sources

Climatological data for the 30-year period 1981 to 2010 was obtained from the South African Weather Service (SAWS). The data readings are taken by SAWS at regular time intervals and systematically stored so as to enable comparison across different geographic sites (WMO, 2011). SAWS is a member of WMO and subscribes to the best guidelines on climatological practices which, among others, include the calibration of instruments, setting of climatological stations, the design of climatological networks, on-site quality control and data management. This enhances the accuracy of the data. However, for the purpose of this study, the data received was correlated to select stations that revealed homogeneity and also checked and tested for normality using the Kolmogorov-Smirnov test corrected with the Lilliefors test and Shapiro-Wilk (SW) Test. All the stations showed high correlation and mostly normal frequency distributions in the data.

Data on malaria cases between 1998 and 2010 were obtained from the Regional Malaria Control Institute (RMCI) at Tzaneen in Limpopo Province. The RMCI keeps validated records of the malaria cases collected in the province by health facilities. Data on human population in the various local municipalities of Vhembe District (see Figure 1.3a) between 1998 and 2007 were acquired from the state statistics agency Statistics South Africa (StatsSA). StatsSA has conducted a population census every 5 years, the census years being 2001 and 2006 for the malaria analysis period of 1998 to 2010. Therefore, for the non-census years 2008, 2009 and 2010 population values were calculated using the latest official growth rates from StatsSA and compared with figures in the Integrated Development Plans (IDPs) for the four local municipalities in Vhembe District.

3.2.1 Climatological Data

The climatological parameters that were used in the study are rainfall, temperature and relative humidity. The main reason for the inclusion of relative humidity in the study was the fact that the two main climate elements that were under study, i.e. temperature and rainfall, should not analysed in isolation. Normally one or two climate parameters can influence the effect of another parameter. In this case, for example, temperature and rainfall affect relative humidity and in response the ground temperature gets affected or modified by humidity.

The daily range of a weather parameter can, in some cases, become more significant than the daily mean. For example, brief periods of heat or cold can be more significant than long term averages (Rieter, 2008). Monthly weather data for the 30 years (1981 to 2010) were obtained from the 49 SAWS weather stations in Vhembe District (Figure 3.1), of which 18 record temperature and 11 record relative humidity. Rainfall data of 30 year period were used to detect trends and possibly recurring of rainfall events such as normal, above or below normal rainfall in the study area. The rainfall data from 1998 to 2010 was used in analysing and determining the relationships between rainfall and malaria.

According to the WMO, the 30 years period is ideal for dealing with climate data and enables the detecting of climate variability in the data (WMO, 1983; WMO, 2007). Therefore, stations with continuous rainfall data for more than 30 years and those that reported more than 80% data were used. This is in accordance to WMO (2011) which recommends that for the purposes of calculating averages, stations with more than 80% data can be used and data from the nearest highly correlating station may be used to fill in the missing figures. Nyenzi (1988) and Nenwiini (2011) applied the use of the nearest highly correlated station to fill in the missing data in their work.

There are few weather stations in the study area that have temperature and relative humidity records of more than 30 years. However, the WMO (2011) guidelines advise that for most parameters, a period of 5 to 10 years has the same predictive power as a 30 year period. This supports the inclusion and use of reported results on temperature and relative humidity from the stations within the study area. WMO (2007) indicates that while a fixed 30-year period may be appropriate as a reference period when average values are used for predictive purposes, shorter averaging periods of 10 years or more for most parameters perform as adequately as 30-year periods. Based on these (WMO, 2007; WMO, 2011) guidelines, relative humidity and temperature stations which have reported results for at least 5 years were used. Since limited information was being used and in order to maximise on the accuracy of the available data, only the available temperature and relative humidity data was used. Appendix 1 shows all the weather stations within Vhembe District, their location (as in Figure 3.1) and the weather parameters that they measure.

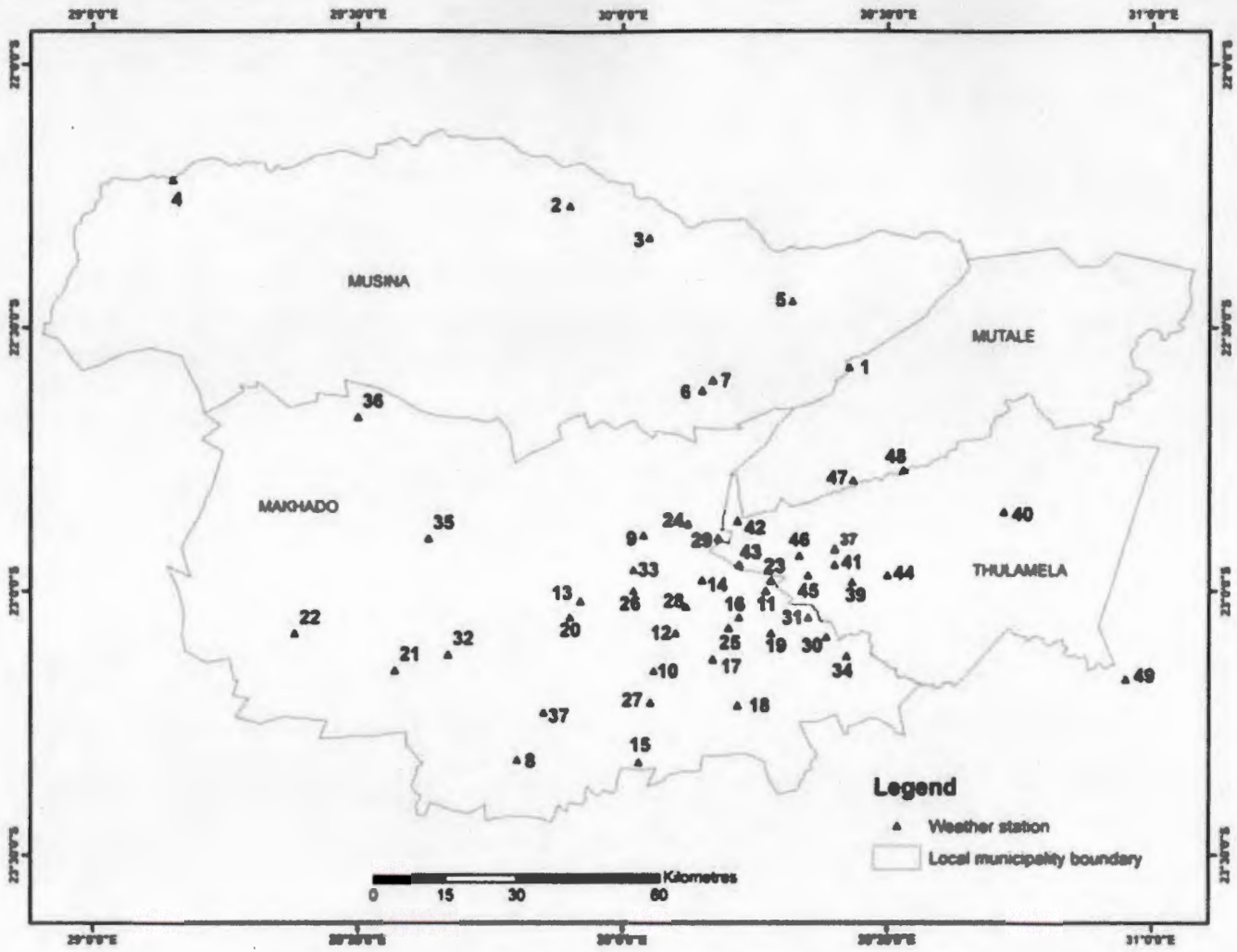


Figure 3.1: Location of the weather stations in Vhembe District that were used in the study.

In determining the climate, calculation of the annual averages was done using the available monthly data obtained from SAWS. Missing data was fitted for rainfall using the nearest highly correlated station. For temperature and relative humidity on the other hand only the available data was used and, therefore, no data fitting was done due to the short periods being used; in order to maximise on the actual representation of the climate and minimise on extrapolations. According to the WMO (2010) guide, period averages can be calculated using the available data only. Year-on-year monthly averages were calculated for the different climate parameters using available data for temperature and relative humidity, and using data fitted tables for rainfall calculation.

Before further statistical analysis could be done, the climatological data was tested for normality so as to establish the applicability of the parametric and non-parametric tests used in this research. This was important since for some weather station and in certain instances small datasets ($n < 30$) were used. There are various formal tests which are available for testing normality, but the three most common methods include the Kolmogorov-Smirnov (KS) test, Lilliefors (LS) test, Shapiro-Wilk (SW) test and the Anderson-Darling (AD) test (Razali and Wah, 2011). The Kolmogorov-Smirnov test corrected with the Lilliefors test and Shapiro-Wilk (SW) Test; and all three tests are available on SPSS 22 and were used to review the data. Focus was made on the results of the Shapiro-Wilk test since various studies have indicated that it is the strongest test for normality on $n < 50$ samples (Razali and Wah, 2011; Yap and Sim, 2011). The histograms and Q-Q plots that were generated were also visually analysed for normal distribution trends and conformed. The results indicated that climate data being analysed generally fulfilled the characteristics of the normal distribution.

3.2.1.1 Rainfall

Annual rainfall data was used to determine if there had been change in the pattern and quantity of rainfall in the area from 1981 to 2010, and to evaluate the influence of rainfall on the prevalence of malaria. Annual rainfall values were obtained by summing up the monthly rainfall data obtained from the South African Weather Service (SAWS). Out of the 49 SAWS weather stations in Vhembe District, 7 are in Musina Local Municipality, 9 in Thulamela, 30 in Makhado and 3 are in Mutale Local Municipality. Musina and Mutale Local Municipalities are largely constituted of commercial farms and a few towns or growth points. The weather monitoring network is, therefore, set up near residential areas. Makhado and Thulamela Local

Municipalities on the other hand have more weather stations, covering most of the residential areas.

Rainfall is one of the climate parameters that will be used in this study. According to previous studies (Eckhoff, 2011; Huang *et al.*, 2011; Olwoch, 2008; Palmer *et al.*, 2004), rainfall influences the number of malaria cases in a particular geographic area. This influence can either be directly or indirectly induced on the vector reproduction cycle. The direct effect of rainfall on the malaria vector is noticed when abundant rainfall, for example when there are floods, results in the washing away of mosquito breeding sites (Kuhn *et al.*, 2005). On the other hand rainfall has an indirect effect on malaria, for example, when there are water pools after rain showers. The water pools create breeding areas for the mosquitoes, which increases the vector population and in turn increases the chances of malaria transmission in malaria endemic areas.

3.2.1.2 Temperature

The monthly average (mean), for air, minimum and maximum temperature data for Vhembe District were obtained from 18 weather stations: 3 in Musina, 8 in Thulamela, 6 in Makhado and the one in Mutale Local Municipality which had temperature records between 1983 and 1995. The selection of the air, minimum and maximum temperature variables was based on previous studies which have highlighted how different malaria endemic areas are influenced by different temperature parameters. It was, therefore, vital to analyse various temperature variables in order to determine their variability in the area and the effect of the variation on the prevalence of malaria. Takken *et al.* (2005) and Martens *et al.* (1995) pointed out that variations in temperature across geographical areas may not be significantly different but that, however, it is the small incremental changes in temperature that tend to boost the population of *Anopheles* mosquitoes. On the other hand lower temperatures tend to reduce malaria transmission.

The incremental change in temperature accelerates the gonotrophic cycle of *Anopheles* mosquitoes and the development cycle of the parasite (Basurko *et al.*, 2011; Kuhn *et al.*, 2005). Such temperature increments affect an area by extending the duration of the season in which mosquito vectors are transmitting the disease by several weeks, due to changes in feeding behaviour, which then results in the infection of a larger population (Takken *et al.*, 2005). A higher temperature increases the rate of digestion in mosquitoes, and hence the rate

of feeding, whereas cooler temperatures result in reduced digestion and hence reduced rate of feeding. Temperature also affects the metabolic rate and activity of the parasite (Olivier and Grobler, 1992). Martens *et al.* (1995) indicate that there are minimum and maximum temperatures which favour the survival or death of mosquitoes. Omumbo *et al.* (2011), in their study on the relationship between malaria and temperature, used the minimum and maximum temperature in the analysis. There was, therefore, a need to establish the basis of the temperature ranges in the area and whether or not the temperatures are stable, increasing or decreasing. This information was useful in understanding the influence of temperature variability on malaria.

As stated in Section 2.4, the *Anopheles* mosquito breeds well in temperature conditions between 16-35°C (Craig *et al.*, 2004); and there is a relationship between rainfall and temperature in most instances. According to Omumbo *et al.* (2011), above average monthly rainfall is negatively correlated with the maximum temperature, but positively correlated with the minimum temperature. On the other hand, months with below average rainfall have higher temperatures and suppressed minimum temperatures. A consideration of these temperature parameters is, therefore, required in assessing malaria since the mosquito vector is sensitive to slight changes in temperature and rainfall.

3.2.1.3 Relative Humidity

Relative humidity (RH) as a weather parameter is normally used for weather forecasts as well, since it is an indicator for the likelihood of precipitation, dew or fog. These environmental factors have an impact on mosquito breeding through providing suitable habitat as breeding areas. According to literature (see Section 2.4), relative humidity above 60% characterises malaria infected areas (Martens *et al.*, 1995; Kuhn *et al.*, 2005). This underscores the need to analyse the relative humidity data in the Vhembe District.

There are a number of ways of expressing humidity; among which are absolute humidity, specific humidity and relative humidity. Absolute humidity measures the mass of water vapour per unit volume of total air and water vapour mixture. This results in absolute humidity being sporadic since it gets affected by any change in temperature or pressure, hence it was not chosen for use in this study. Specific humidity is the ratio of water vapour to dry air in a particular mass. In other words, it is a measure of the amount of water vapour available for conversion to liquid water. Specific humidity was also not selected for use in

this study. Relative humidity is the partial pressure of water vapour in the air-water mixture related to the saturated vapour pressure of water at those conditions (Stephens, 1998). It is calculated as indicated in Equation 3.1.

$$RH = \frac{Actual\ vapour\ density}{Saturation\ vapour\ density} x\ 100\% \qquad \text{Equation 3.1}$$

Relative Humidity (RH) was selected for use in this research since it is affected by temperature changes; temperature is one of the variables that were used in this study. Monthly average relative humidity data was acquired from SAWS. Out of the 49 weather stations in Vhembe District (Figure 3.1) only some had Relative Humidity records: 2 in Musina Local Municipality, 5 in Thulamela, one in Mutale (with RH records from 1983 to 1994) and 4 in Makhado Local Municipality.

3.2.2 Malaria Cases

Data from the 165 medical centres in Vhembe District for the 13-year period 1998-2010 were obtained from the Regional Malaria Control Institute (RMCI) at Tzaneen, Limpopo Province. The medical centres in Vhembe District are distributed as indicated in Table 3.1. Malaria data for the period before 1998 were not reported in a format similar to that for the 1998-2010 data, for example, the aspect of including the details of the village of origin of the malaria patient. Secondly, the municipal demarcations that were implemented after the 1994 political changes in South Africa resulted in adjusted municipality boundaries. The implementation of malaria treatment programmes during the Apartheid era was not as extensive as the programmes after the political freedom. The treatment programmes that were implemented after 1994, and in place currently, are not selective between black and white communities. Finally, the data from 1998 to 2010 is clinically confirmed using blood smears, enabling the capturing of actual cases and eliminating suspected cases.

In the malaria cases data that were obtained, only confirmed cases are recorded. Confirmation is done by using blood smears of the suspected individuals. The data obtained indicated the municipality in which the malaria case was reported, the blood smear date, sex and age of the individual; whether the malaria case was reported in a hospital or clinic, and the village the individual came from. The data also captured the origin or travel movements of the person, which allowed the Department of Health to locate the probable origin of the disease. For the

purposes of this study, only malaria cases detected for individuals residing in the study area were considered. All the malaria cases for people who came into Vhembe District from other provinces, districts or countries were not included.

Table 3.1: Number and types of health facilities per municipality in Vhembe District.

Local Municipality	Clinic	Community Health Centre	District Hospital	Mobile Service	Total
Thulamela	49	3	2	15	**69**
Makhado	44	4	3	16	**67**
Mutale	16	1	1	6	**24**
Musina	3	0	0	2	**5**
Total	**112**	**8**	**6**	**39**	**165**

Source: Limpopo Health Profile (2012).

The data on monthly number of reported malaria cases that were obtained was analysed based on the number of cases per 10 000 people. This was done in order to cater for the changes in population dynamics (which are discussed in section 3.2.3). Factoring in of population dynamics allows for comparisons between different areas. According to the WHO, prevalence is defined as the proportion of people in a population who have a particular disease at a specified point or over a specified period of time, and is calculated as indicated in Equation 3.2.

$$Prevalence = \frac{Malaria\ cases\ during\ a\ time\ period}{Population\ during\ the\ same\ time\ period}\ x\ 10^n \qquad \text{Equation 3.2}$$

Where n = any number from 1 to ∞ depending on the size of population.
In this study n = 4 (10000). However, in other research, n is normally 3, 4 or 5.

3.2.3 Demographic data

Demographic data on Vhembe District were acquired from StatsSA and from the Municipal IDPs. The data gave the total number of people in each local municipality per annum. Demographic changes are important in understanding the prevalence of malaria since the *Plasmodium falciparum* parasite needs a host. Highly populated areas favour the transmission of malaria transmission due to the availability of a host (Martens *et al.*, 1995; Deresa *et al.*, 2006). As indicated by Kuhn *et al.* (2005), climate conditions influence human behaviour

since people can get exposed to mosquito bites depending on the prevailing conditions. It was, therefore, important to understand how the population was distributed in Vhembe District, as well as the influence of population on malaria. The populations for the different municipalities for the years 2008, 2009 and 2010 was calculated using the population growth rate (GR) for the respective municipalities as established in the 2011 census (StatsSA). The growth rates were 5.53% for Musina, 0.43% for Makhado, 1.03% for Mutale and 0.62% for Thulamela Local Municipality.

3.3 Data Analysis Techniques

Data analysis in this study followed quantitative approaches using methods that have been used or recommended in previous studies by, among others, Craig *et al.* (2004), Omumbo *et al.* (2011), Kuhn *et al.* (2005), Nenwiini and Kabanda (2013) and Huang *et al.* (2011). The different statistical techniques used included determination of anomalies (standardisation), Pearson correlation and linear regression. Trend analysis was performed using Microsoft Excel, the Mann-Kendal test and Sen's slope estimate (MAKESENS 1.0). SPSS 22 was used as the statistical software for determining correlation and z-scores. Mapping of the burden of malaria disease in the four local municipalities was done using GIS techniques using ArcGIS 10.1.

3.3.1 Standardisation Procedure

The standardised value was computed for each weather parameter (rainfall, temperature, Relative Humidity) per municipality using the climate data that were obtained (see Section 3.2.1). The standardised value (Z) was calculated as in Equation 3.3; by subtracting the municipality (area) mean for each parameter (rainfall, temperature, RH) and dividing by its standard deviation, with the mean and standard deviation calculated from the area's historical data. This was done in order to determine the extent of deviation (anomalies), from the area mean, over time.

$$z = \frac{x - \mu}{\sigma} \qquad \text{Equation 3.3}$$

Where z = standardised value

x = area value

μ = area mean

σ = area standard deviation

The quantity Z in Equation 3.3 represents the distance between the raw value and the population mean in units of the standard deviation. A negative standardised value means that the original value was below the mean. A positive standardised value means that the original value was above the mean. The actual value corresponds to the number of standard deviations the value is from the mean in that direction. However, it is important to note that a standardised value transformation changes the central location of the distribution and the average variability of the distribution. It does not change the skewness or kurtosis.

The method has been used by Kabanda (2011) and Omumbo *et al.* (2011) in determining anomalies on climatological data to indicate the deviation from the mean. The standardised value was used in order to enable the calculation of the probability of a value occurring within a normal distribution and to enable the comparison of two values from different normal distributions.

3.3.2 Correlation Analysis

Statistical correlation was applied in this study in order to determine relationships between climate variables and malaria. This method has been used in previous studies on analysing the relationships between climate and disease (Kuhn *et al.*, 2005). Two different correlation analyses are available, namely the Pearson correlation coefficient and the Spearman rank correlation. These can be used depending on whether parametric or non-parametric methods are employed. Both measure the extent of a relationship between two variables and give a number between -1 and +1.

As indicated in section 3.2.1, climatological data was initially tested for normality using the Kolmogorov-Smirnov test corrected with the Lilliefors test and Shapiro-Wilk (SW) Test. It was established that the bulk of this data followed the normal (Gaussian) distribution. On this basis the parametric Pearson correlation test was chosen in establishing relationships between the climate elements and malaria. The Pearson correlation coefficient (r, calculated as in Equation 3.4) has also been found to be more sensitive and accurate than the Spearman rank correlation in previous studies carried out by the World Meteorological Organisation (WMO, 2011) which has, therefore, recommended it. As in Equation 3.4, for a series (n) of measurements of x and y (written as x_i and y_i, where $i = 1, 2, ..., n$) the sample correlation

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coefficient can be used to estimate the population correlation (ρ) between x and y. The correlation coefficient (ρ) when applied to a sample is commonly represented by r.

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{(n-1)s_x s_y} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}}$$

(Equation 3.4)

where x and y are the sample mean of x and y,
and s_x and s_y are the sample standard deviations.

3.3.3 Trend Analysis Using MAKESENS 1.0

In this analysis, climatological data is considered as a stationary time series since we are using annual data. A stationary time series is one for which the probabilistic behaviour of every collection of values is identical to that of the time shifted set (Shumway and Stoffer, 2006). The climatological data were, therefore, analysed for the trend of annual data using MAKESENS 1.0 Trend Analysis, which is based on the Mann-Kendall Test and Sen's Slope Estimates (Salmi *et al.*, 2002). The MAKESENS Microsoft Excel template is developed for detecting the presence of a monotonic increasing and decreasing trend, which is tested by the nonparametric Mann-Kendall Test followed by the estimation of a linear slope using the nonparametric Sen's method (Salmi *et al.*, 2002). MAKESENS 1.0 uses the two-tailed test for four different significance levels, i.e. α: 0.1, 0.05, 0.01 and 0.001. The combination of these two methods has been found to be favourable in Environmental Science, especially considering the fact that missing values in the time series are allowed and the data need not conform to any particular distribution. Sen's method is not affected by single data errors and outliers. The Mann-Kendall data values are evaluated as an ordered time series and exploit both the S (n < 10 data points) and Z statistics ($n \geq 10$ data points). Each data value is compared to all subsequent data values.

The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (*e.g.*, no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and

decrements yields the final value of S. The Mann-Kendall statistic (S) is computed as in Equation 3.5 (Olofintoye and Sule, 2010).

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)$$

Equation 3.5

where x_j and x_k are the annual values in years j and k, $j > k$, respectively, and $sgn(x_j - x_k)$ as in Equation 3.6.

$$\text{sgn}(x_j - x_k) = \begin{cases} 1 if\ x_j - x_k > 0 \\ 0 if\ x_j - x_k = 0 \\ -1 if\ x_j - x_k < 0 \end{cases}$$

Equation 3.6

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend. The normal approximation (Z statistics) was used when the number of annual values (n) was 10 or more. In this case the variance of S, which is calculated as in Equation 3.7, was computed. The values of S and $VAR(S)$ are used to compute the test statistic Z as indicated in Equation 3.8. Z follows a normal distribution. The Z value is tested at 95% level of significance (Z = 1.96).

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5) \right]$$

Equation 3.7

Where q is the number of tied groups and t_p is the number of data values in the p^{th} group.

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} if\ S > 0 \\ 0 if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} if\ S < 0 \end{cases}$$

Equation 3.8

The graphs that were generated for the three climate variables using MAKESENS 1.0 were analysed for trend significance at 95% confidence level. The trend was categorised as decreasing if Z was negative and the absolute value was greater than the level of significance, but as increasing if Z was positive and greater than the level of significance. If the absolute value of Z was found to be less than the level of significance, this indicated that there was no trend.

The true slope of an existing trend (as change per year) was estimated using Sen's nonparametric method. Calculation of the confidence intervals for the Sen's linear slope estimate is still valid even for time series with as small as 10 values. The first step in the Sen's slope (Q) estimate method is to calculate the slopes of all the data value pairs as in Equation 3.9.

$$Q = \frac{x_{i'} - x_i}{i' - i} \qquad \text{Equation 3.9}$$

where: Q = slope between data points $x_{i'}$ and x_i

$x_{i'}$ = data measurement at time i'

x_i = data measurement at time i

i' = time after time i

During the analysis of trend using MAKESENS 1.0, the statistical computation gives high level of significance with narrow angles between the confidence lines in cases where important significant trends are observed (Salmi *et al.*, 2002). In these cases the trend is significant at the point where the 95% confidence bounds and the Sen's slope estimate line meet.

3.3.4 Linear Regression Analysis

Kuhn *et al.* (2005) recommended the use of linear regression techniques in estimating the probability of an epidemic in disease surveillance and early warning systems. Craig *et al.* (2004) applied linear regression techniques in investigating the relationship between climate and malaria, which led them to the conclusion that climate, may be a contributing factor in malaria in South Africa's KZN Province. However, the driving force may be non-climate elements rather than climate conditions *per se*. In Chapter 2 of this study, this finding by

Craig *et al.* (2004) was discussed and refuted, even though the application of the regression technique by Craig *et al.* (2004) is supported. On the other hand Ott and Longnecker (2010) explain in detail the application and interpretation of linear regression, which satisfies its applications in this study. Based on these, linear regression was applied as part of the methodology in order to determine the extent of the relationships between climate elements and malaria cases. A further reason for applying linear regression to this study was to determine the nature of the relationship between the dependent variable (malaria cases) and y_i the climatological variables (rainfall, temperature and relative humidity). In linear regression for n data points where there is one independent variable x_i, and two parameters β_0 and β_1, the linear regression equation is determined as in Equation 3.10.

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i \qquad \text{Equation 3.10}$$

Where $(i = 1, \ldots\ldots\ldots, n)$

The nature of the relationship in linear regression is, therefore, represented as a linear equation as shown by Equation 3.10, with the coefficient of determination (r^2) always indicated next to it so as to depict the strength of the relationship.

3.3.5 Cross Correlation Analysis

Cross correlation was used in this study to establish the influence of monthly lags or time shifts for the various climate elements on malaria. Cross correlation achieves this by comparing two time series data sets over time and comparing the relationship when there is a time shift; the result is termed the cross correlation function (CCF). In an assessment of climate and malaria patterns for two different ecological zones in Ghana, Klutse *et al.* (2014) applied lag correlation so as to determine at which lead-time climate elements begin to influence malaria. The study established that lag correlations of up to four months yield stronger relationships between climate variables and malaria. In this study the independent variable was the climate elements and the dependent variable malaria cases for the period 1998-2010.

The cross correlation between two time series describes the normalized cross covariance function (Shumway *et al.*, 2006). The cross covariance function is computed as in Equation

3.11. The cross correlation function ρ_{xy} is the normalized cross-covariance function, and is calculated as in Equation 3.12.

$$\gamma_{xy}(\tau) = \mathrm{E}[(X_t - \mu_x)(Y_{t+\tau} - \mu_y)] \qquad \text{Equation 3.11}$$

Where:

X_t, Y_t represent a pair of stochastic processes that are jointly wide sense stationary, and μ_x and μ_y are the means of X_t and Y_t, respectively.

$$\rho_{xy}(\tau) = \frac{\gamma_{xy}(\tau)}{\sigma_x \sigma_y} \qquad \text{Equation 3.12}$$

Where σ_x and σ_y are the standard deviations of processes X_t and Y_t, respectively.

In Equation 3.12, if $X_t = Y_t$ for all t then the cross correlation function is simply the autocorrelation function. In this study X_t represented the set of data (i.e. rainfall, temperature or relative humidity) at time t and Y_t represented the number of malaria cases at time t. The SPSS computer package was used for this analysis. A cross-correlation matrix for the different areas in Vhembe District and the three climate elements (rainfall, temperature, RH) was generated. After establishing the most significant lag for the various elements, Pearson's correlation analysis then done (as described in Section 3.3.2), in order to detect the significance of the malaria-climate relationship. Then Linear Regression analysis was performed, in order to establish whether the relationship was linear, as described in Section 3.3.4.

3.4 Geographic Information System Mapping

There has been an increase in the use of Geographic Information Systems (GIS) tools in public health (Kuhn *et al.*, 2005). Different types of diseases like HIV & Aids, yellow fever, cancer and malaria have been mapped based on the available information, which in turn helped medical workers to focus their energies and finances in the right places when tackling

the diseases. The mapping helps in the visualisation and identification of endemic areas where treatment and preventive measures can be focused (Johnson and Johnson, 2001; Srivastava *et al.*, 2009). With regards to malaria, GIS mapping has been applied in the generation of global and regional maps (Martens *et al.*, 1995; Palmer *et al.*, 2004). Global and regional maps are, however, too broad to be useful at a local level; hence the need to GIS mapping at the local level so that the maps become more area specific and management of malaria can be more focussed. Although the responsible institutions have begun to appreciate the value of mapping diseases in the medical fraternity, the use of GIS still remains minimal since GIS software is still not readily accessible and still expensive to acquire. The other challenge is that if the coordinates of an area are not captured correctly or if the name of the village was wrongly quoted, then the case may be plotted in the wrong area as identified by Sipe and Dale (2003) from work on malaria in Indonesia. Due diligence and quality control of data is, therefore, of paramount importance in the application of GIS in the public health sector, so as to avoid errors in capturing the data. In this study only verified data obtained from the Regional Institute for Malaria Centre was used, as indicated in section 3.2.2.

Using the software ArcGIS 10.1, mapping techniques and a Digital Elevation Model (DEM) were, therefore, employed in mapping the occurrence and location of malaria in Vhembe District. The maps that were generated were used to analyse spatial patterns in the distribution of malaria in the area, for the analysis years 1998 to 2010 whose data were plotted in order to understand the spatial distribution of malaria under the influence of various climate conditions and altitude.

3.4.1 General Mapping

Several maps which indicate the spatial distribution of malaria cases were generated for the area and used during the interpretation of the results. Shape files of the area were obtained from the University of Limpopo, corrected and georeferenced to the Universal Transverse Mercator (UTM) projection, WGS84 (World Geodetic System of 1984) datum. Vhembe District was then extracted from the shape file of municipalities in South Africa. Attribute tables for the local municipalities within the district municipality indicating the villages were exported onto a Microsoft Excel spreadsheet for ease of use in statistical analysis. For Musina Local Municipality the attribute table about the farms was also extracted, since the area

consists mostly of commercial farms and the malaria cases are captured using the farm name where the individual resides.

Using data obtained from the Department of Health all the villages that had malaria cases between 1998 and 2010 were identified and assigned the code 1 in the Microsoft Excel spreadsheet for the year, and those without malaria were left blank. The complete Excel spreadsheet attribute table was then imported back to ArcMap 10.1, and used to generate the spatial distribution maps for the various years in order to detect spatial patterns and distribution.

3.4.2 Orographic Mapping

In order to identify the orographic effect on malaria in their study area, Moss *et al.* (2011) used the Digital Elevation Model (DEM) technique. A DEM is a raster continuous surface representation of the surface of the earth, which enables us to have insight into the affected area of study. Nmor *et al.* (2013) used the DEM approach in mapping mosquito habitats in Kenya, which enabled the detection of malaria hot spot areas. In the present study, a 30-meter-resolution DEM was used in order to understand the spatial distribution of malaria within Vhembe District in relation to the altitude. According to Martens *et al.* (1995) an increase in malaria prevalence at high altitudes is likely with climate change and variability. Water resources (i.e. rivers, streams and wetlands) were included on the DEM maps in order to depict the convergence of flow across the natural terrain surface.

3.5 Ethical Considerations

The study used secondary data from SAWS and RIMC and hence no ethical issues were involved since there was no direct interaction with the patients. Ethical clearance was, however, obtained from the North-West University Ethics Committee and from the Department of Health (Limpopo Province) Research Unit. The study was, therefore, conducted in a way which fulfilled all the necessary ethics protocols.

3.6 Assumptions

The following assumptions were factored into this study:

1. The climate data supplied by the South African Weather Service (SAWS) is trustworthy and it was recorded in line with WMO standards.

2. The current malaria control methods, which are based on the Department of Health's Guidelines for the Prevention of Malaria in South Africa (Baker *et al.*, 2009) and other related documents, are being followed and are effective in Vhembe District. Based on this assumption, therefore, the non-climate elements pertaining to the prevalence of malaria are assumed to be well managed in the study area.

3. The current malaria prevalence figures are suppressed by current control methods, following on from *Assumption 2*.

4. The reported malaria cases have been consistent throughout the period of study. This implies that all the cases that could have been reported in a normal case scenario were reported and properly captured.

5. An increase in the abundance of mosquitoes leads to an increase in malaria prevalence, since more mosquitoes will be feeding on human blood and hence the number of chances for a person to be bitten by the mosquito will be increased.

6. The weather stations in the study area are adequate for the determination of climate conditions.

3.7 Limitations

This research had the following limitations:

1. In certain instances, the names given for the village of origin for the individual with malaria did not appear on the maps. This may have been due to typographical errors at the heath institutions, the use of old names or the use of the chief's name.

2. Consideration was not given to non-climate elements that can affect malaria, except for the population density (see *Assumption 2* in Section 3.6).

3. The malaria cases reported to the health officials are limited to cases of people who went to a medical facility for treatment. Some cases may not have been reported since patients who have knowledge of the diseases may have managed to treat themselves without reporting the case at a medical facility.

4. The available malaria data, in the required format, for the period of study was only limited to the 13 years 1998 to 2010, which restricted long-term trend analysis.

Chapter 4

CLIMATE TRENDS AND VARIABILITY

4.1 Introduction

In this chapter, the results on long-term (1981-2010) climate trends and variability in Vhembe District based on the parameters rainfall, temperature and relative humidity are presented. Therefore, the chapter addresses *Objective 1* of the research, as stated in Section 1.5. The chapter examines and describes the climate anomalies and trends in the four local municipalities of Vhembe District (Musina, Makhado, Mutale and Thulamela; Figure 1.3a).The climate in Vhembe District, especially rainfall, has received attention from previous studies such as Kabanda and Munyati (2010), Tshiala *et al.* (2010), Munyati and Kabanda (2009), Mpandeli (2014) and Kabanda and Nenwiini (2015). These previous studies all observed that there are climate disparities at both temporal and spatial scales in the area. Nenwiini and Kabanda (2013) detected a decrease in rainfall in Vhembe District observed since the mid-1990s. On the other hand Nenwiini, (2011) was able to subdivide Vhembe District into various rainfall zones of different rainfall characteristics that indicated areas of humid, sub humid and semi-arid.

The departures of the various climate elements from their long-term mean, and the corresponding spatial distribution in a particular area, are a measure of climate variability. These values are ideal for explaining the magnitude of change from a particular climate parameter. This study was concerned about these variations, because they might be the driving factors behind malaria prevalence in the study area. Other studies that used departures from long-term mean (anomalies) to explain climate variation include the National Oceanic and Atmospheric Administration (NOAA) which uses the Oceanic Niño Index (ONI) for identifying El Niño (warm) and La Niña (cool) events in the tropical Pacific. The ONI is defined as the 3-month running mean Sea Surface Temperature (SST) anomaly where climate events are defined as five consecutive overlapping 3-month periods at or above the +0.5°C anomaly for warm (El Niño) events and at or below the -0.5°C anomaly for cold (La Niña) events. Various event thresholds have been established: Weak (with a 0.5 to 0.9 SST anomaly), Moderate (1.0 to 1.4), Strong (1.5 to 1.9) and Very Strong ($\geq$ 2.0). Null (2015) categorised events as weak, moderate, strong or very strong when a threshold has been

equalled or exceeded for at least 3 consecutive overlapping 3-month periods rather than the usual NOAA 5 consecutive overlapping 3-month periods. This shows that categorisation can be adjusted to suit the usage of the data, especially in the study of vector borne diseases where short periods can affect the upsurge or decline of the disease. However, since neither NOAA nor SAWS have established the standardised monthly 30 year-period climate data baseline for Vhembe District and its local municipalities, this study applied the thresholds on the annual anomalies not just for temperature, but also rainfall and relative humidity, in determining the magnitude of the events.

As detailed in Section 3.3.3., trend analysis for each climate element in the four municipalities in Vhembe District was performed using the Microsoft Excel MAKESENS 1.0 spreadsheet that was developed by Salmi *et al.* (2002). The *Z* value is tested at 95% level of significance (Z = 1.96) and presented in tabular and graphic fashion. The trend is said to be decreasing if *Z* is negative and increasing if *Z* is positive. The MAKESENS template application uses the two-tailed test for four different significance levels i.e. α: 0.1, 0.05, 0.01 and 0.001.Where significant trends are observed, the results and level of significance are highlighted within the MAKESENS result table. The magnitude of change per unit over time, direction and significance of the trends are calculated using Sen's slope estimator (Q[units] y^{-1}) as shown by Equation 3.9. A negative sign represents a downward slope and a positive sign indicates an upward slope.

4.2 Musina Local Municipality Climate Anomalies and Trends

4.2.1 Climate Anomalies

The climate anomalies for Musina Local Municipality are illustrated by Figures 4.1 - 4.5. Figure 4.1 shows the rainfall anomalies. For the 30-year analysis period 1998-2010 the area experienced mostly below average rainfall, with only 8 years that had above average rainfall. The year 2000 had the highest positive anomaly (approximately +4) and 2002 experienced the least rainfall with the anomaly of above -1. Figure 4.2 shows the temperature anomalies, and the annual maximum temperatures for Musina are presented in Figure 4.3. There were temperature anomalies of greater than 1 (> +1) in 1983, 1992, 2005 and 2008, while 1988, 1993, 1994 and 2000 observed the least anomalies (< -1). For the first 20 years the maximum temperatures depicted below normal characteristics as compared with the long term mean,

with the exception of 1992 which was > +2 above the mean. In the more recent years (2002-2008), maximum temperatures were above normal, with a peak (> +2) in 2005. The pattern of minimum temperatures (Figure 4.4) was alternating between above, below and near normal. From 2003 to 2005 there were three consecutive years of above normal minimum temperature. Generally, 11 years out of the 30 years had below normal minimum temperatures.

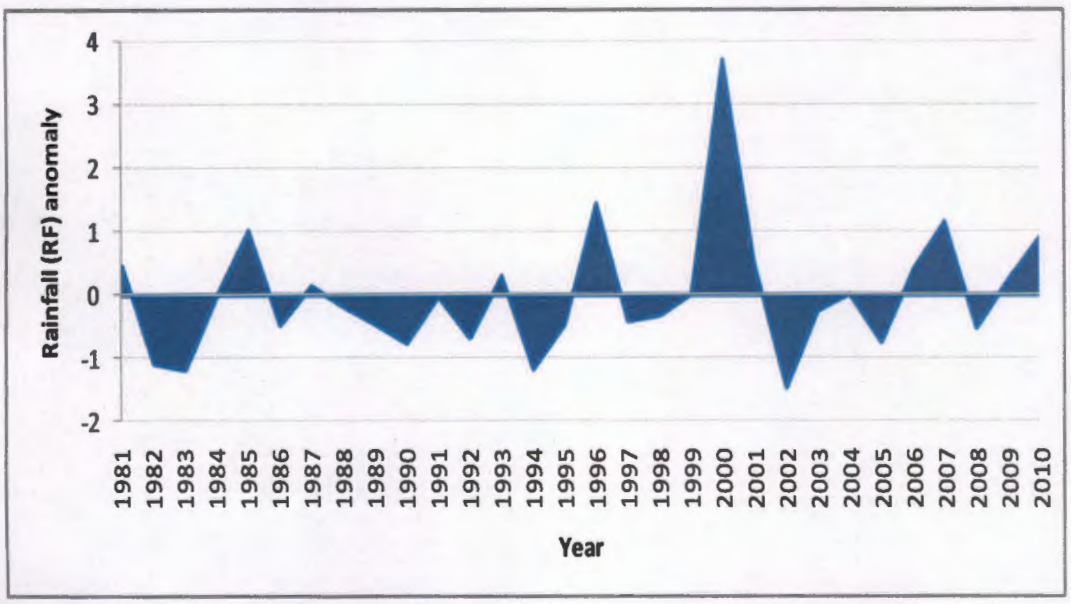


Figure 4.1: Rainfall anomalies in Musina Local Municipality, 1981-2010.

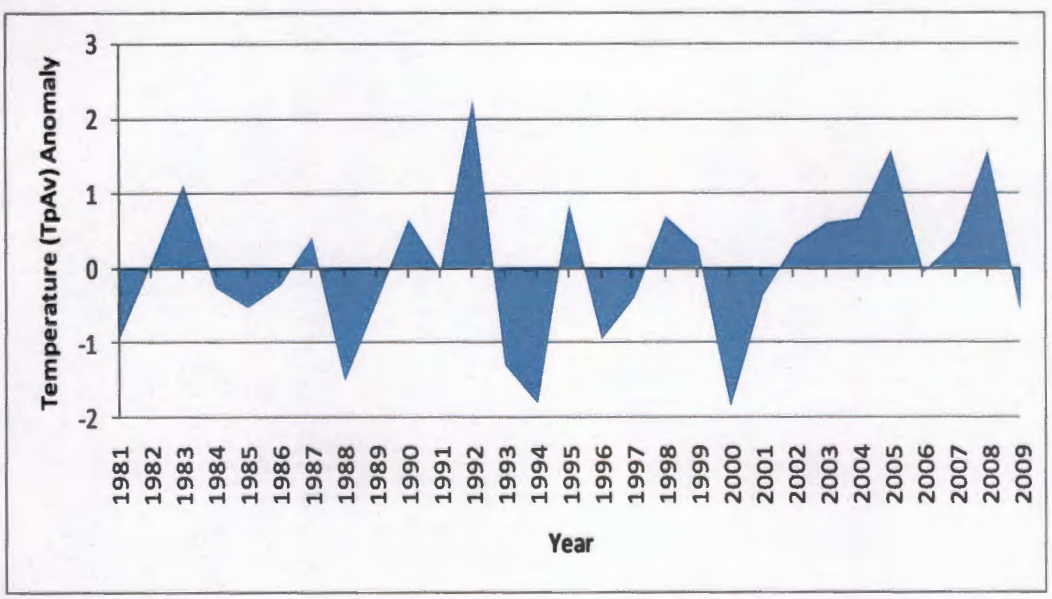


Figure 4.2: Anomalies in air temperature in Musina Local Municipality, 1981-2010.

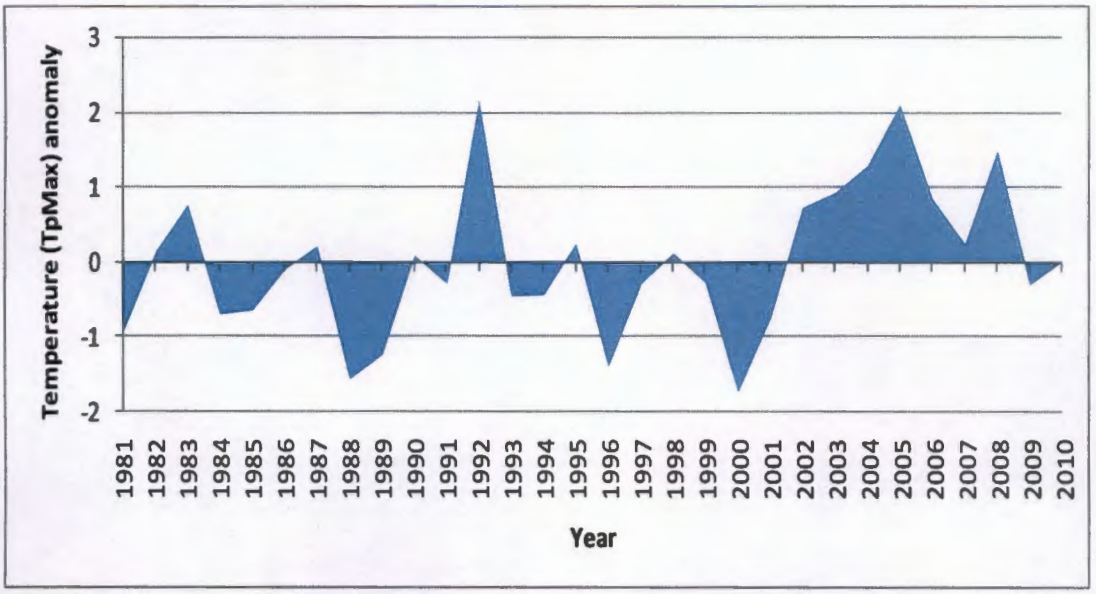


Figure 4.3: Anomalies in maximum temperature in Musina Local Municipality, 1981-2010.

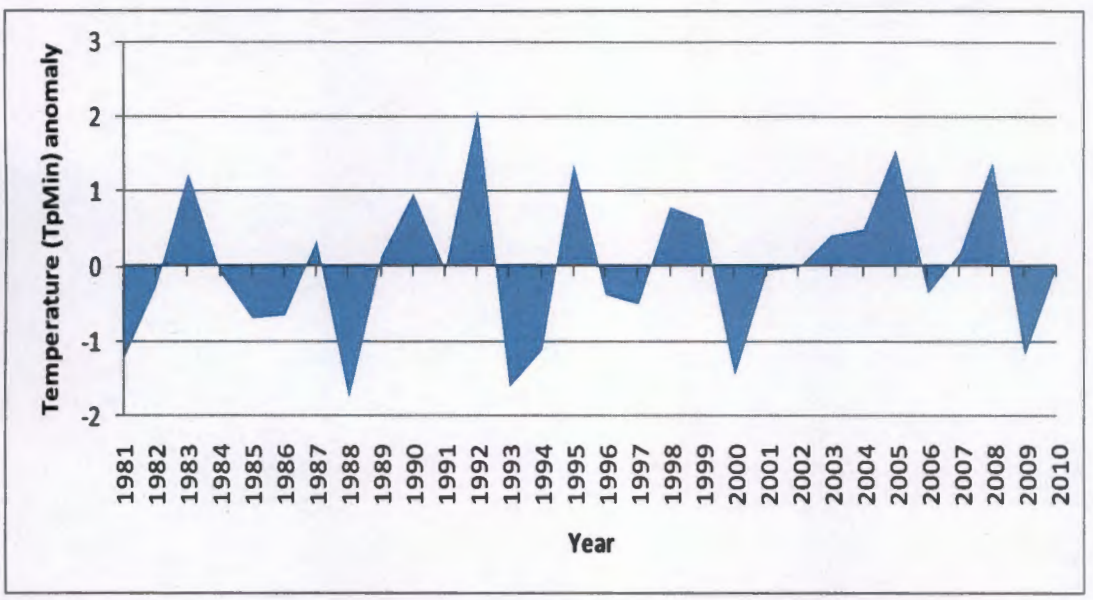


Figure 4.4: Anomalies in minimum temperature in Musina Local Municipality, 1981-2010.

Figure 4.5 illustrates the anomalies in relative humidity for the period 1981 to 2006. It is evident from Figure 4.5 that from 1982 to 1995 the area experienced below normal moisture in the atmosphere, with the exception of 1985 which depicted above normal relative humidity. Thereafter, the most conspicuous period was 1999 to 2001 which experienced above normal humidity with a peak of +2 in 2000.

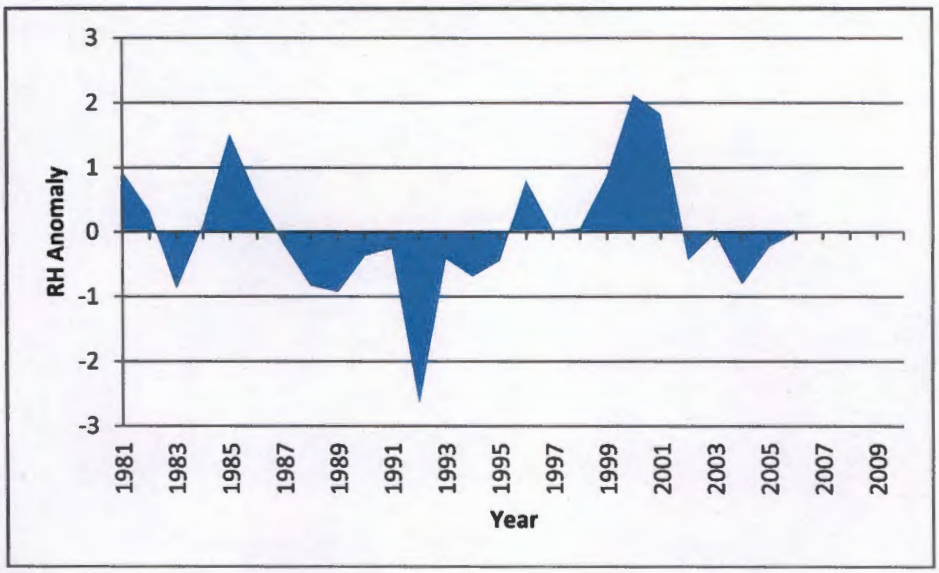


Figure 4.5: Anomalies in Relative Humidity in Musina Local Municipality, 1981-2006.

4.2.2 Climate Trends

The Mann-Kendall test and Sen's slope estimate results for the climate parameters in Musina Local Municipality are shown in Table 4.1. The analysis indicates an increasing trend in all parameters. However, it was only in the annual maximum temperature where a statistically significant increasing trend was detected, though only a weak relationship ($Z = 1.93$; $\alpha = 0.1$). The magnitude of Sen's slope estimate for the increasing maximum temperature trend was 0.04°C/year.

Table 4.1: Mann-Kendall test and Sen's slope estimate results - Musina Local Municipality.

Parameter	First year	Last Year	*n*	Z value and significance	Sen slope estimate (Q)	Units (Q)
Rainfall (Musina RF)	1981	2010	30	1.14	3.103	mm year^{-1}
Air temperature (Musina TpAv)	1981	2009	29	1.11	0.024	°C year^{-1}
Maximum temperature (Musina TpMax)	1981	2009	29	1.93 +	0.040	°C year^{-1}
Minimum temperature (Musina TpMin)	1981	2009	29	1.18	0.021	°C year^{-1}
Relative Humidity (Musina RH)	1981	2005	25	0.00	0.000	% year^{-1}

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

Figures 4.6 - 4.10 are graphical representations of the results in Table 4.1. With the exception of Figure 4.10 (showing Relative Humidity), all the graphs show an increasing trend in the climate elements. No statistically significant trends were detected in all parameters except the weak trend for annual maximum temperature, as shown in Table 1.

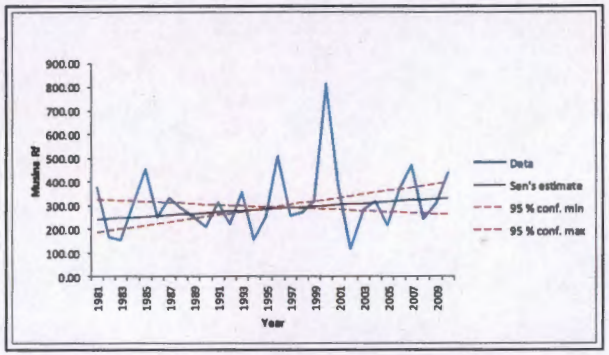


Figure 4.6: Trend analysis for rainfall – Musina.

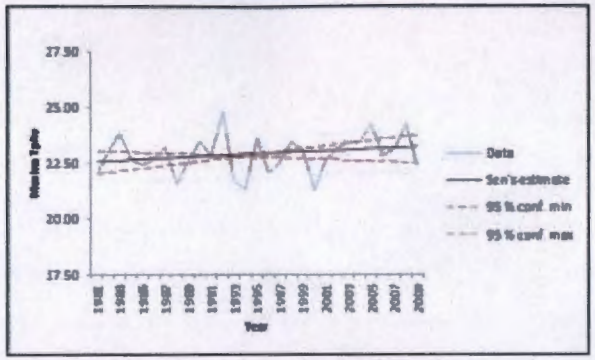


Figure 4.7: Trend analysis for air temperature – Musina.

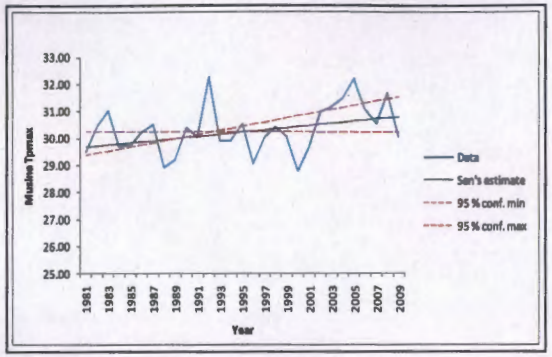


Figure 4.8: Trend analysis for maximum temperature – Musina.

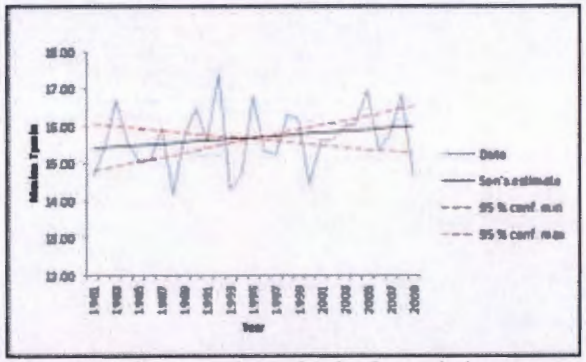


Figure 4.9: Trend analysis for minimum temperature – Musina.

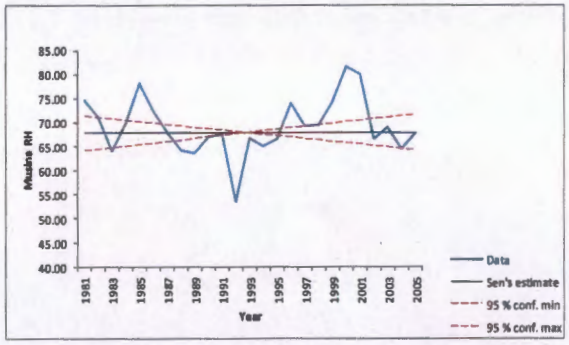


Figure 4.10: Trend analysis for Relative Humidity – Musina.

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4.3 Makhado Local Municipality Climate Anomalies and Trends

4.3.1 Climate Anomalies

The rainfall in Makhado municipality was generally below normal for most of the time except for 1996 and 2000 (Figure 4.11). Air temperature trends showed years of below normal, above normal and near normal temperature (Figure 4.12). From 2002 to 2009, the air temperatures were consistently above normal, but 1981, 1988 and 2000 had very low negative anomalies.

In Figure 4.13 the maximum temperatures in the period of analysis are shown. There were years of above and below normal temperature in the years 1981-1993, followed by seven consecutive years (1994-2001) of below normal temperature, while in recent years (2002-2010) the temperatures have been above normal. The minimum temperatures (Figure 4.14) show three consecutive years of above normal temperatures (1982-1984) followed by nine years of below normal temperature that started in 1985 and culminated in 1994. Thereafter, ten years in succession had above normal temperatures, with only 2000 being cooler. The year 1983 was the warmest year in the analysis period, registering an anomaly of >+1.7.

Figure 4.15 shows the Relative Humidity (RH) anomalies. There were positive anomalies from 1981 to 1985 with near normal Relative Humidity in 1983. A period of eight years that exhibited negative anomalies (1987-1994) then followed. Above normal events were later experienced in 1995 to 2003, with the exception of 1999 which was a dry year. There were no records for 3 years between 2005 and 2008. On resumption of recording of the RH data, negative anomalies were observed in 2009 and 2010.

4.3.2 Climate Trends

Table 4.2 shows the Mann-Kendall test and Sen's slope estimate results for the climate parameters in Makhado Local Municipality. The analyses indicate a statistically significant increasing trend (Z = 2.03, P < 0.05) for the minimum temperature. The magnitude of increase as detected by the Sen's slope estimate (Q) is 0.038°C per year. The other climate parameters did not reveal any statistically significant trend but were mostly increasing, except for the Relative Humidity which showed a decreasing trend. Figures 4.16-4.20 graphically illustrate the data in Table 4.2.

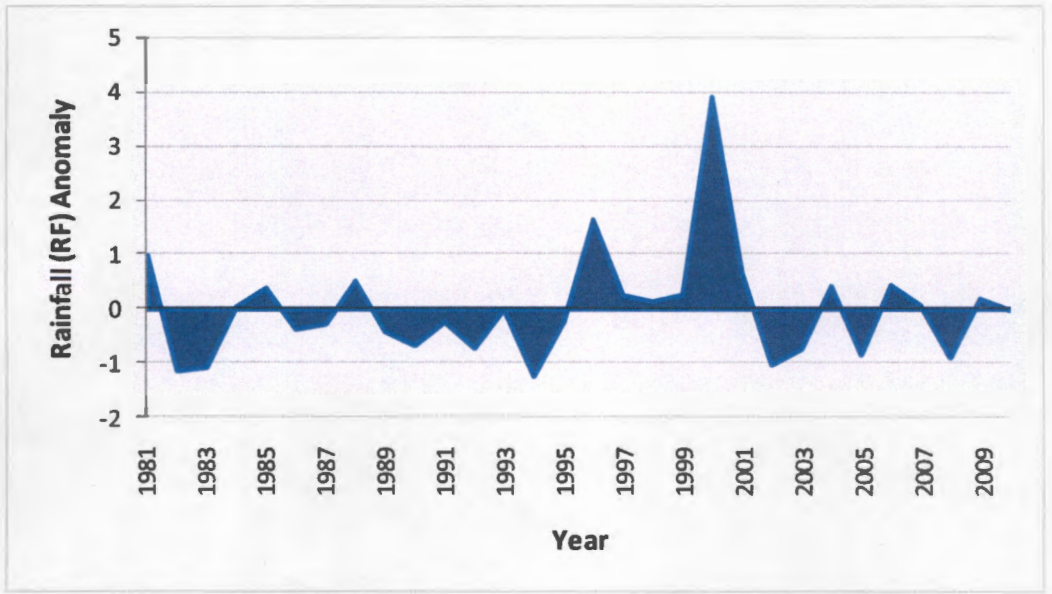


Figure 4.11: Rainfall anomalies in Makhado Local Municipality, 1981-2010.

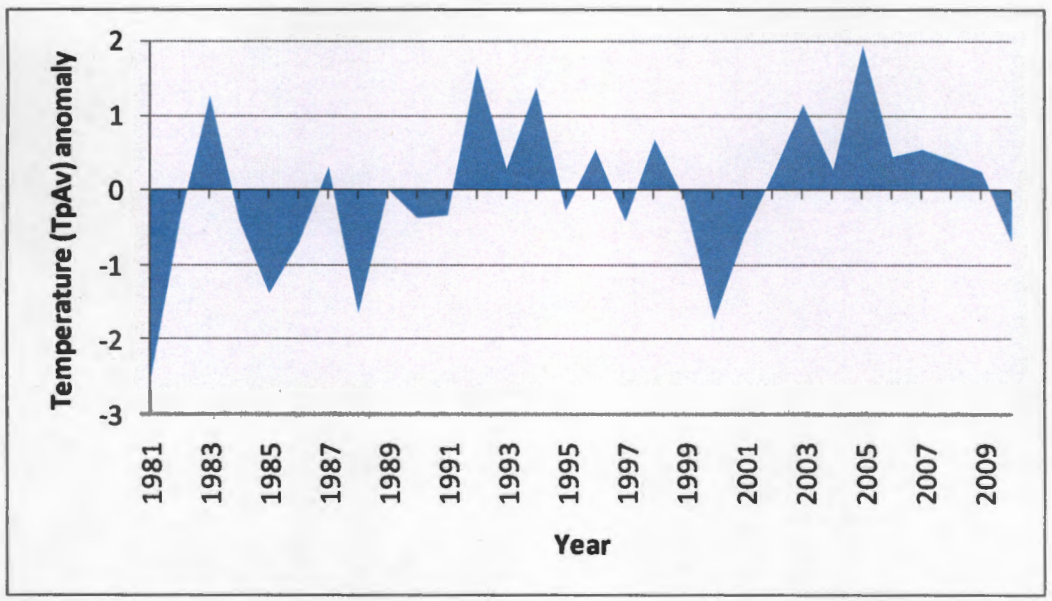


Figure 4.12: Anomalies in air temperature in Makhado Local Municipality, 1981-2010.

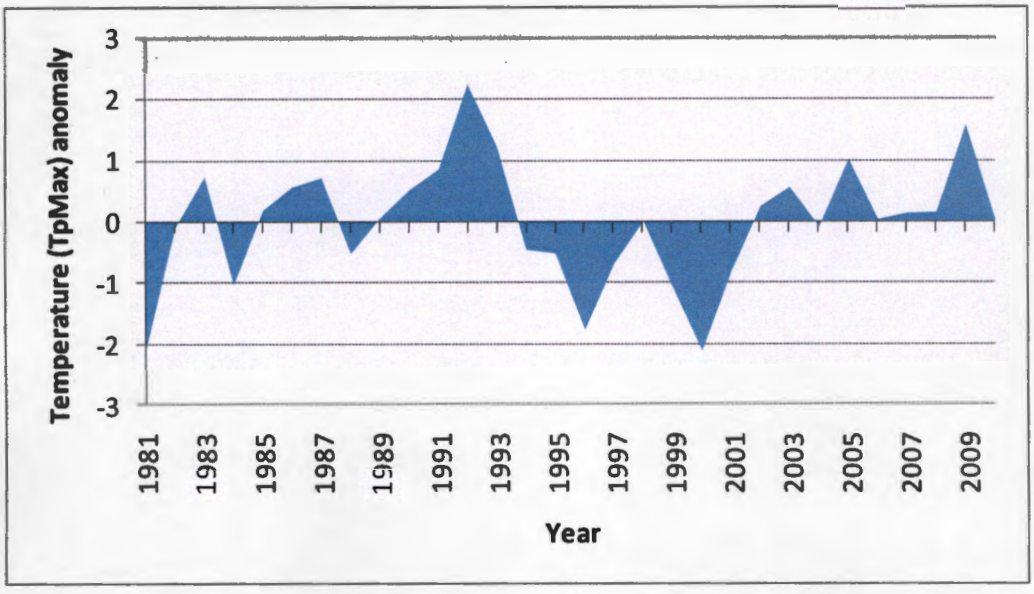


Figure 4.13: Anomalies in maximum temperature in Makhado Local Municipality, 1981-2010.

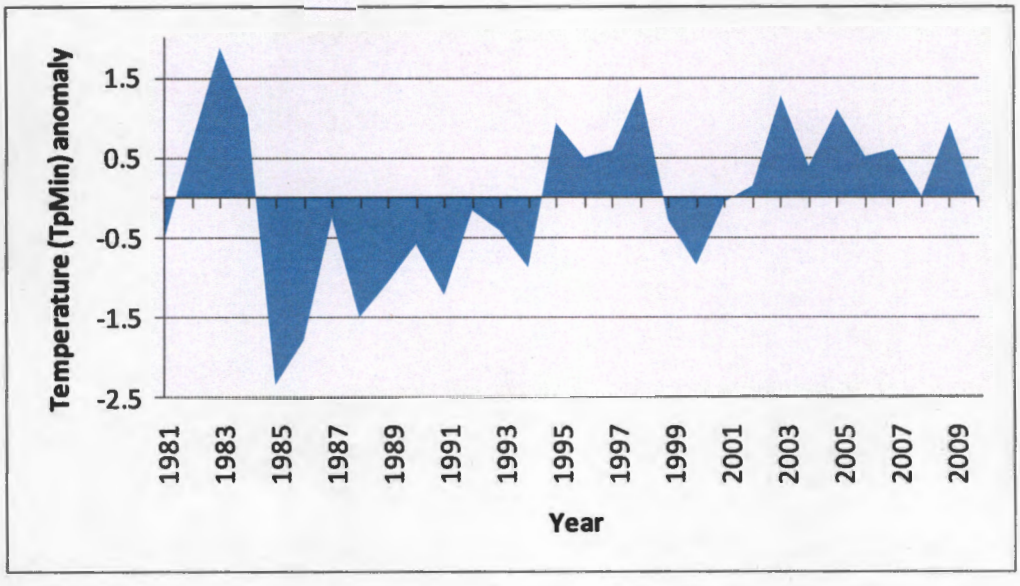


Figure 4.14: Anomalies in minimum temperature in Makhado Local Municipality, 1981-2010.

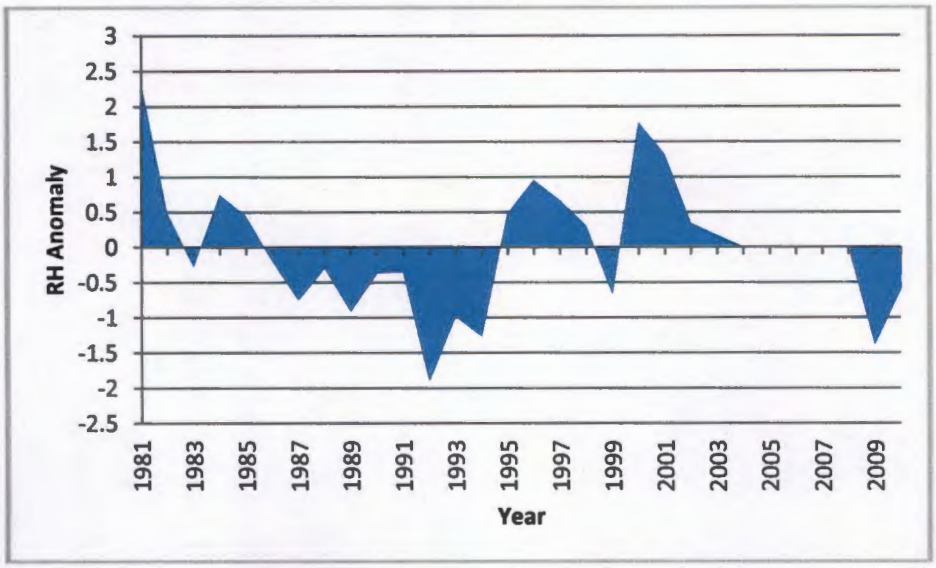


Figure 4.15: Anomalies in Relative Humidity in Makhado Local Municipality, 1981-2010.

Table 4.2: Mann-Kendall test and Sen's slope estimate results - Makhado Local Municipality.

Parameter	First year	Last Year	*n*	Z value and significance	Sen slope estimate (Q)	Units (Q)
Rainfall (Makhado RF)	1981	2010	30	0.61	2.743	mm year^{-1}
Air temperature (Makhado TpAv)	1981	2010	30	1.64	0.018	°C year^{-1}
Maximum temperature (Makhado TpMax)	1981	2010	30	0.50	0.010	°C year^{-1}
Minimum temperature (Makhado Tpmin)	1981	2010	30	2.03*	0.038	°C year^{-1}
Relative Humidity (Makhado RH)	1981	2010	25	-0.82	-0.083	% year^{-1}

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

4.4 Thulamela Local Municipality Climate Anomalies and Trends

4.4.1 Climate Anomalies

The rainfall in Thulamela Local Municipality decreased between 1981 and 2010 (Figure 4.21). There were only four notable above average rainfall years during the period under study; namely 1981, 1988, 1996 and 2000. The rest of the period had below average rainfall, with twelve years experiencing deviations below -0.5. The average air temperatures (Figure 4.22) in Thulamela remained mostly below the area's long-term mean for much time of the period of study. Noticeable positive anomalies were in 1983, 1992, 2003 and 2006; with cooler years being 1988, 2000 and recently in 2010. Figure 4.23 shows the anomalies in maximum temperature, indicating that the warmest year was 1992 which had an anomaly of +2.

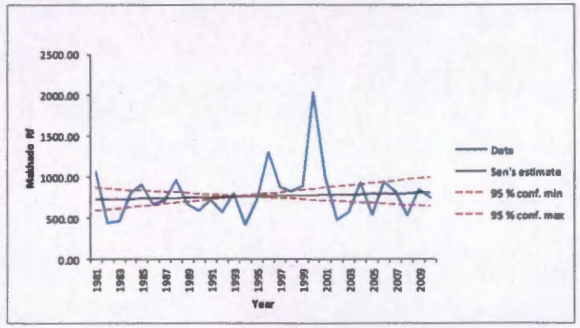


Figure 4.16: Trend analysis for rainfall – Makhado.

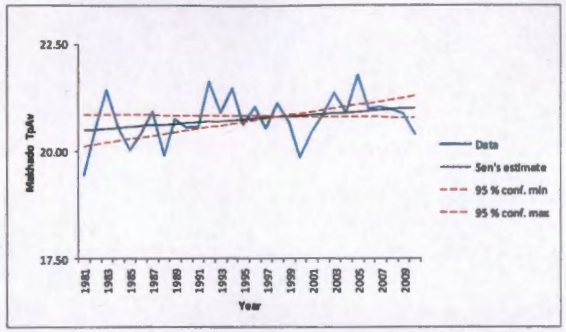


Figure 4.17: Trend analysis for air temperature – Makhado.

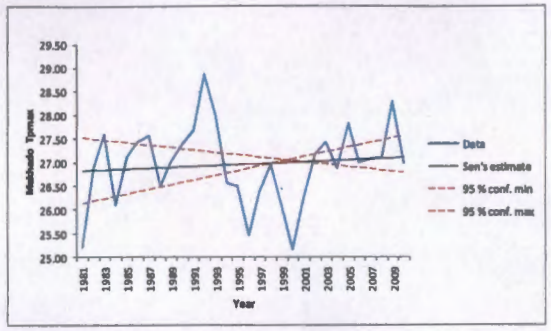


Figure 4.18: Trend analysis for maximum temperature – Makhado.

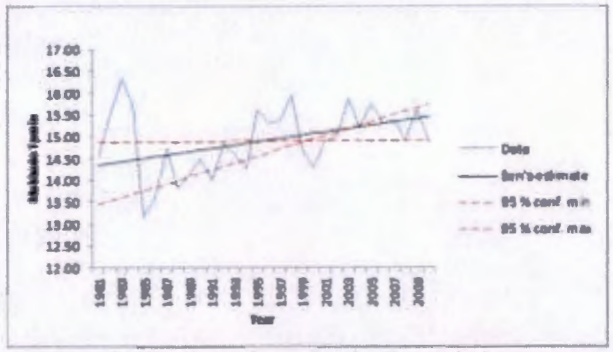


Figure 4.19: Trend analysis for minimum temperature – Makhado.

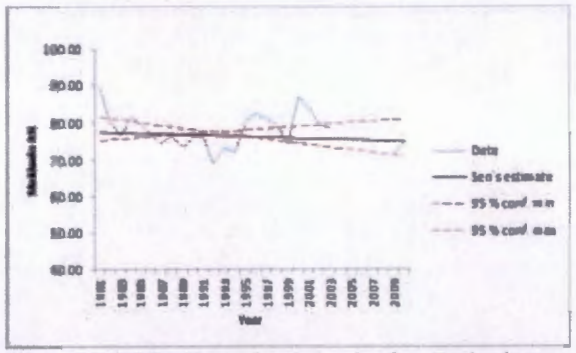


Figure 4.20: Trend analysis for Relative Humidity – Makhado.

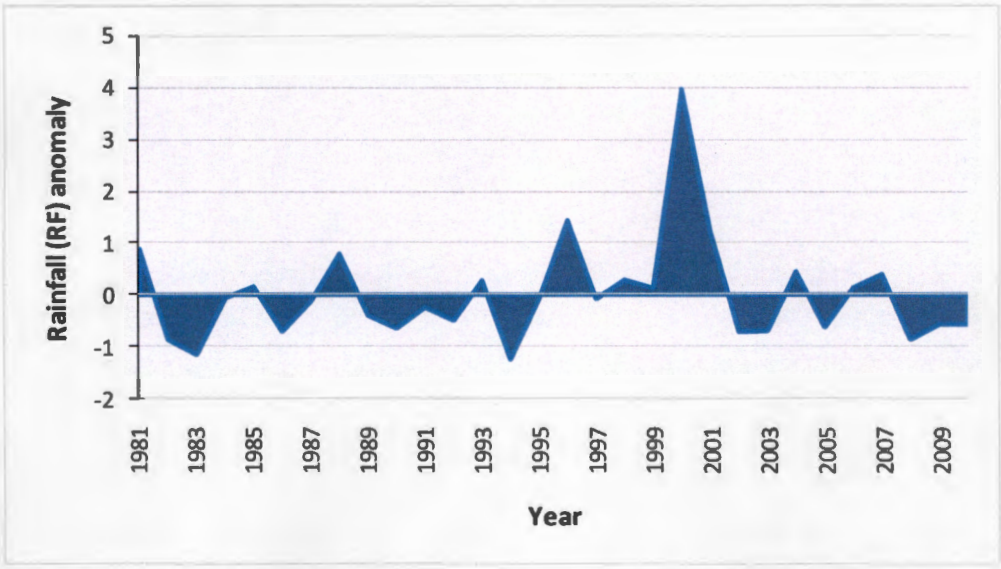


Figure 4.21: Rainfall anomalies in Thulamela Local Municipality, 1981-2010.

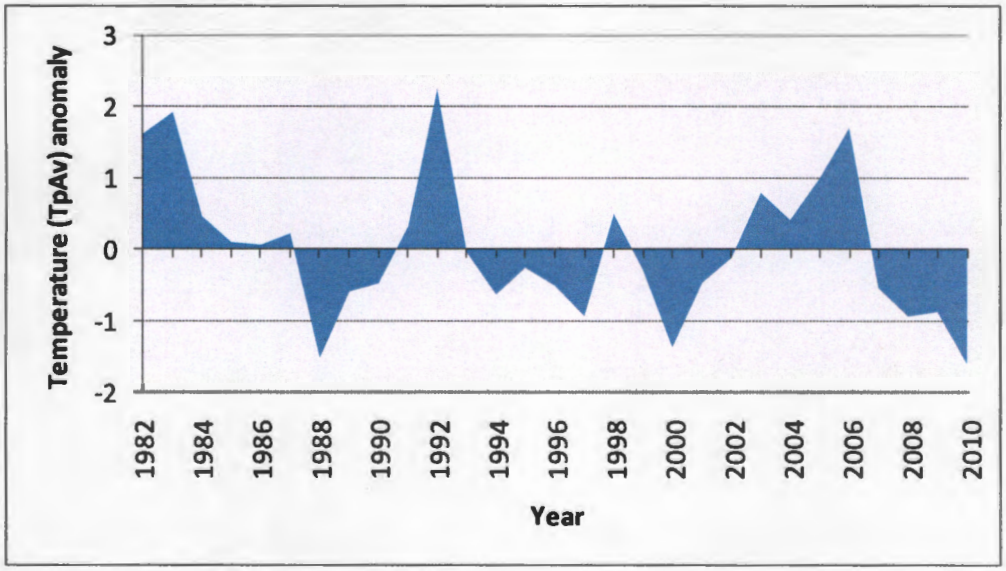


Figure 4.22: Anomalies in air temperature in Thulamela Local Municipality, 1981-2010.

The minimum temperatures (Figure 4.24) started with three years of warm conditions, which were followed by thirteen years of cool events (1981 to 2003). That period was interrupted by three years (1992, 1995 and 1996) of near normal events, and ended with warm years. Figure 4.25 shows the Relative Humidity anomalies, showing that Thulamela experienced an extended dry environment from 1990 to 1995 and moist from 1996 to 2004 when the relative humidity monitoring ceased.

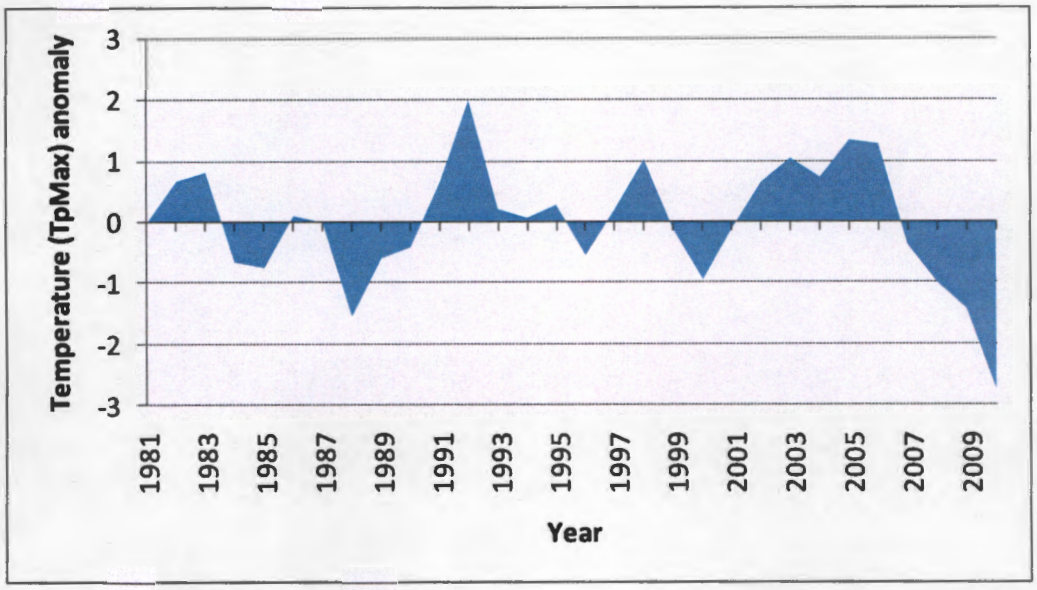


Figure 4.23: Anomalies in maximum temperature in Thulamela Local Municipality, 1981-2010.

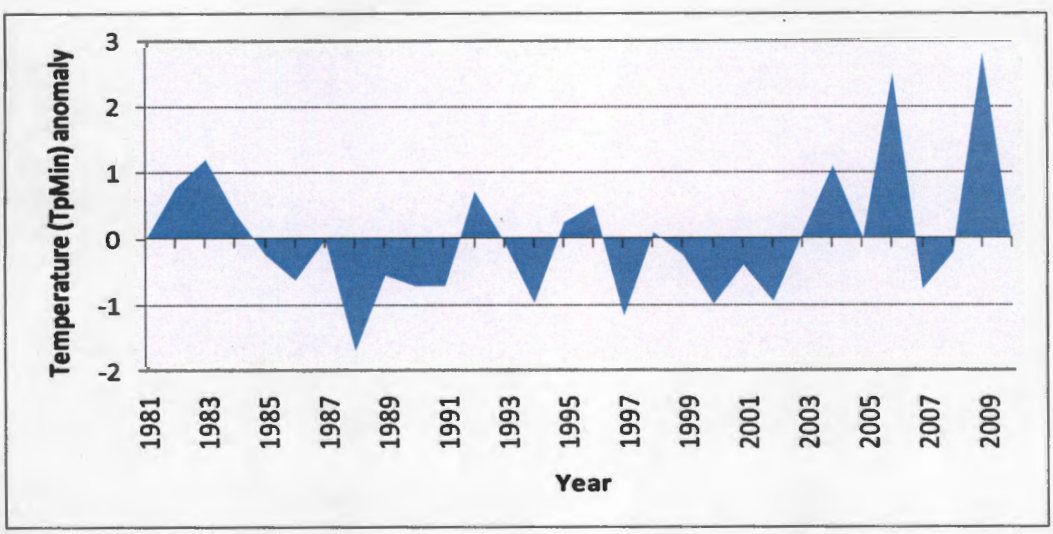


Figure 4.24: Anomalies in minimum temperature in Thulamela Local Municipality, 1981-2010.

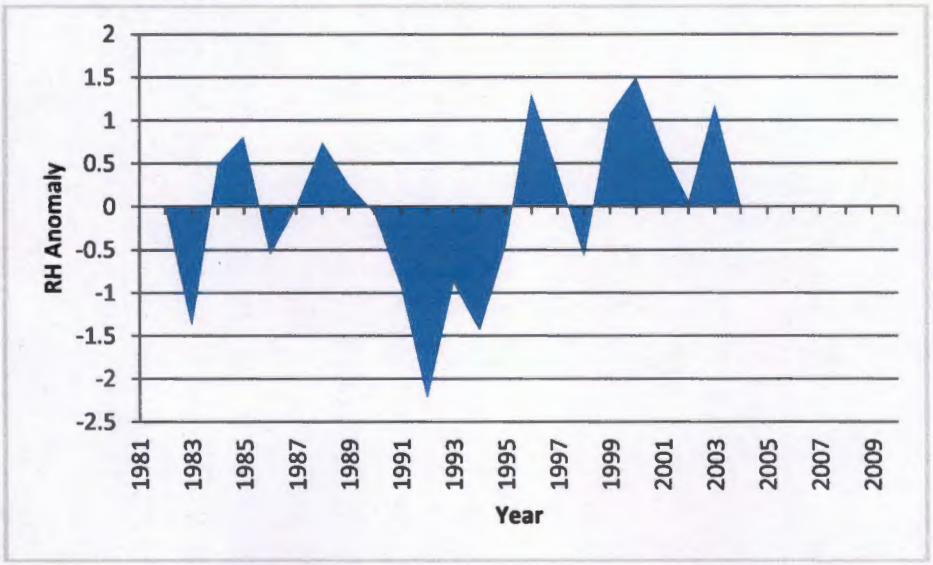


Figure 4.25: Anomalies in Relative Humidity in Thulamela Local Municipality, 1981-2003.

4.4.2 Climate Trends

The trend analysis results for Thulamela Local Municipality are shown in Table 4.3, and graphically illustrated in Figure 4.26 – 4.30. The analysis indicates an increasing trend for the three parameters rainfall, minimum temperature and Relative Humidity, but a decreasing trend for the two parameters air temperature and maximum temperature. Only air temperature showed a statistically significant trend – a weak decreasing trend ($Z = -1.67$, at $\alpha = 0.1$). The magnitude of Sen's slope estimate for the decreasing air temperature trend was -0.031°C/year.

Table 4.3: Mann-Kendal test and Sen's slope estimate results - Thulamela Local Municipality.

Parameter	First year	Last Year	*n*	Z value and significance	Sen slope estimate (Q)	Units (Q)
Rainfall (Thulamela RF)	1981	2010	30	0.21	1.914	mm year^{-1}
Air temperature (Thulamela TpAv)	1982	2010	29	-1.67 +	-0.031	°C year^{-1}
Maximum temperature (Thulamela TpMax)	1982	2010	29	-0.02	-0.003	°C year^{-1}
Minimum temperature (Thulamela TpMin)	1982	2010	29	0.09	0.002	°C year^{-1}
Relative Humidity (Thulamela RH)	1983	2003	21	1.30	0.226	% year^{-1}

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

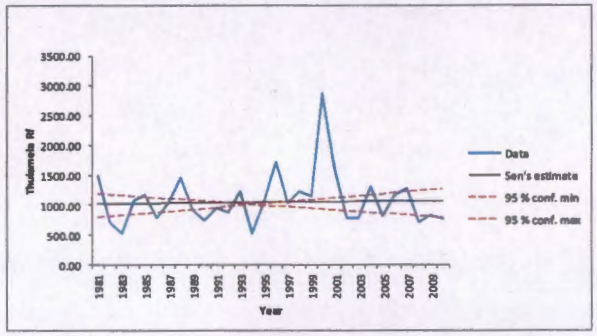


Figure 4.26: Trend analysis for rainfall – Thulamela.

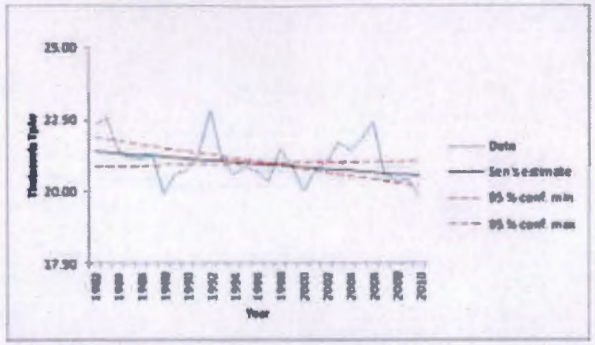


Figure 4.27: Trend analysis for air temperature – Thulamela.

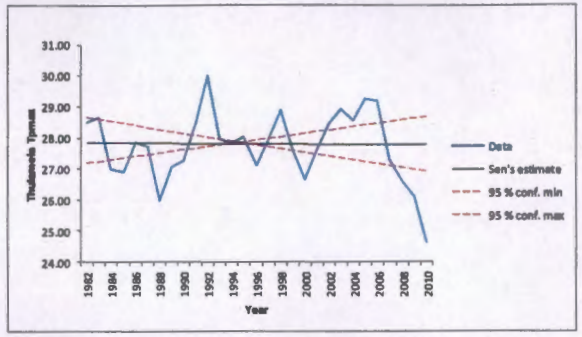


Figure 4.28: Trend analysis for maximum temperature – Thulamela.

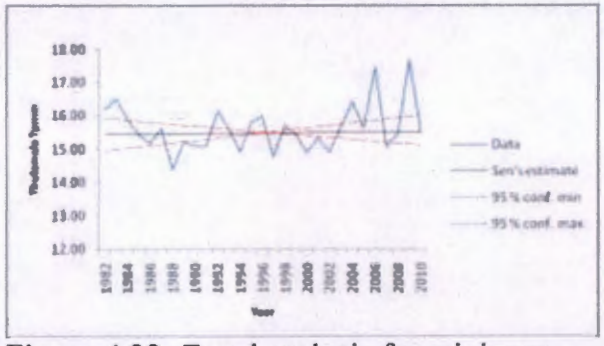


Figure 4.29: Trend analysis for minimum temperature – Thulamela.

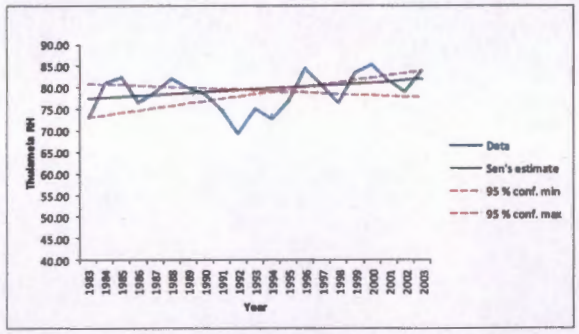


Figure 4.30: Trend analysis for Relative Humidity – Thulamela.

4.5 Mutale Local Municipality Climate Anomalies and Trends

4.5.1 Climate Anomalies

The climate anomalies in Mutale Local Municipality are shown in Figures 4.31- 4.34. For this local municipality only rainfall patterns are considered in depth for the ensuing discussion about climate variability since the records for the other weather parameters (temperature, RH) were too short. However, plots for the short period are provided in order to give inference later when an event coincides with an occurrence that is crucial to the analysis in general.

4.5.2 Climate Trends

Table 4.4 shows the trend analysis statistical results for Mutale Local Municipality, which are graphically illustrated in Figures 4.36-4.40. The results obtained show that only the relative humidity had a statistically significant trend, one of decreasing over time (Z = -1.71, at 90% confidence level). The magnitude of decrease as detected by the Sen's slope estimate (Q) is -0.571% per year. The rainfall and air temperature showed decreasing trends that, however, were not statistically significant. Maximum and minimum temperature showed increasing trends that were also not statistically significant.

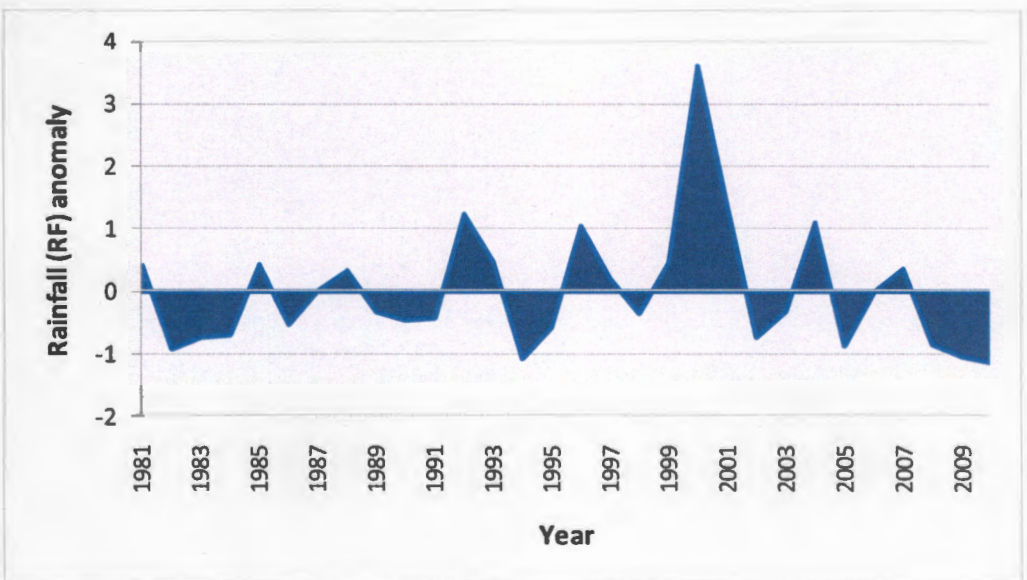


Figure 4.31: Rainfall anomalies in Mutale Local Municipality, 1981-2010.

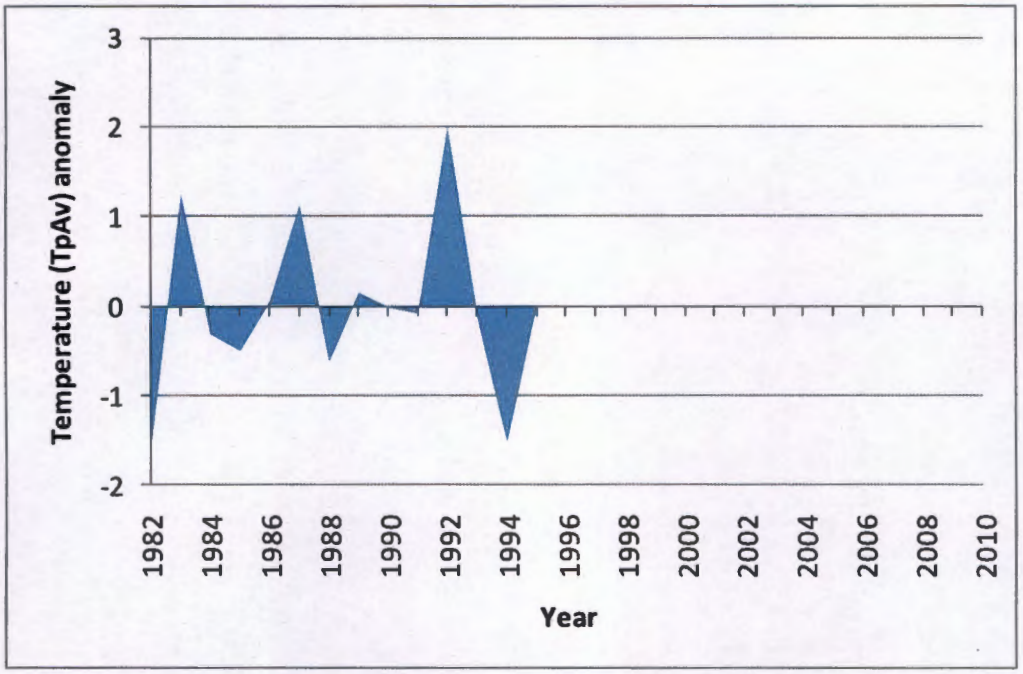


Figure 4.32: Anomalies in air temperature in Mutale Local Municipality, 1982-1995.

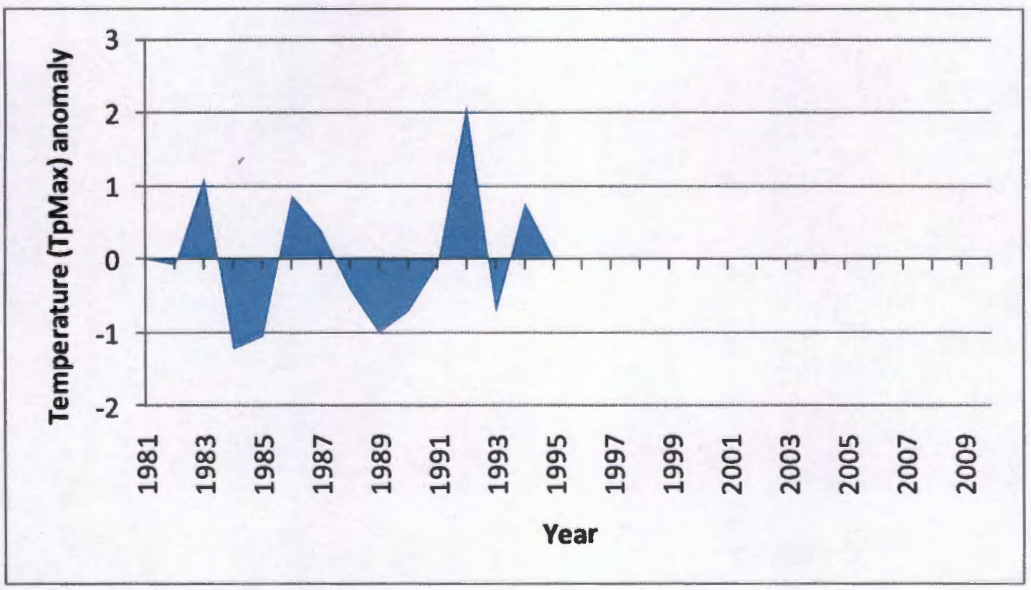


Figure 4.33: Anomalies in maximum temperature in Mutale Local Municipality, 1981-1995.

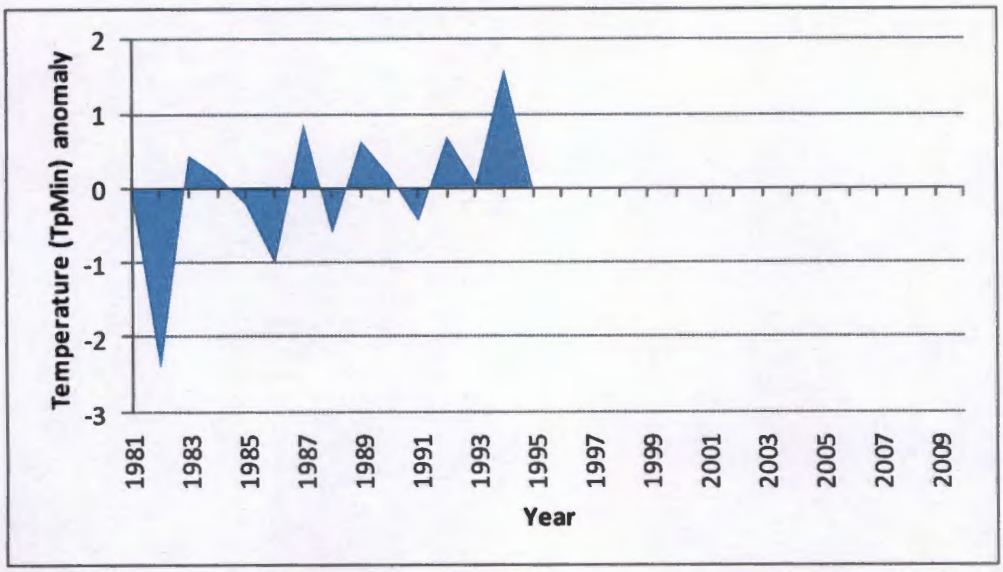


Figure 4.34: Anomalies in minimum temperature in Mutale Local Municipality, 1981-1995.

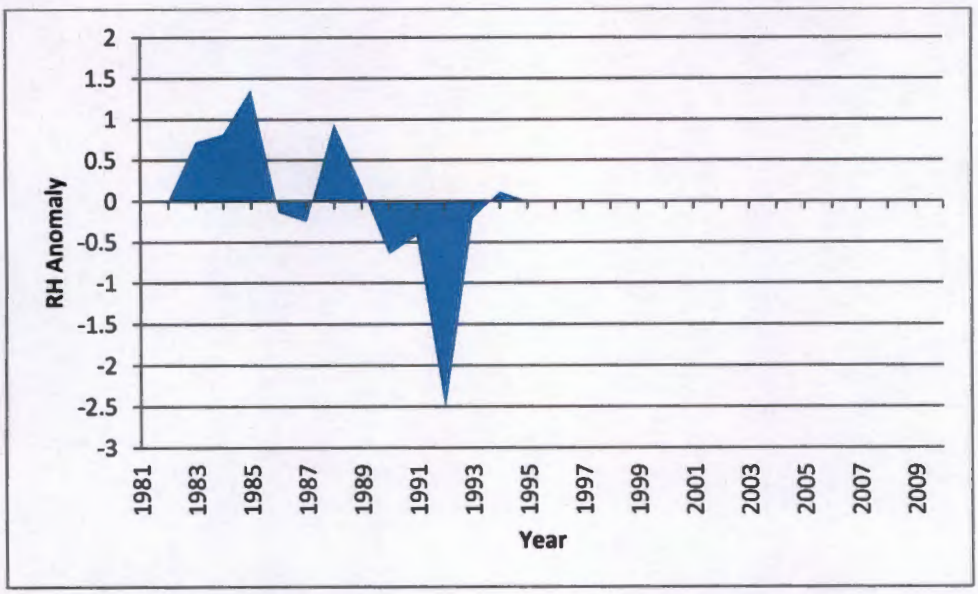


Figure 4.35: Anomalies in Relative Humidity in Mutale Local Municipality, 1982-1995.

Table 4.4: Mann-Kendal test and Sen's slope estimate results – Mutale Local Municipality.

Parameter	**First year**	**Last Year**	***n***	**Z value and significance**	**Sen slope estimate (Q)**	**Units (Q)**
Rainfall (Mutale RF)	1981	2010	30	-0.07	-0.933	mm year^{-1}
Air temperature (Mutale TpAv)	1982	1994	13	-0.06	-0.003	°C year^{-1}
Maximum temperature (Mutale TpMax)	1982	1994	13	0.43	0.031	°C year^{-1}
Minimum temperature (Mutale TpMin)	1982	1994	13	1.40	0.086	°C year^{-1}
Relative Humidity (Mutale RH)	1983	1994	12	-1.71 +	-0.571	% year^{-1}

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

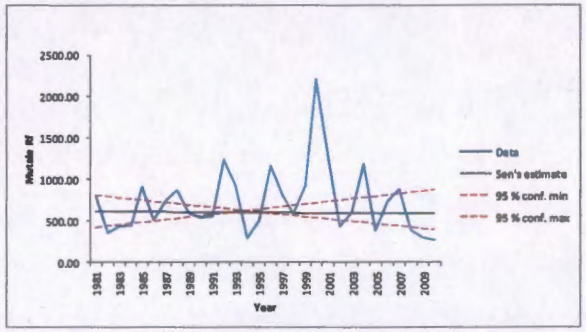


Figure 4.36: Trend analysis for rainfall – Mutale.

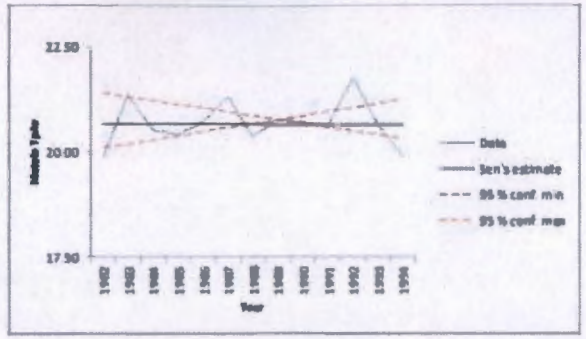


Figure 4.37: Trend analysis for air temperature – Mutale.

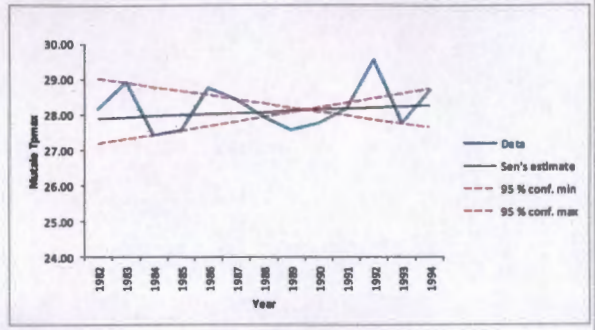


Figure 4.38: Trend analysis for maximum temperature – Mutale.

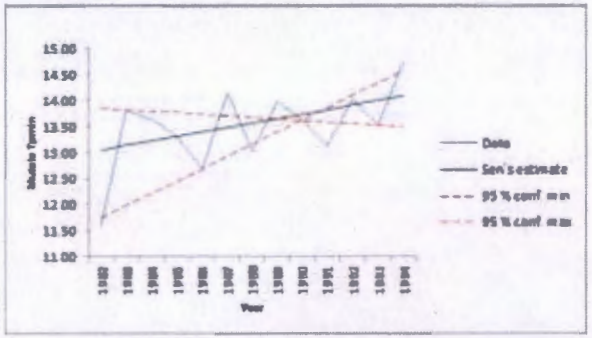


Figure 4.39: Trend analysis for minimum temperature – Mutale.

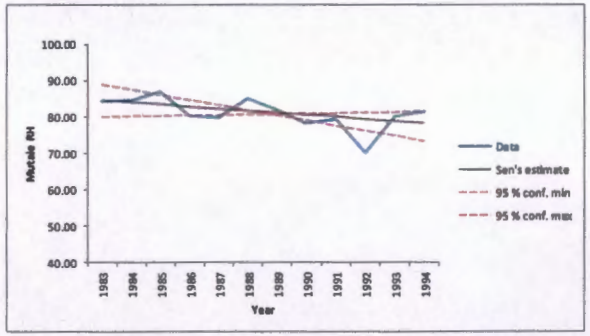


Figure 3.40: Trend analysis for Relative Humidity – Mutale.

4.6 Climate Anomalies and Trends in Vhembe District

In this section the data from individual municipalities are combined in analysis of climate variability in Vhembe District as a whole. The resulting patterns for the various climate elements are discussed in the subsequent subsections.

4.6.1 Climate Anomalies

Figure 4.41 shows the rainfall anomalies in Vhembe District between 1981 and 2010. Generally, most of the years experienced reduction in rainfall with over 60% of the study period having below normal rainfall. Striking positive anomalies were in 1996 and 2000, their anomaly values being +1.6 and +4, respectively.

The anomalies in air temperature are presented in Figure 4.42. The years 1983, 1992 and 1998 had above normal air temperature, while 5 years consecutive (2002 to 2009) were also anomalously warm with anomaly values ranging from +0.5 to +2. The years 1988, 2000 and 2010, on the other hand, had notably below normal air temperatures with 2010 having an anomaly exceeding -2. The maximum temperatures (Figure 4.43) trend shows a cool period from 1984 to 1990, and a warm period from 2002 to 2007 as the two prominent features. In between these two features were years of alternating warm, near normal and cool situations. The year 2010 recorded extremely low temperatures, with an anomaly below -2.5.

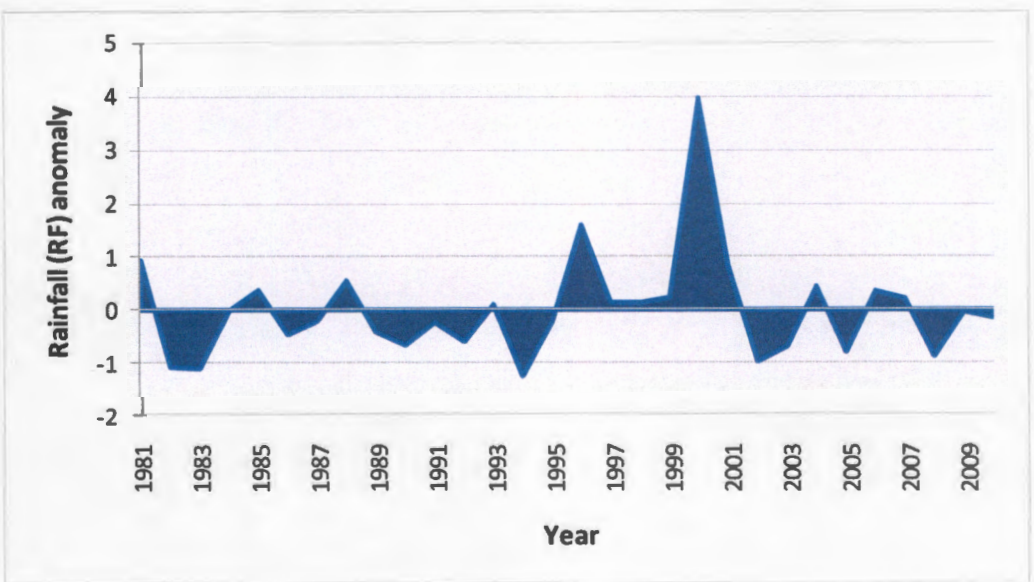


Figure 4.41: Rainfall Anomalies in Vhembe District, 1981-2010.

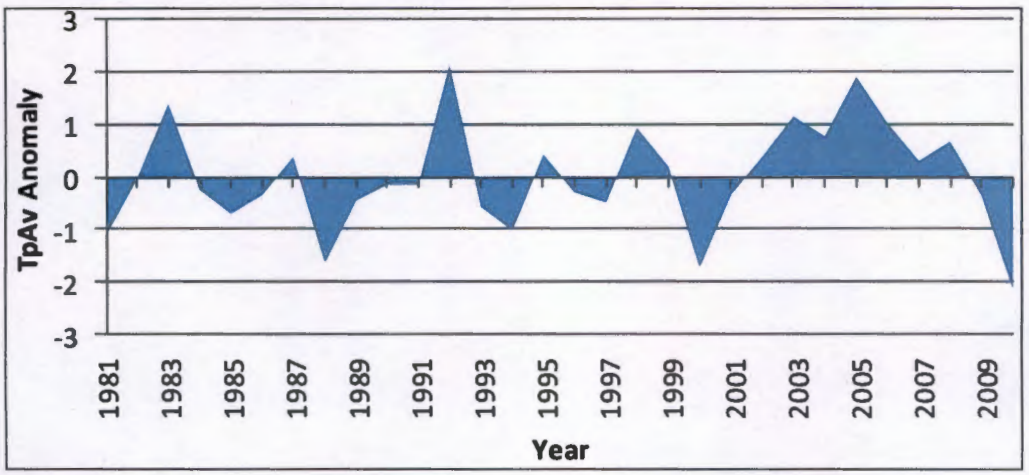


Figure 4.42: Anomalies in air temperature in Vhembe District, 1981-2010.

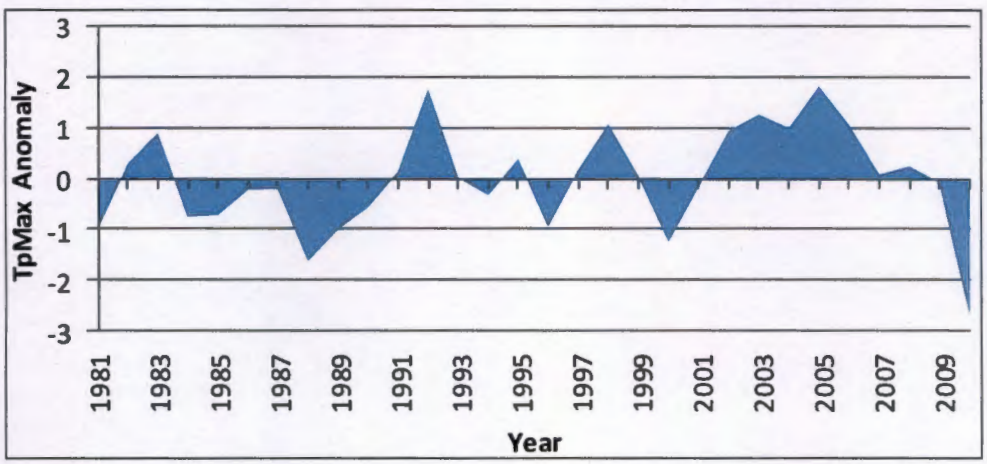


Figure 4.43: Anomalies in maximum temperature in Vhembe District, 1981-2010.

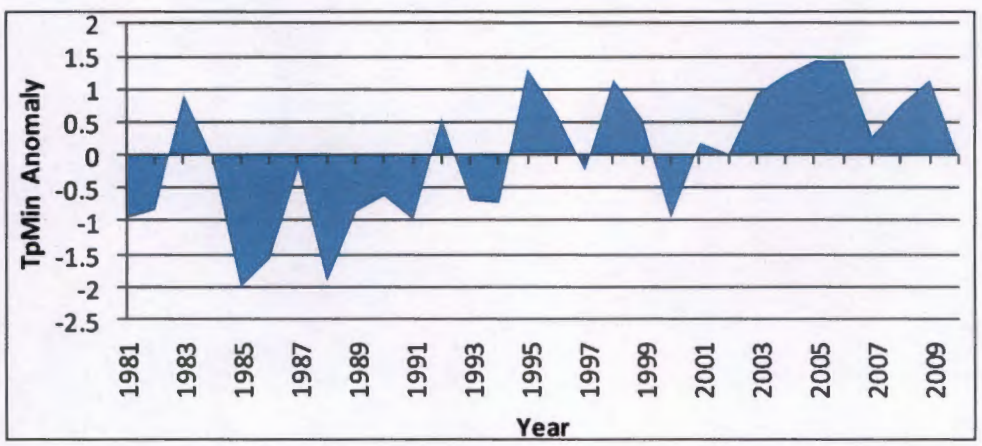


Figure 4.44: Anomalies in minimum temperature in Vhembe District, 1981-2010.

The minimum average temperatures trends (Figure 4.44) featured extended cooling from 1981 to 1994 with brief interruptions in 1983 and 1992. From 1995 to 2010, minimum temperatures were higher, except for the year 2000.

The Relative Humidity anomalies in Vhembe District in the study period are illustrated in Figure 4.45. The atmosphere was relatively moist from 1981 to 1988. Thereafter, a dry period which reached a peak of negative anomalies (-2) in 1992 was observed from 1989 to 1995. High positive anomalies were registered in 1996, 2000 and 2001, while 2004 had an anomalously dry atmosphere.

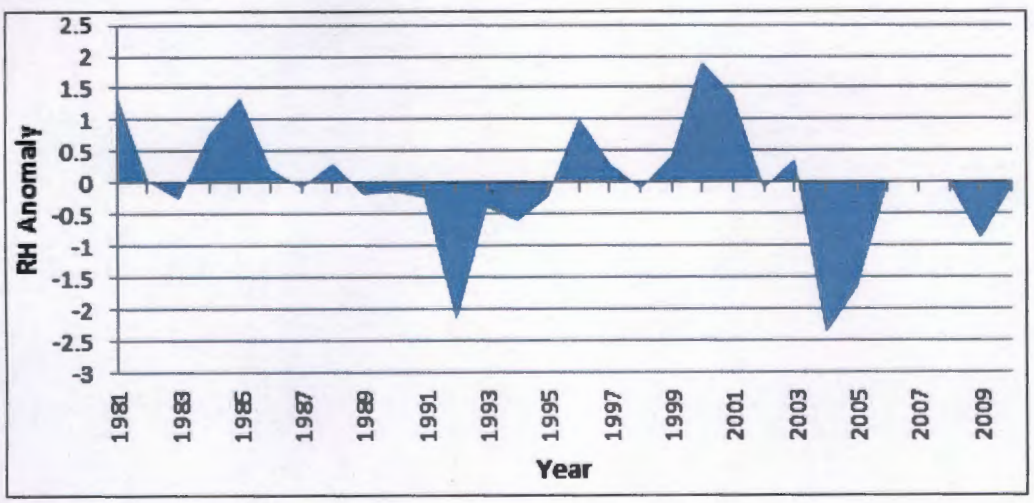


Figure 4.45: Anomalies in Relative Humidity in Vhembe District, 1981-2010.

4.6.2 Climate Trends

Table 4.5 shows the Mann-Kendall test and Sen's slope estimate results for the climate parameters in Vhembe District as a whole. The increasing trend in minimum temperature was statistically significant, with Z value of 3.28 (at a significance level of 99%). The Sen's slope estimate (Q) was 0.050°C per year. Another statistically significant trend, though weak, was the trend of increase in maximum temperature ($Z = 1.17$, at $\alpha = 0.1$) shown in Figure 4.48. The magnitude of the Sen's slope estimate was 0.032°C/year. Rainfall and air temperature depicted increasing trends which, however, were not statistically significant. Relative Humidity had a decreasing trend which was also not statistically significant. Figures 4.46 - 4.50 show the trend analysis graphs of these climate parameters.

Table 4.5: Mann-Kendal test and Sen's slope estimate results – Vhembe District Municipality.

Parameter	First year	Last Year	*n*	Z value and significance	Sen slope estimate (Q)	Units (Q)
Rainfall (Vhembe RF)	1981	2010	30	0.39	2.611	mm year^{-1}
Air temperature (Vhembe TpAv)	1981	2010	30	1.07	0.017	°C year^{-1}
Maximum temperature (Vhembe TpMax)	1981	2010	30	1.71+	0.032	°C year^{-1}
Minimum temperature (Vhembe TpMin)	1981	2010	30	3.28**	0.050	°C year^{-1}
Relative Humidity (Vhembe RH)	1981	2010	27	-1.13	-0.121	% year-1

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

4.7 Summary and Discussion

The Mann-Kendall trend analysis and Sen's slope estimate were performed for the weather parameters of total annual rainfall, air temperature, maximum temperature, minimum temperature and Relative Humidity in the four local municipalities in Vhembe District. The same analysis was conducted for the combined data of Vhembe District. An analysis of results for Musina Local Municipality showed a weak statistically significant increasing trend ($Z = 1.93$, at $\alpha = 0.1$) and the magnitude of Sen's slope estimate for the increasing maximum temperature trend was 0.040°C/year. For Makhado Local Municipality there was a statistically significant increasing trend ($Z = 2.03$, at 95% level of significance) for the minimum temperature. The magnitude of increase for the Makhado minimum temperature was detected by the Sen's slope estimate (Q) as 0.038°C per year.

For Thulamela Local Municipality, only the average annual air temperature showed a statistically significant increasing trend ($Z = -1.67$, at $\alpha=0.1$ and $Q = -0.031$°C/year). The results for Thulamela showed that only Relative Humidity had a statistically significant decreasing trend (Z value = -1.71 at 90% confidence level). The magnitude of decrease as detected by the Sen's slope estimate (Q) was -0.571% per year. For Vhembe District as a whole, there were only two statistically significant increasing trends: maximum temperature ($Z = 1.71$ at 90% level of significance) and minimum temperature ($Z = 3.28$ at 99% significance level). The magnitude of increase as detected by the Sen's slope estimate was 0.032°C per year for the maximum temperature and 0.050°C per year for the minimum temperature. Table 4.6 summarises the trends and their significance for the various climatological elements analysed as discussed in sections 4.2 to 4.6.

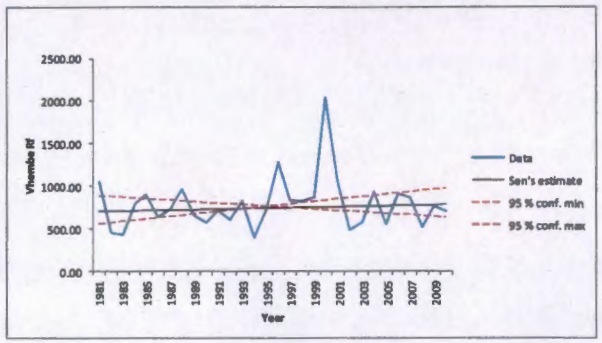


Figure 4.46: Trend analysis for rainfall in Vhembe District.

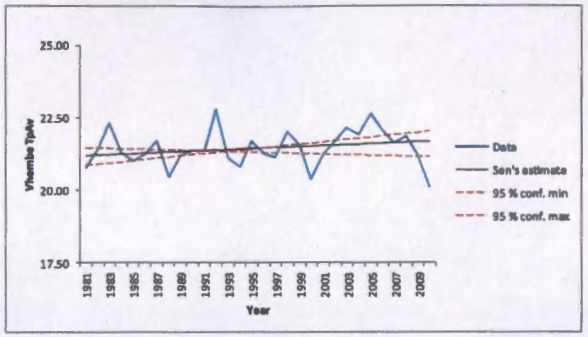


Figure 4.47: Trend analysis for air temperature in Vhembe District.

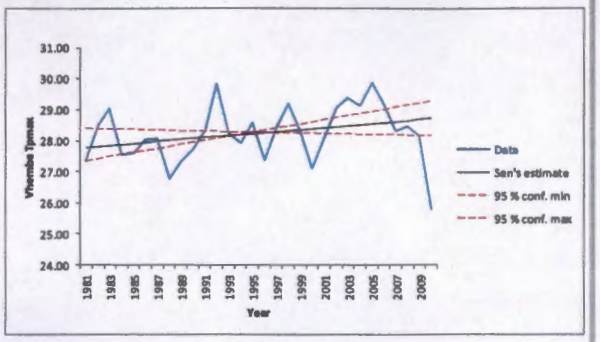


Figure 4.48: Trend analysis for maximum temperature in Vhembe District.

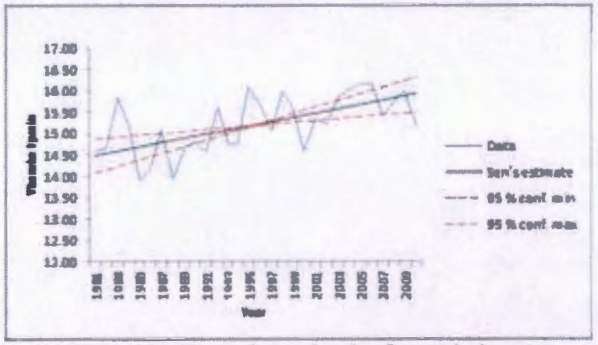


Figure 4.49: Trend analysis for minimum temperature in Vhembe District.

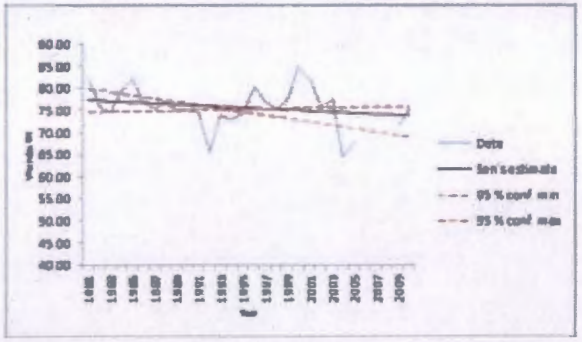


Figure 4.50: Trend analysis for Relative Humidity in Vhembe District.

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Table 4.6: Summary of trend analysis for climate elements in Vhembe District, 1981-2010.

Climatological Element	Municipality	Z-Statistic for Statistical Significance	Z-Statistic for Statistical non-Significance
Rainfall (RF)	Musina		1.14 $\alpha > 0.1$
	Makhado		0.61 $\alpha > 0.1$
	Mutale		-0.07 $\alpha > 0.1$
	Thulamela		0.21 $\alpha > 0.1$
	Vhembe		0.39 $\alpha > 0.1$
Average Temperature (T_pAv)	Musina		1.11 $\alpha > 0.1$
	Makhado		1.64 $\alpha > 0.1$
	Mutale		-0.06 $\alpha > 0.1$
	Thulamela	-1.67 $\alpha = 0.1$	
	Vhembe		1.07 $\alpha > 0.1$
Average Maximum Temperature (T_pMax)	Musina	1.93 $\alpha = 0.1$	
	Makhado		0.5 $\alpha > 0.1$
	Mutale		0.43 $\alpha > 0.1$
	Thulamela		-0.02 $\alpha > 0.1$
	Vhembe	1.71 $\alpha = 0.1$	
Average Minimum Temperature (T_pMin)	Musina		1.18 $\alpha > 0.1$
	Makhado	2.03 $\alpha = 0.05$	
	Mutale		1.4 $\alpha > 0.1$
	Thulamela		0.09 $\alpha > 0.1$
	Vhembe	3.28 $\alpha = 0.001$	
Relative Humidity (RH)	Musina		0 $\alpha > 0.1$
	Makhado		-0.82 $\alpha > 0.1$
	Mutale	-1.71 $\alpha = 0.1$	
	Thulamela		1.3 $\alpha > 0.1$
	Vhembe		-1.13 $\alpha > 0.1$

Table 4.7: Summary of climate parameter ranges and averages for the local municipalities in Vhembe District, 1981-2010.

Municipality	Statistic	Rainfall (mm)	Air Temperature (°C)	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative Humidity (%)
Musina	Range	115-815	21.2-24.8	28.7-32.3	14.1-17.4	53.5-81.8
	Average	313	22.9	30.3	15.7	69.2
Makhado	Range	475-2027	19.4-21.8	25.1-28.9	13.1-16.3	68.9-89.7
	Average	796	20.8	27	14.9	78.2
Thulamela	Range	779-2876	19.8-22.8	24.6-30.0	14.3-17.7	69.2-85.4
	Average	1089	21.1	27.7	15.6	78.9
Mutale	Range	428-2204	19.8-21.8	27.4-29.6	11.6-14.7	70-87
	Average	726	20.7	28.2	13.5	81
Vhembe District	Range	485-2093	20.1-22.8	25.8-29.9	13.8-16.2	64.4-84.7
	Average	789	21.4	28.2	15.2	75.7

Table 4.7 summarises the 30-year period climate ranges for the four local municipalities in Vhembe District. Musina Local Municipality showed the lowest rainfall range and Thulamela had the highest. Musina's Relative Humidity was the lowest at 69.2% in comparison with the other municipalities. The temperature ranges were similar but with very trifling differences. In terms of rainfall, Musina experienced the least amount of rainfall at 313 mm per annum, and Thulamela the highest at 1089 mm per annum. This can be attributed to the Orographic effect as winds rise over the Soutpansberg Mountains from the south east, as stated in Section 1.8 and illustrated in Figure 1.6. The rainfall pattern in Musina Local Municipality was quite varied in the analysis period 1981-2010. This is reflected in the anomalies pertaining to Musina Local Municipality (Section 4.2). Although there was a positive Z statistic value of 1.14, the trend was not statistically significant, which reveals the degree of variation in the annual rainfall.

Musina Local Municipality had the lowest annual rainfall range of between 115 mm and 815mm, and an average of 313mm in comparison with the other municipalities within Vhembe District during the same period. The highest rainfall in Musina was experienced in 2000. The annual air temperature in Musina ranged between 21°C and 25°C, with no

significant trend established between 1981 and 2010. In general the air temperatures were below the average during the period of study.

The annual maximum temperature for Musina Local Municipality usually ranges between 28°C and 33°C. From 1982 to 2010, the annual maximum was consistently above average. This explains why a statistically significant trend of increase in maximum temperature was observed in Musina, with a Z statistic 1.93 at α=0.1. Such an increase in temperature is conducive to the breeding of mosquitoes if the other conditions are conducive as well. Studies have shown that mosquitoes proliferate faster and show higher biting rates as temperature increases (Yang *et al.*, 2012). However, increases in the maximum temperature above 35°C may jeopardise the survival of adult anopheles mosquitoes and dry up ponds rapidly, which will then affect further propagation of malaria beyond a certain threshold (Basurko *et al.*, 2011). The annual minimum temperature for Musina, which usually ranges between 14 and 18°C, was fluctuating but it showed a statistically non-significant slightly increasing trend. The relative humidity in Musina Local Municipality, which ranges between 53% and 82%, showed no statistically significant trend between 1981 and 2010; thereby highlighting its variability.

In Makhado Local Municipality the rainfall showed a positive Z statistic value of 0.61. Makhado rainfall ranges between 475 mm and 2030 mm as indicated in Table 4.7. The annual air temperature in Makhado ranges between 19 and 22°C, and from 1982 to 2010 the air temperatures were above average. Trend analysis revealed a positive but statistically non-significant Z statistic. The maximum temperature for Makhado, which usually ranges between 25 and 29°C, was consistently above average from 1982 to 1993 and 2002 to 2010. Makhado Local Municipality's annual minimum temperature showed a statistically significant increase (Z = 2.03, α=0.05). Such temperature increases in malaria endemic areas make the conditions more favourable for mosquito breeding if the other conditions are conducive. The annual minimum temperature ranged between 13°C and 17°C between 1981 and 2010, with an initial colder period from 1981 to 1993, and then warmer climate from 1994 to 2010. Relative Humidity in Makhado ranged between 68% and 90%, and showed a decreasing trend which, however, was not statistically significant.

The annual rainfall in Thulamela Local Municipality showed no statistically significant trend in the period under study. The highest rainfall was received in 2000, with other wet years being 1996 and 2001. The average rainfall ranged between 779 mm and 2 880 mm, making Thulamela Local Municipality the wettest in Vhembe District. The years 1983 and 1994 received notably low rainfall amounts. The annual air temperatures which usually range between 19 and 23°C, revealed a weak statistically significant trend for the period 1981 to 2010 with a negative Z statistic of -1.67 at α=0.1. The annual maximum temperature for Thulamela, which usually ranges between 24°C and 30°C, was varied and declining in the more recent years. The annual minimum temperature, which ranges between 14°C and 18°C, showed a fluctuating but increasing trend between 1982 and 2010. There were more years with high minimum temperatures in comparison with years that had lower minimum temperatures. However, no statistically significant trend was detected for Thulamela's minimum temperature. The annual Relative Humidity ranged between 69% and 86%, making Thulamela Local Municipality the second most humid in Vhembe District.

Mutale Local Municipality had a lot of rainfall variability between 1981 and 2010, with no significant trend. The rainfall ranged between 428 mm and 2 204 mm, with an average of 726mm. This positions Mutale in an intermediate position among the local municipalities on Vhembe District in terms of the amount of rainfall received. The annual air temperature, which usually ranges between 19°C and 22°C, was equally variable. Trend analysis did not detect any statistically significant trend for the period 1982 to 1994. The annual maximum temperature for Mutale, which usually ranges between 27°C and 30°C, showed fluctuations; hence no statistically significant trend was identified. The minimum temperature ranged between 11°C and 15°C, with high variability. Relative Humidity ranged between 70% and 85%, with a weak significant decreasing trend (Z = -1.71, at α=0.1).

For Vhembe District overall the climate was quite variable between 1981 and 2010, which is reflected in the related anomaly and trend analysis graphs (Figures 4.41-4.50). This may be attributed to among other things, orographic differences within the local municipalities. It was noted that the two seasons centred on 1996 and 2000 reveal high rainfall anomalies. These two seasons are found to coincide with La Niña events, where 1996 falls under weak La Niña while 2000 was a strong La Niña episode (Null, 2015). The high rainfall during the year 2000 was also a result of Tropical Cyclone Eline (Malherbe *et al.*, 2012; SAWS, 2015).

The years under study belong to the dry part of a complete cycle of wet and dry spells rainfall reduction that constitute 18 to 20 years (Kabanda, 2004; Makarau, 1995; Mason, 2001; Preston-Whyte and Tyson, 1988; Tyson, 1990). Although there was a positive Z statistic value of 0.39 at $\alpha>0.1$ for Vhembe District the trend was not statistically significant, which indicates the extent of variability in rainfall in the study area. The average rainfall was between 485 mm and 2 093 mm, with an average of 789 mm in the 30 years.

The annual air temperature in Vhembe District as a whole ranged between 20°C and 23°C and was equally variable, with no statistically significant trend. The annual maximum temperature for Vhembe District, which ranged between 25°C and 30°C, showed that the area experienced high maximum temperatures. There was a weak statistically significant increase in maximum temperature, with a Z statistic of 1.71 at $\alpha=0.1$. The annual minimum temperature ranged between 13°C and 17°C, and showed a trend similar to that of the maximum temperature. A statistically significant increasing trend in minimum temperature was established, with a Z statistic of 3.28 at $\alpha=0.01$. The annual Relative humidity in Vhembe District ranged between 64% and 85%.

A number of notable trends can be observed throughout the local municipalities. In 1983 there was a drop in rainfall in all the municipalities. The same year saw an increase in the annual air temperature and the annual minimum temperatures in Musina, Makhado and Thulamela. In Mutale the annual air temperature and annual maximum temperature were notably high. The Relative Humidity for Thulamela Local Municipality dropped significantly in 1983. The year 1985 had high Relative Humidity and rainfall for Musina and Mutale, high Relative Humidity and low maximum temperature for Mutale Local Municipality. In 1988, there was a drop in all the temperature variables in Musina and Thulamela Local Municipalities, and in Vhembe District as a whole. The annual air and maximum temperature were very high, and low Relative Humidity prevailed in all municipalities in 1992. In Musina the minimum temperatures also rose, with the rainfall increasing in Mutale.

The year 1994 saw a decrease in rainfall in Musina, Makhado and Mutale Local Municipalities. The air temperature increased in Makhado, but decreased notably in Mutale and Musina Local Municipalities. The minimum temperature and Relative Humidity were significantly low in Musina and Makhado, respectively. The year 1996, which happened to be a La Niña year, experienced significantly high rainfall and Relative Humidity in Thulamela

Local Municipality and in Vhembe District as a whole; and the maximum temperatures dropped in the district. Tropical Cyclone Eline and La Niña are attributed with the 2000 high rainfall, which also brought about significantly high Relative Humidity in all the municipalities. For Mutale Local Municipality only the rainfall value was available. The air temperature in Thulamela experienced a large drop. All the temperature variables were quite low in Musina Local Municipality as well. The maximum and air temperatures for Makhado Local Municipality were low; and for Vhembe District as a whole, the maximum temperatures were low. However, the air temperature was quite high in 2000. The temperatures were quite high in 2005 in all municipalities in Vhembe District. Thulamela, Makhado and Vhembe had a high maximum temperature, the air and minimum temperatures were high in Musina, Makhado and in Vhembe as a whole. Then in 2006 all temperatures were high in Thulamela Local Municipality and Vhembe District. A low maximum temperature and high minimum temperature was observed in Thulamela in 2009, with a low Relative Humidity and high maximum temperatures occurring in Makhado. Low minimum temperatures were also experienced in Musina and low rainfall in Mutale Local Municipality.

One of the notable trends from the results is the fact that in the years when one of the climate elements had a strong/extreme event, chances were that one or two more elements responded similarly or inversely; for example, the years 1992 and 1988. In 1992, the area experienced high temperatures which resulted in a drought. Low Relative Humidity was recorded. In 1988 all the temperature variables (air temperature, maximum temperature and minimum temperature) were lower compared to other years.

In summary, the following emerged from an analysis of 1981-2010 climate data per local municipality in Vhembe District:

1. Musina Local Municipality has the lowest rainfall in Vhembe District, but the highest air temperature, maximum temperature and minimum temperature. Musina also has the lowest amount of Relative Humidity. A statistically significant increase in maximum temperatures was detected for Musina Local Municipality.

2. Mutale Local Municipality has the second lowest amount of rainfall, which is double the amount of rainfall in Musina. It experiences the lowest air temperature, has the second highest maximum temperature, the lowest minimum temperature and the

highest Relative Humidity. Mutale had a statistically significant decreasing trend in Relative Humidity.

3. Makhado Local Municipality receives the second highest amount of rainfall in Vhembe District, which is just above Mutale Local Municipality. It has the second lowest air temperature and experiences the lowest maximum temperatures. Makhado Local Municipality also experiences the second lowest minimum temperature and Relative Humidity, and had a statistically significant increasing trend in minimum temperature.

4. Thulamela Local Municipality receives the highest rainfall in Vhembe District, and experiences the second highest Relative Humidity. It has the second highest air temperatures, is third in Vhembe District in terms of maximum temperatures and second highest in minimum temperature. Thulamela had a significant decreasing trend in air temperature.

5. Overall Vhembe District had significant increasing trends in the minimum temperatures and maximum temperatures.

6. The years 1988, 1992 and 1996 had extreme weather events, which affected two or more of the climate parameters under study. This reveals the intrinsic relationships among the climate elements rainfall, temperature, and Relative Humidity.

The observations are crucial in determining the influence of climate variability and change on the number of malaria cases identified in Vhembe District.

Chapter 5

MALARIA AND HUMAN POPULATION DENSITY

5.1 Introduction

The malaria life cycle (Figure 2.1) relies on the availability of a human host. In other words the availability of a host for the parasite to be incubated, and availability of people for the mosquitoes to bite and transmit malaria to, are requirements for the propagation of the disease. An analysis of the density of the human population in relation to the number of malaria cases in Vhembe District was, therefore, required. For this reason, the population density of Vhembe District, as the only non-climatic factor, was analysed in this study. High population pressure areas tend to favour malaria transmission than low population density areas (Deresa *et al.*, 2006). This chapter focused on identifying locations in Vhembe District that had the highest population density and malaria prevalence. Also in this chapter, trend analysis (Mann-Kendall trend analysis) was used in an attempt to quantify the magnitude, and to determine the significance of trends in the number of malaria cases in the study area. The results obtained from all the analyses in the chapter were used to explain the spatial distribution of malaria in Vhembe District, as discussed later in Chapter 7.

5.2 Population Density in Vhembe District

According to the 2007 census data from Statistics South Africa (StatsSA), the total population of the Vhembe District was approximately 1.2 million people. Thulamela Local Municipality had the largest population in the district, with a population close to 590 000 people; followed by Makhado (490 000). Mutale and Musina Local Municipalities had the lowest population of 91 500 and 48 000, respectively. Although Thulamela had a large population, its area was smaller than that of Makhado or Musina Local Municipalities. The population density for the municipalities varied from 6.3 to 203.4 people per square kilometre, with Musina Local Municipality having the lowest population density and Thulamela the highest, as indicated in Table 5.1.

Table 5.2 shows the yearly population figures in Vhembe District from 1998 to 2010, indicating that Vhembe District had a population increase of 123 523 people from 1998 to 2010. The largest contribution to this total increase in Vhembe District's population was from

Thulamela Local Municipality, whose population increased by 57 552 during the period. Makhado contributed an increase of only 197 people, and at one time (in 2007) Makhado Local Municipality's population actually decreased compared to the previous year. Another striking demographic change was the sharp population increase of 19 478 in Mutale Local Municipality between 2006 and 2007.

Table 5.1: Human population and population density per local municipality in Vhembe District based on the 2006 census.

	Local municipality				Vhembe District
	Musina	Makhado	Mutale	Thulamela	
Population	47,722	489,433	91,466	589,583	1,218,204
Area (km^2)	7,576.84	8,299.70	2,345.92	2,898.69	21,121.15
Population density (persons km^{-2})	6.3	58.97	38.99	203.4	57.68

Data: Statistics South Africa (StatsSA).

Table 5.2: Population per local municipality in Vhembe District, 1998-2010.

Year	Local municipality				Vhembe District
	Musina	Makhado	Mutale	Thulamela	
1998	36 201	477 724	76 837	556 555	1,147,317
1999	37 426	482 695	78 579	563 489	1,162,189
2000	38 726	487 716	80 341	570 503	1,177,286
2001	39 313	492 345	82 051	577 086	1,190,795
2002	41 510	496 740	83 652	582 784	1,204,686
2003	42 876	500 928	85 127	588 146	1,217,077
2004	44 148	504 810	86 458	593 041	1,228,457
2005	45 328	508 521	87 677	597 623	1,239,149
2006	46 381	511 714	88 737	601 538	1,248,370
2007	57 196	471 808	108 215	602 825	1,240,044
2008	60 359	473 837	109 330	606 563	1,250,089
2009	63 697	475 874	110 456	610 323	1,260,350
2010	67 219	477 921	111 593	614 107	1,270,840

Source: Statistics South Africa (StatsSA). Data for 2008, 2009 and 2010 calculated using the population growth.

5.3 Malaria Cases and Prevalence in Vhembe District

Malaria data from only the period 1998 to 2010 were used in this study, for the reasons explained in Section 3.2.2. Vhembe District had 31 188 reported malaria cases in this period, Thulamela Local Municipality accounting for 14 948 of the cases (Table 5.3) followed by

Mutale with 11 904 cases. The remaining 4 336 malaria cases reported were shared almost equally between Makhado and Musina.

Table 5.3: Number of malaria cases in Vhembe District, 1998-2010.

Year	Number of Cases				
	Musina	Makhado	Mutale	Thulamela	Vhembe District
1998	271	217	779	982	2 249
1999	328	322	1 660	2 121	4 431
2000	195	319	1 193	2 206	3 913
2001	152	309	1 142	1 561	3 164
2002	298	173	880	989	2 340
2003	244	248	1 022	1 639	3 153
2004	157	151	756	883	1 947
2005	12	59	659	660	1 390
2006	33	76	986	1 179	2 274
2007	73	90	765	604	1 532
2008	118	94	905	1 050	2 167
2009	45	98	383	640	1 166
2010	107	147	774	434	1 462
Total	**2 033**	**2 303**	**11 904**	**14 948**	**31 188**

Data Source: Malaria Control Institute (Tzaneen) - Limpopo Province.

5.3.1 Malaria Cases in Musina Local Municipality

The number of malaria cases in Musina Local Municipality fluctuated between 328 (in 1999) and 12 (in 2005). Higher numbers of malaria cases were reported between 1998 and 2003. Figure 5.1 illustrates the malaria cases reported in Musina Local Municipality from 1998 to 2010. It is evident from Figure 5.1 that malaria showed a decrease in Musina until 2005. Thereafter, there was a gradual increase.

Mann-Kendall trend analysis of the malaria cases data for Musina Local Municipality was carried out and results are presented in Table 5.4. There was a statistically significant decreasing trend in malaria cases: Z = -2.38 at 95% significance level. The magnitude of decrease according to Sen's slope estimate was -20.318 cases per year. According to Salmi *et al.* (2002), in the case where important significant trends are observed, the statistical computation gives a high level of significance with narrow angles between the confidence lines. In these cases the trend is significant at the point where the 95% confidence bounds and the Sen's slope estimate line meet. Figure 5.2 shows that the significant change in Musina was observed around the year 2005.

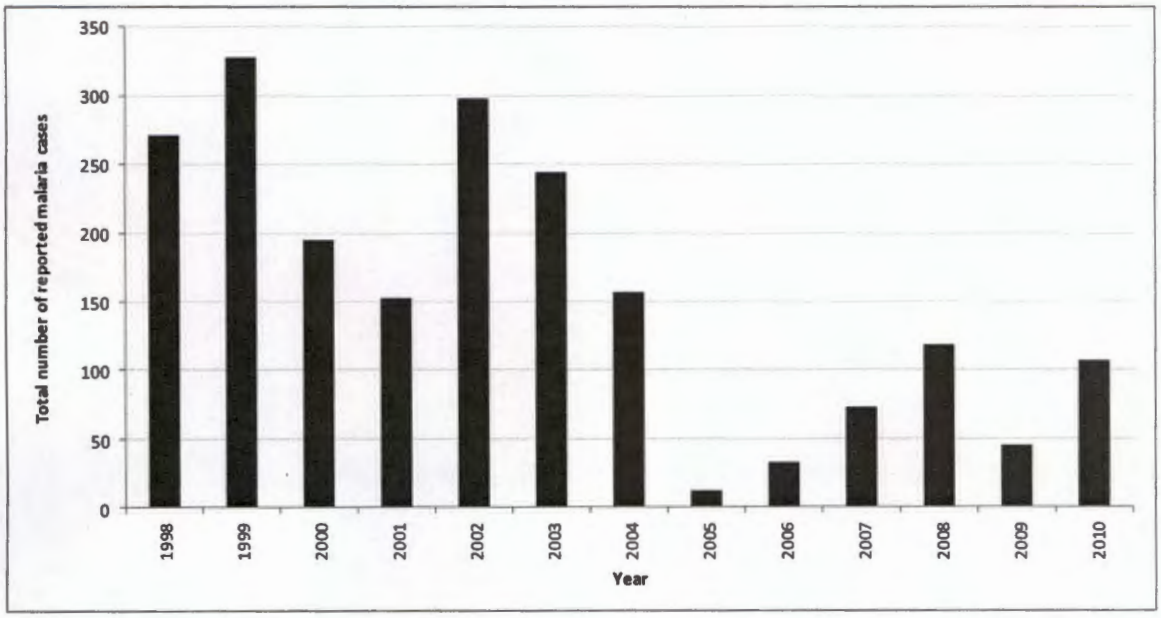


Figure 5.1: Annual malaria cases in Musina Local Municipality, 1998-2010. Data: Malaria Control Institute (Tzaneen) - Limpopo Province.

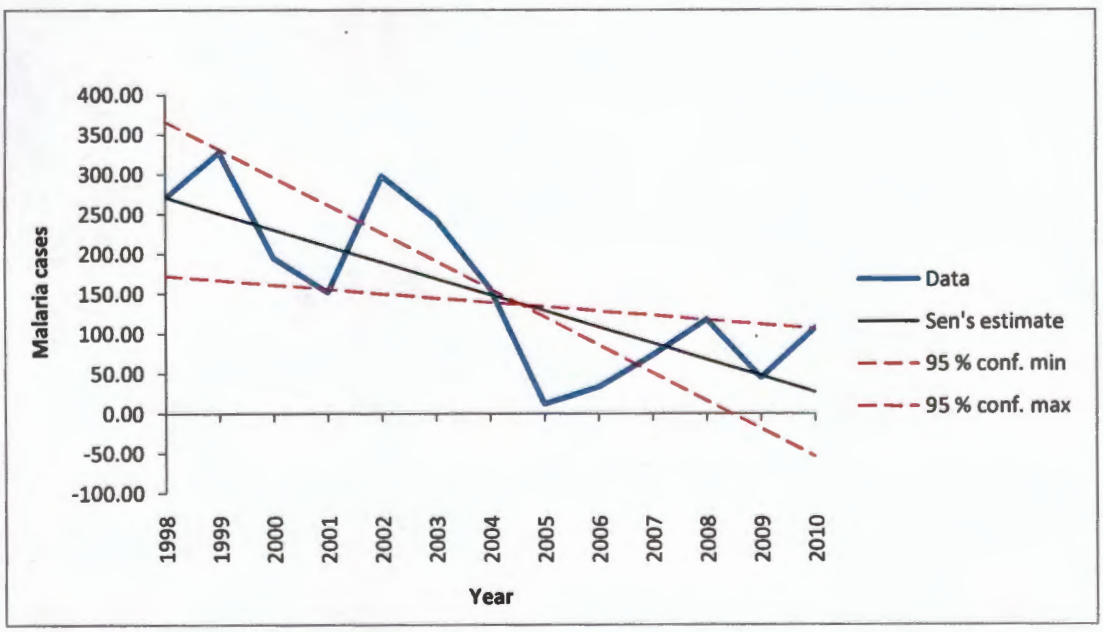


Figure 5.2: Trend analysis for number of malaria cases in Musina, 1998-2010.

Table 5.4: Trend analysis for reported malaria cases in Musina Local Municipality, 1998-2010.

Variable	First year	Last Year	*n*	Z value and significance	Sen slope estimate (Q)	Units (Q)
Musina malaria cases	1998	2010	13	-2.38*	-20.318	cases year^{-1}
+: $\alpha = 0.1$	*: $\alpha = 0.05$			**: $\alpha = 0.01$		***: $\alpha = 0.001$

5.3.2 Malaria Cases in Makhado Local Municipality

In Makhado Local Municipality malaria cases exceeding 200 were reported between 1998 and 2003 as follows: 217 in 1998, 322 in 1999, 319 in 2000, 309 in 2001 and 248 in 2003. The lowest number of cases (59) was reported in 2005. Figure 5.3 shows that malaria cases in Makhado Local Municipality declined until 2005, after which there was a slight increase. Trend analysis results for the data in Figure 5.3 are presented in Table 5.5, and they indicate that there was a statistically significant decreasing trend in the number of malaria cases in Makhado Local Municipality (Z = -2.26 and Q = -16.9, at a significance level of 95%). Figure 5.4 shows that the notable change in number of reported malaria cases Makhado was around 2005, where the 95% confidence bounds and the Sen's slope estimate lines meet.

Table 5.5: Trend analysis for reported malaria cases in Makhado Local Municipality, 1998-2010.

Variable	First year	Last Year	*n*	Z value and significance	Sen slope estimate (Q)	Units (Q)
Makhado malaria cases	1998	2010	13	-2.26*	-16.900	cases year^{-1}
+: $\alpha = 0.1$	*: $\alpha = 0.05$			**: $\alpha = 0.01$		***: $\alpha = 0.001$

5.3.3 Malaria Cases in Thulamela Local Municipality

Figure 5.5 depicts the number of malaria cases Thulamela Local Municipality from 1998 to 2010. The highest number of cases was observed from 1999 to 2003: 2121, 2206, 1561 and 1639 cases in 1999, 2000, 2001 and 2003 respectively. The lowest numbers were 660 and 604 reported in 2005 and 2007, respectively.

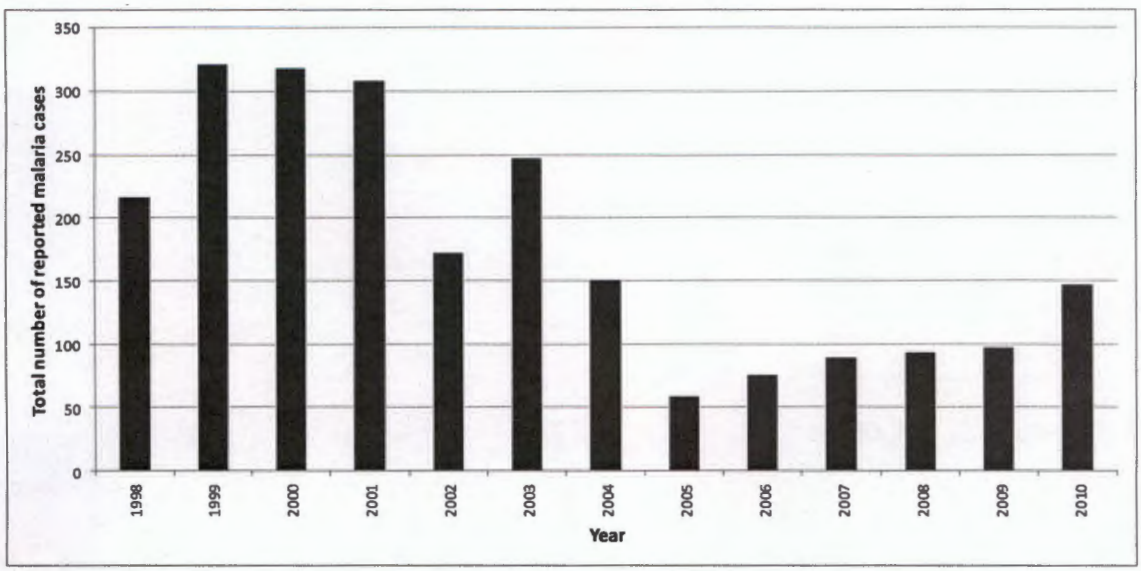


Figure 5.3: Annual malaria cases in Makhado Local Municipality, 1998-2010. Data: Malaria Control Institute (Tzaneen) - Limpopo Province.

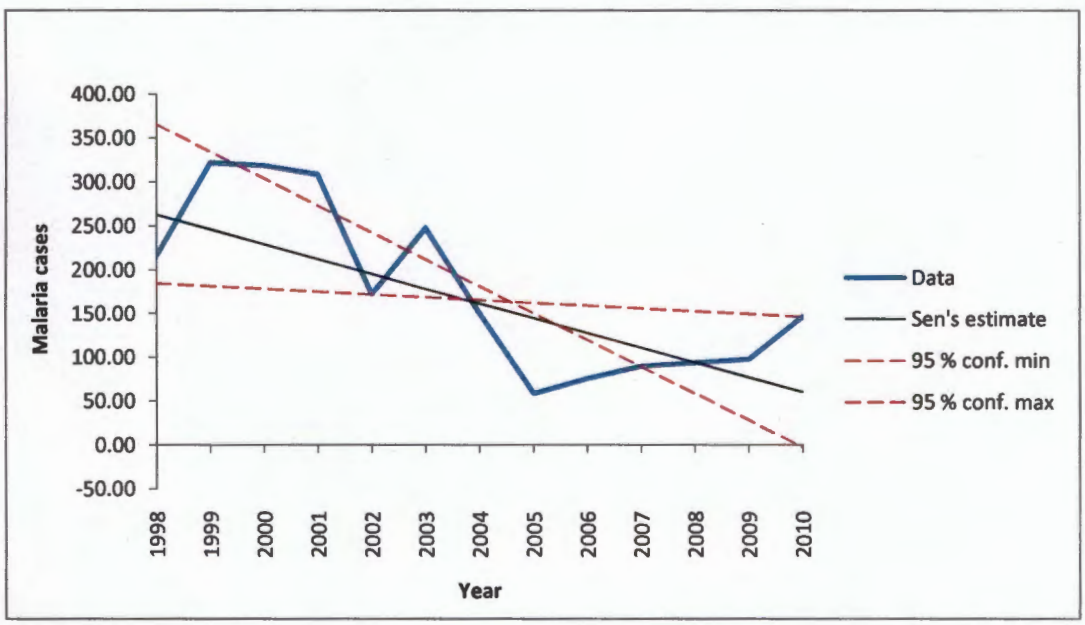


Figure 5.4: Trend analysis for number of malaria cases in Makhado, 1998-2010.

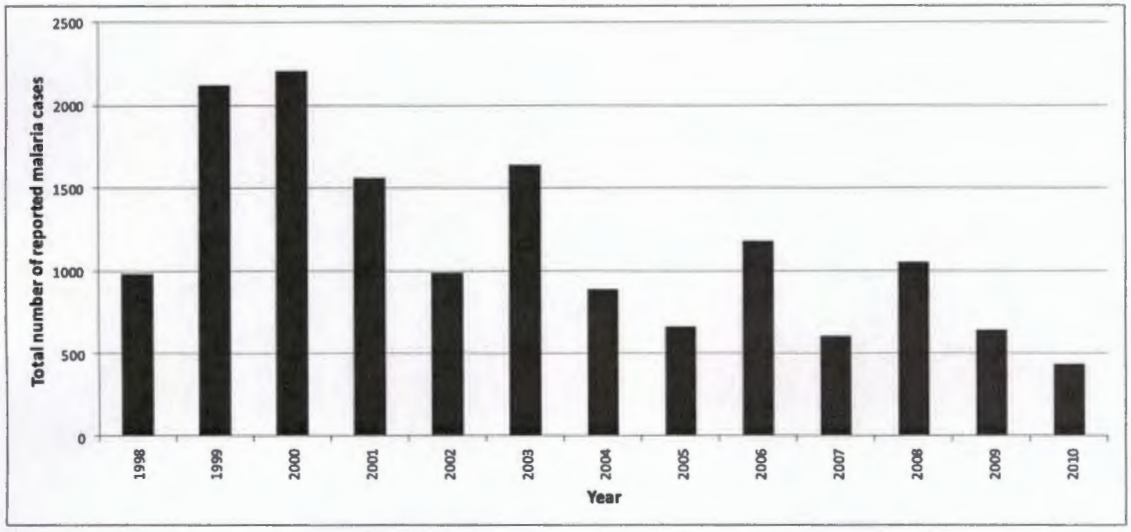


Figure 5.5: Annual malaria cases in Thulamela Local Municipality, 1998-2010. Data: Malaria Control Institute (Tzaneen) - Limpopo Province.

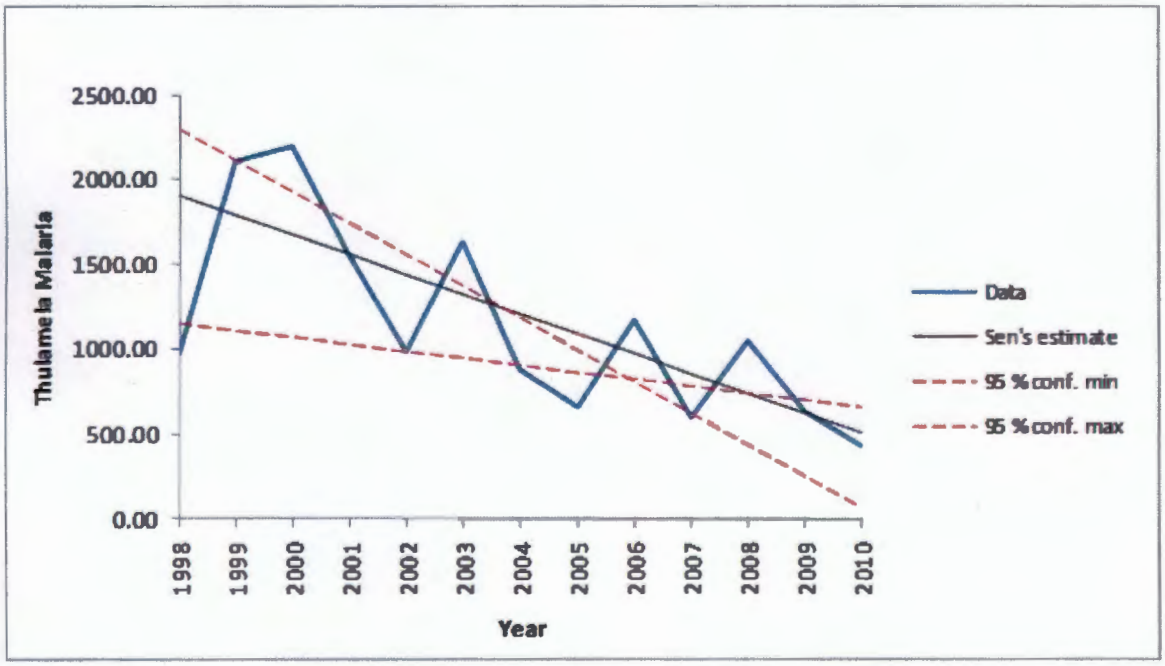


Figure 5.6: Trend analysis for number of malaria cases in Thulamela, 1998-2010

Table 5.6: Trend analysis for reported malaria cases in Thulamela Local Municipality, 1998-2010.

Variable	First year	Last Year	*n*	Z value and significance	Sen slope estimate (Q)	Units (Q)
Thulamela malaria cases	1998	2010	13	-2.50*	-116.463	cases year^{-1}

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

Figure 5.5 indicates that the number of malaria cases was generally decreasing over time in the Thulamela Local Municipality. Trend analysis for Thulamela is presented in Table 5.6, indicating a statistically significant decreasing trend (Z = -2.50 at α=0.05) at a rate of -116.463 per year. Although there is a statistically significant decreasing trend in malaria cases in Thulamela, Figure 5.6 does not present a clear point of change where the 95% confidence bounds and the Sen's slope estimate line meet; therefore, the year of change could not be established.

5.3.4 Malaria Cases in Mutale Local Municipality

In Mutale Local Municipality the highest numbers of malaria cases were recorded between 1999 and 2003 as was the case with Thulamela Local Municipality. These numbers were they 1660 in 1999, 1193 in 2000, 1142 in 2001, and 1022 in 2003. Figure 5.7 shows a decline in the number of malaria cases in Mutale Local Municipality from 1998 to 2010. The lowest number of malaria cases, 659 and 383, were reported in 2005 and 2009, respectively. The decreasing trend in number of malaria cases in Mutale was statistically significant (Z = -2.14, α = 0.05), as shown in Table 5.7. Sen's slope estimate (Figure 5.8) detected a decreasing rate of -52.0 cases per year. However, Figure 5.8 does not present a clear point of change where the 95% confidence bounds and the Sen's slope estimate line meet; therefore, the year of change could not be established.

Table 5.7: Trend analysis for reported malaria cases in Mutale Local Municipality, 1998-2010.

Variable	First year	Last Year	*n*	Z value and significance	Sen slope estimate (Q)	Units (Q)
Mutale malaria cases	1998	2010	13	-2.14*	-52.000	cases year^{-1}
+: α = 0.1	*: α = 0.05			**: α = 0.01		***: α = 0.001

5.3.5 Malaria Cases in Vhembe District

In order to get an overall indication of the combined prevalence of malaria in Vhembe District as a whole, the data from the four local municipalities (Sections 5.3.1-5.3.4) was combined in a synthesis analysis. The synthesis analysis high cases of malaria being detected from 1999 to 2003: the numbers being 4431, 3913, 3164 and 3153, respectively (Figure 5.9). The lowest numbers, 1462 and 1166, were reported in 2010 and 2009, respectively. Figure 5.9 indicates a general decrease in the number of malaria cases in Vhembe District from 1998

to 2010. This trend was statistically significant (Z = -2.87, at 99% significance level; Table 5.8). The Sen's slope estimate (Q) established a decreasing rate of magnitude -200.1 malaria cases per year. Figure 5.10 shows that the point of significant change occurred between 2005 and 2006, where the point where the 95% confidence bounds and the Sen's slope estimate line meet.

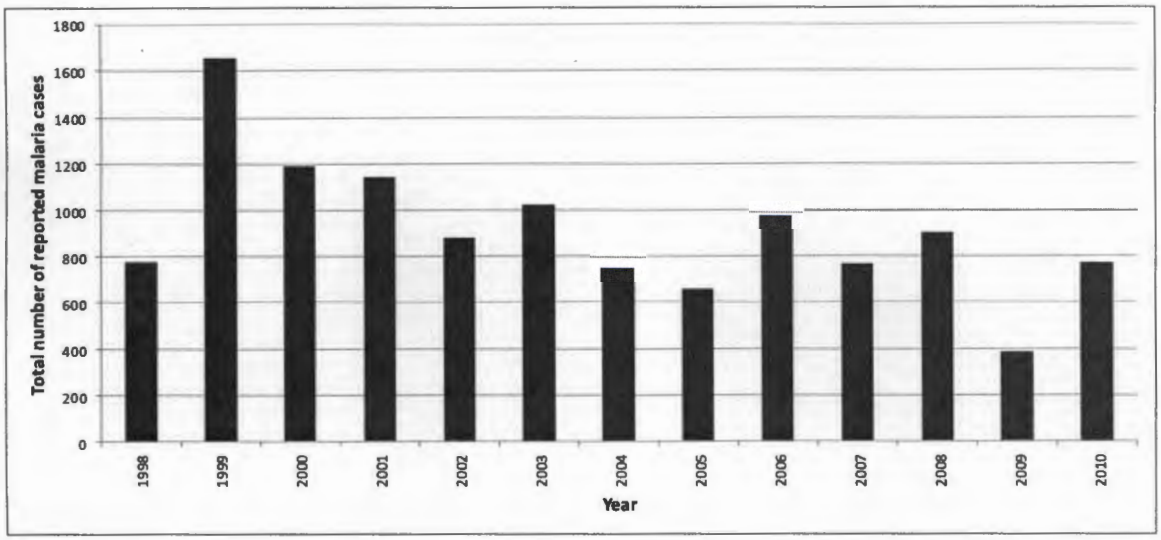


Figure 5.7: Annual malaria cases in Mutale Local Municipality, 1998-2010. Data: Malaria Control Institute (Tzaneen) - Limpopo Province.

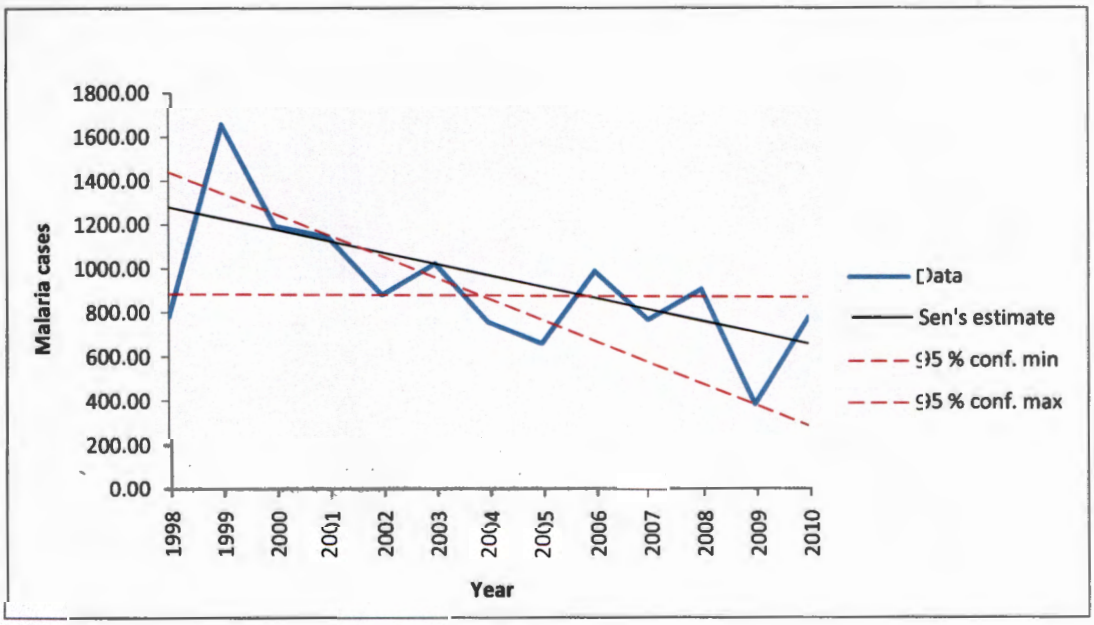


Figure 5.8: Trend analysis for number of malaria cases in Mutale, 1998-2010.

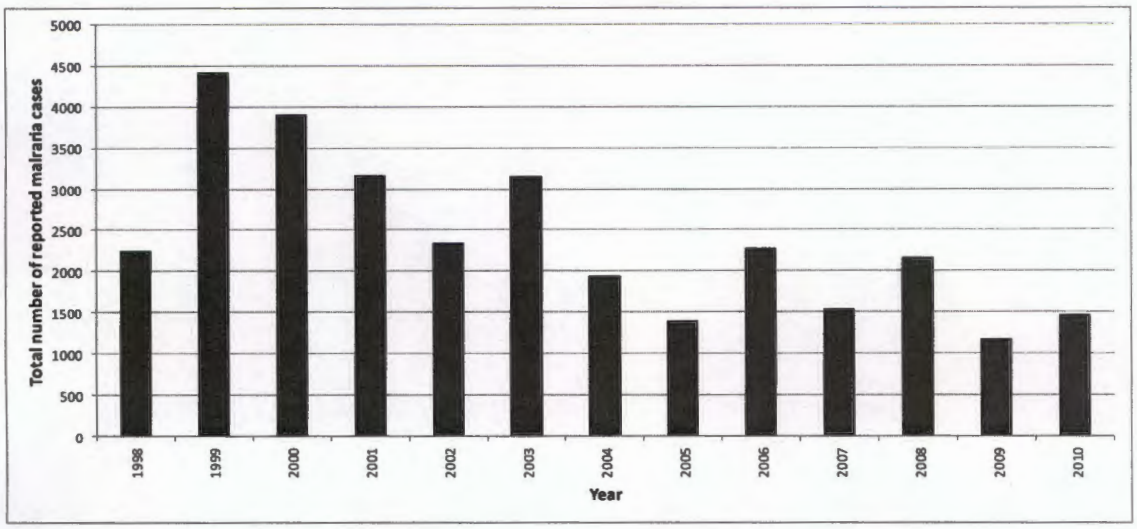


Figure 5.9: Annual malaria cases in Vhembe District, 1998-2010. Data: Malaria Control Institute (Tzaneen) - Limpopo Province.

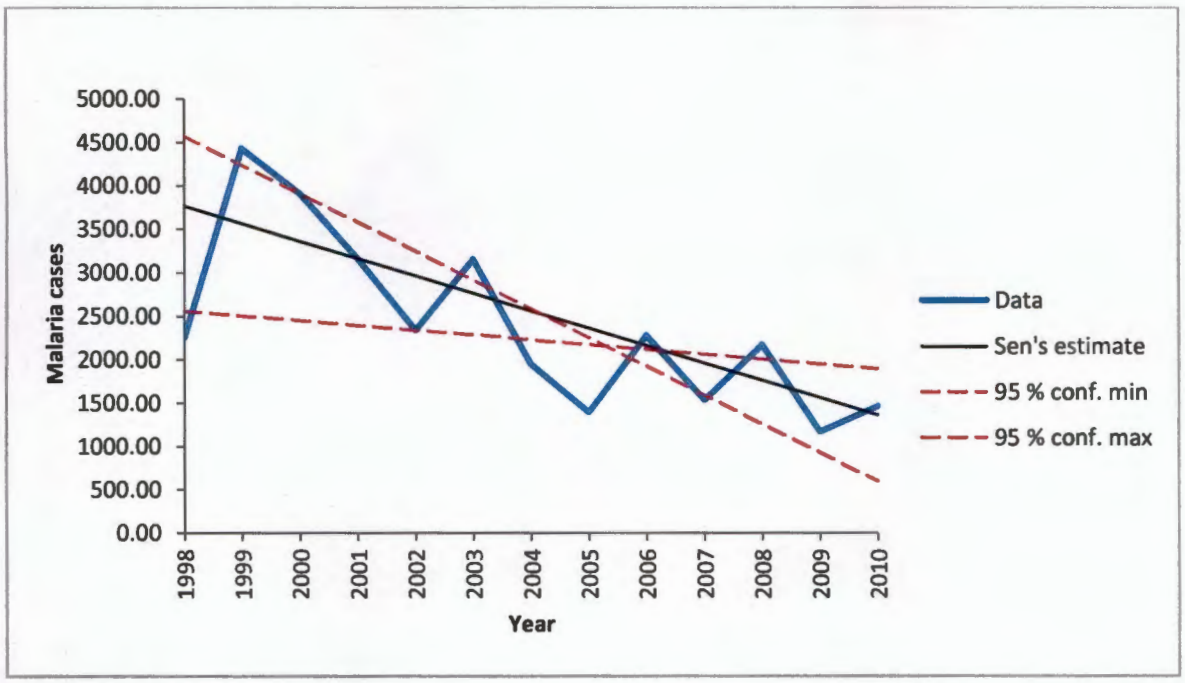


Figure 5.10: Trend analysis for number of malaria cases in Vhembe District, 1998-2010.

Table 5.8: Trend analysis for reported malaria cases in Vhembe District, 1998-2010.

Variable	First year	Last Year	*n*	Z value and significance	Sen slope estimate (Q)	Units (Q)
Vhembe malaria cases	1998	2010	13	-2.87**	-200.100	cases year^{-1}

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

5.3.6 Malaria Prevalence in Vhembe District

Malaria prevalence was calculated using Equation 3.2 (Section 3.2.2). Figure 5.11 graphically illustrates the fluctuations in the malaria prevalence figures that resulted from the calculation, for the four local municipalities and then for Vhembe District as a whole over the time period of analysis. Mutale Local Municipality had the highest malaria prevalence followed by Musina, then Thulamela and finally Makhado. The prevalence of malaria in Vhembe District closely followed that of Thulamela Local Municipality, the most populated local municipality (see Section 5.2; Tables 5.1 and 5.2).

The fluctuations in the prevalence of malaria in Vhembe District in Figure 5.11 follow those pertaining to the total number of malaria cases (Figure 5.9). However, the prevalence gives an indication of the magnitude of malaria intensity within the district. The higher the prevalence, the more an area is prone to malaria and the lower the prevalence, the lower individuals are prone to contacting malaria in that particular area. The ranges of malaria prevalence within the district are presented in Table 5.9. Mutale Local Municipality had higher malaria prevalence than the other municipalities, its prevalence values ranging between 34.7 and 211.3, followed by Musina (2.6 and 87.6), then Thulamela and Vhembe District (ranging between 7 and 39). The local municipality with the least prevalence was Makhado, with a range between 1.1 and 6.7.

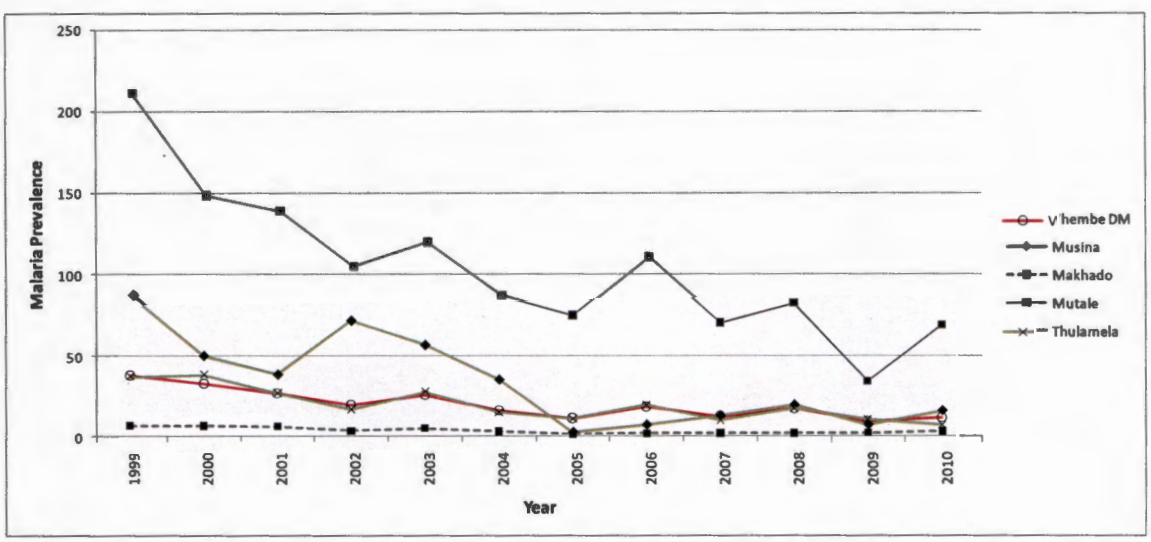


Figure 5.11: Prevalence of malaria in Vhembe District and its local municipalities, 1998-2010.

Table 5.9: Malaria prevalence range values for Vhembe District and its local municipalities, 1998-2010.

	Local municipality				Vhembe District
	Musina	Makhado	Mutale	Thulamela	
Malaria prevalence range	2.6 – 87.6	1.1 – 6.7	34.7 – 211.3	7.1 – 38.7	9.3 – 38.1

5.4 Summary and Discussion

An analysis of demographic data for Vhembe District from 1998 to 2010 (Table 5.2) indicates that Musina Local Municipality had the lowest population. Musina also had the lowest population density, at 6.30 persons km^{-2} (Table 5.1); its population is sparsely distributed. This suggests why Musina Local Municipality reported the lowest number of malaria cases value of 2 033 (Table 5.3) in the analysis period 1998-2010. The low figure of 2 033 was 7% of the total for the period under review. This can be attributed to the fact that the bulk of the land within the municipality is under commercial farming and hence there are very few villages within the area (Figure 1.5). The data indicated that the number of malaria cases in Musina decreased between 1998 and 2010 (Figure 5.1), with the significant point of change observed around 2005 (Figure 5.2).

Makhado Local Municipality had the second highest number of human population, but for a total of 2 303 between 1998 and 2010 (almost 7% of the total) it had the second lowest number of malaria cases in Vhembe District. It also had the second highest population density in Vhembe District, at 58.97 people per km^2 (Table 5.1). The high altitude Soutpansberg Mountain range (Figures 1.3b, 1.6) almost cuts the municipality in the middle as it crosses from the west towards the east across the tip of Thulamela and through the central part of Mutale as the altitude drops towards the Kruger National Park (KNP) and into the Limpopo River. Makhado had a statistically significant decreased number of malaria cases between 1998 and 2010 (Table 5.5), with the significant point of change observed around 2005 like was the case with Musina Local Municipality.

Thulamela had a population of almost 580 000 squeezed in an area of about 3 000km^2, giving it a population density of 203.40 people per km^2 (Table 5.1), the highest in Vhembe District. Thulamela is even smaller in size than Musina Local Municipality, the latter with a

population 14 times smaller; yet more than 2.5 times bigger in area than Thulamela. Thulamela reported the highest number of malaria cases of 14 948 (Table 5.3), which was 48% of the total number of cases. The high number of malaria cases in Thulamela Local Municipality can, therefore, be attributed not only to climatic conditions but also to the fact that the bulk of the municipality is predominantly made up of rural villages (Figure 1.5).

An analysis of the demographic for Vhembe District indicated that Mutale Local Municipality had the second lowest human population (Table 5.2) but reported the second highest number of malaria cases from 1998 to 2010 (Table 5.3). This can be attributed to the fact that Mutale is the smallest municipality in terms of area hence the population is confined within a small area, creating conditions that are in favour of malaria transmission. Mutale Local Municipality had the second lowest population density, at 38.99 people per km^2 (Table 5.1). It contributed 38% of the reported malaria cases.

Malaria prevalence was higher from 1999 to 2003 in Vhembe District. However, a statistically significant decreasing trend occurred thereafter ($Z = -2.87$, $\alpha = 0.01$; Table 5.8). Trend analysis of the district's malaria cases showed that the significant point of change occurred between 2005 and 2006 (Figure 5.10).

The following are the key findings from the analyses in Chapter 5:

1. In the period of analysis (1998-2010), the number of malaria cases reduced significantly in all municipalities in Vhembe District.

2. Higher cases of malaria were recorded from 1999 to 2003 in all the municipalities in Vhembe District.

3. The point of significant change in malaria trends for Musina and Makhado Local Municipalities occurred in 2005, while for Vhembe District as a whole it occurred between 2005 and 2006. The other municipalities do not have clear cut points (year) of change.

4. Population density seems to affect malaria prevalence. Areas with a high population density have a high prevalence and a low density in lower prevalence.

5. Mutale Local Municipality showed higher malaria prevalence than the other municipalities in the analysis period (1998-2010), with prevalence values ranging between 34.7 and 211.3 (Table 5.9), followed by Musina (ranging 2.6 - 87.6) then Thulamela and Vhembe District (ranging 7 - 39). The least prevalence was in Makhado Local Municipality, with a range between 1.1 and 6.7.

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Chapter 6

CLIMATE VARIABILITY AND MALARIA RESULTS

6.1 Introduction

In Literature Review (Chapter 2), it was established that there are trends and relationships between climate conditions and malaria. The magnitude of these relationships, however, varies from one area to the other, as a result of the complex nature of the malaria disease which is not only influenced by climatological elements but by other non-climatic elements like human population dynamics as stated in Chapter 5. The non-climatic elements tend to propagate or retard the spread of malaria during transmission seasons. This chapter analyses the annual and monthly relationships and interactions between climate parameters (rainfall, temperature, Relative Humidity) and malaria cases in Vhembe District from 1998 to 2010. Mann-Kendall test and Sen's slope estimates for all the three climate variables were conducted so as to establish the trends during the period of analysis.

The outcome of the analysis revealed evolving and dynamic relationships on the influence of climate variability on malaria. Pearson correlation coefficients (r) were generated for the various municipalities in order to determine the extent of relationships between climate elements and reported malaria cases. As stated in Chapter 3, a value of $r > \pm 0.5$ between malaria cases and climate element indicates a strong (positive/negative) relationship, whereas values of $r < \pm 0.5$ will indicate a weak (positive/negative) relationship; and no relationship at all when $r = 0$.

6.2 Annual Climate Variability and Malaria in Musina Local Municipality

Pearson correlation analysis between malaria and climate conditions in Musina showed that there was no statistically significant relationship between malaria and any of the climate variables in Musina Local Municipality. There were, however, significant relationships among the climate variables themselves (Table 6.1). This is to be expected, because the rain season in Vhembe District (and much of South Africa) is in summer when temperatures (and consequently humidity due to moist winds) are high. Between the air temperature and rainfall, r = -0.786 (P value = 0.002); between the maximum temperature and rainfall, r = -

0.734 (P = 0.007); and between the minimum temperature and rainfall r = -0.658 (P = 0.020). Relative Humidity had a significant positive correlation with rainfall (r = 0.774, P = 0.024).

Table 6.1: Pearson correlation coefficient (r) values between malaria and annual climate variables, Musina Local Municipality.

Variables	Malaria cases	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
Malaria cases	1.000	-0.135	-0.09	-0.304	0.044	0.035
Rainfall (RF)		1.000	-0.786**	-0.734**	-0.658*	0.774*
Air temperature (TpAv)			1.000	0.894**	0.947**	-0.820*
Maximum temperature (TpMax				1.000	0.760**	-0.890**
Minimum temperature (TpMin)					1.000	-0.67
Relative Humidity (RH)						1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Figures 6.1 to 6.5 show the relationship between malaria cases and the climate variables in Table 6.1, with linear regression trend lines inserted for each relationship. Figure 6.1 indicates an initial increase in rainfall from 1998, reaching its highest in 2000, and then dropping to its lowest in 2002. From 2003 to 2010, the rainfall pattern was fluctuating between 200mm and 500 mm per annum. Malaria cases on the other hand had an initial increase from 1998 to 1999, then dropped in 2000 and their lowest was in 2005. From 2006 to 2008 the number of malaria cases increased slightly again, reduced in 2009 and rose again in 2010. There were fluctuations in temperature (Figures 6.2-6.4) and Relative Humidity (Figure 6.5).

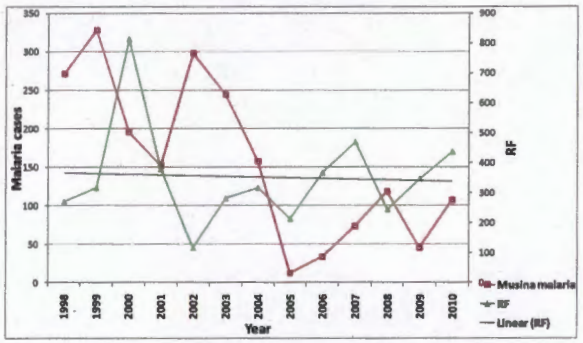


Figure 6.1: Malaria cases and annual rainfall in Musina, 1998-2010.

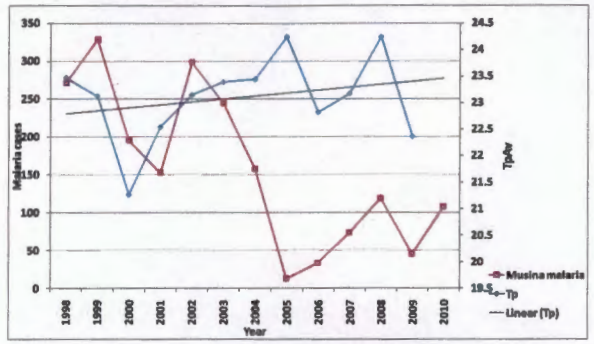


Figure 6.2: Malaria cases and annual air temperature in Musina, 1998-2010.

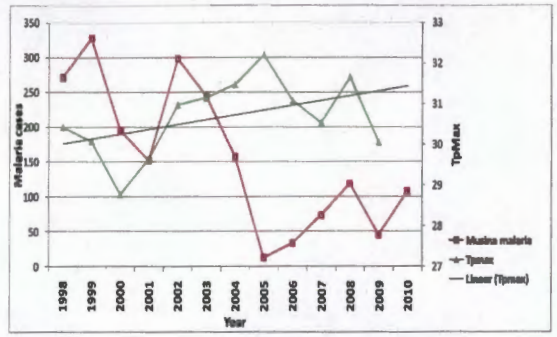


Figure 6.3: Malaria cases and annual maximum temperature in Musina, 1998-2010.

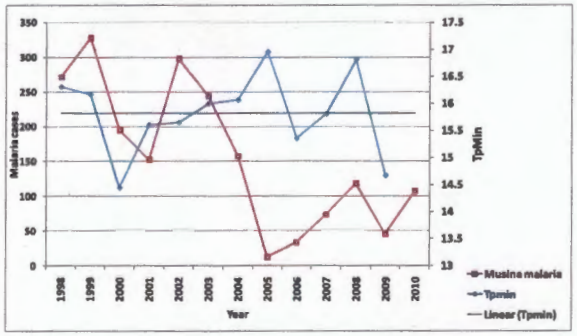


Figure 6.4: Malaria cases and annual minimum temperature in Musina, 1998-2010.

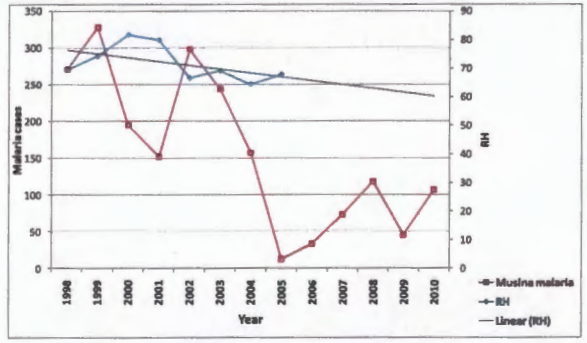


Figure 6.5: Malaria cases and annual Relative Humidity in Musina, 1998-2010.

Several key notable aspects can be observed for the relationship between climate variable and malaria in Musina Local Municipality. There was a reduction in malaria cases when the rainfall and Relative Humidity escalated to their highest levels in 2000. However, it can be observed that the temperatures were quite low during that year. In 2005 the temperatures took a slight upsurge, rainfall was low while Relative Humidity was at its lowest for the analysis period, which resulted in a decline in the number of malaria cases.

Another malaria upsurge of note was experienced in 2008. The temperatures increased slightly while the rainfall was low, but the number of malaria cases increased. Finally, in 2009, there was an increase in the amount of rainfall; however, the temperatures were declining and this resulted in a drop in malaria cases. An analysis of the climate trends using Mann-Kendal test (Table 6.2) shows increasing trends for rainfall, air temperature and maximum temperature; and decreasing trends for minimum temperature and Relative Humidity from 1998 to 2010. However, all the trends are not statistically significant. Linear regression analysis of all the climate elements with malaria for Musina was performed as explained in Chapter 3.

Table 6.2: Climate versus malaria Mann-Kendall test and Sen's slope estimate results for 1998-2010 annual data, Musina Local Municipality.

Parameter	First year	Last Year	*n*	Z/S value and significance	Sen slope estimate (Q)	Units (Q)
Rainfall (Musina RF)	1998	2010	13	0.43	5.311	mm year^{-1}
Air temperature (Musina TpAv)	1998	2009	12	0.48	0.052	°C year^{-1}
Maximum temperature (MusinaTpMax)	1998	2009	12	1.30	0.140	°C year^{-1}
Minimum temperature (Musina TpMin)	1998	2009	12	-0.07	-0.031	°C year^{-1}
Relative Humidity (Musina RH)	1998	2005	8	-12.0	-1.091	% year^{-1}

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

Table 6.3 shows the linear regression equations and coefficient of determination (R2) values that were derived from the analysis. The analysis between malaria and rainfall indicates that only 1.83% of the variation in the number of malaria cases can be explained by the amount of rainfall. The linear relationship between malaria and air temperature had an R2 value of 0.0081 (Table 6.3), which means that only 0.81% of the variation in number of malaria cases can be explained by the changes in air temperature, 9.25% by the changes in maximum

temperature, 0.19% by the changes in minimum temperature and 0.12% by changes in Relative Humidity.

Table 6.3: Linear regression equations for annual climate variables and malaria, Musina Local Municipality.

Climate Element	R^2 value
Annual Rainfall	0.0183
Annual Air Temperature	0.0081
Annual Maximum Temperature	0.0925
Annual Minimum Temperature	0.0019
Annual Relative Humidity	0.0012

6.3 Annual Climate Variability and Malaria in Makhado Local Municipality

Table 6.4 shows the Pearson correlation coefficient (r) matrix for malaria and climate elements in Makhado. The results show that there were statistically significant negative relationships between malaria and maximum temperature (r = -0.743, P = 0.004), and between malaria and air temperature (r = -0.576, P = 0.039). This means that as the air and maximum temperatures increased the number of malaria cases decreased significantly. There were some statistically significant relationships between the climatological elements. Rainfall and air temperature indicate a negative correlation (r = -0.767, P = 0.002). The maximum temperature and rainfall had a significant negative correlation (r = -0.749, P = 0.003), and rainfall has a statistically significant negative relationship with the minimum temperature (r = -0.571, P = 0.041). The minimum temperature and air temperatures have a significant positive relationship (r = 0.842, P = 0.000 at α = 0.01). Relative Humidity and maximum temperature had a negative correlation (r = -0.715, P = 0.046).

Figures 6.6 to 6.10 show the fluctuations in the climate variables and malaria, as well as their trend lines over time. There was an escalation in the amount of rainfall from 1998 to 2000, the amount of rainfall then declined to its lowest in 2002, then from 2003 to 2010 the amount of rainfall fluctuated between 500mm and 1000mm per annum (Figure 6.6). The number of malaria cases on the other hand also started with an initial rise from 1998 to 1999, then there

was a slight drop in 2000 and 2001 followed by a steep decline in 2002. In 2003 there was an increase in malaria which then reduced for consecutive years until it's lowermost for the period in 2005. From 2006 to 2010 the number of malaria cases was gradually increasing. Fluctuations of temperature and Relative Humidity were experienced between 2000 and 2010, with lower temperatures than usual detected in 2000 which also recorded the highest Relative humidity.

Table 6.4: Pearson correlation coefficient (*r*) values between malaria and annual climate variables, Makhado Local Municipality.

Variables	Malaria cases	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
Malaria cases	1.000	0.508	-0.576*	-0.743**	-0.448	0.664
Rainfall (RF)		1.000	-0.767**	-0.749**	-0.571*	0.582
Air temperature (TpAv)			1.000	0.758**	0.842**	-0.474
Maximum temperature (TpMax				1.000	0.777**	-0.715*
Minimum temperature (TpMin)					1.000	-0.398
Relative Humidity (RH)						1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

The decline in the number of malaria cases in Makhado Local Municipality in 2002 came after two consecutive years (2001 and 2002) that recorded increasing temperatures following their lowest level in 2000. The trend of rising temperature continued until 2003 which recorded even higher malaria cases than 2002. In 2005 the temperatures escalated again, with lower rainfall which resulted in the lowest number malaria cases for the analysis period. The year 2009 recorded high maximum and minimum temperatures, which resulted in a slight increase in the number of malaria cases in comparison with 2008 when even lower maximum and minimum temperatures were recorded. Trend analysis (Table 6.5) shows a weak but statistically significant increasing trend for the maximum temperature, with a Z statistic of 1.89 at $\alpha = 0.1$; and Sen's slope estimate of magnitude 0.114°C per year.

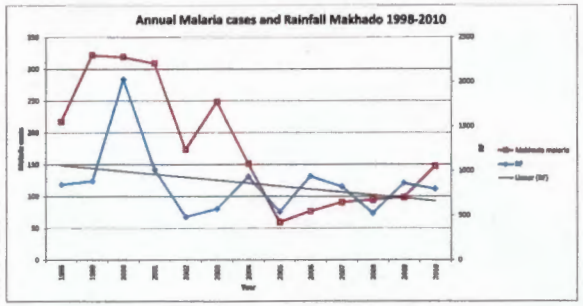


Figure 6.6: Malaria cases and annaual rainfall in Makhado, 1998-2010.

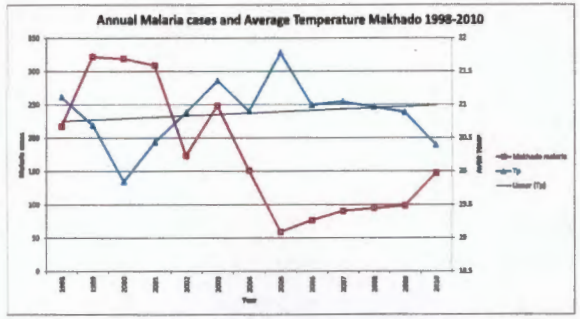


Figure 6.7: Malaria cases and annual air temperature in Makhado, 1998-2010.

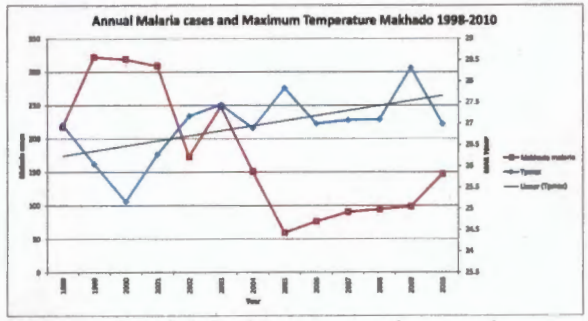


Figure 6.8: Malaria cases and annual maximum temperature in Makhado, 1998-2010.

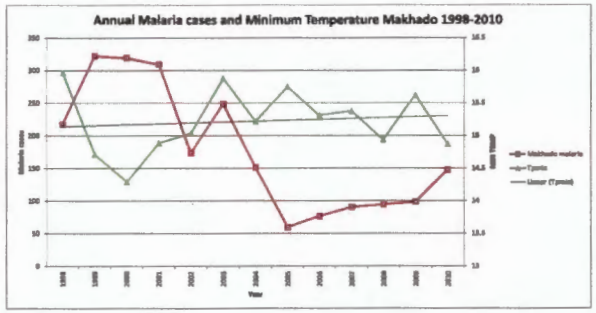


Figure 6.9: Malaria cases and annual minimum temperature in Makhado, 1998-2010.

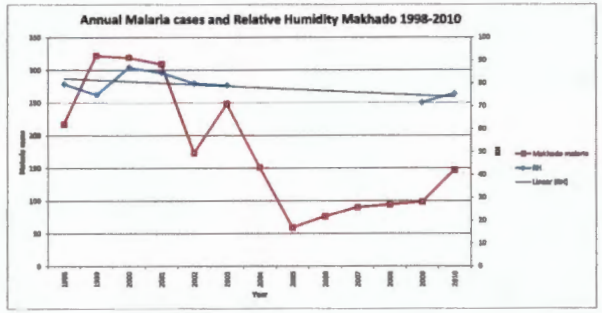


Figure 6.10: Malaria cases and annual Relative Humidity in Makhado, 1998-2010.

Table 6.5: Climate versus malaria Mann-Kendall test and Sen's slope estimate results for 1998-2010 annual data, Makhado Local Municipality.

Parameter	First year	Last Year	*n*	Z/S value and significance	Sen slope estimate (Q)	Units (Q)
Rainfall (Makhado RF)	1998	2010	13	-0.92	15.240	mm year^{-1}
Air temperature (Makhado TpAv)	1998	2010	13	0.18	0.012	°C year^{-1}
Maximum temperature (Makhado TpMax)	1998	2010	13	1.89+	0.114	°C year^{-1}
Minimum temperature (MakhadoTpMin)	1998	2010	13	0.31	0.036	°C year^{-1}
Relative Humidity (Makhado RH)	1998	2010	8	-10.0	-0.657	% year^{-1}

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

Rainfall and Relative Humidity were decreasing while air temperature and minimum temperature were increasing in Makhado Local Municipality. However, these trends were not statistically significant.

The linear relationships between malaria cases and climate variables in for Makhado Local Municipality are presented in Table 6.6. The maximum temperature can explain 55.27% of variation in number of malaria cases. This is followed by the Relative Humidity which can explain 44.04% of the cases, 33.21% for air temperature, 25.76% for annual rainfall and 20.09% for minimum temperature.

6.4 Annual Climate Variability and Malaria in Thulamela Local Municipality

The Pearson correlation coefficient (r) matrix for malaria and climate elements in Thulamela Local Municipality (Table 6.7), shows that there were statistically significant positive correlations between malaria and Relative Humidity ($r = 0.909$, $P = 0.012$) and between malaria and rainfall ($r = 0.600$, $P = 0.030$ in the number of malaria cases. The air temperature and maximum temperature showed a strong and highly significant correlation ($r = 0.916$, $P = 0.000$). Figures 6.11 to 6.15 show the fluctuations in the climate variables and malaria in Thulamela Local Municipality, as well as their trend lines over time. There was initial increase in rainfall from 1998, which reached its highest in 2000 (Figure 6.11).

Table 6.6: Strength of linear regression relationships between annual climate variables and malaria, Makhado Local Municipality.

Climate Element	R^2 value
Annual Rainfall	0.2576
Annual Air Temperature	0.3321
Annual Maximum Temperature	0.5527
Annual Minimum Temperature	0.2009
Annual Relative Humidity	0.4404

Table 6.7: Pearson correlation coefficient (*r*) values between malaria and annual climate variables, Thulamela Local Municipality.

Variables	Malaria cases	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
Malaria cases	1.000	0.600*	-0.023	0.149	-0.288	0.909*
Rainfall (RF)		1.000	-0.278	-0.099	-0.276	0.461
Air temperature (TpAv)			1.000	0.916**	0.381	-0.473
Maximum temperature (TpMax				1.000	0.093	-0.248
Minimum temperature (TpMin)					1.000	-0.67
Relative Humidity (RH)						1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Table 6.8: Climate versus malaria Mann-Kendall test and Sen's slope estimate results for 1998-2010 annual data, Thulamela Local Municipality.

Parameter	First year	Last Year	*n*	Z/S value and significance	Sen slope estimate (Q)	Units (Q)
Rainfall (Thulamela RF)	1998	2010	13	-1.53	-50.447	mm $year^{-1}$
Air temperature (Thulamela TpAv)	1998	2010	13	-0.79	-0.054	°C $year^{-1}$
Maximum temperature (Thulamela TpMax)	1998	2010	13	-1.16	-0.162	°C $year^{-1}$
Minimum temperature (Thulamela TpMin)	1998	2010	13	1.04	0.047	°C $year^{-1}$
Relative Humidity (Thulamela RH)	1998	2003	6	3.00	0.688	% $year^{-1}$

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

The amount of rainfall then decreased to its lowest in 2002 and 2003. From 2004 to 2010, the amount of annual rainfall fluctuated between 700mm and 1 500mm, with low rainfall amounts recorded in 2005 and 2008. Malaria cases also started on the rise from 1998 to a high in 1999 and 2000, followed by a decline in 2001 and 2002. An increase in malaria was observed in 2003 which then dropped for consecutive years until 2005. The number of cases increased in 2006, declined in 2007, rose again in 2008 and dropped in 2009 to 2010. The air and maximum temperatures declined from a high in 1998 to a low in 2000. There was an increase in temperature from 2001 to 2006 followed by a decline until 2010. The minimum temperature showed inconsistent change, with higher than normal minimum temperatures recorded in 2004, 2006 and 2009 and lower minimum temperatures in 2000, 2002 and 2007. The Relative Humidity rose to high levels in 1999, 2000 and 2003 with low humidity levels in 2002.

In 2000, Thulamela Local Municipality received the highest amount of rainfall, the highest number of malaria cases and the highest humidity levels, but the temperatures decreased (Figures 6.11-6.15). In 2002, the malaria cases declined with a reduction in the amount of rainfall and decrease in minimum temperatures, while the maximum and air temperatures were on the increase. The year 2003 saw a rise in malaria cases, together with the Relative Humidity and temperatures, while the amount of rainfall remained low. In 2005 there was a drop in the number of malaria cases, rainfall and minimum temperature. However, the maximum and air temperatures increased. Malaria cases and all the climate elements went up in 2006. The year 2007 saw a drop in malaria cases and all temperature variables with only rainfall increasing. In 2008 the number of malaria cases increased and the minimum temperature slightly increased. However, rainfall reduced and the maximum/air temperatures declined. Mann-Kendal trend analysis (Table 6.8) shows statistically non-significant trends of decreasing rainfall, air temperature and maximum temperature but increasing minimum temperature and Relative Humidity. Table 6.9 presents the R^2 values as indicators of the strengths of relationships between malaria and climate variables in Thulamela. Relative Humidity had the highest R^2 value (0.8266) versus malaria cases, meaning that 82.66% of the variation in malaria cases can be explained by the Relative Humidity. Rainfall explained 36.01% of the variation in malaria cases, air temperature explained 0.05%, maximum temperature explained 2.22%, and 8.28% of the variation in malaria cases can be explained by the minimum temperature.

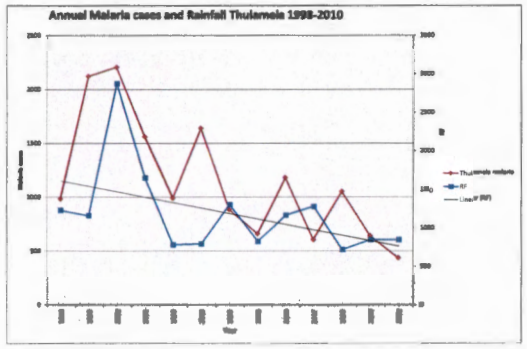


Figure 6.11: Malaria cases and annual rainfall in Thulamela, 1998-2010.

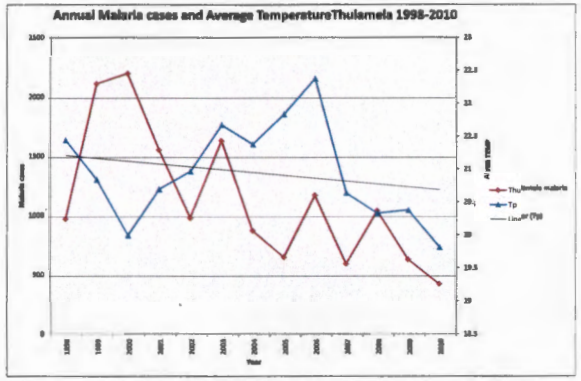


Figure 6.12: Malaria cases and annual air temperature in Thulamela, 1998-2010.

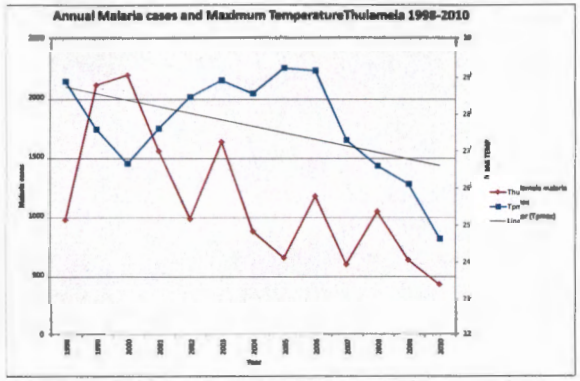


Figure 6.13: Malaria cases and annual maximum temperature in Thulamela, 1998-2010.

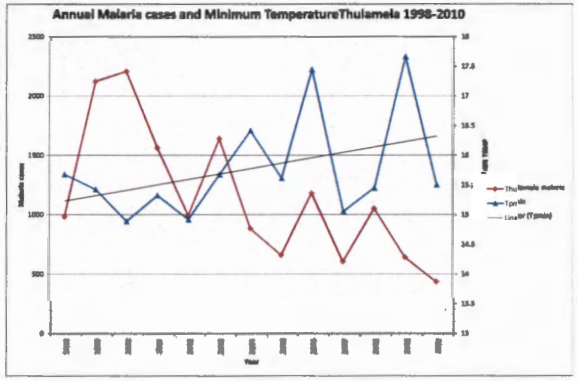


Figure 6.14: Malaria cases and annual minimum temperature in Thulamela, 1998-2010.

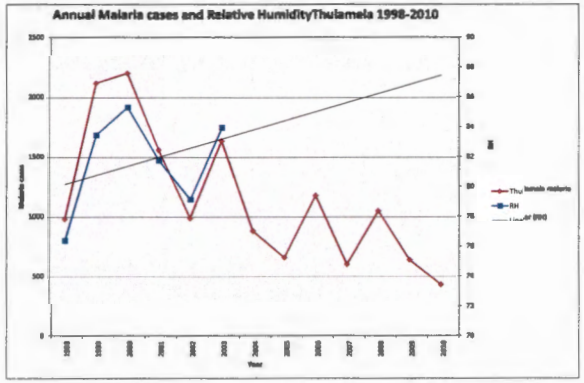


Figure 6.15: Malaria cases and annual Relative Humidity in Thulamela, 1998-2010.

Table 6.9: Strength of linear regression relationships between annual climate variables and malaria, Thulamela Local Municipality.

Climate Element	R^2 value
Annual Rainfall	0.3601
Annual Air Temperature	0.0005
Annual Maximum Temperature	0.0222
Annual Minimum Temperature	0.0828
Annual Relative Humidity	0.8266

6.5 Annual Climate Variability and Malaria in Mutale Local Municipality

In the period under analysis (1981-2010), Mutale Local Municipality had a complete set of data for rainfall only. Therefore, a complete correlation matrix of Pearson correlation coefficients similar to those in Tables 6.1, 6.4 and 6.7 pertaining to Mutale Local Municipality could not be produced. For Mutale Local Municipality there was a non-significant correlation between annual rainfall totals and the total number of malaria cases (r = 0.495).

Figure 6.16 shows the joint variations between the number of malaria cases and total annual rainfall in Mutale over time. Total annual rainfall increased from 1998 and peaked in 2000. The amount of rainfall then dropped to its lowest in 2002. From 2003 to 2010, rainfall exhibited fluctuations between 200mm and 1 200 mm per annum, with low rainfall being received in 2005. From 2007 to 2010, the amount of rainfall was decreasing. There was an increase in the number of malaria cases from 1998 to 1999, then a decline from 2000 to 2002. There was then a slight increase in malaria cases in 2003, followed by a drop in 2004 and 2005. In 2006 the number of malaria cases rose again, dropped in 2007 and went up again in 2008, declining in 2009 but rising in 2010.

In terms of the malaria peaks In Mutale Local Municipality, the highest number was in 1999 (1 600 cases) with the total rainfall being around 900 mm. The rainfall then doubled to 2 200 mm in 2000, but the number of cases dropped to 1 200. In 2002 and 2005, the malaria

cases dropped together with a decline in rainfall, but 2003 and 2006 saw a rise in both malaria and the amount of rainfall, with 2007 experiencing a drop in the number of malaria cases but an increase in rainfall. Malaria then dropped to its lowest for the analysis period in 2009, with the amount of rainfall dropping towards its lowest in 2010. However, there were missing temperature and Relative Humidity data for Mutale Local Municipality (Figures 4.32-4.35).

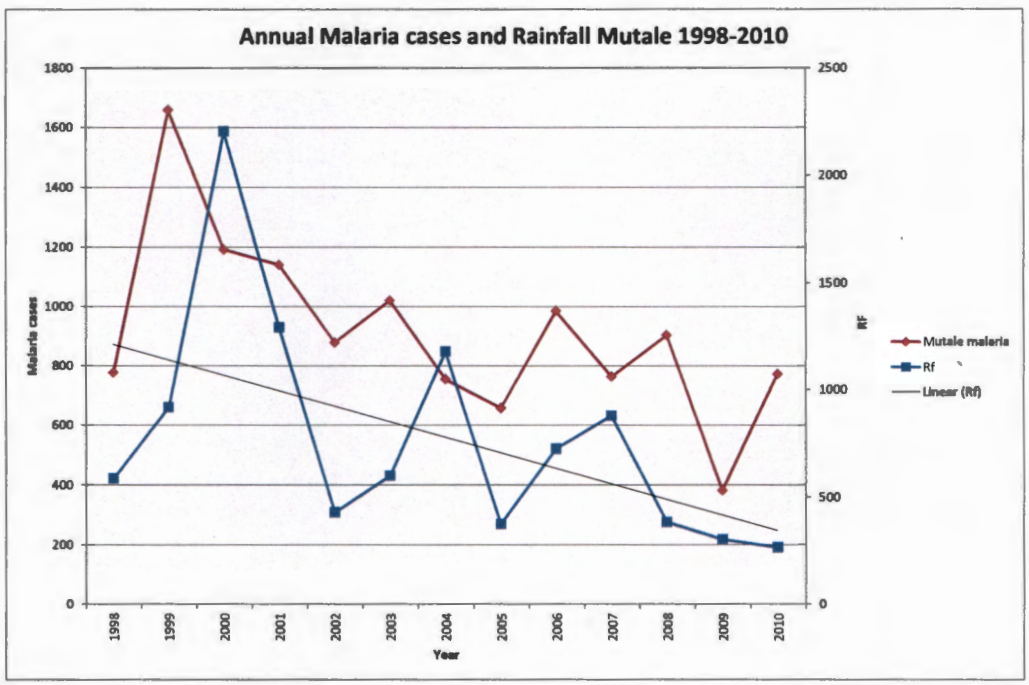


Figure 6.16: Malaria cases and annual rainfall in Mutale, 1998-2010.

Trend analysis (Table 6.10) yielded a statistically significant decreasing trend in the amount of rainfall in Mutale Local Municipality ($Z = -2.14$ at $\alpha = 0.05$ significance level). The magnitude of decrease as determined by Sen's slope estimate (Q) was -54.342 mm/year. The R^2 value for the linear relationship between malaria and annual total rainfall in Mutale was 0.2454, meaning that 24.54% of the variation in malaria cases can be explained by the annual rainfall totals.

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Table 6.10: Rainfall versus malaria Mann-Kendall test and Sen's slope estimate results for 1998-2010 annual data, Mutale Local Municipality.

Parameter	First year	Last Year	*n*	Z value and significance	Sen slope estimate (Q)	Units (Q)
Rainfall (Mutale RF)	1998	2010	13	-2.14*	-54.342	mm year^{-1}

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

6.6 Annual Climate Variability and Malaria in Vhembe District

The Pearson correlation coefficient matrix for malaria and climate elements in Vhembe District is given in Table 6.11. The results show that there was a statistically significant positive correlation between malaria and Relative Humidity (r = 0.709, P = 0.022). There were statistically significant negative correlations between rainfall and air temperature (r = -0.563, P = 0.045) and between rainfall and minimum temperature (r = -0.597, P = 0.031). There were also positive and statistically significant correlations between the air temperature and the maximum temperature (r = 0.962, P = 0.000) and between air temperature and minimum temperatures (r = 0.789, P = 0.000). Further, there was a positive and statistically significant correlation between minimum temperature and maximum temperature (r = 0.706, P = 0.007 at α=0.01), with the relative humidity and minimum temperature showing a statistically significant negative correlation (r = -0.774, P = 0.009).

Figures 6.17 to 6.21 show the joint change in malaria and annual climate data in Vhembe District over time. The rainfall graph (Figure 6.17) illustrates an initial increase in rainfall from 1998 which peaked in 2000. The amount of rainfall then dropped to its lowest in 2002, increased up until 2004, and then dropped in 2005. The rainfall went up again in 2006 and 2007 before dropping in 2008, and then increased until 2010. From 2003 to 2010 annual rainfall in Vhembe District between 500mm and 1000mm, with a general pattern of reduction overall.

Table 6.11: Pearson correlation coefficient (r) values between malaria and annual climate variables, Vhembe District.

Variables	Malaria cases	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
Malaria cases	1.000	0.485	-0.158	-0.077	-0.429	0.709*
Rainfall (RF)		1.000	-0.563*	-0.432	-0.597*	0.568
Air temperature (TpAv)			1.000	0.962**	0.789**	-0.534
Maximum temperature (TpMax				1.000	0.706**	-0.46
Minimum temperature (TpMin)					1.000	-0.774**
Relative Humidity (RH)						1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Table 6.12: Climate versus malaria Mann-Kendall test and Sen's slope estimate results for 1998-2010 annual data, Vhembe District.

Parameter	**First year**	**Last Year**	***n***	**Z value and significance**	**Sen slope estimate (Q)**	**Units (Q)**
Rainfall (Vhembe RF)	1998	2010	13	-1.16	-26.060	mm year^{-1}
Air temperature (Vhembe TpAv)	1998	2010	13	-0.43	-0.017	°C year^{-1}
Maximum temperature (Vhembe TpMax)	1998	2010	13	-0.55	-0.068	°C year^{-1}
Minimum temperature (Vhembe TpMin)	1998	2010	13	0.43	0.020	°C year^{-1}
Relative Humidity (Vhembe RH)	1998	2010	10	-1.07	-0.759	% year^{-1}

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

Table 6.13: Strength of linear regression relationships between annual climate variables and malaria, Vhembe District.

Climate Element	**R^2 value**
Annual Rainfall	0.2356
Annual Air Temperature	0.0248
Annual Maximum Temperature	0.0059
Annual Minimum Temperature	0.1836
Annual Relative Humidity	0.5030

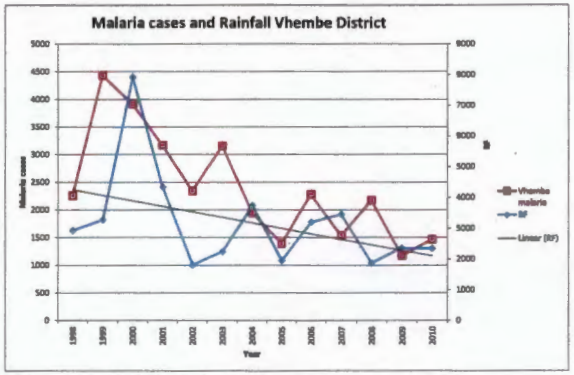


Figure 6.17: Malaria cases and annual rainfall in Vhembe District, 1998-2010.

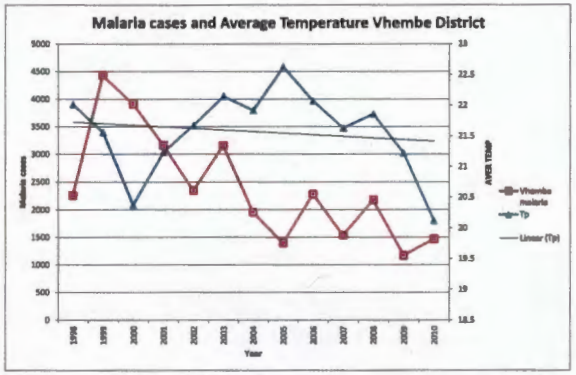


Figure 6.18: Malaria cases and annual air temperature in Vhembe District, 1998-2010.

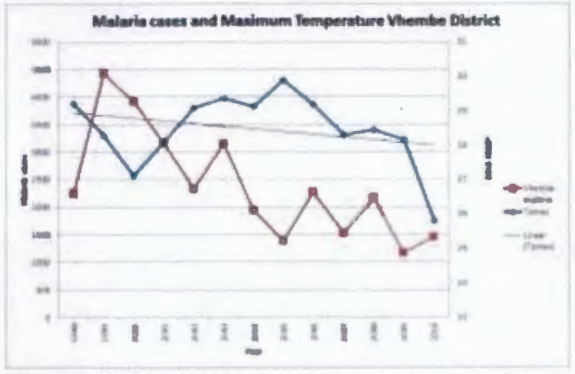


Figure 6.19: Malaria cases and annual maximum temperature in Vhembe District, 1998-2010.

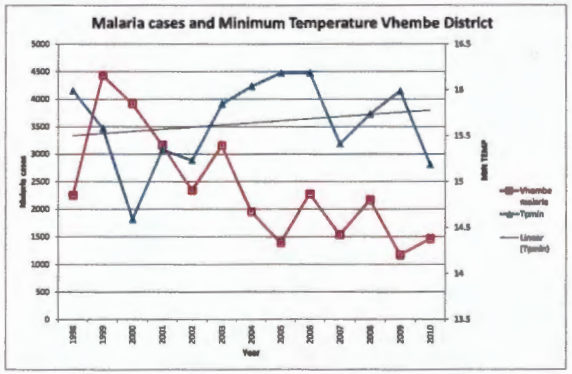


Figure 6.20: Malaria cases and annual minimum temperature in Vhembe District, 1998-2010.

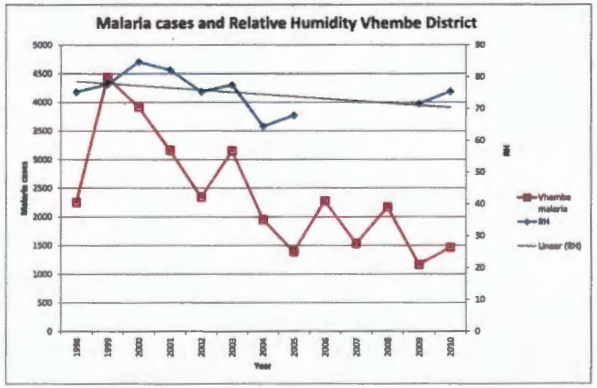


Figure 6.21: Malaria cases and annual Relative Humidity in Vhembe District, 1998-2010.

The number of malaria cases started off with an initial increase from 1998 to 1999, then underwent a gradual drop from 2000 to 2002 followed by an increase in 2003, and then drops for consecutive years until 2005. In 2006 the number of malaria cases increased and but dropped in 2007 before going through a small increase in 2008 followed by a decline in 2009 and then a slight increase in 2010. An analysis of the temperature variables shows that there was a decrease in all three temperature parameters from 1998 to 2000 followed by an increase in temperature between 2001 and 2005. There were gradual decreases in air and maximum temperature from 2006 to 2010. However, the minimum temperature shows a different pattern, with a decrease from 2006 to 2007 and an increase from 2008 to 2009, then a decrease in 2010. The Relative Humidity showed an increase from 1998 to a high in 2000 and gradually dropped until 2004. There were increases in Relative Humidity between 2009 and 2010.

From Figures 6.17 to 6.21, a number of key points in the relationship between the number of malaria cases and climate in Vhembe District emerge. The year 1999 had an upsurge in malaria but there was only a slight rainfall increase, a slight increase in Relative Humidity from the previous year and a slight drop in temperatures. In 2000, Vhembe District received its highest rainfall in the period of analysis (1981-2010). However, the number of malaria cases declined, all the temperature variables dropped further, and the Relative Humidity increased to its highest for the period under study. Malaria cases, rainfall and Relative Humidity plummeted in 2002, while temperatures increased from 2001 to 2005. The year 2003 saw an increase in malaria cases and also increases in all the climate variables. In 2005 malaria dropped, rainfall amount declined, the minimum temperature increased slightly from 2004, the air and maximum temperatures increased to their highest for the period under review, and the Relative Humidity also rose from the previous year. 2006 then saw an increase in malaria cases, the air/maximum temperatures dropped, the rainfall increased and the minimum temperature remained almost the same as in 2005. Malaria cases and all temperature variables decreased in 2007 with rainfall increasing. In 2008, the malaria cases escalated with an increase in minimum temperature, while the rainfall decreased and the maximum/air temperatures also declined. Finally, of particular note is 2009 that saw a drop in malaria cases, a slight increase in rainfall, further decrease in air temperature and maximum temperature, but an increase in minimum temperature.

Mann-Kendal analysis (Table 6.12) revealed decreasing trends on all parameters except the minimum temperature which showed an increasing trend. The trends are, however, not statistically significant. Table 6.13 shows the strengths of the linear relationships between malaria and climate elements in Vhembe district, indicating that 23.56% of the variation in malaria cases can be explained by the amount of rainfall, 50.30% by the Relative Humidity, 18.36% by the minimum temperature. The other elements explain very little of the variation in malaria cases, with air temperature explaining only 2.48% and maximum temperature 0.59% of the variation.

6.7 Monthly Climate Variability and Malaria in Musina Local Municipality

An analysis of the monthly relationships between malaria and climate elements is necessary because brief changes in climate condition may have an effect of the malaria vector cycle, which tends to be concealed in the long-term (annual) relationships. The initial stage followed in the analysis was to perform cross-correlation on the monthly data averaged between 1998 and 2010 so as to determine the most influential lag period at 95% confidence level. After establishing the lag period which gives the highest correlation, the Pearson correlation coefficient (r) statistical test was then applied to establish the significance of the relationship. Table 6.14 shows the results from the cross-correlation analysis for Musina Local Municipality.

Table 6.14: Malaria versus monthly climate parameter Pearson correlation coefficient cross correlation analysis for Musina Local Municipality.

	Climate variable				
Month lag	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
-6	-0.38	-0.36	-0.35	-0.36	-0.07
-5	-0.39	-0.44	-0.40	-0.46	-0.24
-4	-0.14	-0.28	-0.25	-0.29	-0.32
-3	0.29	0.14	0.14	0.13	-0.29
-2	**0.58**	**0.59**	**0.59**	**0.58**	-0.28
-1	**0.66**	**0.85**	**0.85**	**0.85**	-0.16
0	**0.52**	**0.79**	**0.77**	**0.79**	0.08
1	0.29	0.36	0.32	0.38	0.45
2	0.05	-0.15	-0.22	-0.11	**0.83**
3	-0.39	-0.60	-0.66	-0.57	**0.84**
4	-0.68	-0.74	-0.74	-0.74	0.45
5	-0.65	-0.54	-0.51	-0.55	-0.03
6	-0.40	-0.22	-0.17	-0.24	-0.37

Table 6.14 shows that the highest correlation between malaria and climate elements is obtained at lag 0 month, lag -1 month and lag -2 months. The Relative Humidity however does not show any correlation during this lag time. These results mean that a lag period of a month is experienced in Musina from the time favourable climate conditions for malaria set in to the point when infection is observed. For rainfall, $r = 0.66$ at lag -1, followed by 0.58 at lag -2 and then 0.52 at lag 0. All the values are measured at 95% confidence level. All the temperature variables indicate a value of $r = 0.85$ at lag -1, a value of $r = 0.79$ for air and minimum temperature at lag 0, and $r = 0.77$ for maximum temperature at lag 0.

Having established that the highest correlation is at lag -1 month, the statistical significance was assessed. Table 6.15 shows the results of the statistical significance analysis of this relationship at lag-1 month. The results indicate a strong relationship between malaria and climate elements except for the Relative Humidity. The Pearson correlation for all other climate elements is above 0.7 at $\alpha > 0.01$ significance level. The most significant relationship was between malaria and air temperature ($r = 0.897$, $P = 0.000$), followed by malaria versus the minimum temperature ($r = 0.894$, $P = 0.000$), then malaria versus maximum temperature ($r = 0.893$, $P = 0.000$) and finally malaria versus rainfall ($r = 0.726$, $P = 0.008$). The results also yielded high correlations among all the climate elements except with Relative Humidity.

Table 6.16 shows the strengths of linear regression of malaria cases (dependent variable, Y) and on each of the climate variables (X) variables. Rainfall in Musina Local Municipality explains 26.87% of the variation in malaria cases, air temperature explains 62.25%, minimum temperature 63.18%, and Relative Humidity explains 0.57% of variation in malaria.

The monthly average rainfall for Musina Local Municipality, based on the 1998-2010 data, is shown in Figure 6.22. Musina receives the highest amount of rainfall between November and February with a high of just below 70mm of rainfall in November and December. Although the number of malaria cases did not follow a symmetrical shape as compared to the rainfall as in Figure 6.22, the trend was a general increase in the number of malaria cases during the rainy summer season and very few cases during the winter months. In relation to the rainfall a shift to the right in the distribution of malaria cases is observable in Figure 6.22, which may

explain the -1 month lag result obtained in Table 6.14. April had the highest number of malaria cases based on the 1998-2010 data.

Table 6.15: Pearson correlation coefficient (*r*) values between malaria and monthly climate variables, Musina Local Municipality.

Variables	Malaria cases	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
Malaria cases	1.000	0.726**	0.897**	0.893**	0.894**	-0.18
Rainfall (RF)		1.000	0.871**	0.831**	0.882**	-0.02
Air temperature (TpAv)			1.000	0.992**	0.998**	-0.23
Maximum temperature (TpMax				1.000	0.984**	-0.32
Minimum temperature (TpMin)					1.000	-0.18
Relative Humidity (RH)						1.000

**Correlation is significant at the 0.01 level (2-tailed).

Table 6.16: Strength of linear regression relationships between monthly climate variables and malaria, Musina Local Municipality.

Climate Element	**R^2 value**
Monthly rainfall	0.2687
Monthly air temperature	0.6225
Monthly maximum temperature	0.5996
Annual minimum temperature	0.6318
Annual relative humidity	0.0057

Figure 6.23 shows the variation in monthly air temperatures in a year, and Figure 6.24 the Relative Humidity, in Musina Local Municipality in relation to the number of malaria cases. There were increases in malaria cases at the inception of summer from August to September. However, at the inception of winter in May, the decrease in malaria cases was not as sharp. The -1 month lag factor (Table 6.14) appears to be the cause of this. The number of malaria cases only dropped sharply in June.

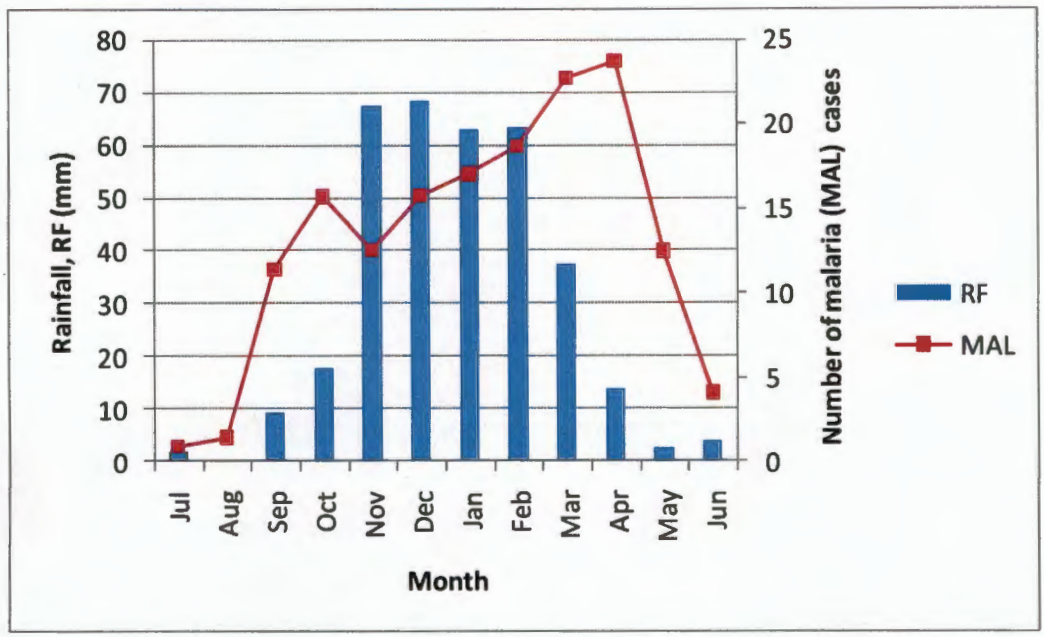


Figure 6.22: Distribution of monthly number of malaria cases in relation to average monthly rainfall in Musina Local Municipality, 1998-2010. Rainfall data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

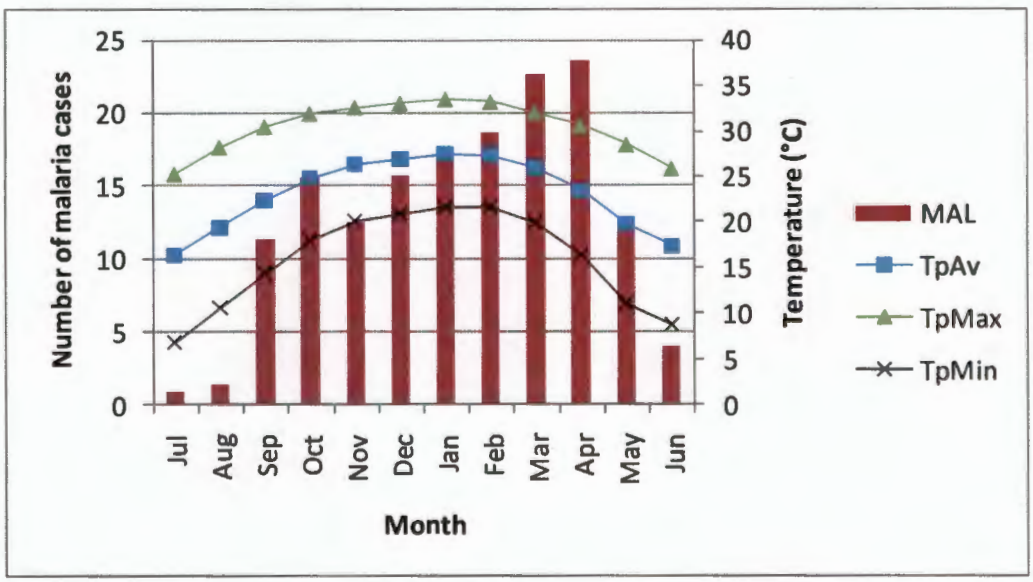


Figure 6.23: Distribution of monthly number of malaria (MAL) cases in relation to monthly air (TpAv), maximum (TpMax) and minimum (TpMin) temperature in Musina Local Municipality, 1998-2010. Temperature data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

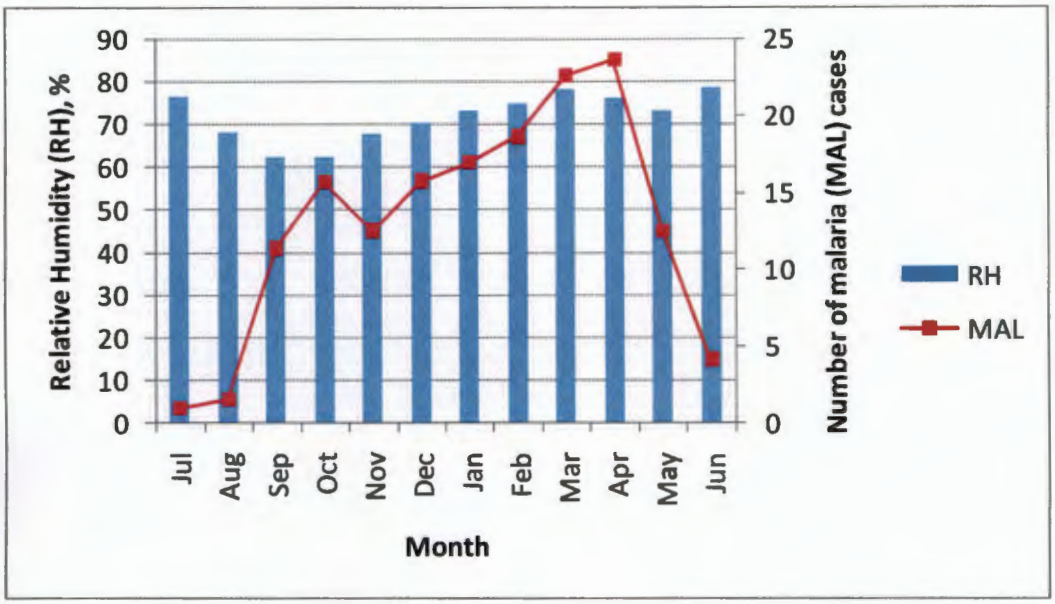


Figure 6.24: Distribution of monthly number of malaria cases in relation to average monthly Relative Humidity in Musina Local Municipality, 1998-2010. Humidity data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

Figure 6.24 indicates that there was still high Relative Humidity in winter, higher than some summer months. Malaria cases are still observed to be higher in the summer months than in the winter months. This may explain the anomaly observed during statistical analysis.

6.8 Monthly Climate Variability and Malaria in Makhado Local Municipality

Table 6.17 shows the cross-correlation (see Section 6.7) results obtained for Makhado Local Municipality. For Makhado Local Municipality, high correlations occur at lag 1 month, lag 0 month and lag -1month. Unlike in Musina Local Municipality (Table 6.14), the results in Table 6.17 indicate that, in Makhado Local Municipality, malaria infections are detected within the same month (lag 0) in which favourable conditions are established. Pearson correlation analysis was then performed in order to establish the significance of the relationship. Table 6.18 shows the results that were obtained at lag 0 month. All the climate parameters are highly and statistically significantly correlated with the number of malaria cases (Table 6.18) – rainfall versus malaria: $r = 0.773$, air temperature versus malaria: $r = 0.944$, maximum temperature versus malaria: $r = 0.935$, minimum temperature versus malaria: $r = 0.936$, and Relative Humidity versus malaria: $r = 0.578$ at 95% confidence

level. There were also high correlations among all the climate elements except between Relative Humidity and maximum temperature (Table 6.18). Linear regression analysis to identify the dependence of malaria on each of the climate variables yielded the strength of dependence results in Table 6.19.

Table 6.17: Malaria versus monthly climate parameter Pearson correlation coefficient cross correlation analysis for Makhado Local Municipality.

	Climate variable				
Month lag	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
-6	-0.59	-0.53	-0.52	-0.54	-0.30
-5	-0.71	-0.72	-0.70	-0.74	-0.56
-4	-0.52	-0.55	-0.50	-0.60	-0.66
-3	-0.13	0.13	-0.06	-0.20	-0.60
-2	0.28	0.40	0.47	0.33	-0.20
-1	**0.58**	**0.78**	**0.81**	**0.73**	0.20
0	**0.77**	**0.94**	**0.93**	**0.94**	**0.58**
1	**0.63**	**0.61**	**0.53**	**0.66**	**0.71**
2	0.34	0.14	0.05	0.23	**0.64**
3	-0.06	-0.28	-0.36	-0.19	0.38
4	-0.36	-0.55	-0.56	-0.48	-0.06
5	-0.41	-0.50	-0.50	-0.48	-0.24
6	-0.33	-0.33	-0.30	-0.34	-0.29

Table 6.18: Pearson correlation coefficient (*r*) values between malaria and monthly climate variables, Makhado Local Municilapity.

Variables	Malaria cases	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
Malaria cases	1.000	0.773**	0.944**	0.935**	0.936**	0.578*
Rainfall (RF)		1.000	0.875**	0.806**	0.906**	0.715**
Air temperature (TpAv)			1.000	0.987**	0.992**	0.587*
Maximum temperature (TpMax				1.000	0.964**	0.48
Minimum temperature (TpMin)					1.000	0.678*
Relative Humidity (RH)						1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Table 6.19: Strength of linear regression relationships between monthly climate variables and malaria, Makhado Local Municipality.

Climate Element	R^2 value
Monthly rainfall	0.5977
Monthly air temperature	0.8918
Monthly maximum temperature	0.8733
Annual minimum temperature	0.8753
Annual relative humidity	0.3343

Rainfall can explain 59.77% of the variation in malaria in Makhado Local Municipality (Table 6.19). All the temperature variables can explain more than 80% variation in malaria cases, the highest being air temperature (89.18% of the variation), then monthly maximum temperature (87.33%), minimum temperature (87.53%), and least Relative Humidity (33.43% of variation).

Figure 6.25 shows average monthly rainfall for Makhado Local Municipality based on the 1998-2010 data. The number of malaria cases follows a symmetrical shape similar to that of rainfall, with the general trend that the number of cases increases during summer (the rainy season) and very few cases reported during the winter months. Notably February, which receives the highest amount of rainfall amount, shows a dip in the number of malaria cases reported (Figure 6.25). The winter months between May and September experience little rainfall and hence have a reduced number of malaria cases. The almost symmetrical shape between rainfall and malaria (Figure 6.25) may explain the 0 month lag (Table 6.17), whereby the impact of climate conditions on malaria incidence is within the same month.

The monthly air temperatures in relation to the number of malaria cases in Makhado Local Municipality are shown in Figure 6.26. The number of malaria cases in the winter months of June, July and August were quite low in Makhado. However, there were drastic increases at the inception of the summer months as can be observed in the jump from August to September in Figure 6.26. However, at the inception of winter in May, the rate of decrease was not as sharp. The number of cases only dropped sharply in June. The number of cases during summer ranged between 10 and 25, with December reporting the highest number of

cases between 1998 and 2010. In terms of average Relative Humidity in Makhado Local Municipality (Figure 6.27) the summer months had slightly higher values than the winter months. In relation to this pattern the number of malaria cases increased during summer and a decreased during winter (Figure 6.27).

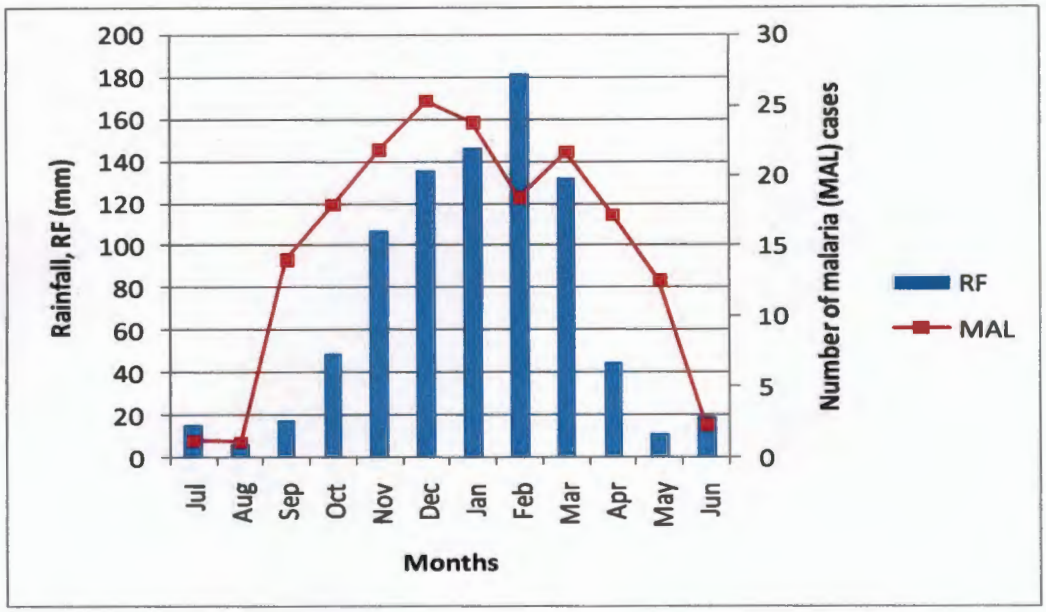


Figure 6.25: Distribution of monthly number of malaria cases in relation to average monthly rainfall in Makhado Local Municipality, 1998-2010. Rainfall data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

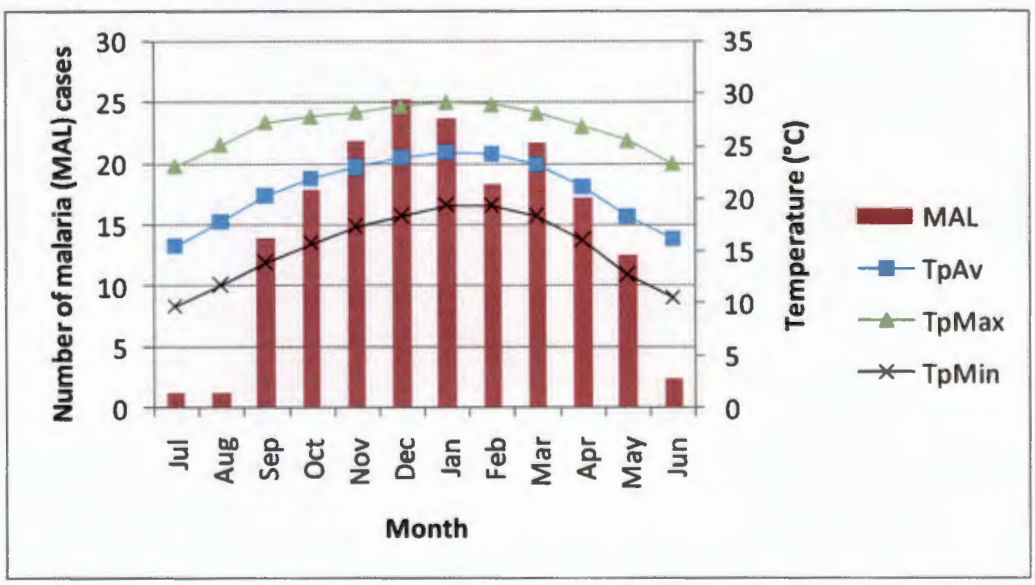


Figure 6.26: Distribution of monthly number of malaria (MAL) cases in relation to monthly air (TpAv), maximum (TpMax) and minimum (TpMin) temperature in Makhado Local Municipality, 1998-2010. Temperature data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

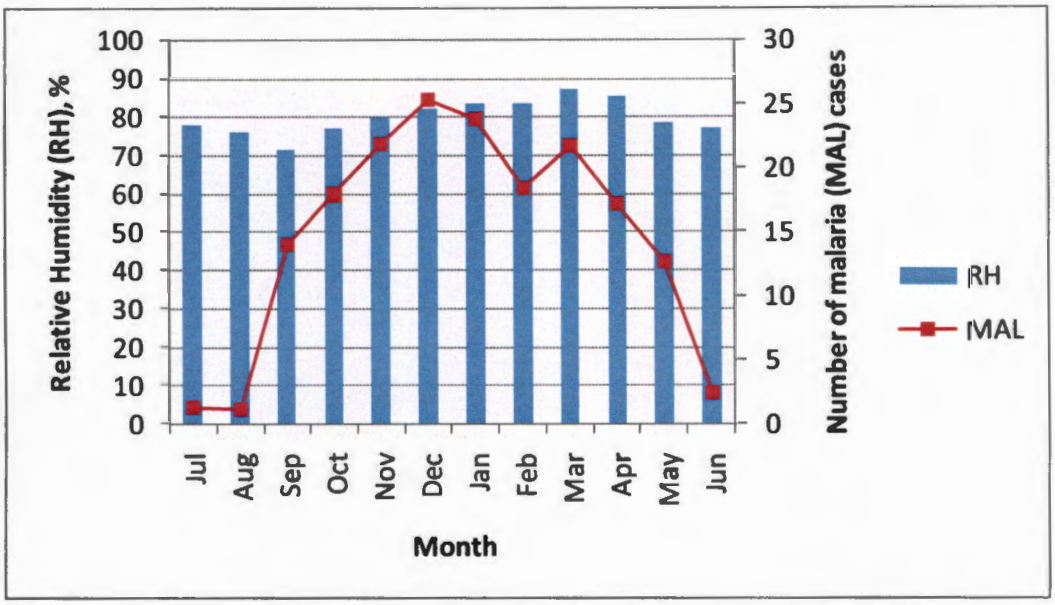


Figure 6.27: Distribution of monthly number of malaria cases in relation to average monthly Relative Humidity in Makhado Local Municipality, 1998-2010. Humidity data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

6.9 Monthly Climate Variability and Malaria in Thulamela Local Municipality

Cross-correlation analysis (explained in Section 6.7) of Thulamela Local Municipality month average malaria and climate data yielded the results in Table 6.20. The lag 0 month had the highest correlation values followed by lag -1 month for all the climate parameters except for Relative Humidity, at 95% confidence interval. Results from Pearson correlation analysis (Table 6.21) indicated that the minimum temperature was the most highly correlated with malaria is (r = 0.96), followed by the air temperature (r = 0.95), then the maximum temperature (r = 0.85) and finally the rainfall (r = 0.83); P = 0.000 for all the variables. There were high correlations among all the climate elements except for Relative Humidity.

Table 6.20: Malaria versus monthly climate parameter Pearson correlation coefficient cross correlation analysis for Thulamela Local Municipality.

Month lag	Climate variable				
	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
-6	-0.54	-0.43	-0.43	-0.44	0.11
-5	-0.59	-0.55	-0.48	-0.57	0.02
-4	-0.38	-0.42	-0.28	-0.44	-0.17
-3	0.00	-0.04	0.16	-0.06	-0.40
-2	0.39	0.42	**0.60**	0.42	-0.61
-1	**0.66**	**0.78**	**0.84**	**0.78**	-0.54
0	**0.83**	**0.95**	**0.85**	**0.96**	-0.32
1	**0.68**	**0.66**	0.43	**0.67**	0.21
2	0.29	0.16	-0.11	0.18	**0.56**
3	-0.18	-0.35	-0.58	-0.34	**0.87**
4	-0.43	-0.63	-0.78	-0.63	**0.71**
5	-0.48	-0.65	-0.68	-0.63	**0.51**
6	-0.42	-0.45	-0.34	-0.44	0.11

Table 6.21: Pearson correlation coefficient (*r*) values between malaria and monthly climate variables, Thulamela Local Municilapity.

Variables	Malaria cases	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
Malaria cases	1.000	0.828**	0.953**	0.848**	0.956**	-0.32
Rainfall (RF)		1.000	0.898**	0.819**	0.908**	-0.22
Air temperature (TpAv)			1.000	0.949**	0.997**	-0.46
Maximum temperature (TpMax				1.000	0.940**	-0.68
Minimum temperature (TpMin)					1.000	-0.44
Relative Humidity (RH)						1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Table 6.22 lists the R^2 values as indicators of the strength of the linear relationships between the climate variables and the number of malaria cases (dependent variable), and indicates that 91.34% of the variation in malaria can be explained by the monthly minimum temperature, 90.74% by the monthly air temperature, 71.86% by the maximum temperature, 68.51% by rainfall, and 10.15% by Relative Humidity. The average monthly rainfall and the monthly number of malaria cases in Thulamela Local Municipality are shown in Figure 6.28.

Table 6.22: Strength of linear regression relationships between monthly climate variables and malaria, Thulamela Local Municipality.

Climate Element	R^2 value
Monthly rainfall	0.6851
Monthly air temperature	0.9074
Monthly maximum temperature	0.7186
Annual minimum temperature	0.9134
Annual relative humidity	0.1015

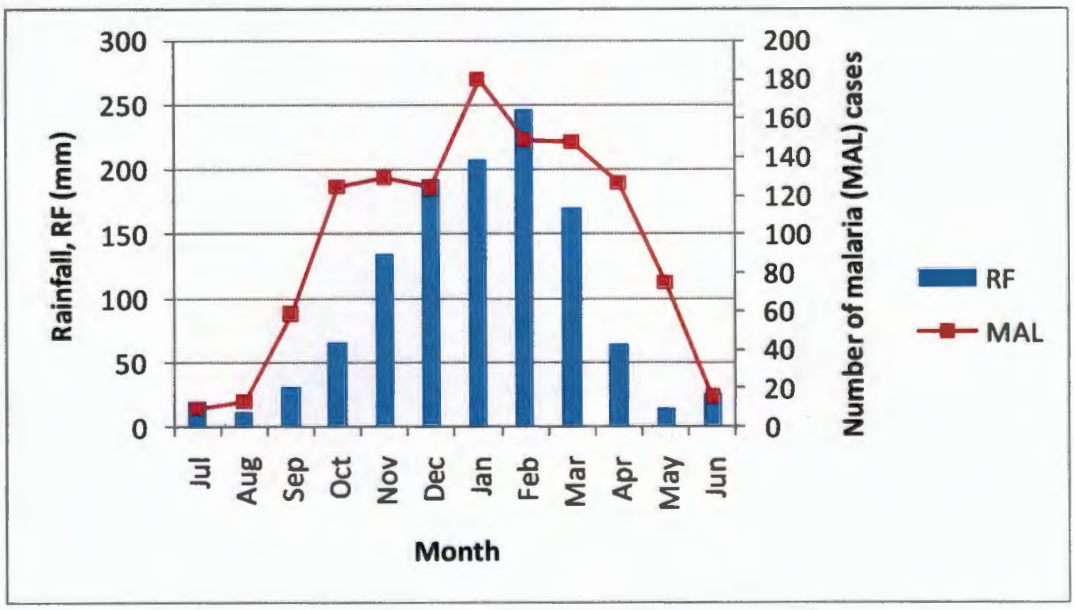


Figure 6.28: Distribution of monthly number of malaria cases in relation to average monthly rainfall in Thulamela Local Municipality, 1998-2010. Rainfall data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

As the case with Musina (Figure 6.22) and Makhado (Figure 6.25) Local Municipalities malaria peaked during the rainy season in Thulamela Local. January reported the highest number of malaria cases. Like in Makhado Local Municipality (Figure 6.25), Figure 6.28 shows for Thulamela Local Municipality there was a drop in the number of malaria cases in February (highest rainfall month) compared to the month before or after.

The number of malaria cases in the winter months of June, July and August were low in Thulamela (Figure 6.29) Municipality. There were drastic increases in the number of malaria

cases at the inception of the summer (rain season) months, as can be observed in the jump from August to September in Figure 6.29. However, at the start of winter in May decrease in number of malaria cases was not as steep. The number of cases only dropped sharply in June. The number of cases during summer ranged between 50 and 175, with January reporting the highest number of cases on average. Relative Humidity (RH) data in Thulamela Local Municipality were available for the period 1998 to 2003 only, and their monthly averages are depicted in Figure 6.30. Surprisingly, some of the highest RH values in Thulamela were in the winter months notably, June and July.

6.10 Monthly Climate Variability and Malaria in Mutale Local Municipality

Mutale Local Municipality could only be analysed for rainfall in relation to the number of malaria cases, due to lack of data for the other climate variables. Cross correlation analysis was performed using the rainfall data to determine the lead time at which malaria was experienced as a result of malaria-conducive climate. Table 6.23 shows the results of the cross correlation, and indicates that month lag 0 was the most highly correlated with malaria, followed by lag -1. Pearson correlation analysis yielded a correlation coefficient (r) 0.744, which was statistically significant at $\alpha = 0.01$ significance level. Linear regression analysis to identify the dependence of malaria on rainfall yielded an R^2 value of 0.5538, meaning that 55.38% of the variation in malaria in Mutale Local Municipality can be explained by the monthly rainfall.

Figure 6.31 shows the variation in number of malaria cases in Mutale Local Municipality in relation to the average monthly rainfall in a year. Like the case with the other local municipalities in Vhembe District, malaria in Mutale Local Municipality peaks during the rainy season and very few cases are reported between May and September. February had the highest average rainfall during summer but the number of malaria cases was lower than in January and March, like the case with Makhado (Figure 6.25) and Thulamela (Figure 6.28) Local municipalities. The highest number of malaria cases occurred in January on average.

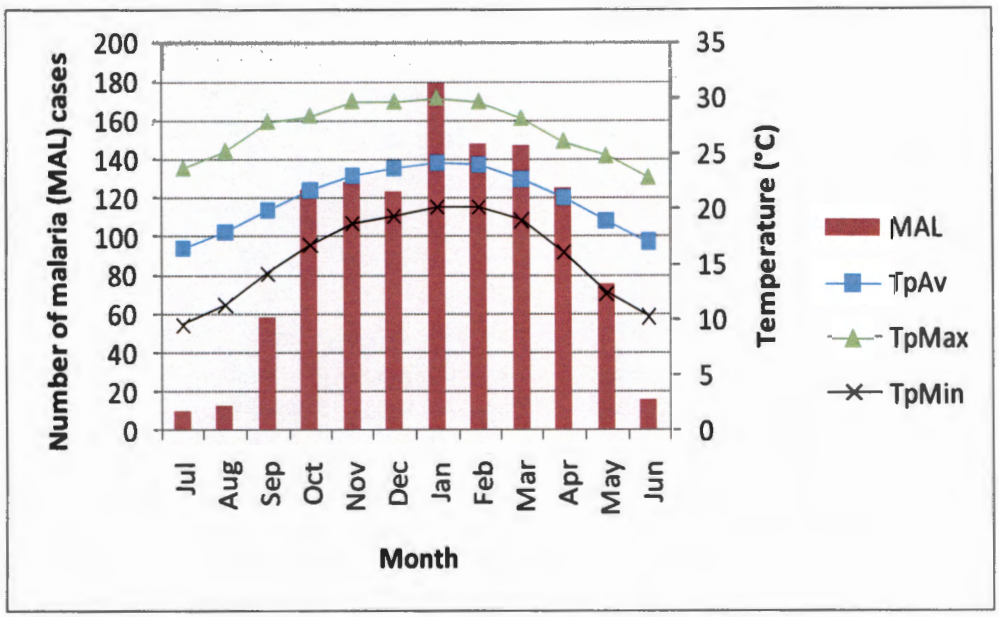


Figure 6.29: Distribution of monthly number of malaria (MAL) cases in relation to monthly air (TpAv), maximum (TpMax) and minimum (TpMin) temperature in Thulamela Local Municipality, 1998-2010. Temperature data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

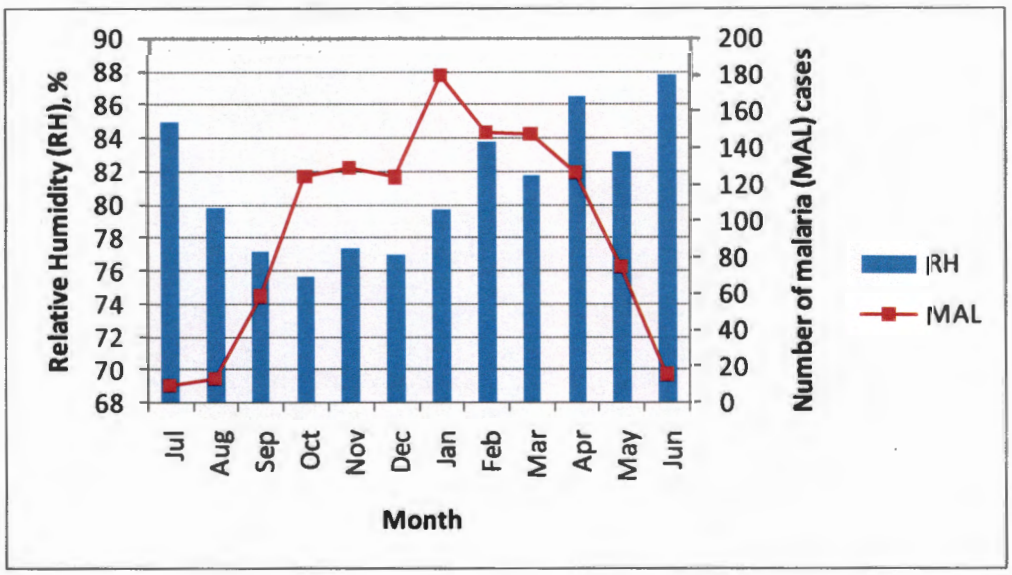


Figure 6.30: Distribution of monthly number of malaria cases in relation to average monthly Relative Humidity in Thulamela Local Municipality, 1998-2003. Humidity data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

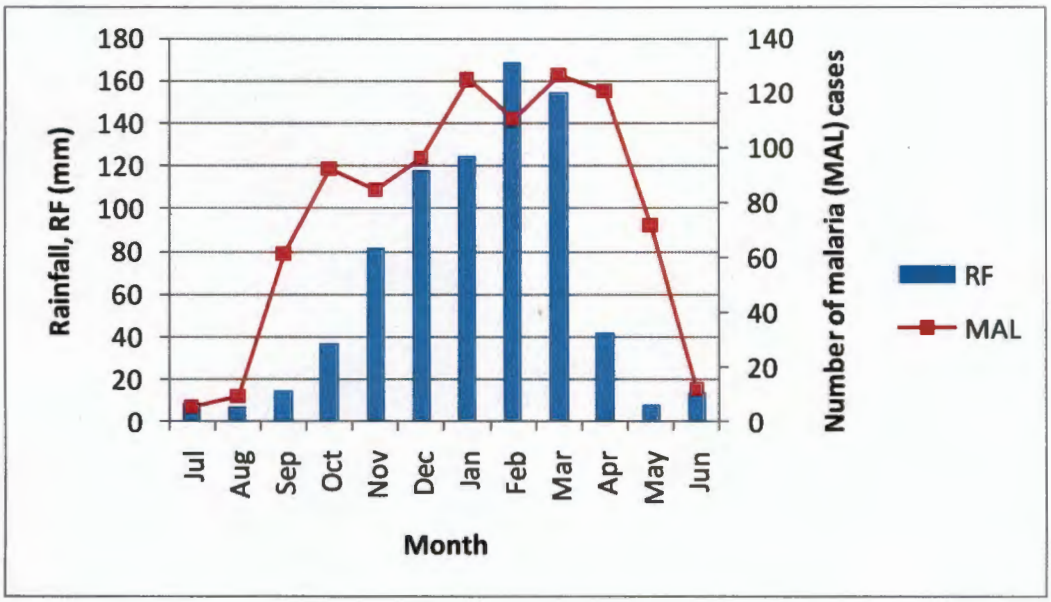


Figure 6.31: Distribution of monthly number of malaria cases in relation to average monthly rainfall in Mutale Local Municipality, 1998-2010. Rainfall data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

Table 6.23: Malaria versus monthly climate parameter Pearson correlation coefficient cross correlation analysis for Mutale Local Municipality.

	Climate variable
Month lag	Rainfall (RF)
-6	-0.47
-5	-0.63
-4	-0.43
-3	0.01
-2	0.49
-1	**0.73**
0	**0.74**
1	**0.55**
2	0.28
3	-0.15
4	-0.41
5	-0.46
6	-0.39

6.11 Monthly Climate Variability and Malaria in Vhembe District

Cross-correlation analysis (explained in Section 6.7) was performed for the combined malaria cases in the four local municipalities in Vhembe District, and the results are shown in Table 6.24. The highest correlating values were at lag 0 month, followed closely by lag -1 month.

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The results of Pearson correlation analysis (Table 6.25) highlighted the strong relationship between malaria and climate elements in Vhembe District since all the climate variables had statistically significant correlations with the number of malaria cases. Minimum temperature had the highest correlation with malaria (r = 0.937, P = 0.000) and the least was rainfall (r = 0.789, P = 0.002). There were high and statistically significant correlations among all the climate elements except with Relative Humidity. Table 6.26 lists the R^2 values as indicators of the strength of the linear relationships between the climate variables and the number of malaria cases (dependent variable), indicating that 87.86% of variation in malaria can be explained by the average monthly minimum temperature, 86.93% by average monthly air temperature, 80.81% by the average monthly maximum temperature, 62.31% by the average monthly rainfall, and 1.81% by the average monthly Relative Humidity.

Table 6.24: Malaria versus monthly climate parameter Pearson correlation coefficient cross correlation analysis for Vhembe District.

	Climate variable				
Month lag	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
-6	-0.52	-0.43	-0.41	-0.43	-0.08
-5	-0.60	-0.55	-0.51	-0.57	-0.26
-4	-0.38	-0.40	-0.35	-0.42	-0.39
-3	0.04	0.00	0.06	-0.01	-0.46
-2	0.45	0.49	**0.54**	0.47	-0.44
-1	**0.69**	**0.83**	**0.85**	**0.82**	-0.22
0	**0.79**	**0.93**	**0.90**	**0.94**	0.13
1	**0.61**	**0.59**	0.49	**0.61**	**0.54**
2	0.26	0.07	-0.06	0.11	**0.84**
3	-0.19	-0.43	-0.53	-0.39	**0.81**
4	-0.47	-0.68	-0.70	-0.66	0.45
5	-0.52	-0.62	-0.61	-0.62	0.12
6	-0.42	-0.39	-0.34	-0.40	-0.19

Like the case with some of the local municipalities that constitute Vhembe District, notably Makhado (Figure 6.25) and Thulamela (Figure 6.28), there was a drop in the Vhembe District wide number of malaria cases February, the month with the highest rainfall (Figure 6.32). In general, the number of malaria cases in Vhembe District follows the rainfall (season) pattern, peaking during the rainy season and with very few cases reported between May and August. The highest number of malaria cases was in January, as was the case in Thulamela and Mutale Local Municipalities (Figures 6.28 and 6.31).

Table 6.25: Pearson correlation coefficient (r) values between malaria and monthly climate variables, Vhembe District.

Variables	Malaria cases	Rainfall (RF)	Air temperature (TpAv)	Maximum temperature (TpMax)	Minimum temperature (TpMin)	Relative Humidity (RH)
Malaria cases	1.000	0.789**	0.932**	0.899**	0.937**	0.13
Rainfall (RF)		1.000	0.883**	0.815**	0.905**	0.24
Air temperature (TpAv)			1.000	0.986**	0.998**	-0.07
Maximum temperature (TpMax				1.000	0.974**	-0.22
Minimum temperature (TpMin)					1.000	-0.01
Relative Humidity (RH)						1.000

**Correlation is significant at the 0.01 level (2-tailed).

Table 6.26: Strength of linear regression relationships between monthly climate variables and malaria, Vhembe District.

Climate Element	**R^2 value**
Monthly rainfall	0.6231
Monthly air temperature	0.8693
Monthly maximum temperature	0.8081
Annual minimum temperature	0.8786
Annual relative humidity	0.0181

Figure 6.33 shows the change in average monthly number of malaria cases with change in temperature parameter monthly averages in Vhembe District in a year. The number of malaria cases in the winter months of June, July and August was low (less than 10). There was a drastic increase in the number of cases towards the summer months, as can be observed in the jump in numbers from August to September. However, at the inception of winter in May, the rate of decrease was not as steep; the number of cases only dropped sharply in June. Relative Humidity data in Vhembe District were from 1998 to 2005 and from 2009 to 2010 only. Their monthly averages in a year are depicted in Figure 6.34. Of particular note is the high Relative Humidity value during winter in comparison with some of the summer months (Figure 6.34).

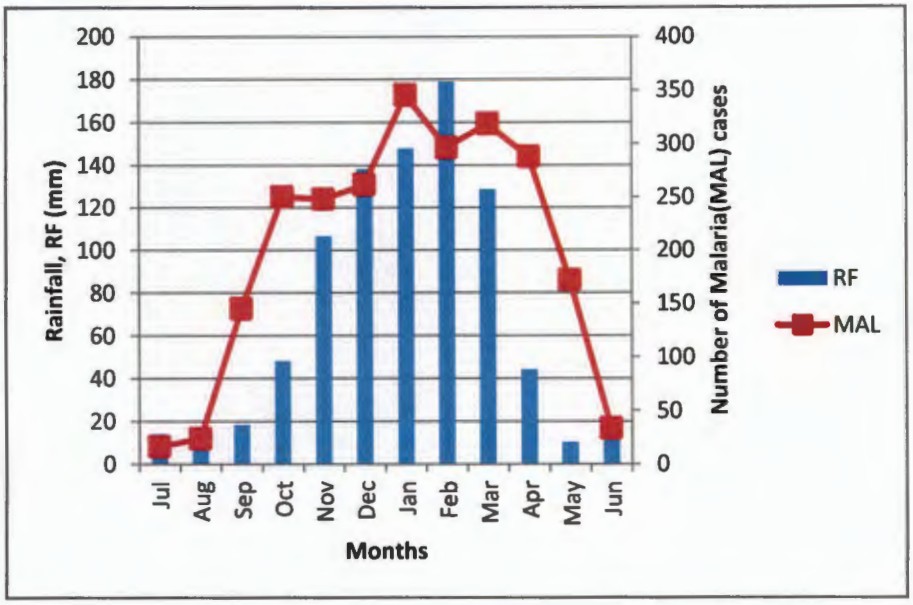


Figure 6.32: Distribution of monthly number of malaria cases in relation to average monthly rainfall in Vhembe District, 1998-2010. Rainfall data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

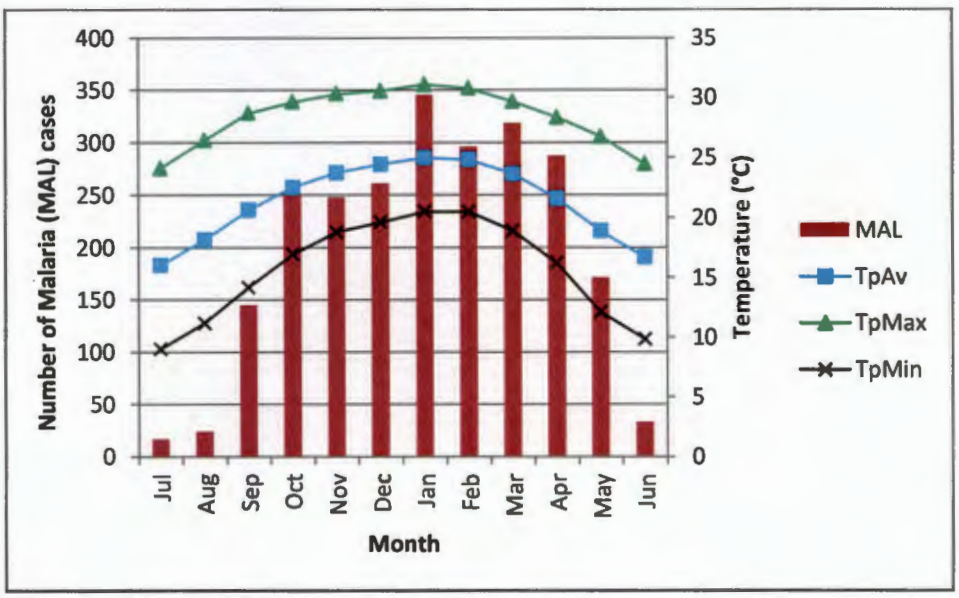


Figure 6.33: Distribution of monthly number of malaria (MAL) cases in relation to monthly air (TpAv), maximum (TpMax) and minimum (TpMin) temperature in Vhembe District, 1998-2010. Temperature data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

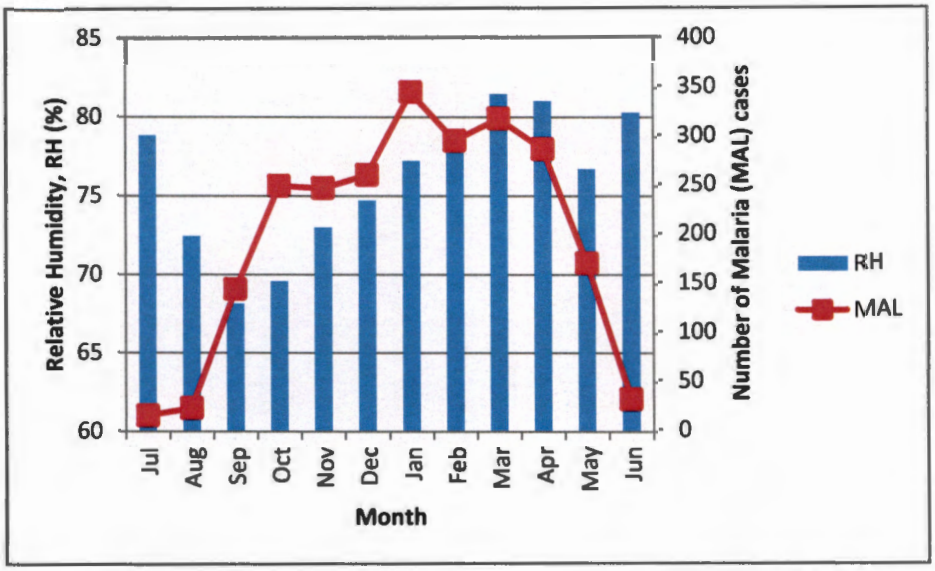


Figure 6.34: Distribution of monthly number of malaria cases in relation to average monthly Relative Humidity in Vhembe District, 1998-2003. Humidity data: South African Weather Service. Malaria cases data: Malaria Control Institute (Tzaneen) - Limpopo Province.

6.12 Summary of 1998-2010 Monthly Climate Parameter Value Ranges in Vhembe District

The ranges in climate parameter value in the four local municipalities in Vhembe District are summarised in Table 6.27, with particular focus on the period 1998-2010 in which the malaria and climate associations were analysed. Musina shows the lowest rainfall range and Thulamela shows the highest. Musina shows the lowest average Relative Humidity of 71.7% and Thulamela the highest at 81.7%. The temperature ranges are similar but with very small differences. Musina temperatures are however, higher than all the other municipalities.

6.13 Summary of Annual Climate and Malaria Trends and Correlations in Vhembe District

Malaria-climate trends and correlation status as established using the various statistical tools presented in this study are summarised in Table 6.28. In order to distinguish between the different number of years used in the study, the period from 1981 to 2010 (30 years) has been defined as a long-term range, and the period 1998 to 2010 (13 years) as medium-term. Table 6.28 shows that in most cases, the long term trends were the same as the medium-term trends even though in some cases the results were not statistically significant. It can be observed that

in isolated cases, the long-term trends were different from the medium-term trends. Table 6.28 highlights situations where malaria may be correlated with a climate variable but not strongly related when analysed using linear regression.

Table 6.27: Summary of 1998-2010 monthly average climate parameter ranges for municipalities in Vhembe District.

Municipality	Range/ Average	Rainfall Range	Average Temperature Range	Maximum Temperature Range	Minimum Temperature Range	Relative Humidity
Musina	Range	116 - 815	21.3 - 24.2	28.8 - 32.2	14.4 - 17	64.4 - 81.8
	Average	351	23.1	30.7	15.8	71.7
Makhado	Range	481 - 2028	19.8 - 21.8	25.2 - 28.3	14.3 - 16	71.4 - 86.1
	Average	865	20.9	26.9	15.2	79.3
Thulamela	Range	714 - 2877	19.8-22.4	24.6-29.3	14.9-17.7	76.4 - 85.4
	Average	1189	21	27.7	15.8	81.7
Mutale	Range	264 - 2204	xxx	xxx	xxx	xxx
	Average	779	xxx	xxx	xxx	xxx
Vhembe	Range	489 - 2040	20.1-22.6	25.8-29.9	14.6 - 16.2	64.4-84.4
	Average	859	21.6	28.5	15.6	75.2

xxx: No data available

6.14 Vhembe District Climate Variability and Malaria Summary and Inferences

- ***Trends in Musina Local Municipality***

Musina Local Municipality showed a decreasing trend in malaria as indicated in Figure 5.2. As discussed in Chapter 4 and as shown in Table 6.27, Musina received the least rainfall in the analysis period. Since this area is dry and hence breeding areas for mosquitoes have been so minimal, there is unlikely to have been a drastic increase in numbers of the *Anopheles* mosquito. Most of the area is virgin land and undeveloped, mostly consisting of nature reserves. There was no statistically significant relationship between malaria and any of the annual climate variables in Musina Local Municipality (Table 6.1). However, there were high correlations among the climate elements except for Relative Humidity. There were statistically significant correlations among both the annual and monthly climate element variables.

Table 6.28: Summary of malaria and annual climate trends and correlation in Vhembe District

Municipality	Variable	Long-term trend Z-statistic (1981-2010)	Medium-term trend Z-statistic (1998-2010)	Medium-term Correlation (r) with Malaria	Correlation (r^2) with Malaria
Musina	Rainfall	Increase NSST	Increase NSST	NSSA	NSSR
	Tpav	Increase NSST	Increase NSST	NSSA	NSSR
	Tpmax	**Increase SST 1.93+**	Increase NSST	NSSA	NSSR
	Tpmin	Increase NSST	Decrease NSST	NSSA	NSSR
	RH	NSST	Decrease NSST	NSSA	NSSR
Makhado	Rainfall	Increase NSST	Decrease NSST	NSSA	NSSR
	Tpav	Increase NSST	Increase NSST	**SSA -0.576***	NSSR
	Tpmax	Increase NSST	**Increase SST 1.89+**	**SSA -0.743****	**SSR 0.5527***
	Tpmin	**Increase SST 2.03***	Increase NSST	NSSA	NSSR
	RH	Decrease NSST	Decrease NSST	NSSA	NSSR
Thulamela	Rainfall	Increase NSST	Decrease NSST	**SSA 0.600***	NSSR
	Tpav	**Decrease SST - 1.67+**	Decrease NSST	NSSA	NSSR
	Tpmax	Decrease NSST	Decrease NSST	NSSA	NSSR
	Tpmin	Increase NSST	Increase NSST	NSSA	NSSR
	RH	Increase NSST	Increase NSST	**SSA 0.909***	**SSR 0.8266***
Mutale	Rainfall	Decrease NSST	**Decrease SST - 2.13***	NSSA	NSSR
	Tpav	Decrease NSST	No data available	No data available	No data available
	Tpmax	Increase NSST	No data available	No data available	No data available
	Tpmin	Increase NSST	No data available	No data available	No data available
	RH	**Decrease SST - 1.71+**	No data available	No data available	No data available
Vhembe	Rainfall	Increase NSST	Decrease NSST	NSSA	NSSR
	Tpav	Increase NSST	Decrease NSST	NSSA	NSSR
	Tpmax	**Increase SST 1.71+**	Decrease NSST	NSSA	NSSR
	Tpmin	**Increase SST 3.28****	Increase NSST	NSSA	NSSR
	RH	Decrease NSST	Decrease NSST	**SSA 0.709***	**SSR 0.503***

Key to Table

NSST: No Significant Statistical Trend; NSSA: No Strong Significant Association;

NSSR: No Strong Significant Relationship SST: Strong Significant Trend;

SSA: Strong Significant Association; SSR: Strong Significant Relationship

+: $\alpha = 0.1$ *: $\alpha = 0.05$ **: $\alpha = 0.01$ ***: $\alpha = 0.001$

Linear regression analysis of the annual data did not indicate strong relationships between malaria and climate elements. However, analysis of the monthly averages revealed strong dependence of malaria on the climate elements, except for Relative Humidity. Annual temperatures in Musina Local Municipality increased in the analysis period (1981-2010), with a statistically significant trend observed on maximum temperature. This may affect the reproduction cycle for the mosquito even further in that the remaining ponds are dried up quickly before much reproduction takes place. Basurko *et al.* (2011), in a study on climate change and river levels, highlighted how an increase in temperature has often been identified as a factor accelerating the gonotrophic cycle (Figure 2.1) of the *Anopheles* mosquito through decreasing the interval between egg-laying episodes and increasing vector abundance and acceleration of the development cycle of the parasite. However, Basurko *et al.* (2011) indicate that if the temperature becomes too high, this may jeopardise the survival of adult mosquitoes and dry up breeding sites more rapidly, particularly during the dry season. According to Basurko *et al.* (2011), between 2003 and 2004 the number of malaria cases in Cacao, French Guiana, fell sharply even when the temperatures were particularly high.

In this study about Vhembe District there were years when the number of malaria cases either peaked or plummeted to lowest levels in Musina Local Municipality (Figure 6.1). These episodes highlight a varying response of malaria to climate conditions. They were the years 2000, 2002, 2005, 2008, 2009 and 2010. The very high rainfall in 2000 (800mm) did not result in an increase in malaria in Musina Local Municipality. The number of malaria cases dropped instead, a change which may have been caused by the drop in temperatures even when the Relative Humidity was quite high. The high rainfall amount may also have washed away some breeding sites. The year 2002 had the least rainfall (below 200 mm), but because of the increasing trend in temperatures, there was a sharp increase in malaria cases, rising to 300. Increased temperatures could also have affected the prevalence of malaria in 2005 since the number of cases dropped. The notably high temperatures in 2005 and the subsequent increase in malaria prevalence demonstrate that there is a threshold of conducive temperatures which encourage increases in the mosquito population. The Relative Humidity in 2005 was also high, a situation which is expected to boost mosquito activity but still the malaria was low. The temperatures in 2008 were also slightly elevated but lower than those in 2005, which resulted in a sharp increase in malaria. The temperature trend affected the prevalence of malaria in 2009 when temperatures dropped (especially the minimum

temperature which went markedly low), which might have caused the reduction in malaria cases in Musina Local Municipality.

The minimum temperatures increased in 2010, even though the maximum temperature decreased and there was a slight increase in rainfall. The number of malaria cases rose to high levels. Statistical significance of correlation between monthly average climate parameter values and malaria cases clearly highlighted the influence of the minimum temperature on malaria prevalence in Musina. Malaria was highly correlated with all temperature parameters, with correlation coefficient above 0.8. The number of malaria cases was correlated with rainfall (r = 0.726, P = 0.008) but was not correlated with Relative Humidity. The air temperature had the highest correlation with the number of malaria cases, at r = 0.897. However, it was on the monthly minimum temperature that malaria showed the strongest relationship (R^2 = 0.6318); 63.18% of the variation in malaria in Musina could be explained by the monthly minimum temperatures at -1 month lag. It can be argued that the lack of statistically significant correlations on the basis of annual data can be the result of malaria infections being driven by immediate monthly short-term climate conditions rather than annual medium-term or long-term climate conditions. The latter most probably merely creates a suitable environment for the *Anopheles* mosquito to survive within the area since the climate conditions are conducive, based on evidence from literature.

- ***Trends in Makhado Local Municipality***

The number of malaria cases in Makhado Local Municipality showed a decreasing trend, similar to the case in Musina Local Municipality. As discussed in Chapter 4 and indicated by Mann-Kendal analysis (Table 6.5), rainfall in Makhado Local Municipality was declining in the study period, which may have led to a decrease in the number of breeding areas for mosquitoes; thereby affecting the amount of *Anopheles* mosquitoes in the area. All the temperature variables in Makhado showed increases, with the annual average air temperature showing a statistically significant increasing trend in the 1981-2010 data and a weak statistically significant increase in annual maximum temperatures in the 1998-210 data. The implication is that as the temperature increases the number of malaria cases reduces, possibly due to the drying off of small water pools thereby reducing mosquito breeding sites. Linear regression analysis highlighted that 55.27% of the variation in the number of malaria cases

could be explained by changes in maximum temperature. The annual minimum temperatures did not reveal any significant trend in any of the local municipalities in Vhembe District.

In the analysis period the key years in the malaria versus climate scenario in Makhado Local Municipality were 2000, 2002 and 2005. As was the case in the other municipalities in Vhembe District, when the rainfall increased in 2000 malaria cases remained constant in comparison with 1999 and there was a drop in all the temperature variables. The years 2002 and 2005 also showed a reduction in the number of malaria cases, with 2005 having the least number of cases. The amount of annual rainfall in 2002 and 2005 also declined, and all temperature variables were on the increase in comparison with the previous year. The average monthly climate data for Makhado Local Municipality showed that all the variables had statistically significant correlations, including the Relative Humidity (Table 6.18). The monthly air temperature drives malaria prevalence followed by the minimum temperature at lag 0 month. The -1 month lag was second in the correlation with malaria prevalence.

Two key points are of note with regard to the results for Musina and Makhado Local Municipalities. Firstly, in the period under study there was a statistically significant decrease in malaria, and mostly increasing trends in the annual temperature variables. This seems to be in agreement with the findings by Basurko *et al.* (2011) that when temperatures become too high, malaria transmission reduces. Secondly, there were generally increasing trends in malaria prevalence in Musina and Makhado from 2005 to 2010. These results support how increasing temperatures may result in the increase in vector borne diseases.

- ***Trends in Thulamela Local Municipality***

Thulamela Local Municipality received reduced amounts of rainfall since 1998. Therefore, this local municipality experienced drier conditions compared to previous years. The number of malaria cases showed a decreasing trend also. The high rainfall in 2000 coincided with an increase in malaria in Thulamela, but a drop in temperatures also resulted. A statistically significant relationship between malaria and annual rainfall and between malaria and annual Relative Humidity was observed. From the linear regression analysis, 82.66% of the variation in the number of malaria cases could be explained by changes in annual Relative Humidity within Thulamela. The years of note with respect to Thulamela Local Municipality were 2000, 2002, 2003, 2005, 2006, 2007 and 2008. In the years 2002, 2005 and 2007 the monthly

air and maximum temperature increased, minimum temperature dropped and there were drops in the number of malaria cases. This highlights the effect of annual temperatures on malaria cases even though there were no statistically significant relationships. For example, it can be inferred that the low minimum temperatures affected malaria transmission in 2002, 2005 and 2007 by inhibiting its propagation even when the air and maximum temperatures were high. Statistically significant relationships were also determined with Monthly minimum temperature was detected as the main driving force of malaria prevalence in Thulamela ($R^2 = 0.9134$), followed by the air temperature ($R^2 = 0.9074$). The years 2003 and 2008, which had increases in the number of malaria cases, had increases in temperature as well.

- ***Trends in Mutale Local Municipality***

Malaria cases in Mutale Local Municipality showed a decreasing trend in the analysis period (1998-2010). There was a statistically significant reduction in annual rainfall between 1998 and 2010, and a statistically significant decreasing trend in annual Relative Humidity from 1981 to 2010. The key years of with regard to Mutale Local Municipality were 1999, 2000, 2002, 2005, 2006, 2007 and 2009. In 2000 and 2007 the number of malaria cases dropped, and yet the amount of rainfall had increased. This was due to the floods which may have washed away breeding sites. In 2002 and 2005, rainfall and the number of malaria cases dropped, while in 2003 and 2006 both rainfall amount and malaria cases increased. The year 2009 saw a drop in malaria cases with a drop in the amount of rainfall towards its lowest in 2010. However, in 2010, the number of malaria cases increased. This highlights the lack of preparedness in handling malaria which could have been detected using climate anomalies.

The relationship between malaria and rainfall showed that 24.54% of variation in malaria cases could be explained by the annual rainfall. On the other hand the monthly rainfall at 0-month lag showed a high correlation with the number of malaria cases ($r = 0.74$ at $\alpha=0.01$ significance level), with 55.34% of the variation in malaria being explained by the monthly rainfall. However in the other local municipalities (Musina, Makhado, Thulamela) temperature, the parameter that highly correlated with malaria the highest, explained more of the variation in malaria: 60% in Musina and above 80% in Makhado, Thulamela and in Vhembe District combined.

- ***Trends in Vhembe District as a Whole***

The number of malaria cases in Vhembe District as a whole (combination of Musina, Makhado, Thulamela and Mutale Local municipalities) showed a decreasing trend between 1998 and 2010. A possible explanation for the reduction in the number of malaria cases in the Vhembe District is that the amount of rainfall is also decreasing in the area as observed from the rainfall trends which are summarised in Table 6.28. This in turn shortens the mosquito breeding days, thereby reducing the intensity of infection; hence the reduction in the number of malaria cases. Vhembe District also received less rainfall between 1998 and 2010. Nenwiini and Kabanda (2013) identified the significant point of change in the reduction of rainfall in the Vhembe District as having occurred around the mid-1990s.

Statistical analysis showed that there was a statistically significant relationship between malaria and annual Relative Humidity (r = 0.709 at α = 0.05 level of significance). Linear regression analysis showed that 50.3% of the variation in the number of malaria cases could be explained by changes in Relative Humidity, 18.36% by the annual minimum temperature, and 23.56% by annual rainfall. The significant years for Vhembe District as whole were 1999, 2000, 2002, 2003, 2005, 2006, 2007, 2008 and 2009. These years showed different responses by malaria to the changes in climate conditions. There was just a slight increase in rainfall in 1999 and the malaria cases shot up, while temperature decreased slightly. However in the subsequent year (2000), the amount of rainfall increased, temperature decreased, the Relative Humidity was high but malaria cases decreased. This highlights the aspect of abundant rainfall reducing malaria breeding sites. The effect of temperature on malaria is also a clear possibility if focus is made on the years 2002, 2005, 2007 and 2009 when there was a drop in malaria cases.

The years 2002 and 2007 had drops in annual minimum temperature, with 2005 and 2009 showing an increase in comparison with the previous year. However, 2002 which had low minimum temperature had increasing maximum temperature and air temperature. The year 2005 had the highest values of air, maximum and minimum temperatures, 2007 had lower air, maximum and minimum temperatures, and 2009 had high minimum temperatures but decreasing air and maximum temperatures. Of particular interest, though, is 2005 which had a constant minimum temperature with extreme highs in the air and maximum temperature (the highest during the period of study), which coincided with a drop in the number of malaria

cases. The effect of warmer temperatures on the mosquito life cycle may have caused a reduction in the number of adult mosquitoes; less biting and less malaria then resulted.

Thomson and Connor (2001) found out that drought periods (which in the case of malaria may reduce malaria prevalence drastically) are normally followed by high malaria prevalence when rainfall gets back to normal. The main reason that can be suggested for the increase in malaria cases is that people, including the government, are caught unprepared and they are at lower immunity levels due to lack of nutritional food during the drought. This was observed in 2003 and 2006 in Vhembe District. The years 2002 and 2005 were dry and malaria cases dropped in all the areas. However, in 2003 and 2006 malaria cases increased in all the municipalities in Vhembe District, possibly due to lack of preparedness or lack of immunity in the people. The analysis of monthly statistical data indicated high correlations between malaria cases and climate variables in Vhembe District at 0-month lag, followed by -1 month lag. Minimum monthly temperature ($R^2 = 0.8786$) was the driving force of malaria prevalence at a short-term (monthly data) level at lag 0-month, followed by the monthly air temperature ($R^2 = 0.8693$).

- ***General Inferences and Summary***

Malaria was most prevalent in the humid zones of Vhembe District, in line with findings by Nenwiini (2011); thereby supporting the notion that humidity has an influence on malaria cases within the district. One of the assertions by Cox *et al.* (1999) was that the effect of rainfall is inherently linked to that of the Relative Humidity. However, the results of this Vhembe study present a different scenario in that winter months continued to record high humidity values even when there was no rainfall. Hence, Relative Humidity in Vhembe District seems to be driven not only by the availability of rainfall, but maybe other ecological factors like vegetation and soil types, as well as land use factors like irrigation and the presence of large dam reservoirs (see Figure 1.5). Proximity to the Indian Ocean on the Mozambique coast to the east could be another factor that brings in high humidity to the area. A study in parts of China, for example, also identified that Relative Humidity is the key restricting factor for the distribution of the mosquito vector, thereby affecting malaria (Yang *et al.*, 2012). Relative Humidity, therefore, plays a key role in the malaria cycle. Fluctuations in Relative Humidity and temperature in Vhembe District were observed. Of particular note are the lower maximum temperatures from 2003 to 2006 and a drop in Relative Humidity

during the period. However, the lower temperatures did not seem to have an effect on malaria.

An important point to note is that the month of February, which has the highest amount of rainfall in all the municipalities in Vhembe District, showed a dip in the number of malaria cases in comparison with the preceding month (January) and the following month (March) highlighting the lag -1 effect. From data on Vhembe District as a whole, the drop occurred when the February rainfall was above 150 mm. For Thulamela Local Municipality the drop occurred when summer rainfall went 200 mm, and above 150 mm and 140 mm, respectively, for Mutale and Makhado Local Municipalities. Musina Local Municipality did not show this trend and its rainfall amount is below 70 mm on average even is summer. The general deduction is that an increase in the amount of rainfall is likely to result in an increase in the number of breeding habitats for mosquitoes, leading to increased population sizes and the rate of malaria transmission (Githeko, 2009). The observation of a drop in malaria may be attributed to the washing away of mosquito breeding areas following increased rainfall. This reduction in breeding areas will affect the mosquito vector's reproduction by reducing the number of mosquitoes that will grow into maturity and hence less biting and less malaria. Hence, increased rainfall does not necessarily translate to transmission, which is why in certain instances there was no statistically significant relationship between the amount of rainfall and malaria infection. In such instances other non-climatic factors may play a more pronounced role.

There are drastic increases in the number of malaria cases at the start of the summer months as can be observed in the jump in number of cases from August to September in all the local municipalities in Vhembe District (Figures 6.22, 6.25, 6.28, 6.31). However, at the start of winter in May, the rate of decrease was not as sharp. The number of cases only dropped sharply in June. This result fits in with previous studies (e.g. Takken *et al.*, 2005) that established that small changes in temperature and precipitation tend to boost the population of mosquitoes and extend by several weeks the duration of the season in which mosquitoes are transmitting the disease. This extended duration ultimately results in the infection of a larger human population. This is observed in all the municipalities in Vhembe District at the inception of winter in that there were still have high malaria incidences in May due to the climate conditions of the previous month.

The following were the key findings from Chapter 6:

1. Musina Local Municipality had no statistically significant relationship with any of the annual climate variables. However, there were very high correlations between the number of malaria cases and all climate variables except the Relative Humidity. The monthly minimum temperature drives malaria in Musina, followed by the air temperature, then maximum temperature and rainfall at lag -1 month.

2. Makhado Local Municipality had a statistically significant negative correlation between malaria and the annual air temperature and maximum temperature. The monthly air temperatures drives malaria prevalence most strongly followed by the minimum temperature, maximum temperature, rainfall and to some extent Relative Humidity at lag 0 followed by lag -1 month.

3. Thulamela Local Municipality had a statistically significant positive correlation between malaria and annual relative humidity and rainfall. The minimum monthly temperature drives malaria prevalence most strongly followed by the air temperature; the maximum temperature and rainfall at lag 0 followed by lag -1 month.

4. Malaria in Mutale Local Municipality had no statistically significant correlation with annual rainfall. However, there was a strong correlation with the monthly rainfall at lag 0 followed by lag -1 month.

5. Vhembe district had a statistically significant correlation between malaria and the annual Relative Humidity. The minimum monthly temperatures drive malaria prevalence most strongly in the district at lag 0 month, followed by lag -1 month, then the monthly air temperature, the maximum temperature, and then rainfall.

6. Most annual and monthly climate parameter variables were highly correlated in all the four local municipalities making up Vhembe District..

7. Malaria cases were found to be still high at the start of winter in May in all the local municipalities making up Vhembe District. The cases only dropped sharply in June.

8. Relative humidity remained high even during winter, sometimes even higher than it was in some summer months.

9. Musina Local Municipality experienced a strong -1 month lag effect followed by lag 0, between the onset of a climate effect and the response in the number malaria of malaria cases. On the other hand Vhembe District, Makhado Local Municipality, Thulamela Local Municipality and Mutale Local Municipality had a stronger 0-month lag followed by lag -1 month, highlighting how quickly the mosquito reproduction cycle went in the areas.

10. February had the highest rainfall in the study area. However, there was a drop in the number of cases in malaria in all the local municipalities in February. This suggests that each municipality had a rainfall threshold beyond which negative effects on the malaria cycle began to be experienced.

11. At the aggregated level of Vhembe District as a whole, the drop in malaria cases occurred when the February rainfall was above 150 mm, above 200 mm for Thulamela Local Municipality, and above 150 mm and 140 mm, respectively, for Mutale and Makhado Local Municipalities. Musina Local Municipality did not show any such trend, and its monthly rainfall amount was below 70 mm on average even in summer.

12. A high number of malaria cases occurred in January in the majority of the local municipalities and Vhembe District.

13. The number of malaria cases in Thulamela Local Municipality, and Vhembe District as a whole, had a positive statistically significant trend with annual Relative Humidity data. Thulamela also had a statistically significant trend with rainfall. Makhado malaria cases showed a negative statistically significant trend with annual air temperature and annual maximum temperature.

14. In Musina and Thulamela Local Municipalities, and at the aggregated level of Vhembe District, among the climate parameters the monthly minimum temperature had the highest correlation with the number of malaria cases, followed by the air

temperature. On the other hand in Makhado malaria is affected most strongly by the air temperature, followed by the minimum temperature.

15. Although not statistically significant at the annual level, the minimum temperature influenced the decrease or escalation of malaria cases especially in Makhado and Thulamela Local Municipalities, and at the aggregated level of Vhembe District. When the minimum temperatures dropped, the number of malaria cases also declined and when there was an increase in minimum temperatures, mostly the number of malaria cases would also escalate.

16. The Relative Humidity seemed to have a long-term influence on malaria since statistically significant trends could only be identified at annual level. Moreover, the fact that in all the local municipalities making up Vhembe District the Relative Humidity was always above 60% on average, even in winter, means that conditions will always be favourable for malaria, and hence its effects may not always be statistically detected.

17. A dry year was followed by an increase in malaria cases when the rainfall got back to normal. This could have been due to lack of immunity in human individuals or unpreparedness by the community and government authorities, since the dryness would have suppressed malaria prevalence to some extent, as observed in 2003 and 2006 following dry years in 2002 and 2005, respectively.

18. An analysis of significantly correlated climatological elements indicated that rainfall was mostly negatively correlated with temperature, Relative Humidity was also negatively correlated with temperature, Relative Humidity and rainfall were positively correlated, and all temperature variables were also positively correlated.

Chapter 7

SPATIAL DISTRIBUTION OF MALARIA

7.1 Introduction

This chapter reports on conditions in settlements that are prone to malaria in the Vhembe District. Several maps showing the spatial distribution of malaria have been generated using ArcGIS 10.1 for the various malaria prone areas. Reported malaria cases are plotted per local municipality for the period 1998-2010. Wherever malaria was detected in an area (village or farm) in a particular year regardless of the number of cases, the area is marked (red) using ArcGIS 10.1. Cell-based 30-metre resolution Digital Elevation Models (DEM) using the same information were plotted for the purpose of determining the altitude of the various areas where malaria was detected.

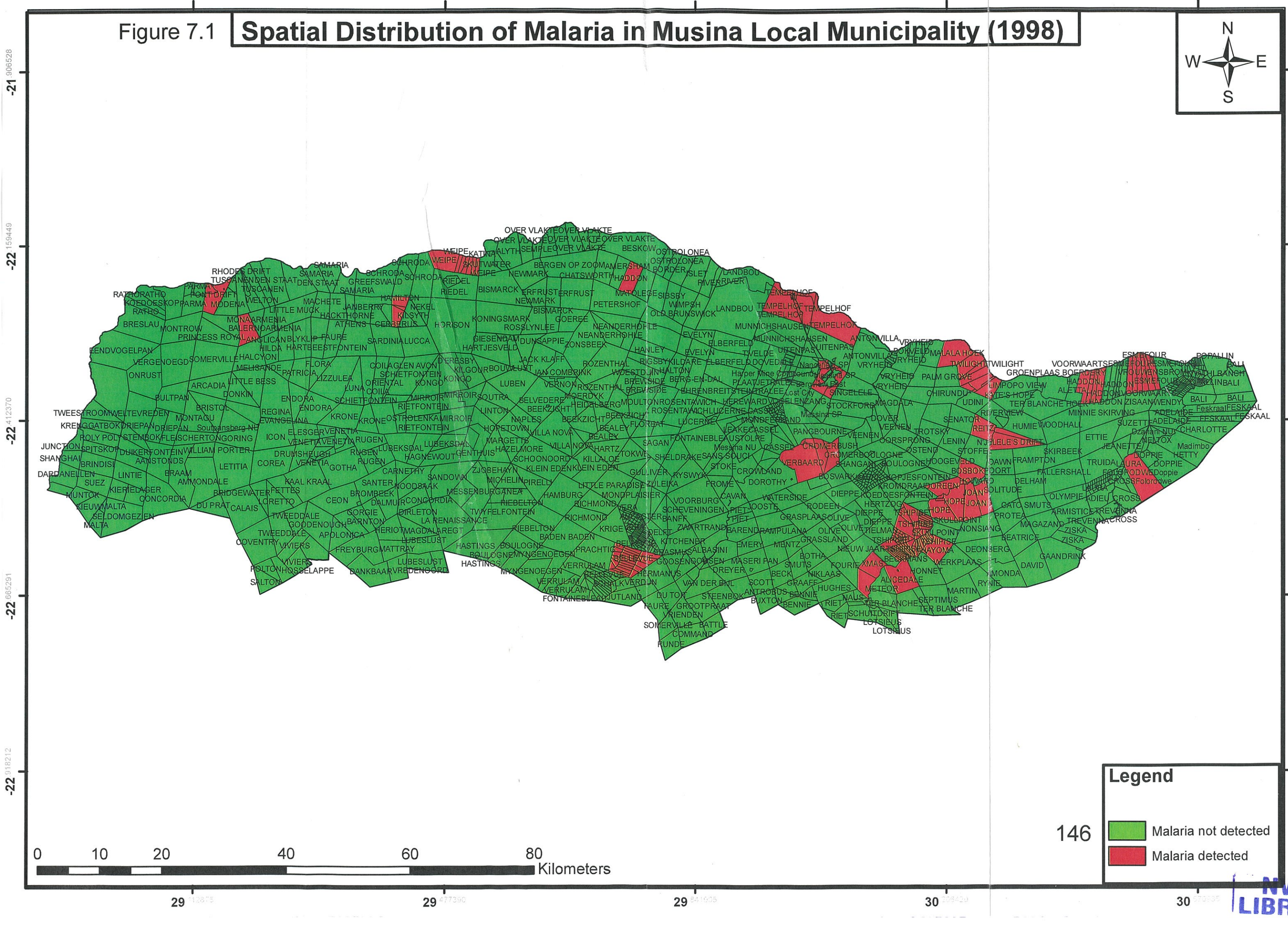
7.2 Malaria in Musina Local Municipality

7.2.1 Spatial Distribution

Information on malaria in Musina is predominantly captured using farm names, since the area is involved mainly in commercial farming and most human settlements are found on the farms. The spatial distribution maps have been plotted in a GIS using farm spatial layers, to enable the capturing of the information as provided by the Department of Health.

Another spatial layer comprising the residential areas was overlaid in the GIS to capture malaria cases emanating from urban centres. The 1998 (Figure 7.1) and 1999 (Figure 7.2) maps show that malaria was detected in scattered sites in the farming communities in the north-western and eastern parts of the municipality. These areas are along the Limpopo River, which forms the border between South Africa and Zimbabwe (Figure 1.3a). Malaria cases were also reported in the town of Musina and, in particular, the residential area of Nancefield.

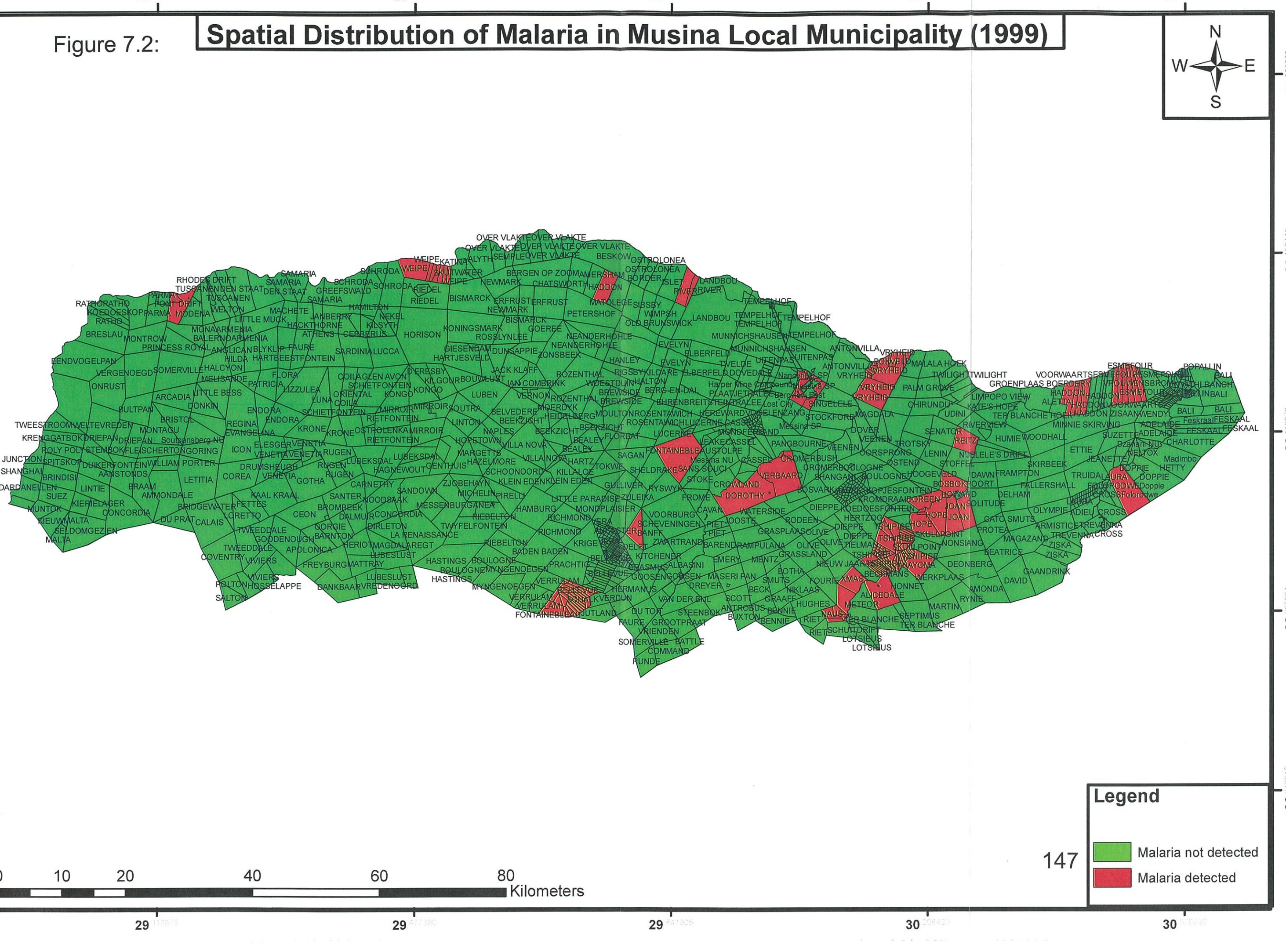
Figure 7.1 **Spatial Distribution of Malaria in Musina Local Municipality (1998)**



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Figure 7.2:

Spatial Distribution of Malaria in Musina Local Municipality (1999)



Malaria cases in 1998 (Figure 7.1) were reported at the Beitbridge border post (Tempelhof Farm), Malalahoek, Haddon, Esmefour, Weipe and Pontdrift which are on the Limpopo River border with Zimbabwe. On the inland side, farms Balerno, Hamilton, Verbaard, Cromerbrush, Bellevue, Xmas, Alicedale, Tshipise, Hayoma, Hope, Joan, Rietz, Njeleledrift and Folorodwe reported malaria. In 1999 (Figure 7.2), most of the areas along the Limpopo River and inland that detected malaria in 1998 reported more cases except at the Beitbridge border post. An additional farm (Dorothy) which is next to Verbaard detected malaria in 1999 as well. No cases were reported in Njeleledrift and in Malaladrift although the farm Vryheid, which is right next to Malalahoek reported malaria cases. In 2000 (Figure 7.3), the bulk of the malaria cases were reported on the eastern side of the municipality which includes the town of Musina. No cases were reported on the western side except in Haddon. Vryheid, Twilight, Esmefour, Folorodwe and the farms near Hope, Joan, Tshipise, Alicedale, Xmas and Cromerbush (henceforth called the cluster), reported malaria cases.

The years 2001 to 2004 (Figures 7.4, 7.5, 7.6 and 7.7, respectively), indicated trends in malaria similar to those in 1998 and 1999. The areas that detected malaria include the cluster around Hope, Joan, Tshipise, Alicedale, Xmas and the nearby Cromerbush. Haddon, Pontdrift, Icon, Musina (Nancefield), Folorodwe also reported malaria. Weipe, Belleview, Islet, River, Verbaard and Terblanche were additions and comebacks in 2002. This can be linked to the climate conditions, particularly the increasing temperature trends discussed in Chapters 4 and 6. In 2003 some areas like Belleview, Cromerbush, Icon, Tempelhof, Malalahoek and Twilight did not detect malaria. The cluster around Hope, Joan, Tshipise, Alicedale, had malaria, as did Musina and Folorodwe. Most of the areas that detected malaria in 2002 had malaria in 2003 and the number of cases also increased following the 2002 dry season. The same areas also reported malaria in 2004 with the notable absence of Esmofour, Haddon and Vryheid. Only two areas (Musina and Tshipise) detected malaria in 2005 (Figure 7.8). As discussed in Chapters 4 and 6, 2005 was a dry year with high temperatures and hence, this pattern in malaria is expected. In 2006 (Figure 7.9) two areas again had malaria: Musina and Verbaard. The cluster farms around Hope were free from malaria.

Figure 7.3:

Spatial Distribution of Malaria in Musina Local Municipality (2000)

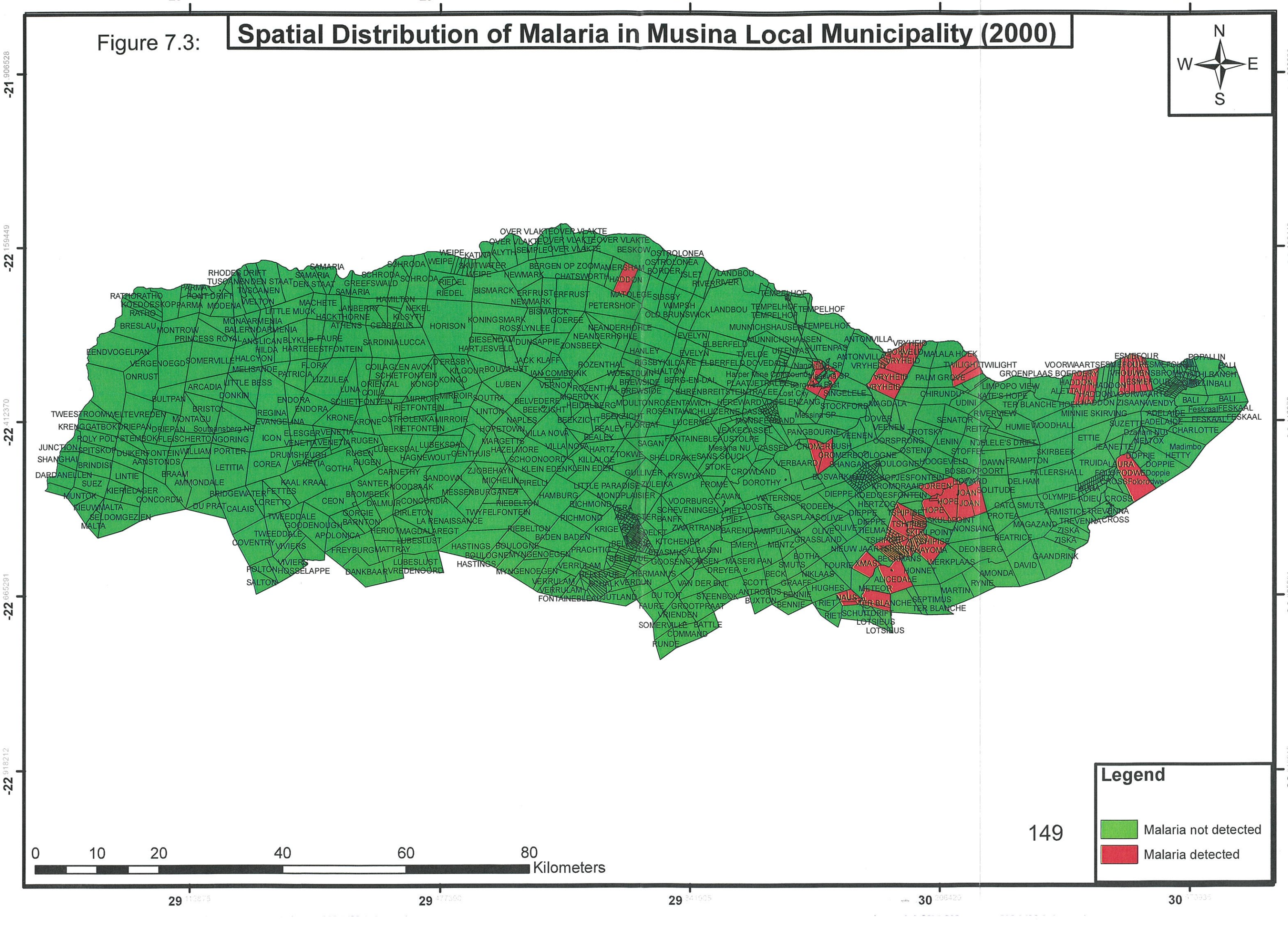


Figure 7.4: **Spatial Distribution of Malaria in Musina Local Municipality (2001)**

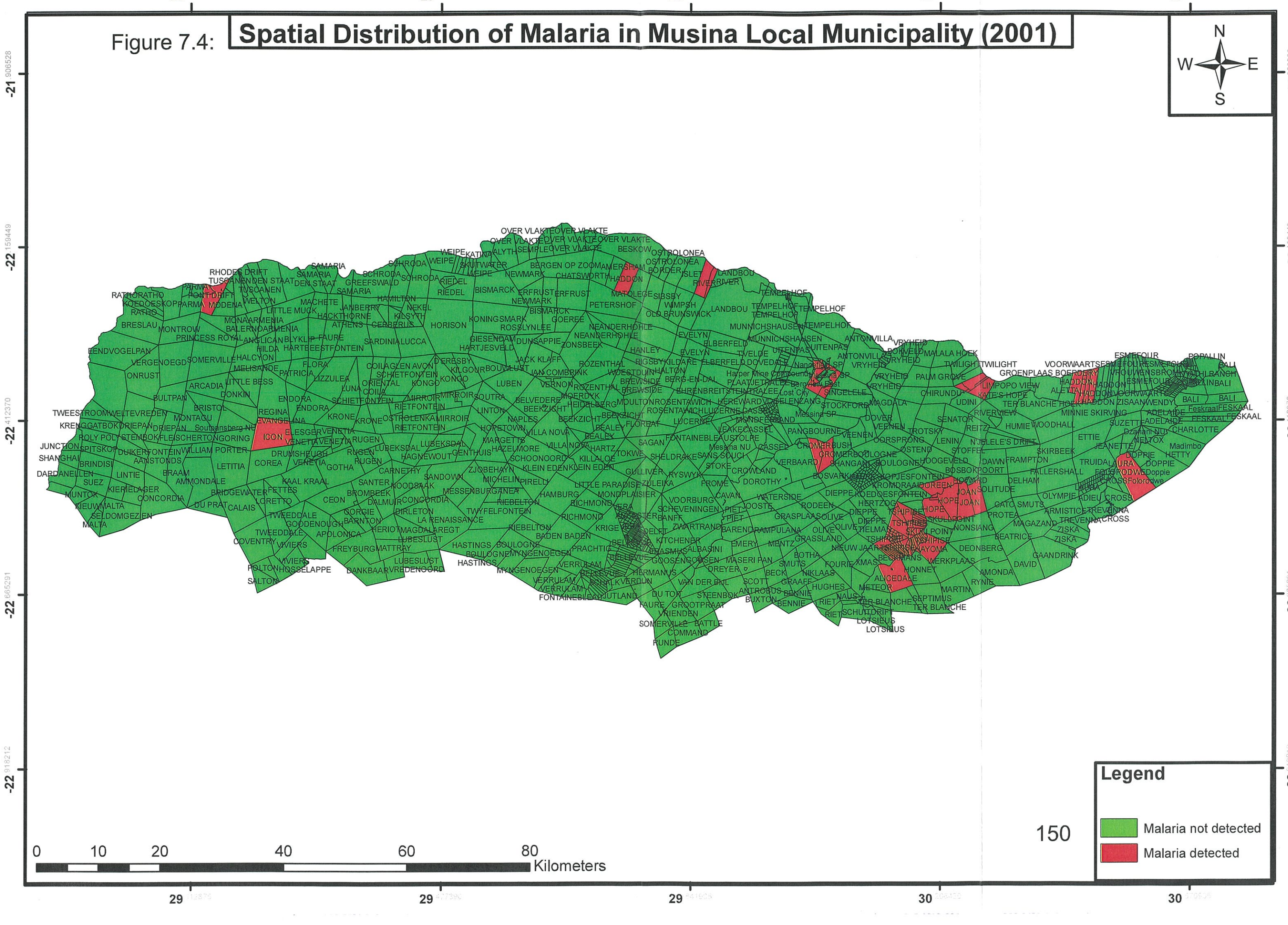


Figure 7.5: **Spatial Distribution of Malaria in Musina Local Municipality (2002)**

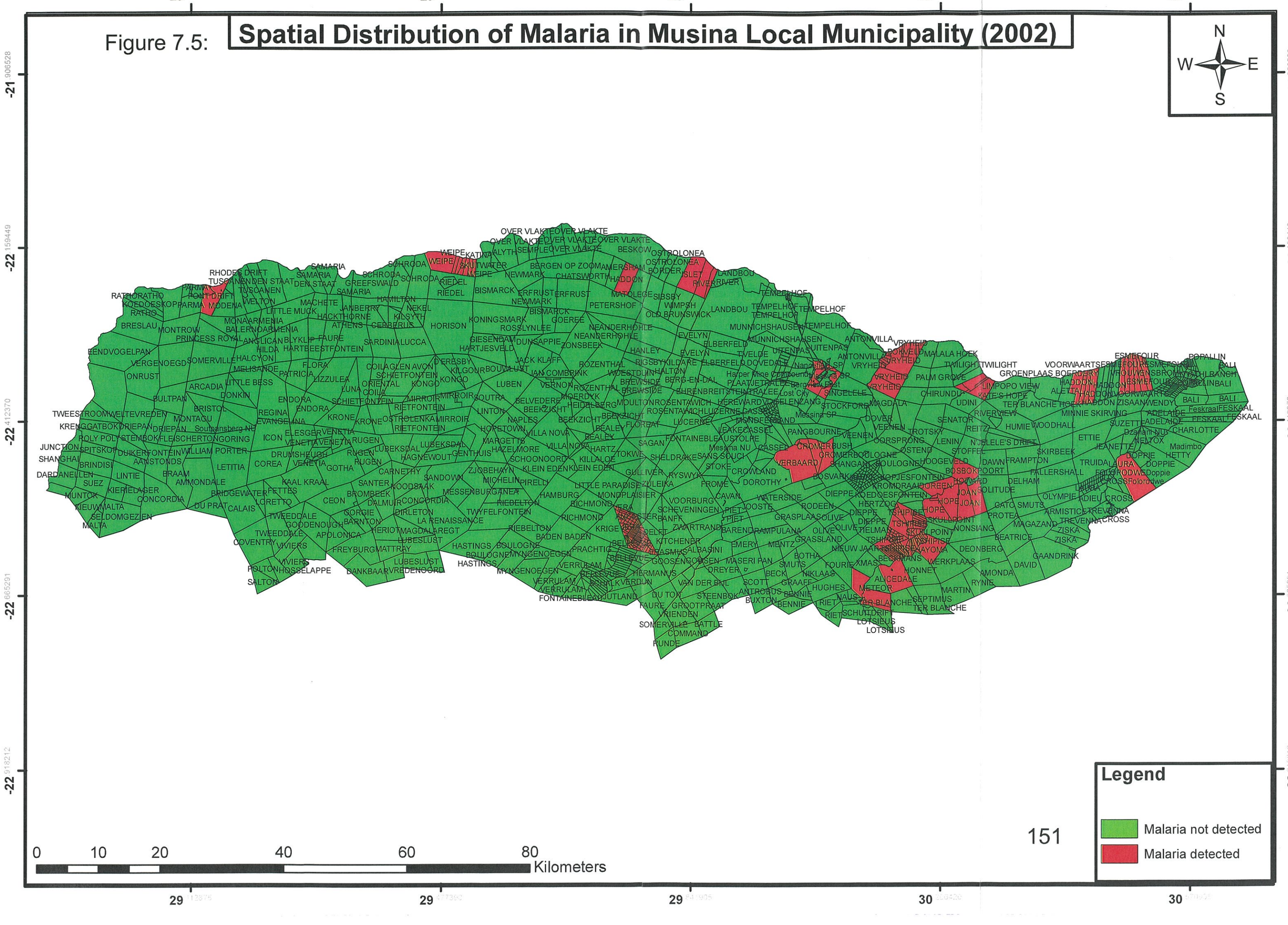


Figure 7.6: **Spatial Distribution of Malaria in Musina Local Municipality (2003)**

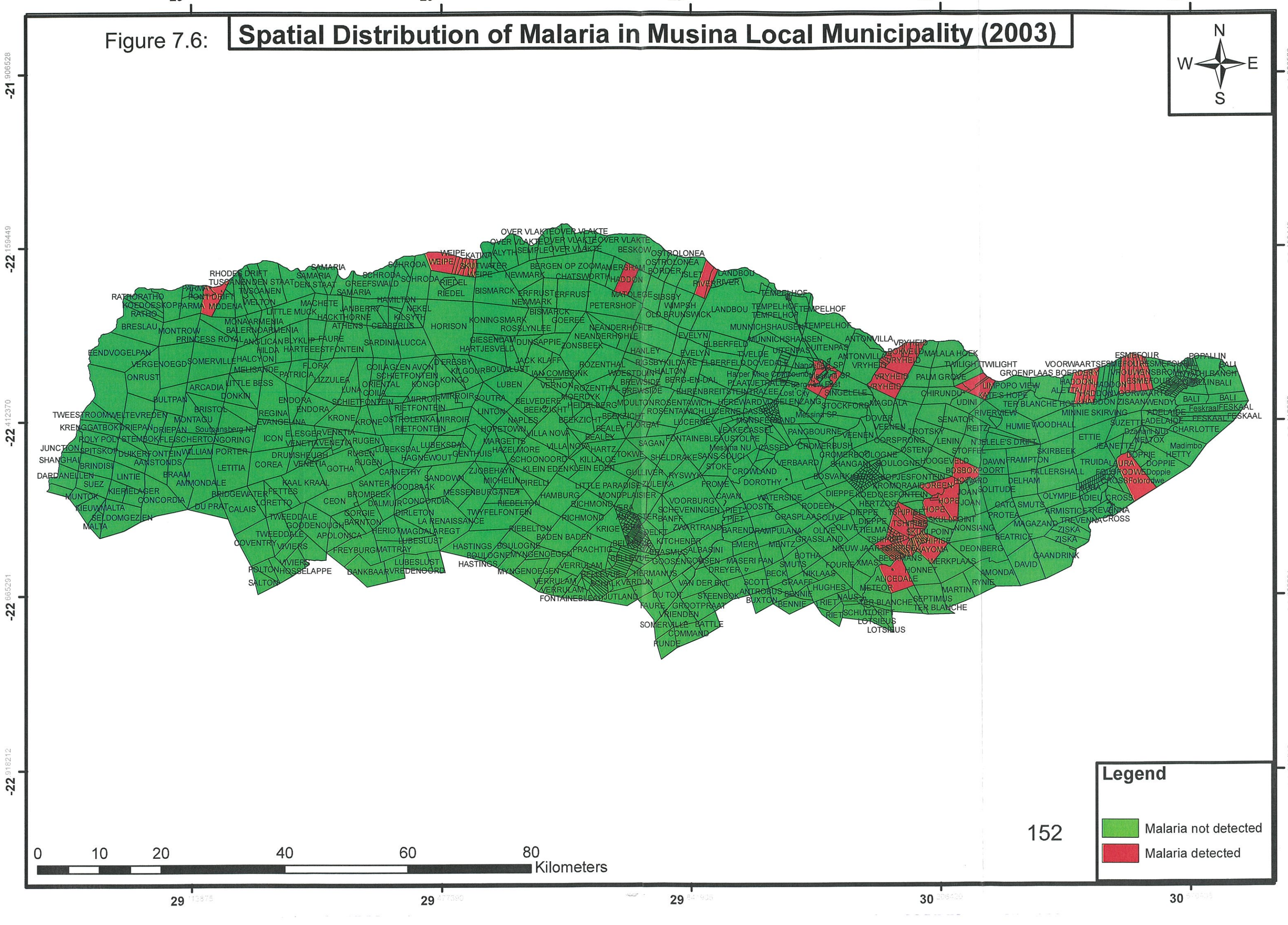


Figure 7.7: **Spatial Distribution of Malaria in Musina Local Municipality (2004)**

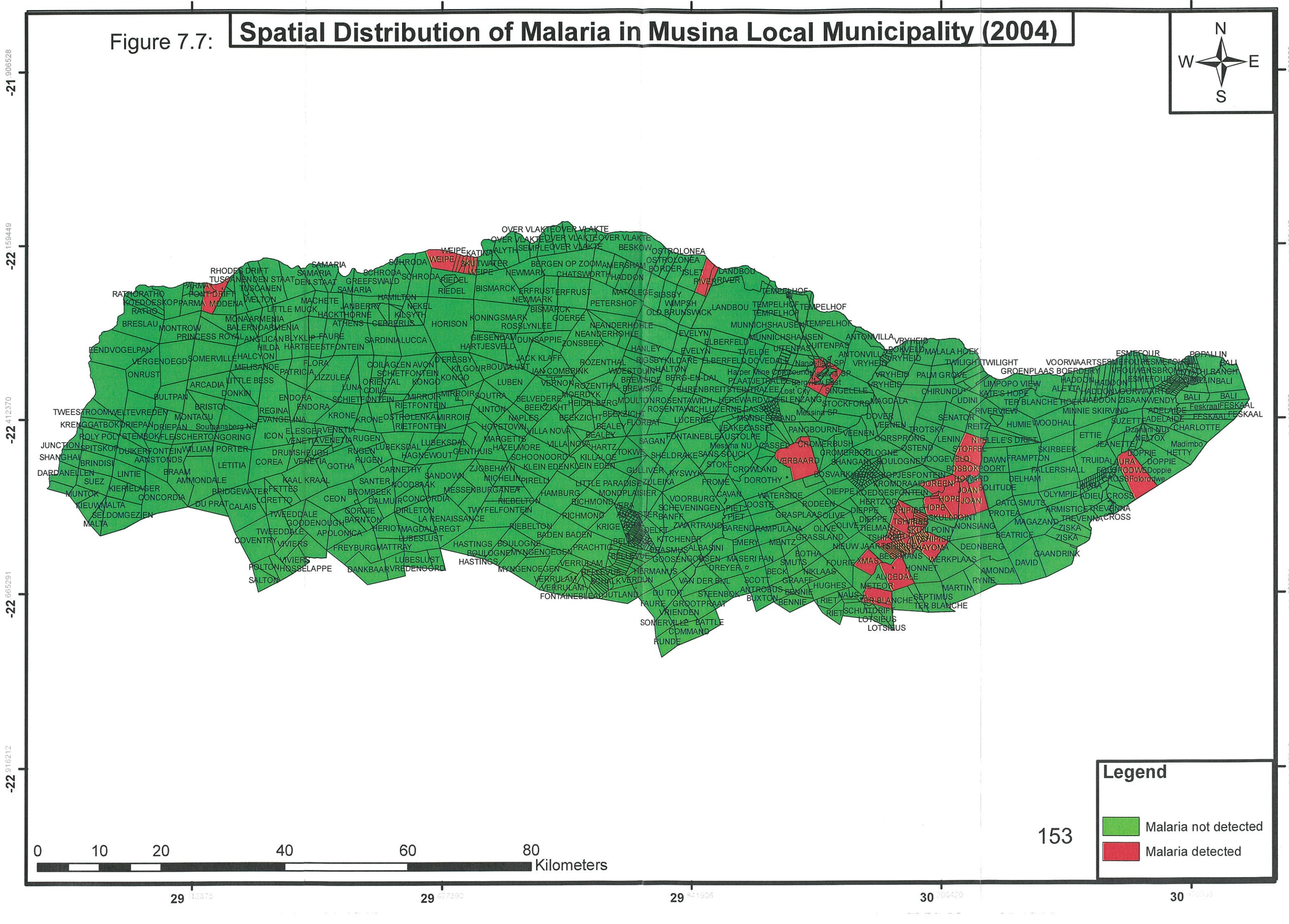


Figure 7.8:

Spatial Distribution of Malaria in Musina Local Municipality (2005)

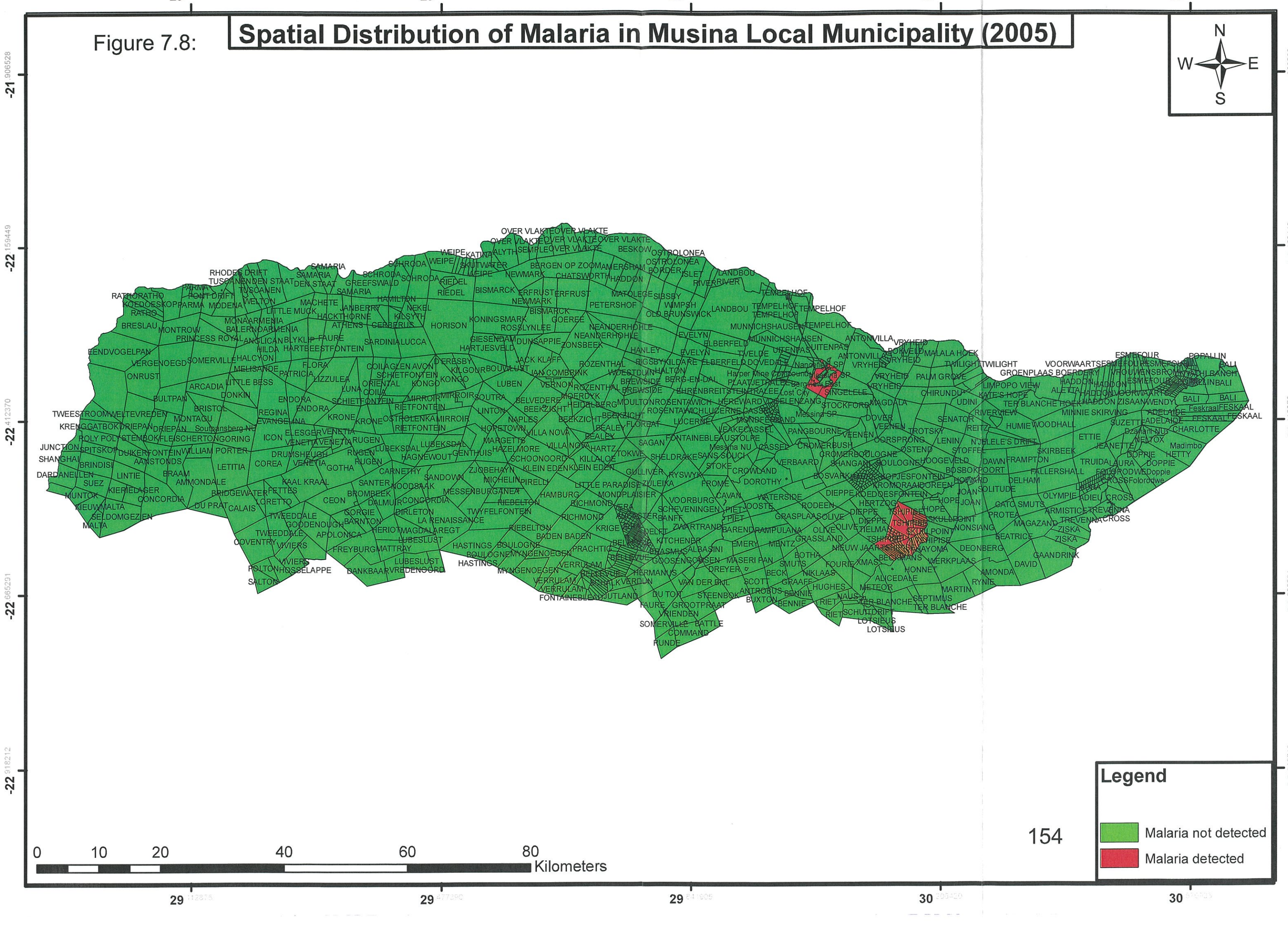


Figure 7.9

Spatial Distribution of Malaria in Musina Local Municipality (2006)

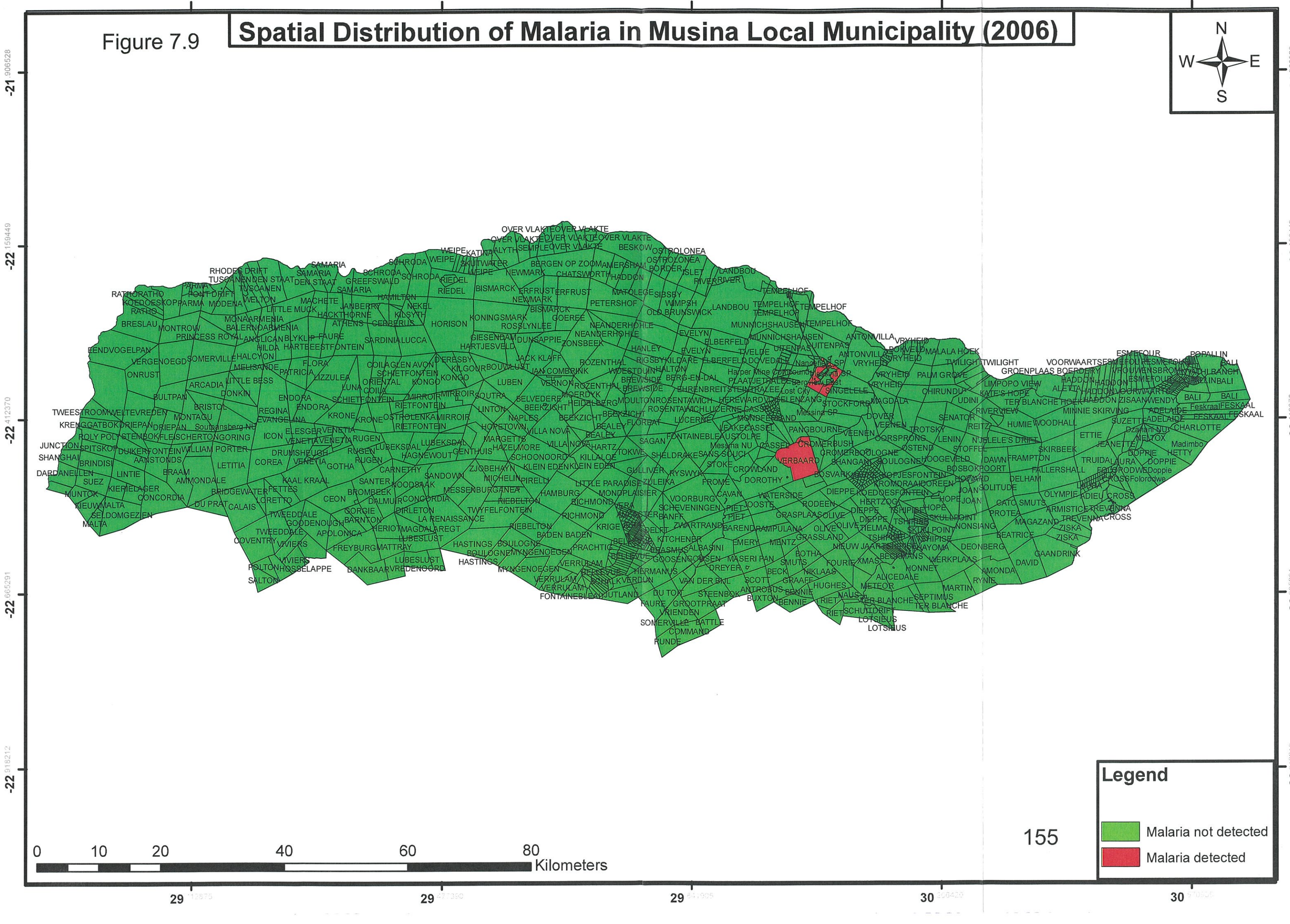


Figure 7.10: **Spatial Distribution of Malaria in Musina Local Municipality (2007)**

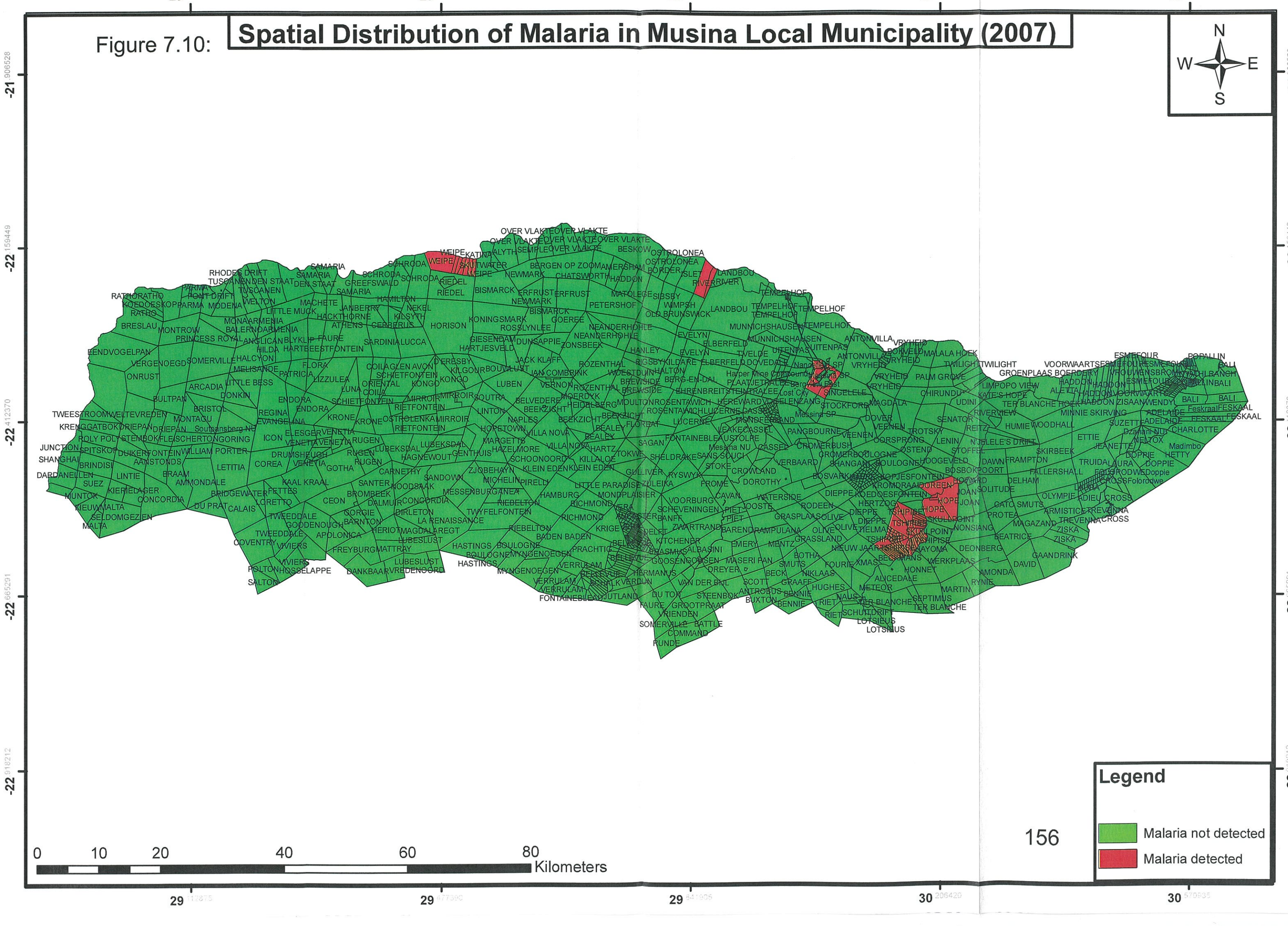
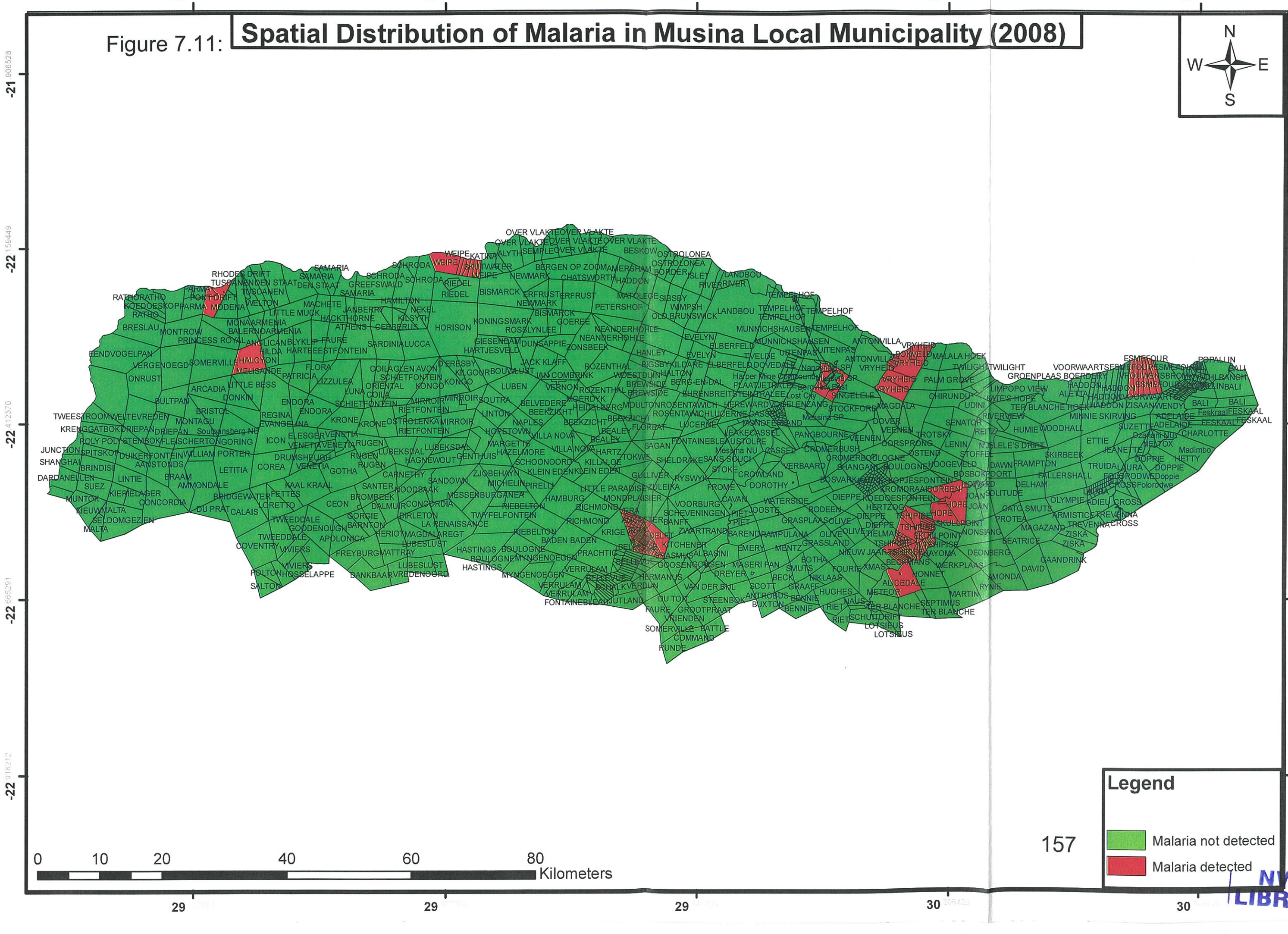


Figure 7.11: **Spatial Distribution of Malaria in Musina Local Municipality (2008)**



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Figure 7.12:

Spatial Distribution of Malaria in Musina Local Municipality (2009)

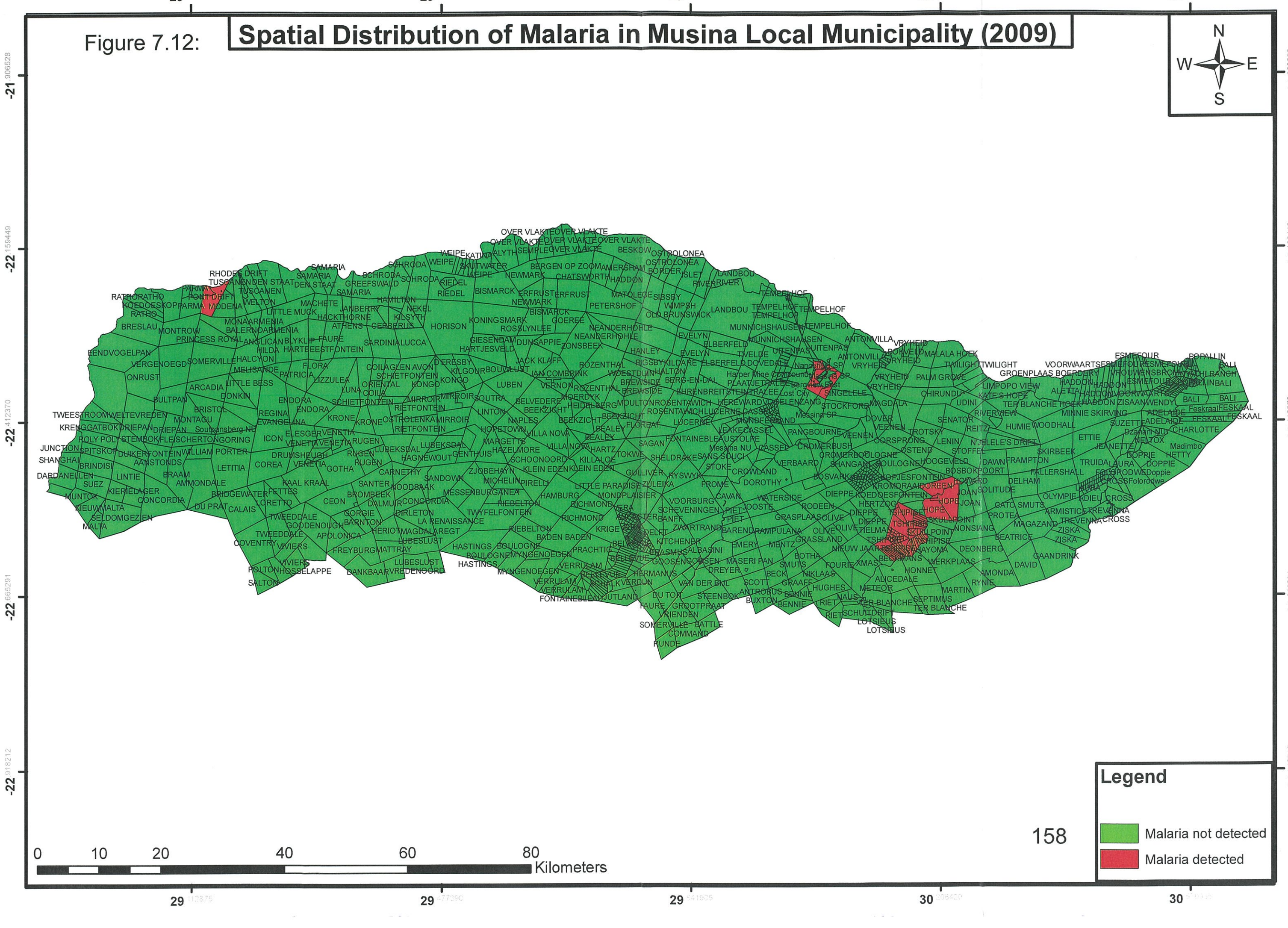
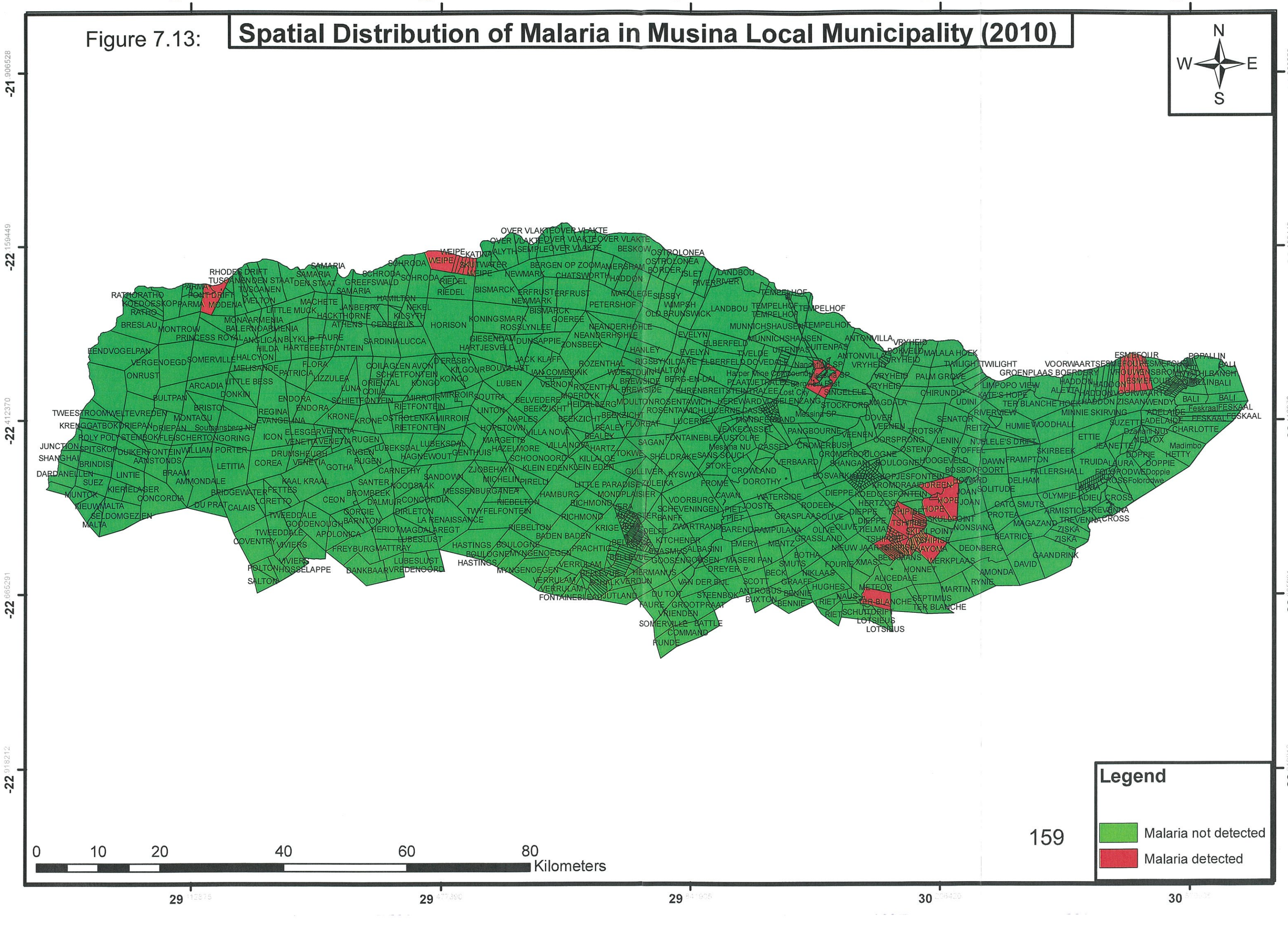


Figure 7.13:

Spatial Distribution of Malaria in Musina Local Municipality (2010)



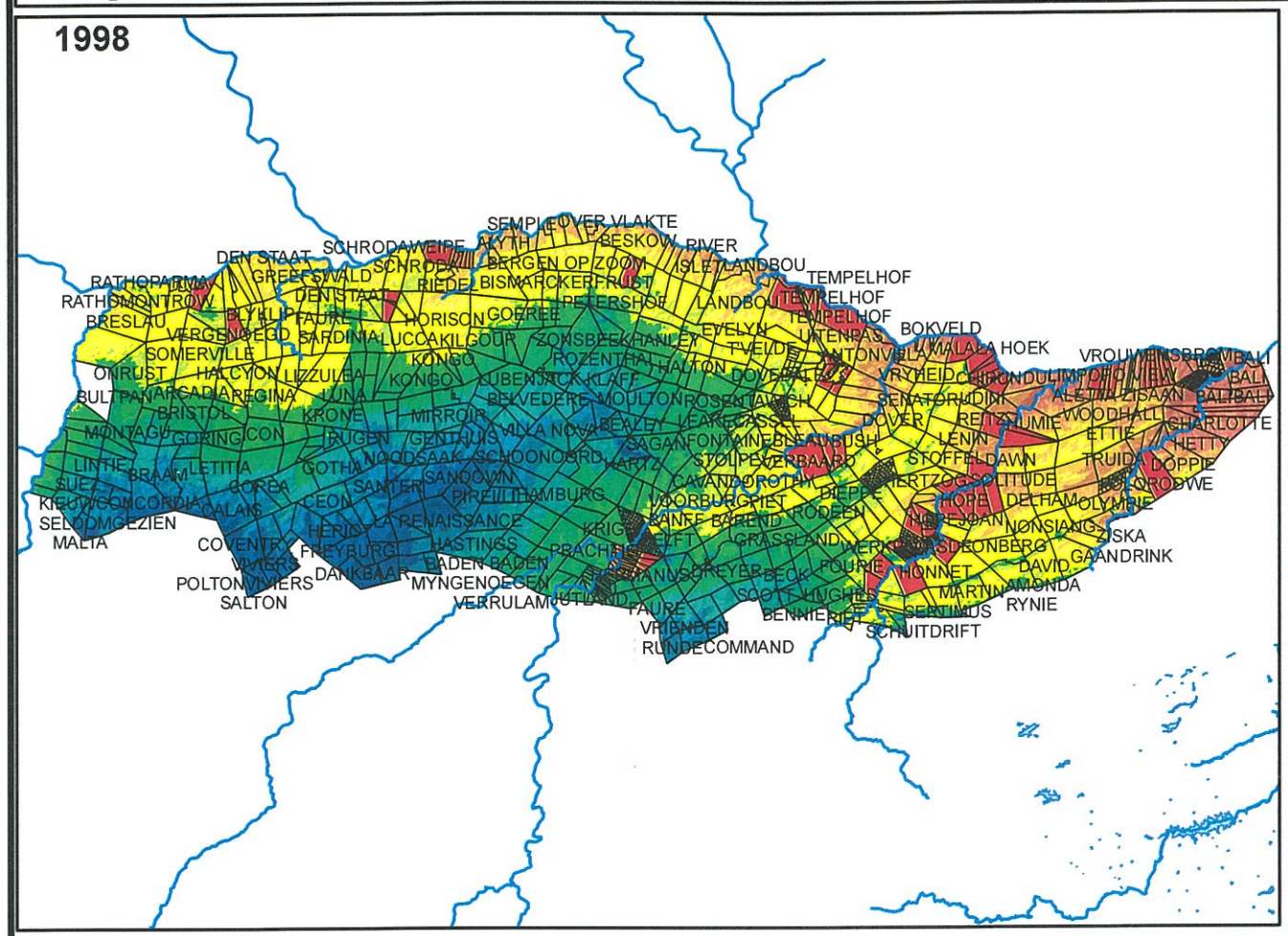
The year 2007 (Figure 7.10) saw a return of malaria in Weipe, River, Hope and Doreen. All the other areas did not detect malaria. The affected areas increased even further in 2008 as observable in Figure 7.11. There was an increase in temperature variables during this period as indicated in Chapter 6 (Figures 6.2-6.4). The cluster areas Hope, Doreen and Alicedale had malaria comebacks too. On the Limpopo River boundary, Esmefour and Vryheid also reported malaria and inland, cases were reported in Belleview and Halcyon. The year 2009 (Figure 7.12), saw a decrease in malaria infected areas which may have been caused by the drop in temperatures although the amount of rainfall increased (Figures 6.1-6.4). The cases were however, restricted to the cluster, Pontdrift and Musina. In 2010 (Figure 7.13), there was an increase in the number of malaria with cases resurfacing in Weipe, Esmefour and Tereblanche near the cluster farms. Musina and the cluster farms of Hope, Doreen and Tshipise had malaria and of notable absence was Folorodwe. The minimum temperature and amount of rainfall increased in this period (Figures 6.1 and 6.4).

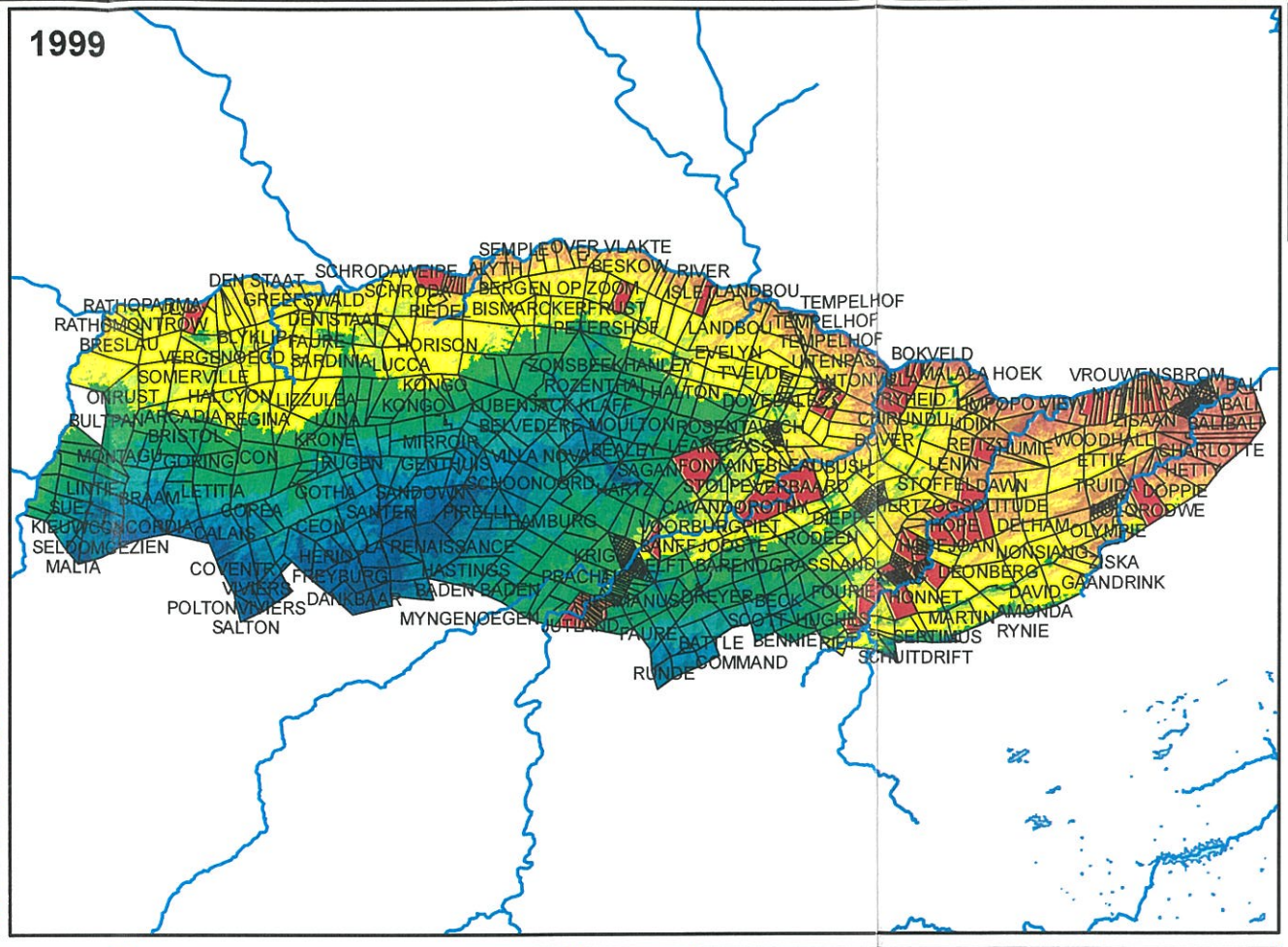
7.2.2 Musina Malaria Distribution Based on a Digital Elevation Model

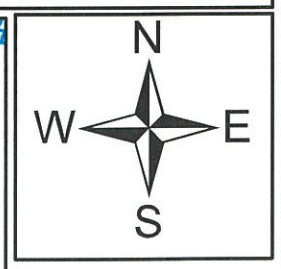
In this section altitude is examined in trying to understand if it affected the spatial distribution of malaria presented in Section 7.2.1. Musina has altitudes ranging between 320 and 1150 meters above sea level (MASL). The maps in Figure 7.14 indicate that in 1998 and 1999, malaria was detected in areas below 500MASL, which are mainly along the Limpopo River and other rivers across the local municipality. In 2000 and 2001, malaria was not detected in some of the areas along the Limpopo River where it had been detected in previous years. In the year 2001, it was detected in Icon, an area which is between 618 and 654MASL. No malaria was detected in areas above 689MASL between 1998 and 2001. The maps in Figure 7.15 show a trend similar to that for 1998 and 1999 for the period between 2002 and 2004. Of the two areas that detected malaria in 2005, both are below 582MASL. No malaria was detected in areas above 582MASL between 2002 and 2005. The DEM maps in Figures 7.16 and 7.17 show that between 2006 and 2010 malaria was detected in areas below 582MASL which are either near the Limpopo River or next to a watercourse. The areas that detected malaria constantly had the following altitudes: Musina, Pontdrift, Verbaard and Tereblanche are below 600MASL; Esmefour, Haddon, Twilight, Vryheid, Doreen, Hope, Xmas, Cromerbush, Folorodwe, Malalahoek,

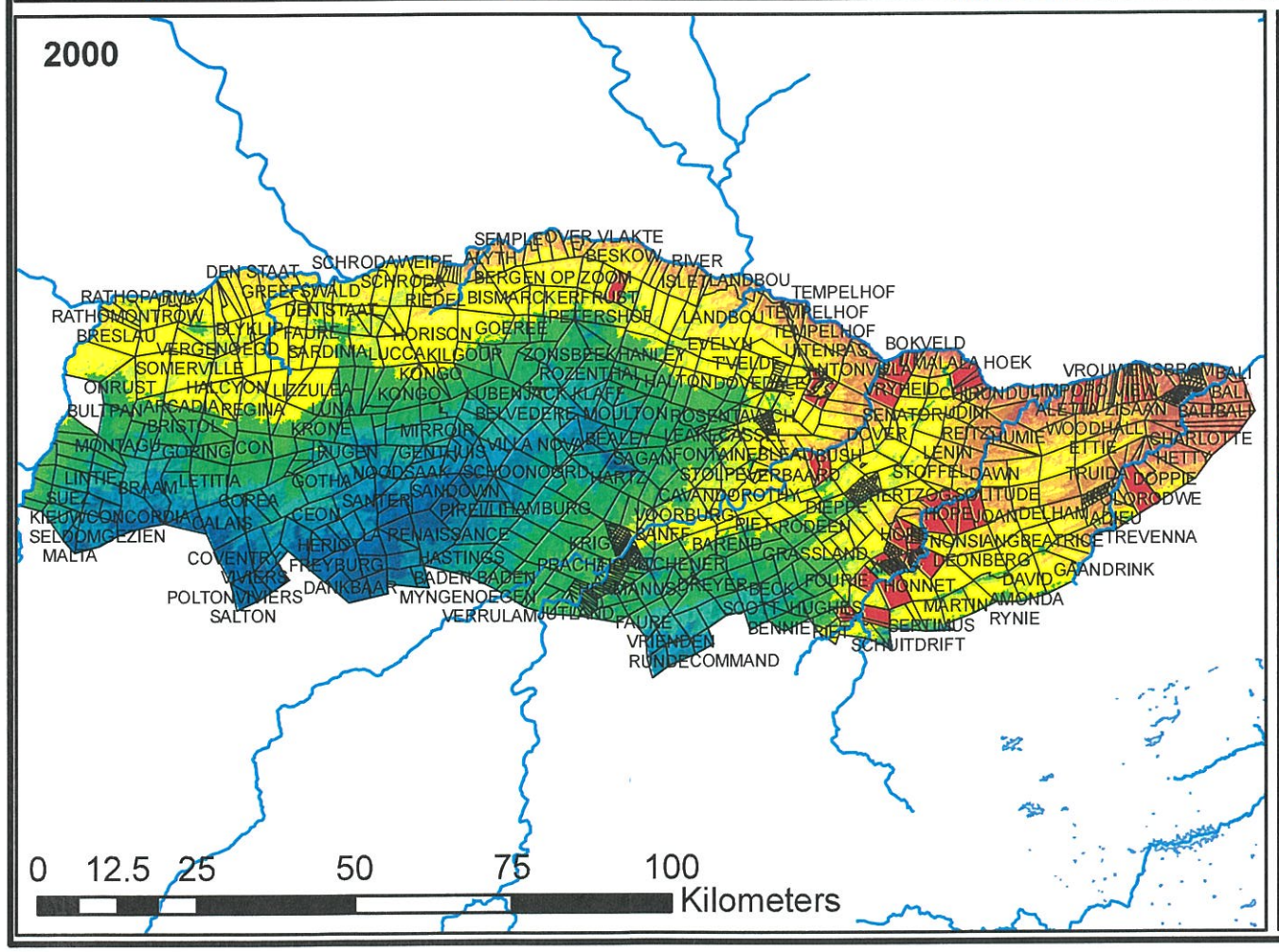
Figure 7.14

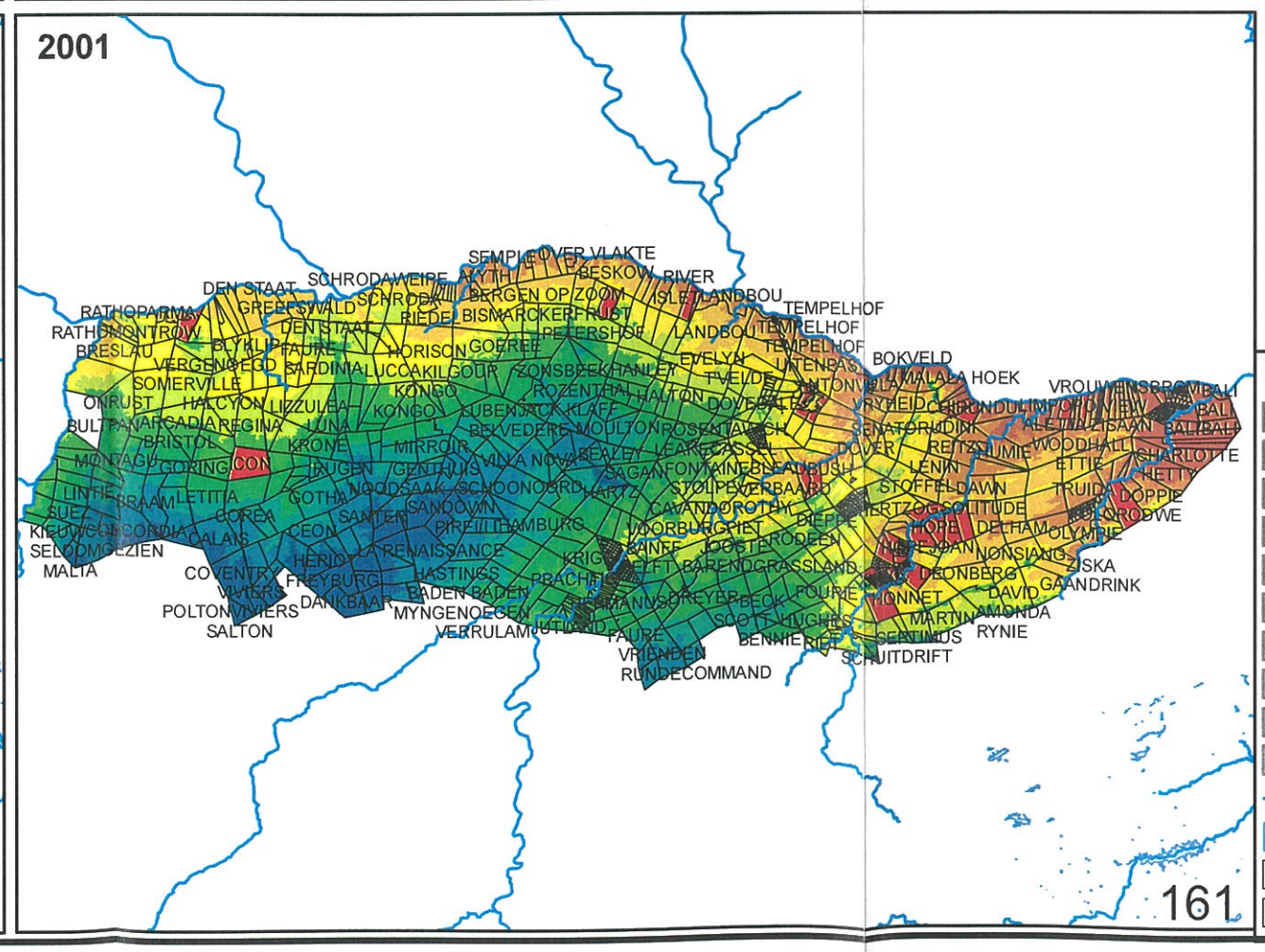
Spatial distribution of Malaria in relation to Altitude in Musina Municipality (1998 to 2001)











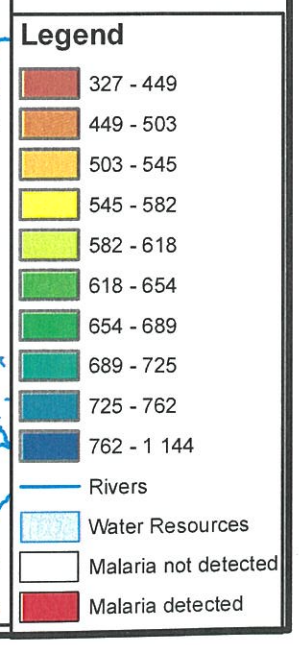
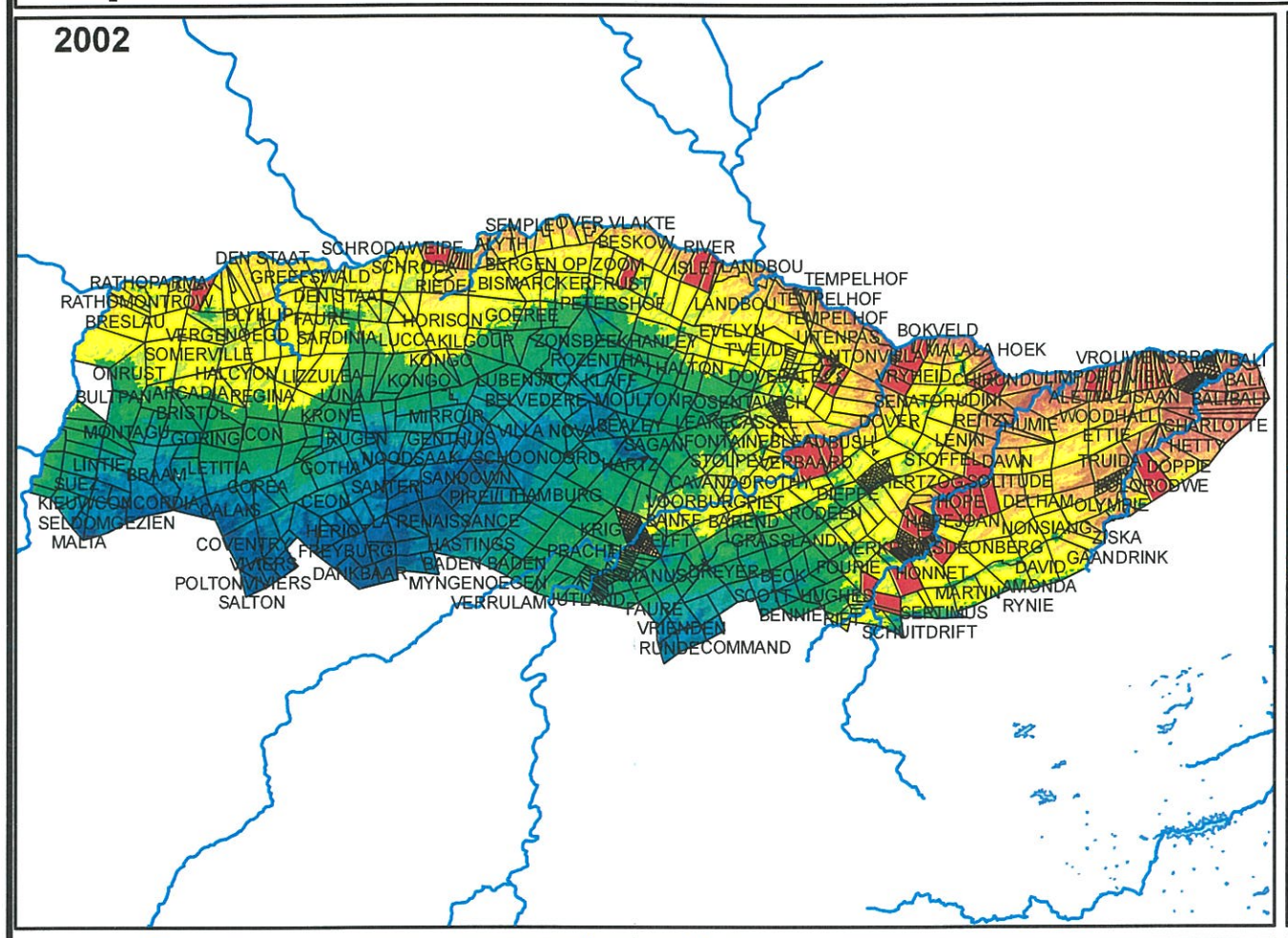
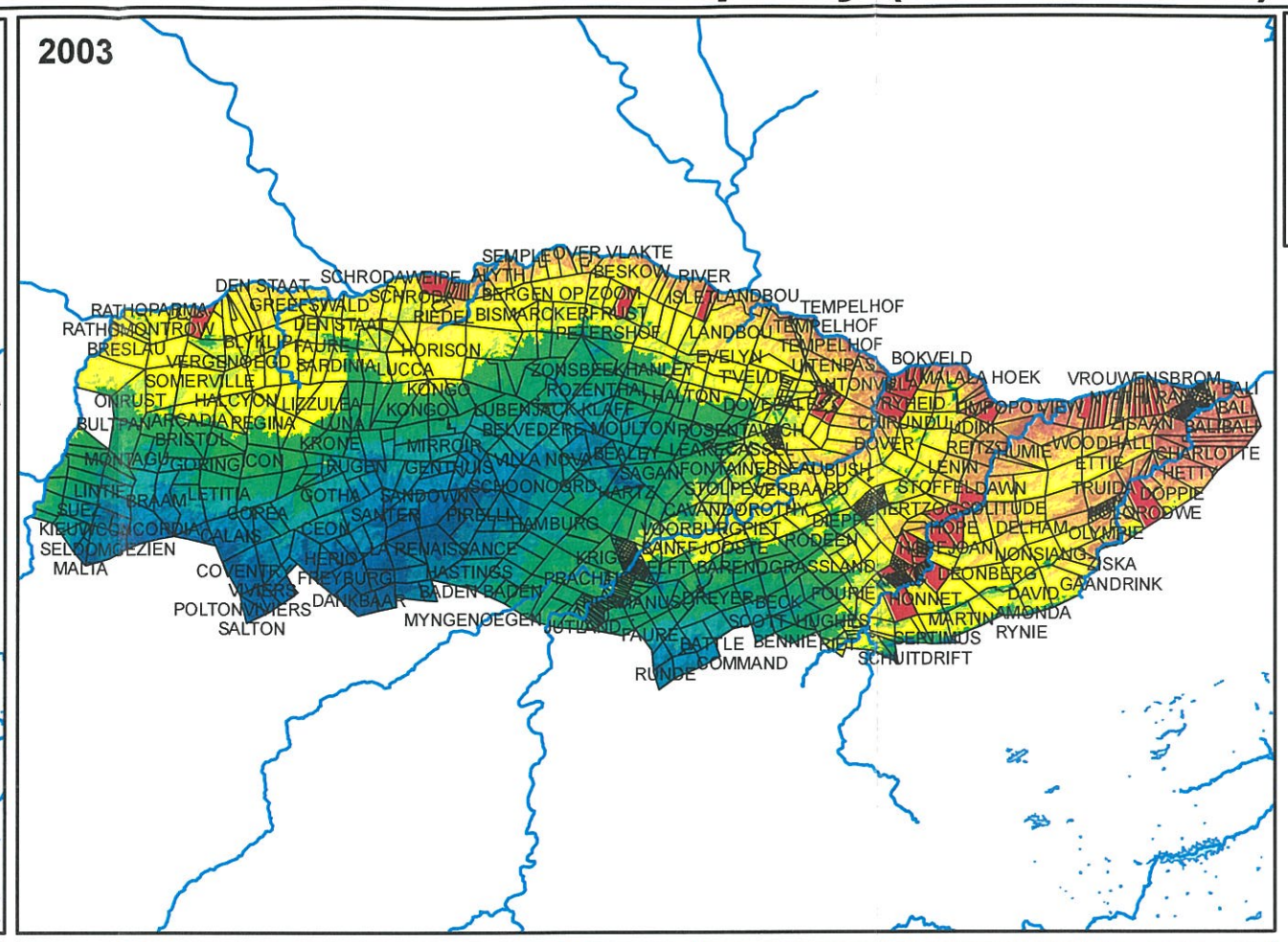
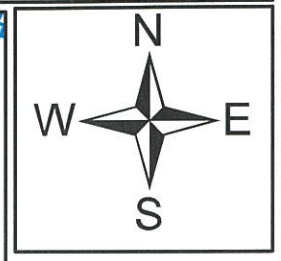


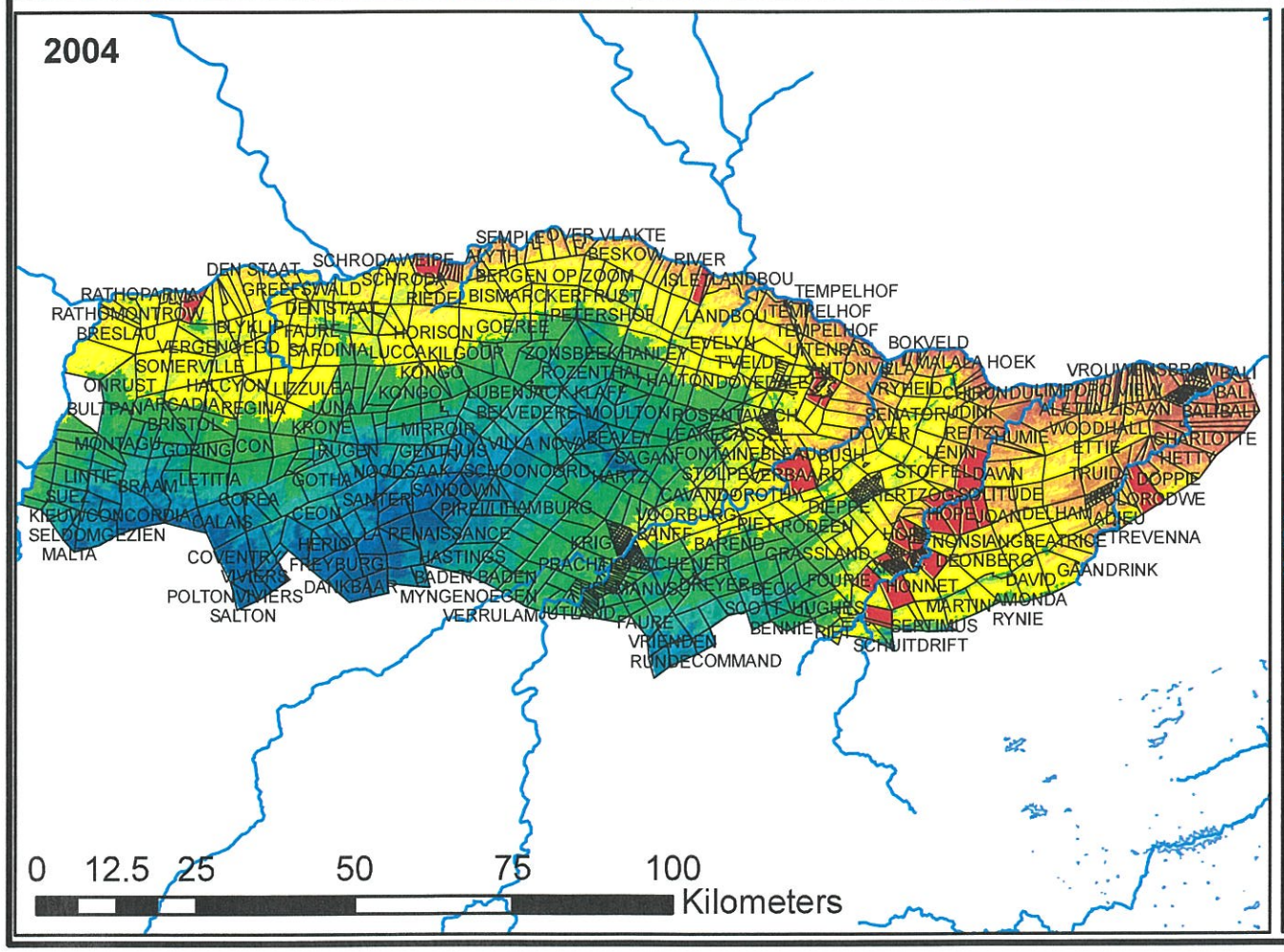
Figure 7.15

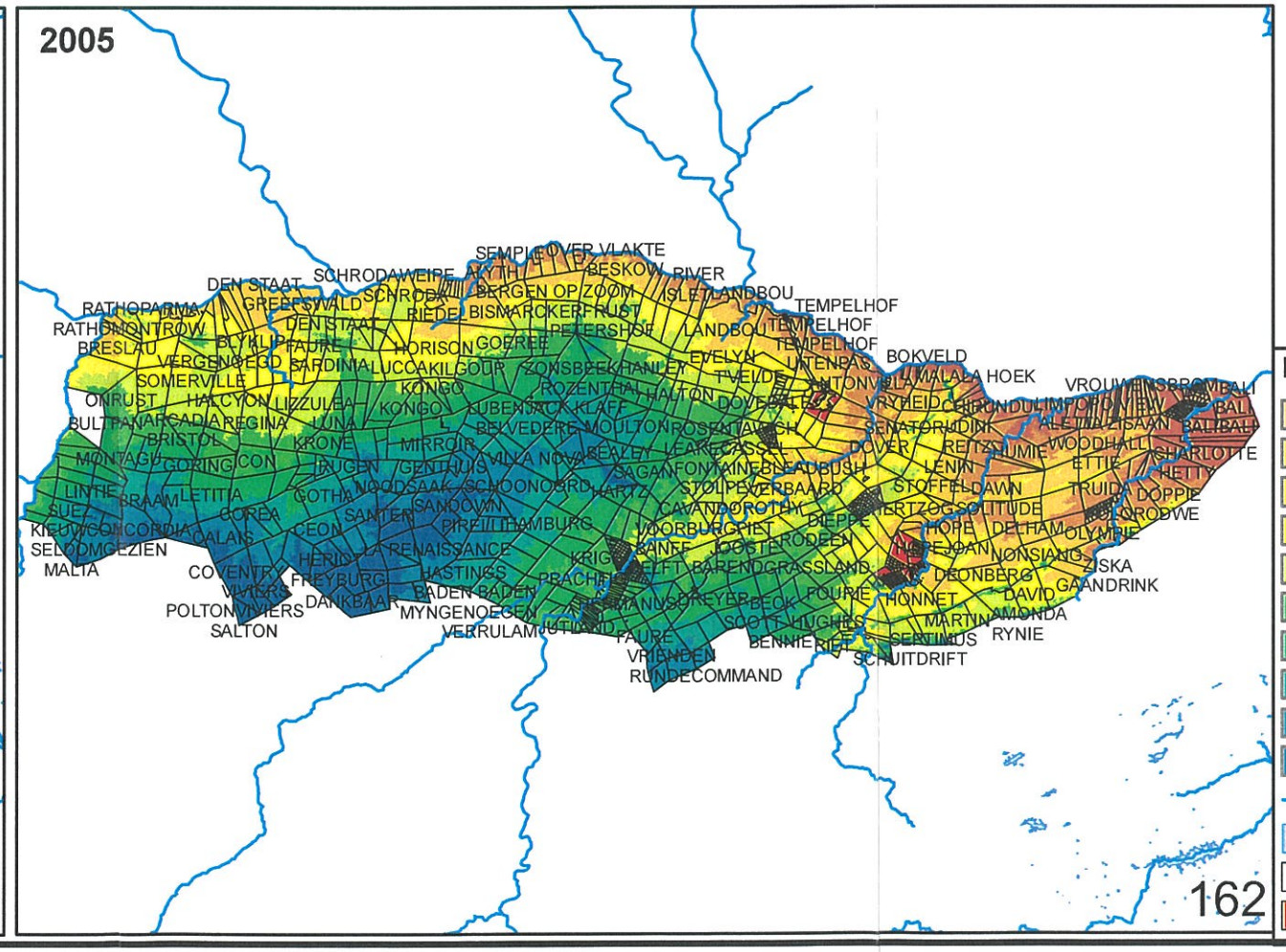
Spatial distribution of Malaria in relation to Altitude in Musina Municipality (2002 to 2005)











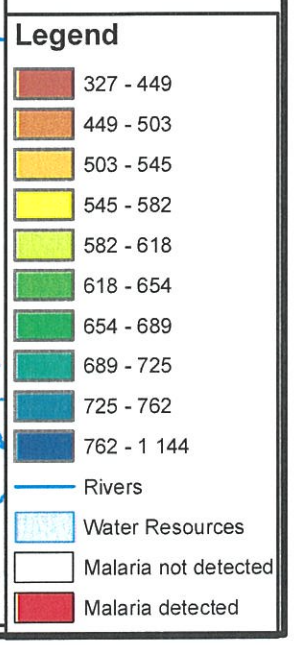
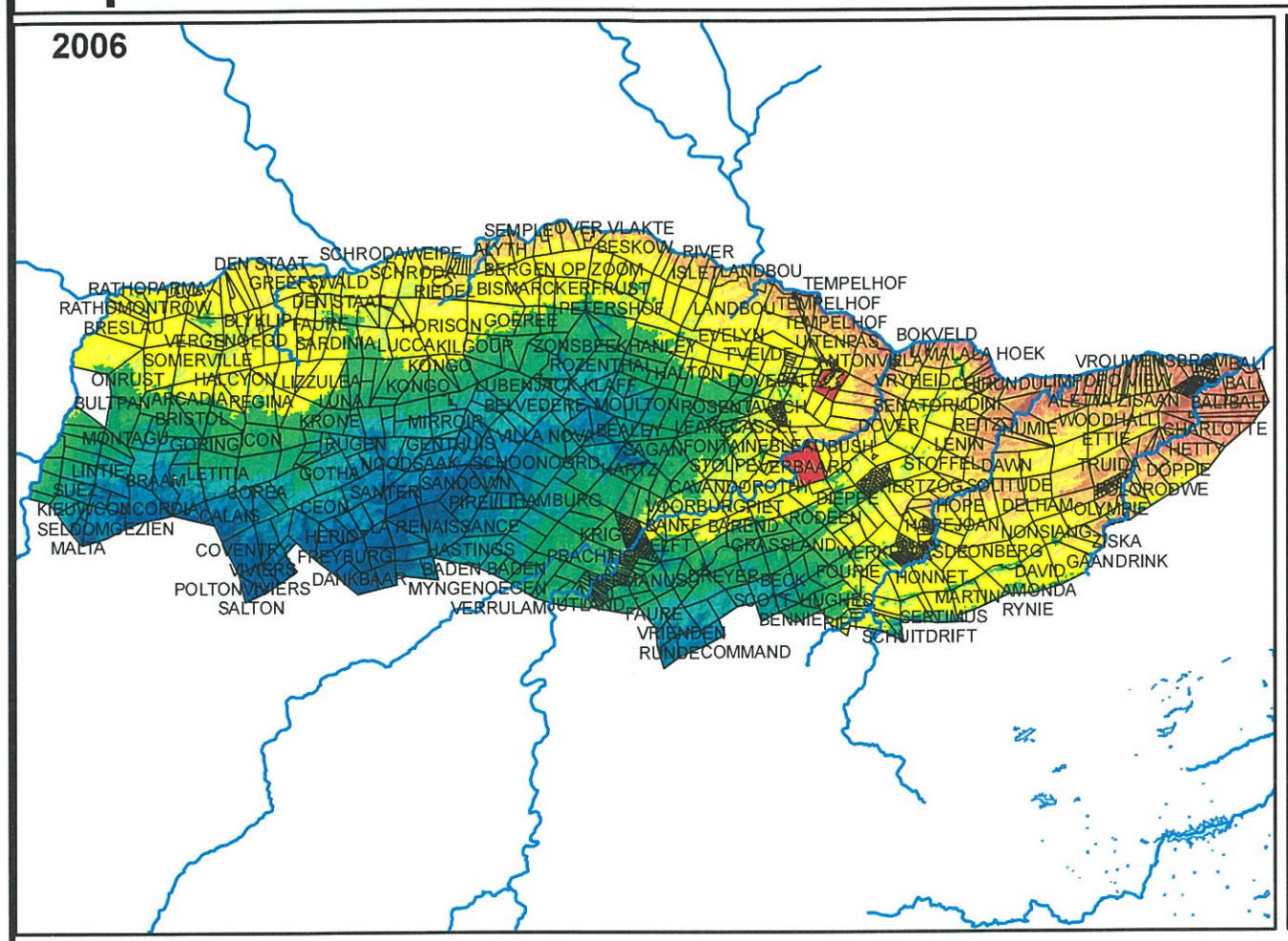
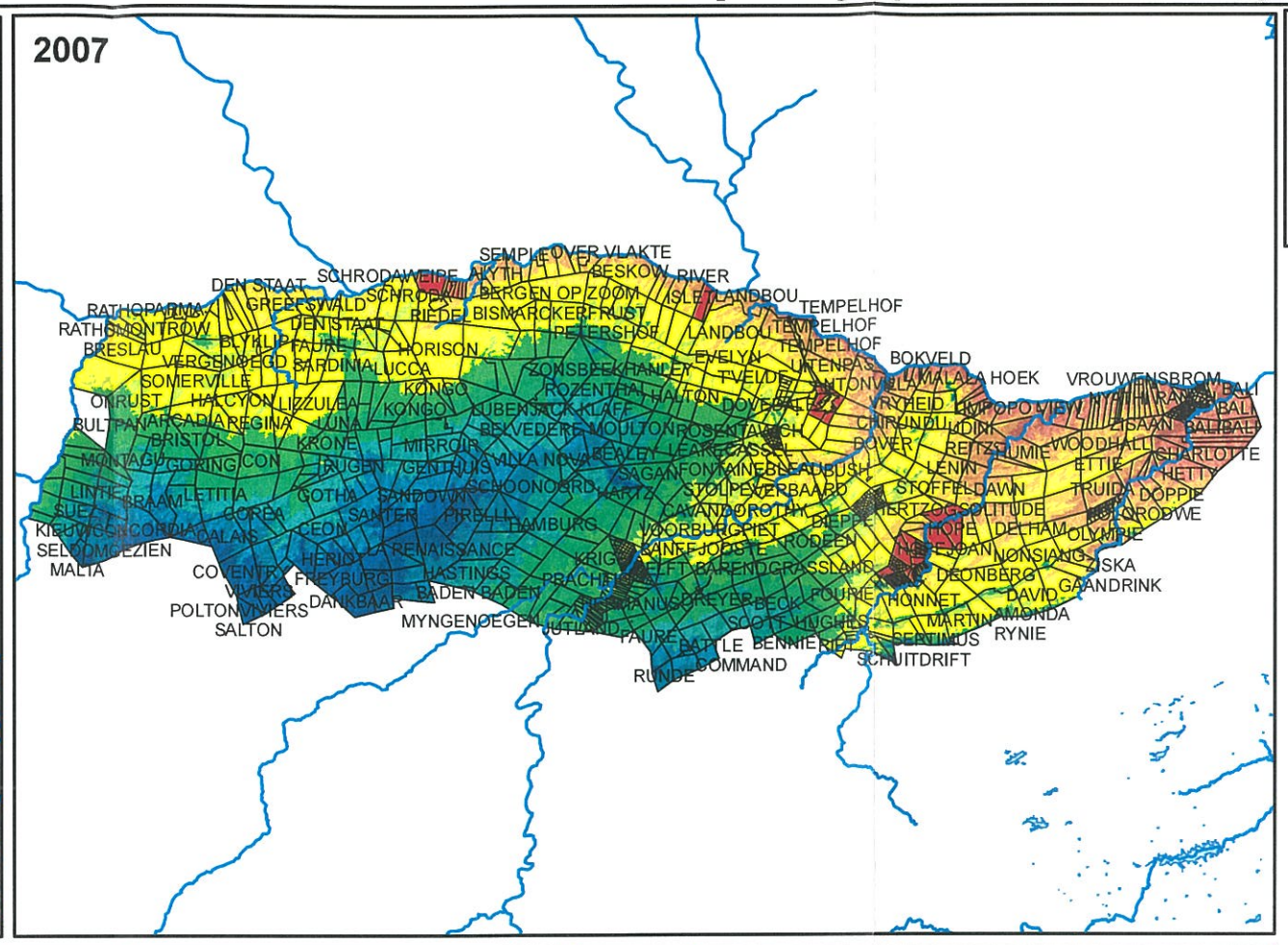
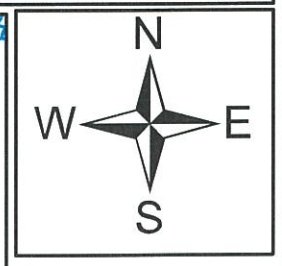


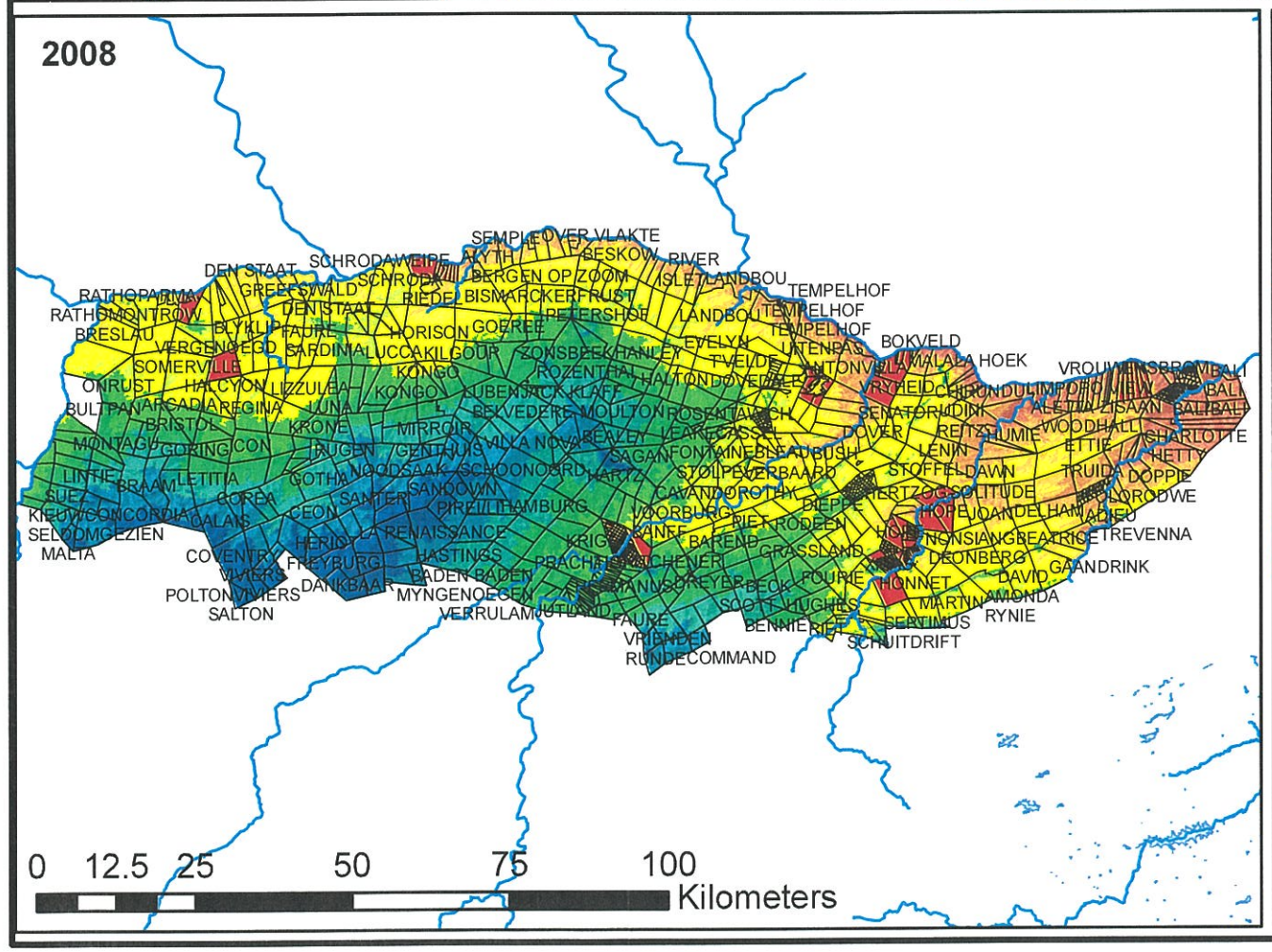
Figure 7.16

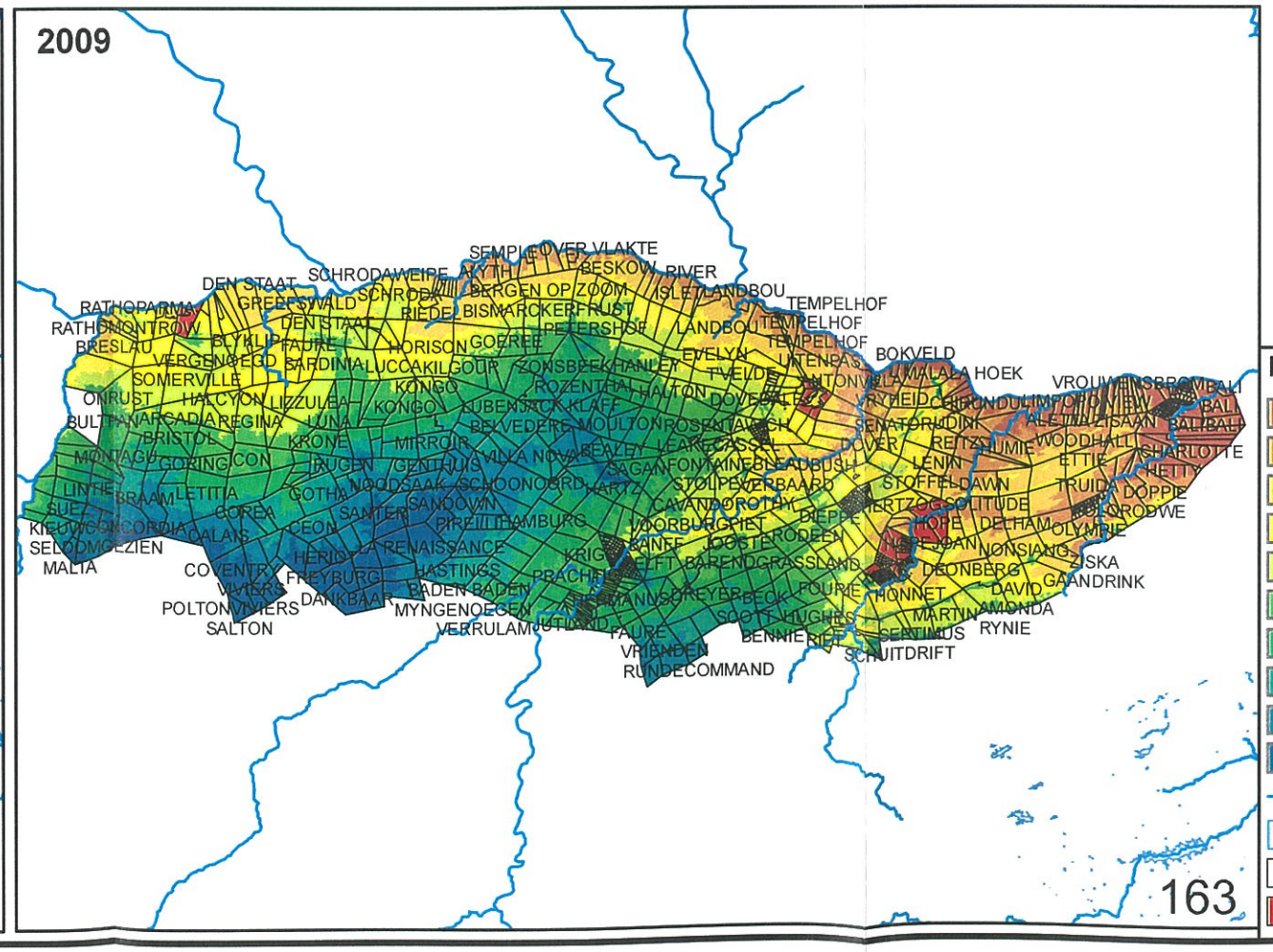
Spatial distribution of Malaria in relation to Altitude in Musina Municipality (2006 to 2009)











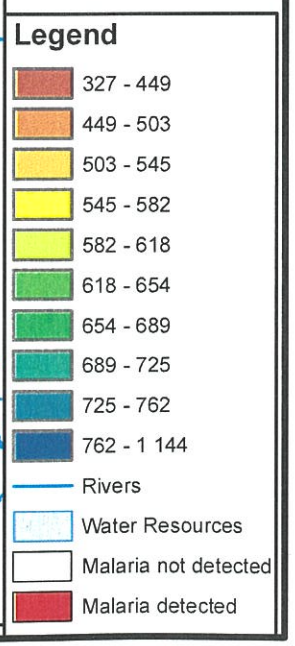
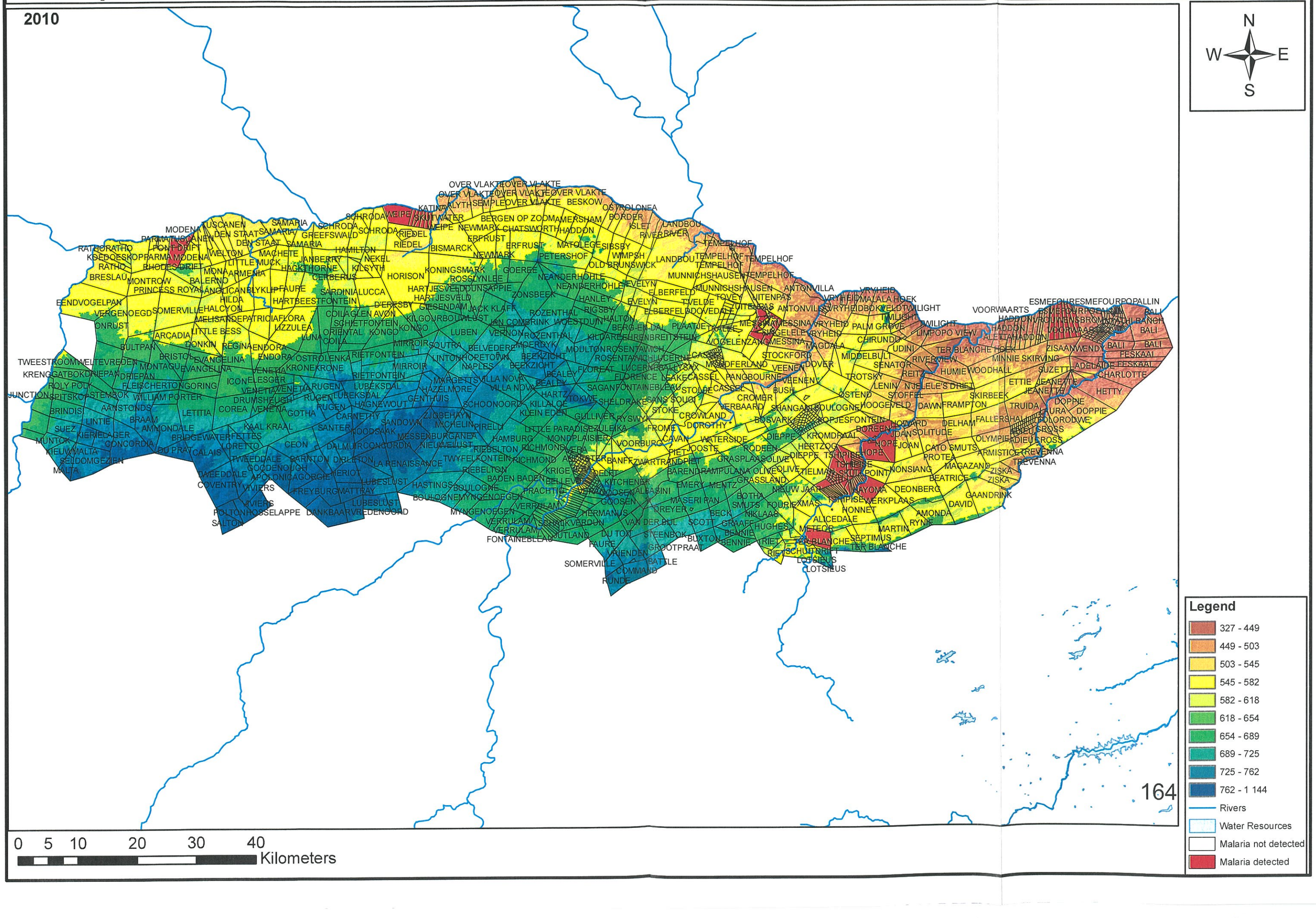


Figure 7.17

Spatial distribution of Malaria in relation to Altitude in Musina Municipality (2010)



Njeleledrift, Tempelhof, River, Islet, Weipe are below 500MASL, Icon and Belleview are above 600MASL, but are found in between valleys.

7.3 Malaria Distribution in Makhado Local Municipality

The main economic activities in Makhado Local Municipality are game and crop farming on the northern side with some village settlements on the eastern, north eastern and south western end (Figure 1.5). The Soutpansberg Mountains cut across almost through the central part towards Thulamela Local Municipality in the east (Figures 1.3b, 1.6).

7.3.1 Spatial distribution

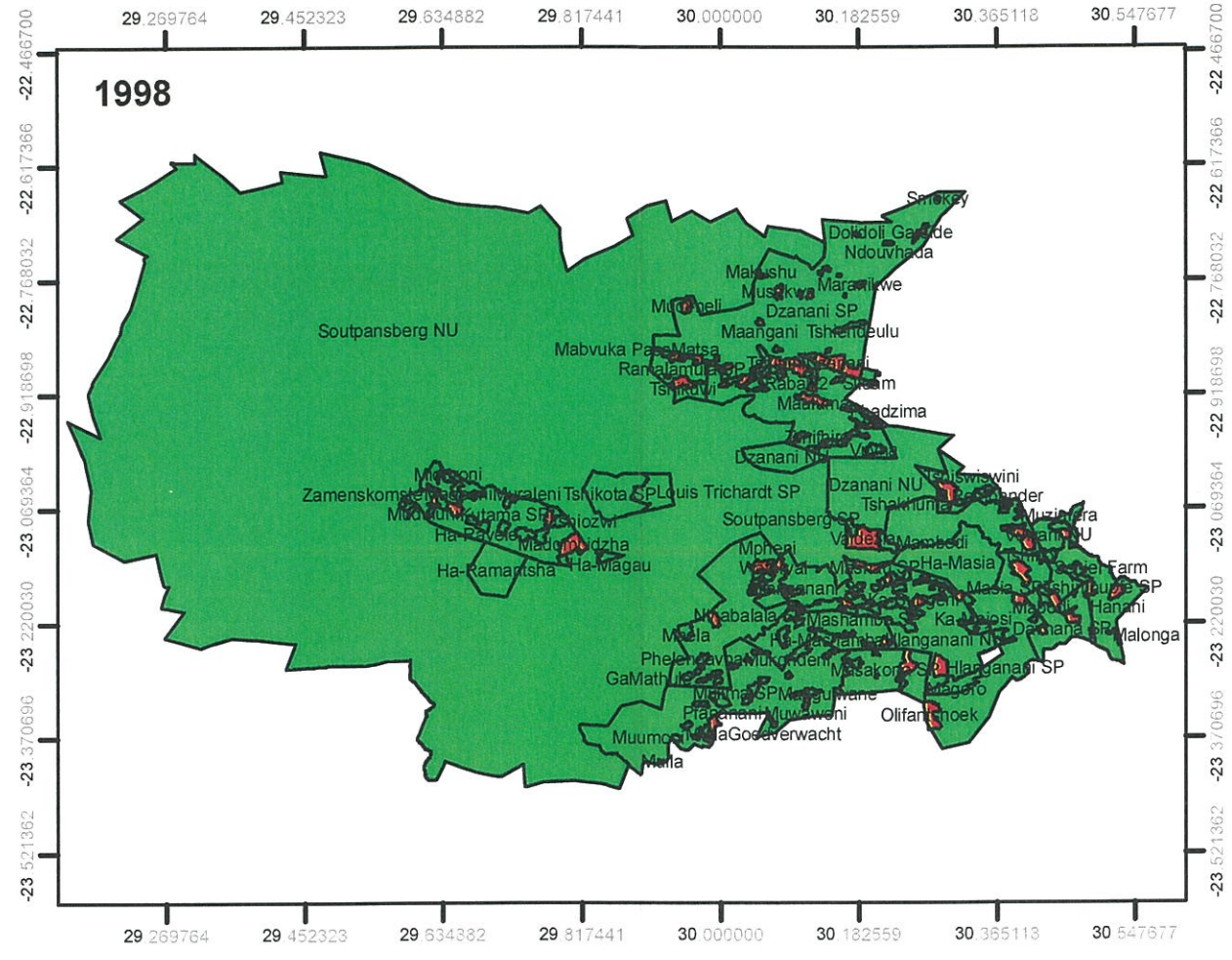
The spatial distribution of malaria in Makhado Local Municipality between 1998 and 2010 is presented in Figures 7.18 to 7.21. The maps for the period from 1998 to 2010 show that malaria was detected mostly in the central and eastern parts of the municipality, along the Mutale/Makhado municipal boundary. The number of reported cases, however, varied from year to year and the settlements where malaria was detected varied from year to year. It can be observed from the maps that the settlements where malaria was detected are mainly adjacent to each other.

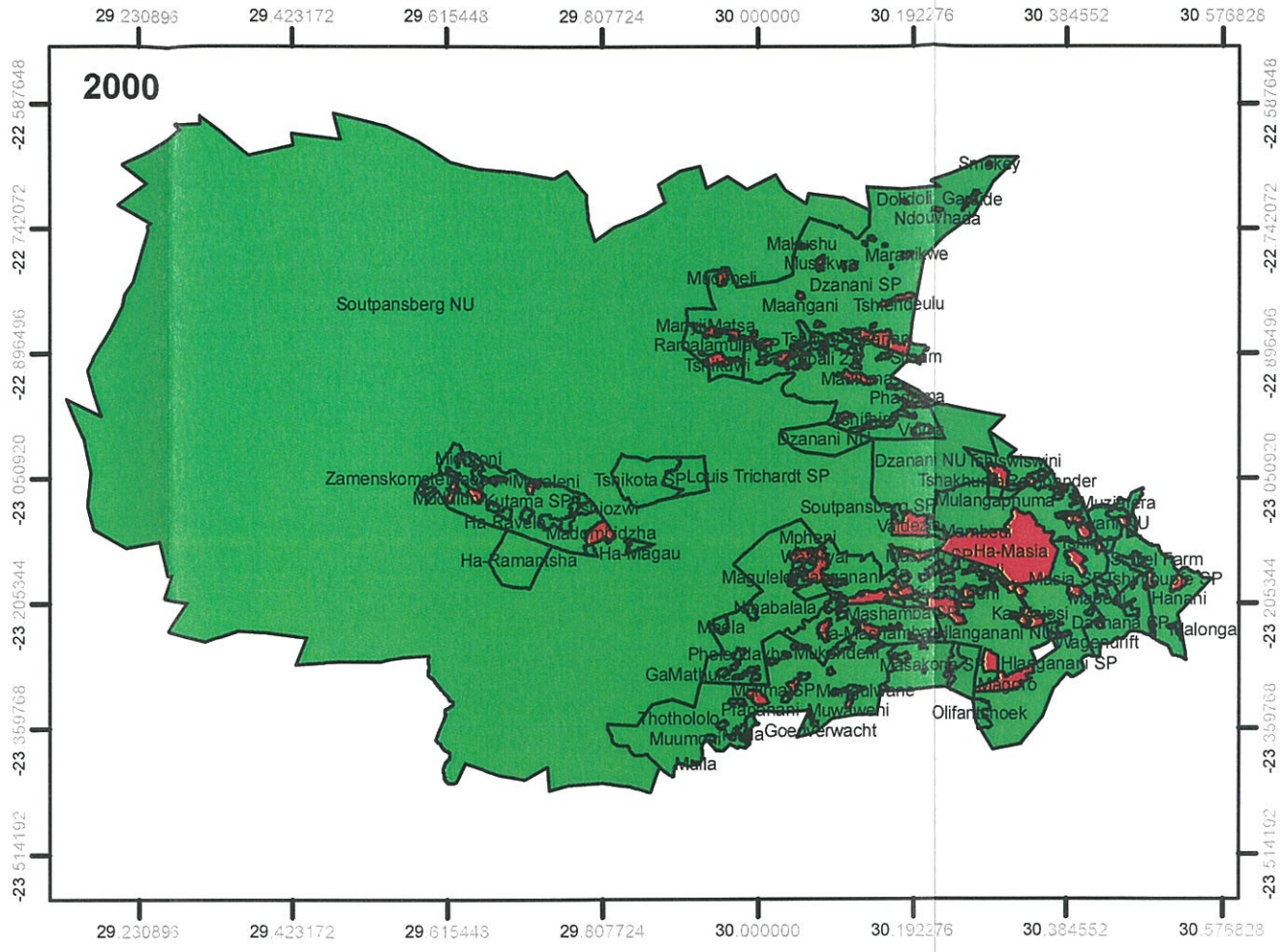
Figure 7.18 shows that malaria cases were reported in the central parts of Makhado around Louis Trichardt, Madomhizha, Tshiozwi and Matitivhala. The north-eastern parts of Mudumeli, Matsa, Dzanani, Tshakuma, Tshiendeulu, Maranikwe, Musekwa and other nearby settlements scattered in that area, detected malaria alternately. Some cases of malaria were detected in the southern eastern part of Valdezia, Muhoni, Chavani, Masakona, Muwaweni, Magoro, Sundani, Mashamba, Ha-Masia and surrounding villages.

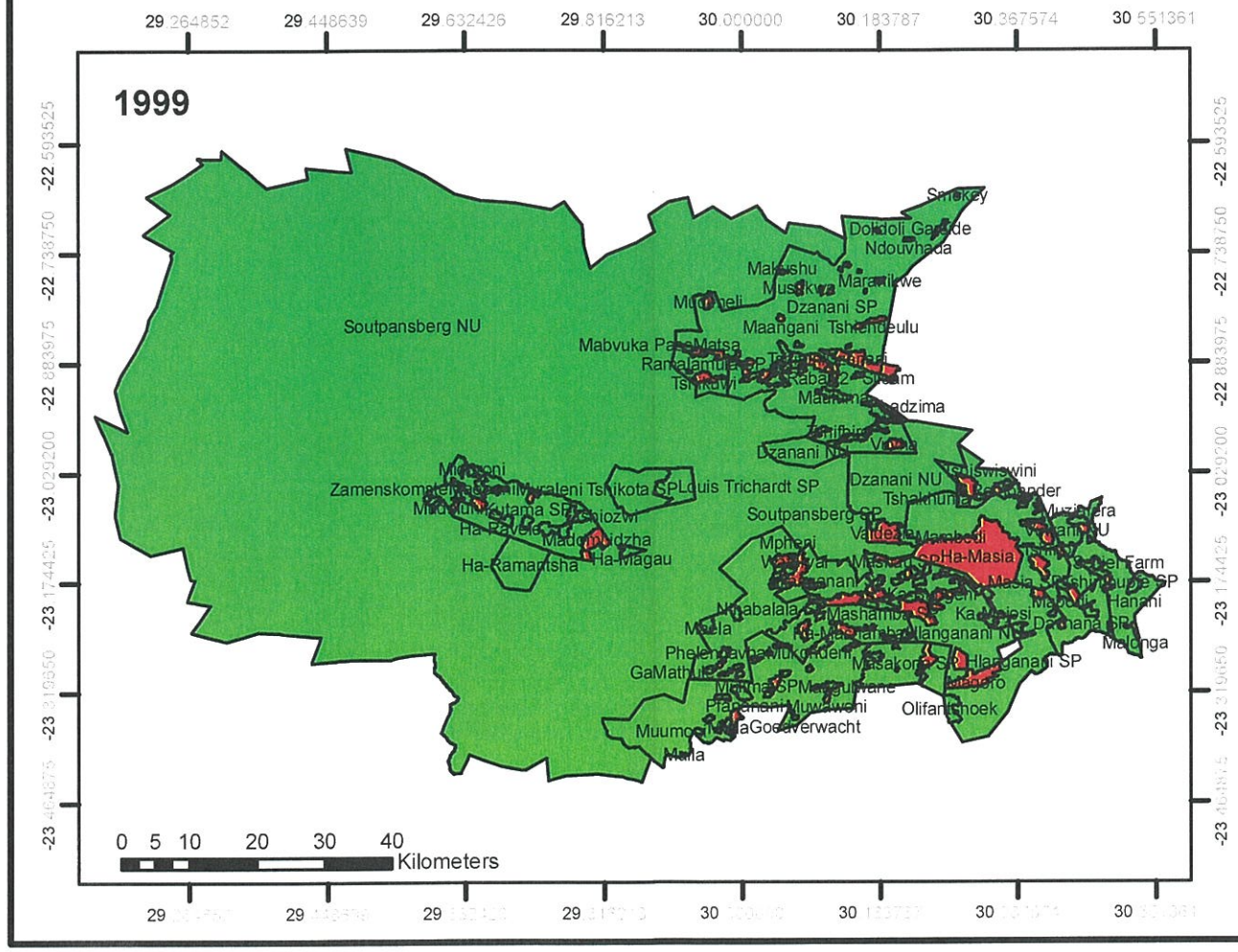
The settlement Ha-Ramantsha reported malaria in 2001 and not previously. A similar trend is observed on Figure 7.19 for the period between 2002 and 2005. A notable observation is that no malaria cases were detected in Ha-Ramantsha from 2001 to 2010 except in 2008.

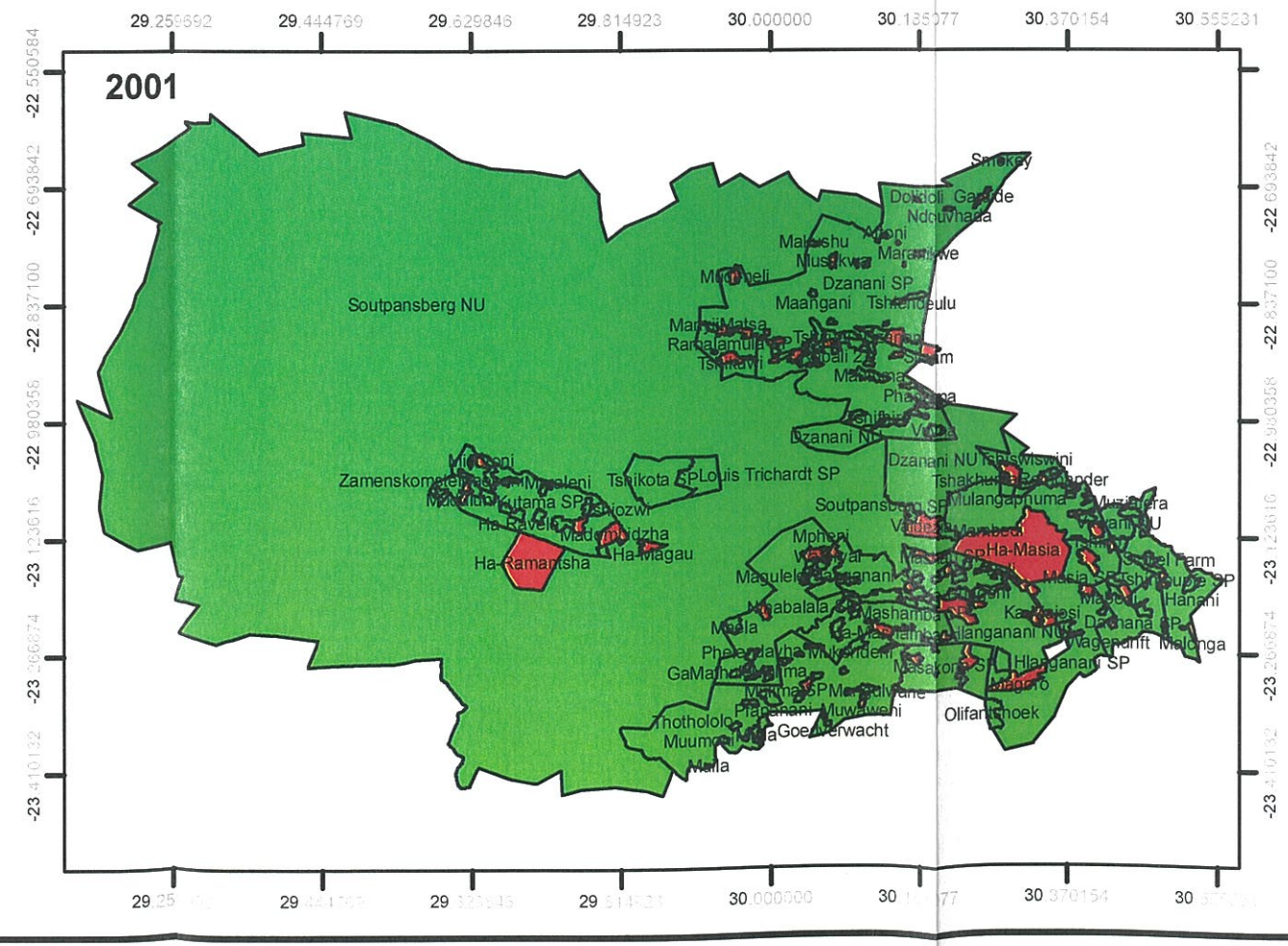
Figure 7.18

Spatial Distribution of Malaria in Makhado Local Municipality (1998 to 2001)









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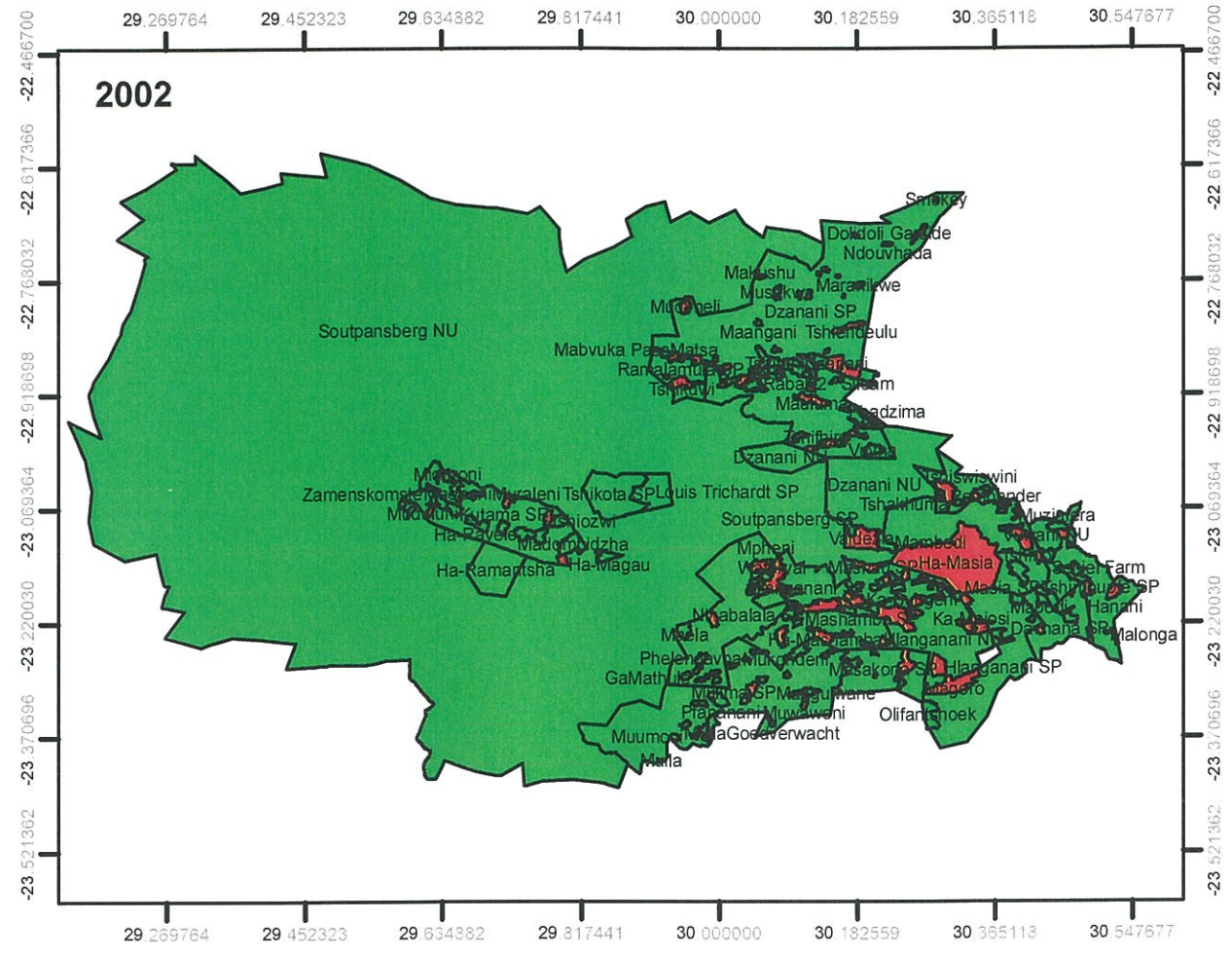
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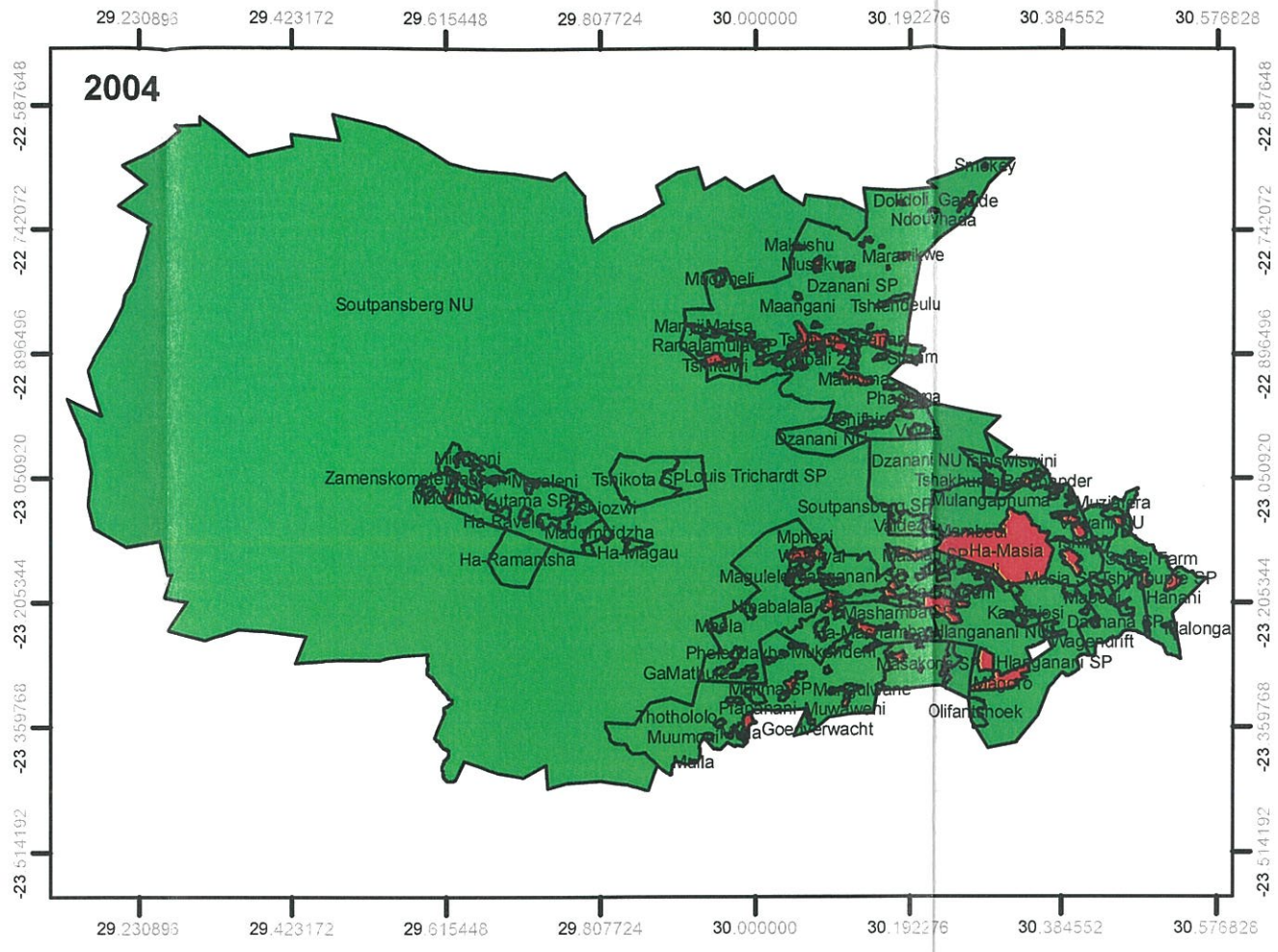
Legend

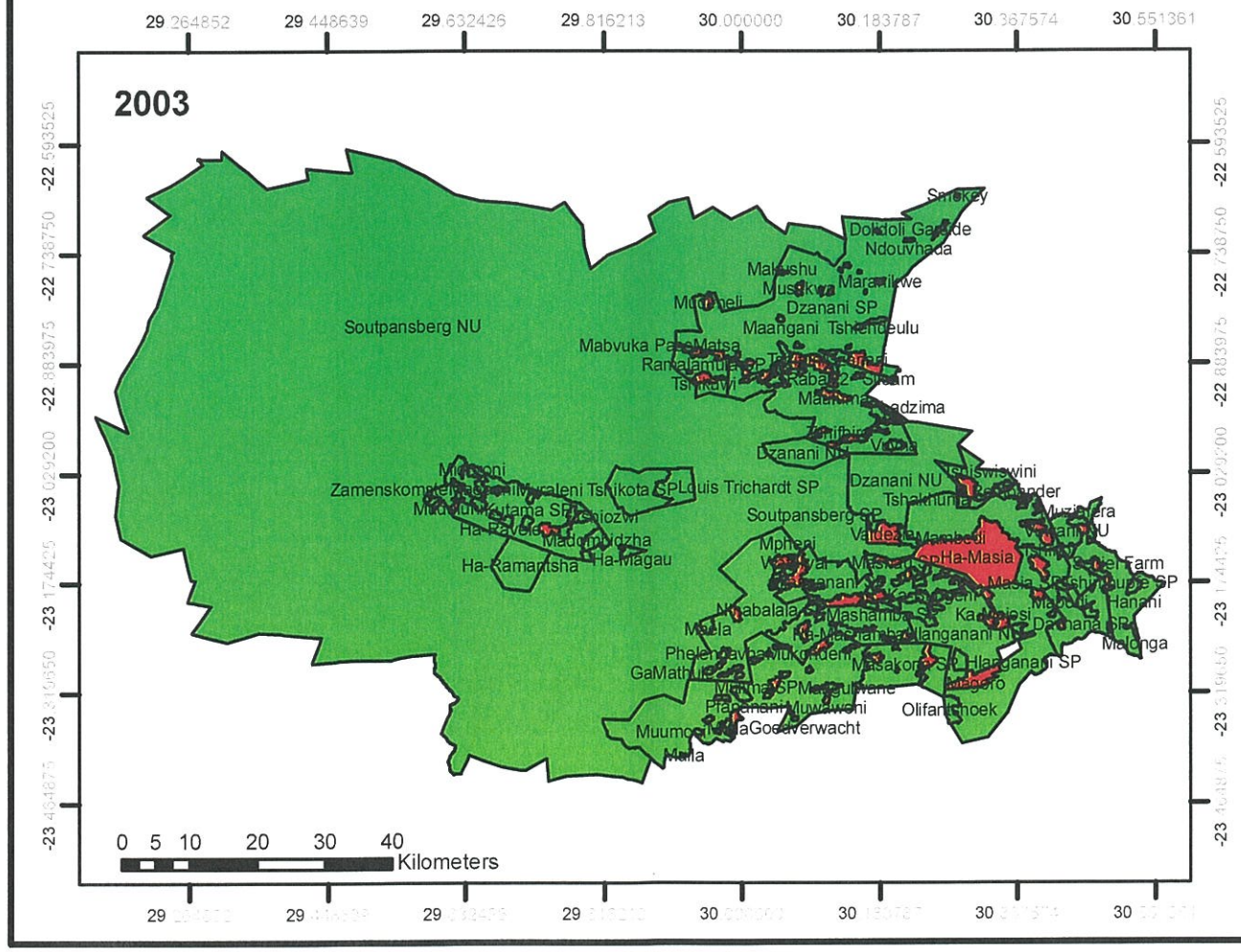
- Malaria not detected
- Malaria detected

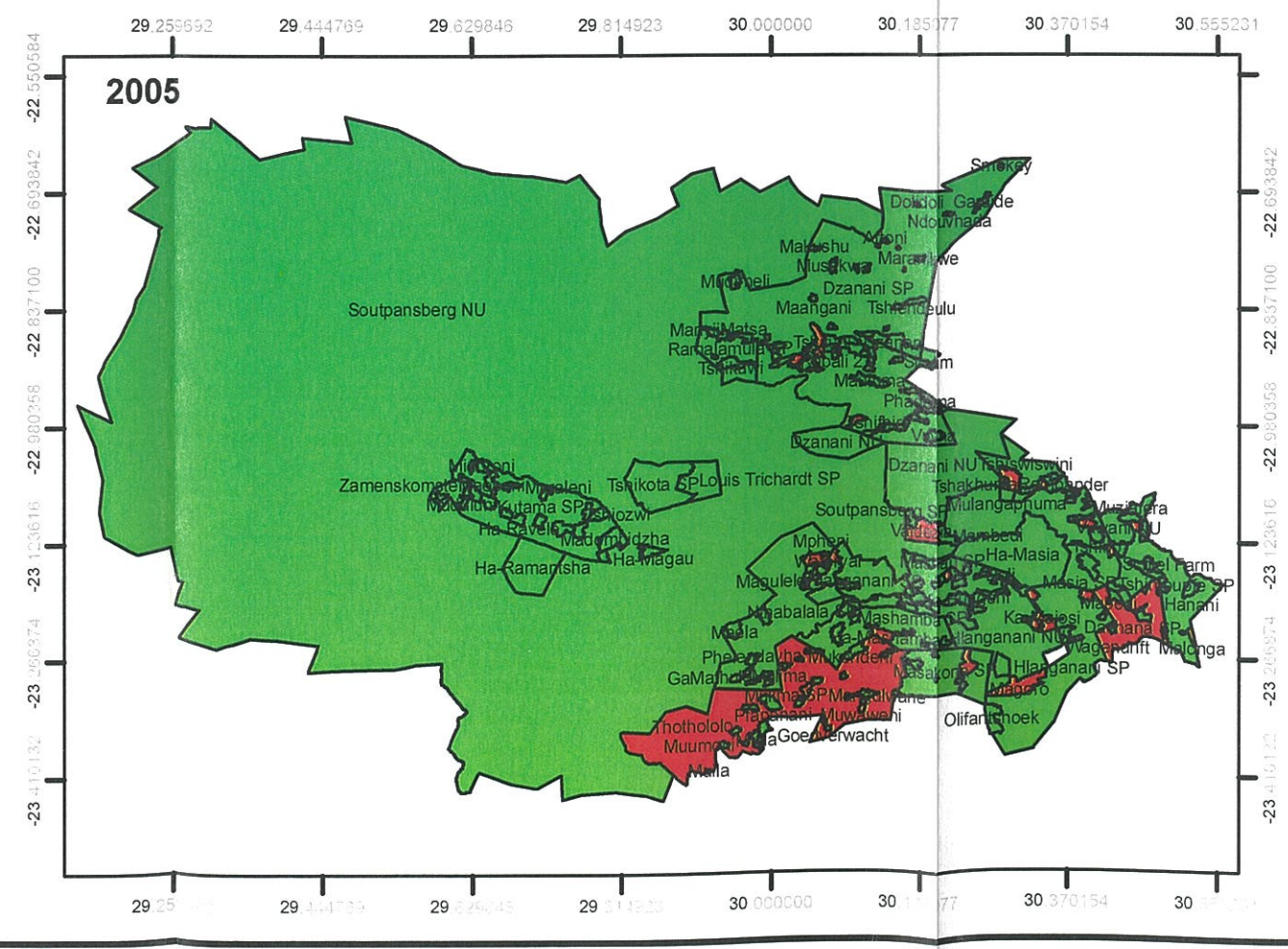
Figure 7.19

Spatial Distribution of Malaria in Makhado Local Municipality (2002 to 2005)









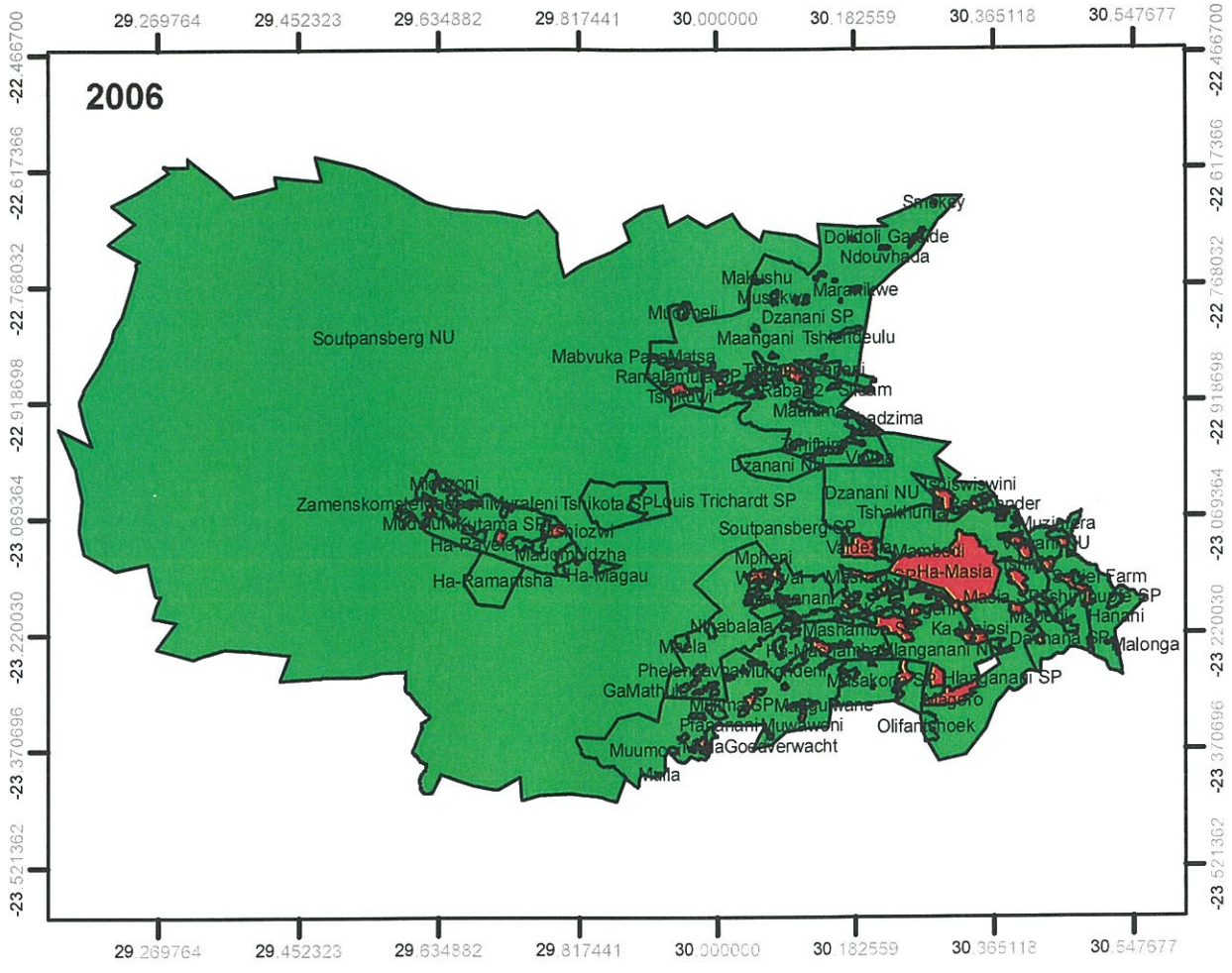
N
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S

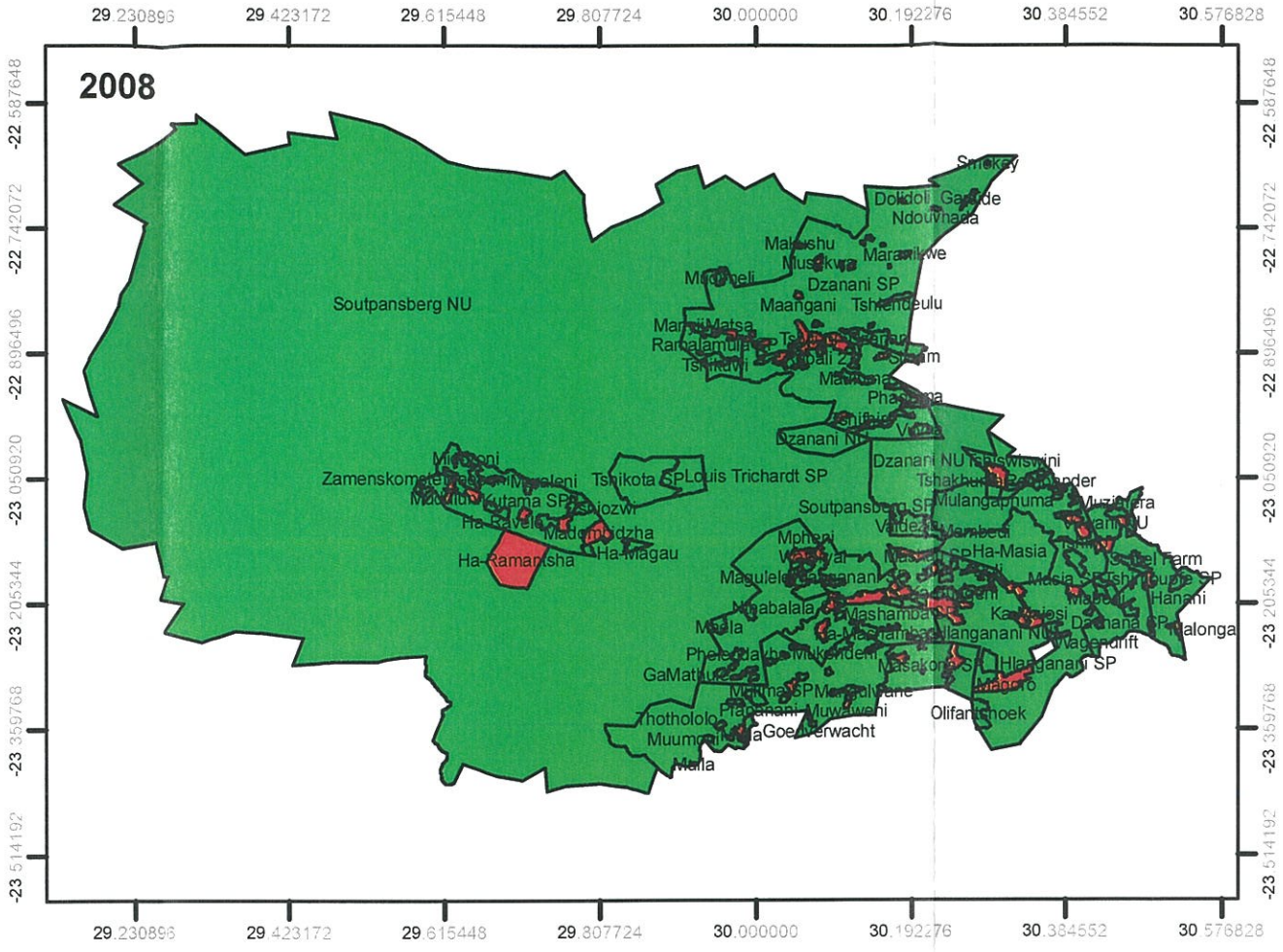
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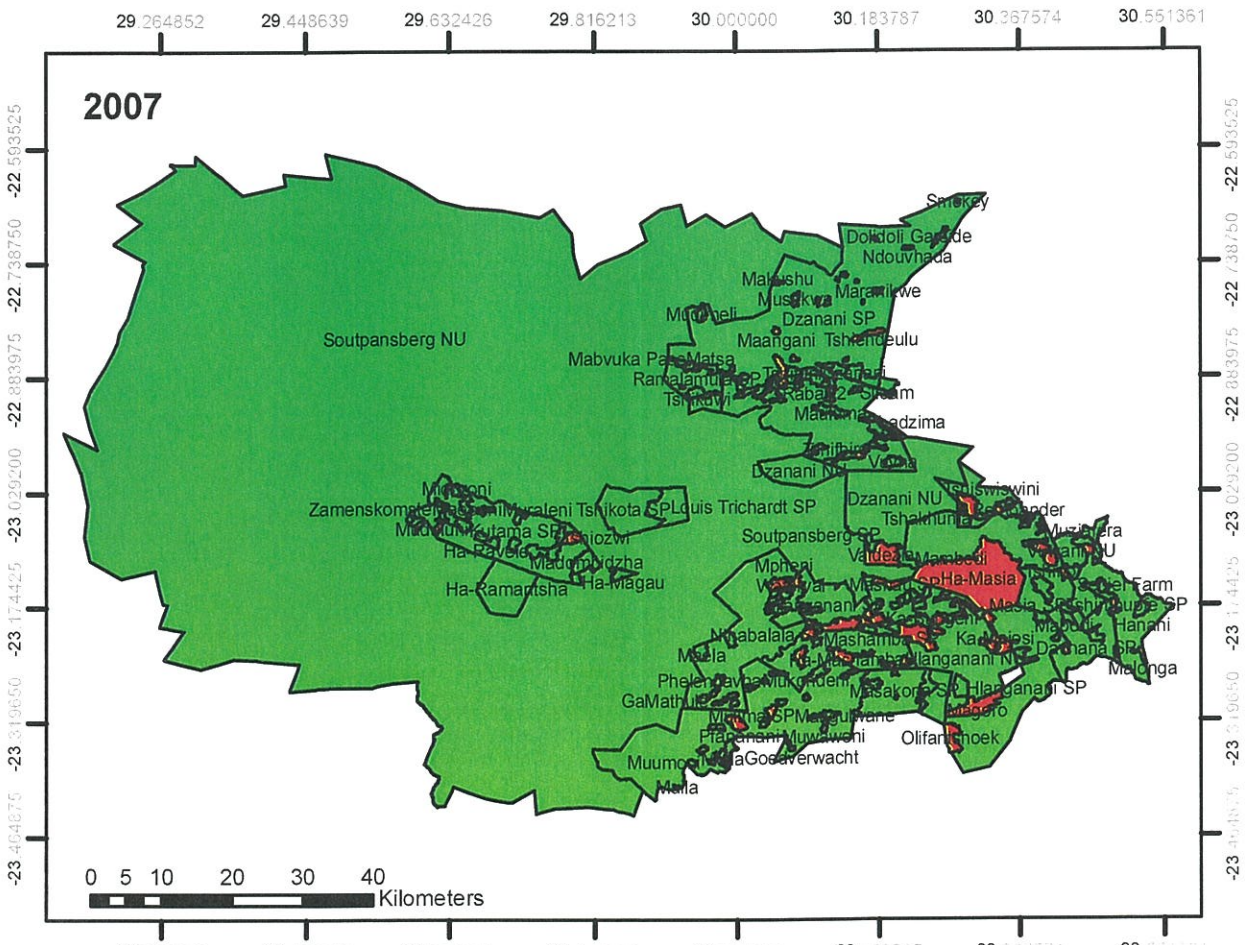
Legend

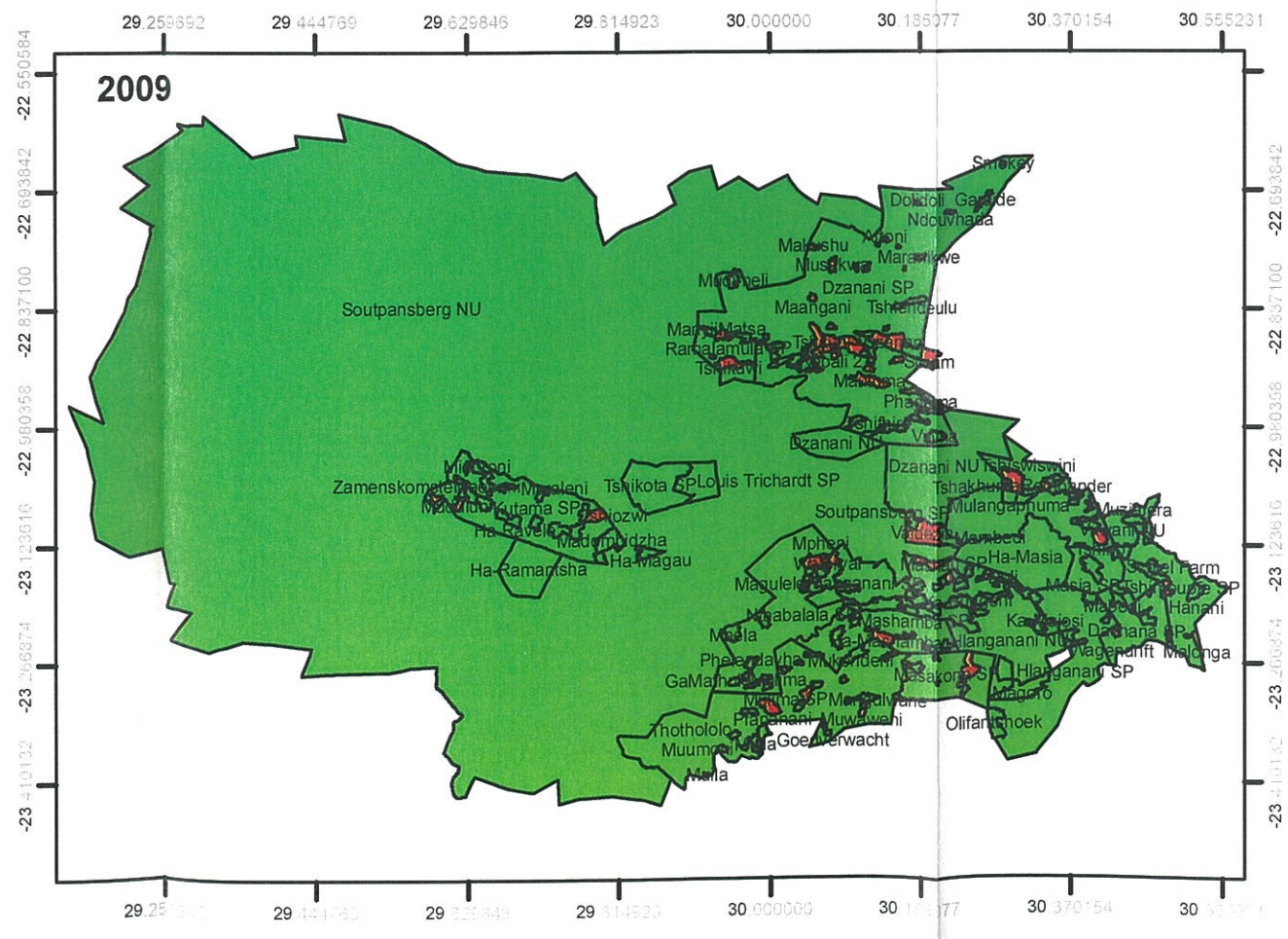
- Malaria not detected
- Malaria detected

Figure 7.20: **Spatial Distribution of Malaria in Makhado Local Municipality (2006 to 2009)**









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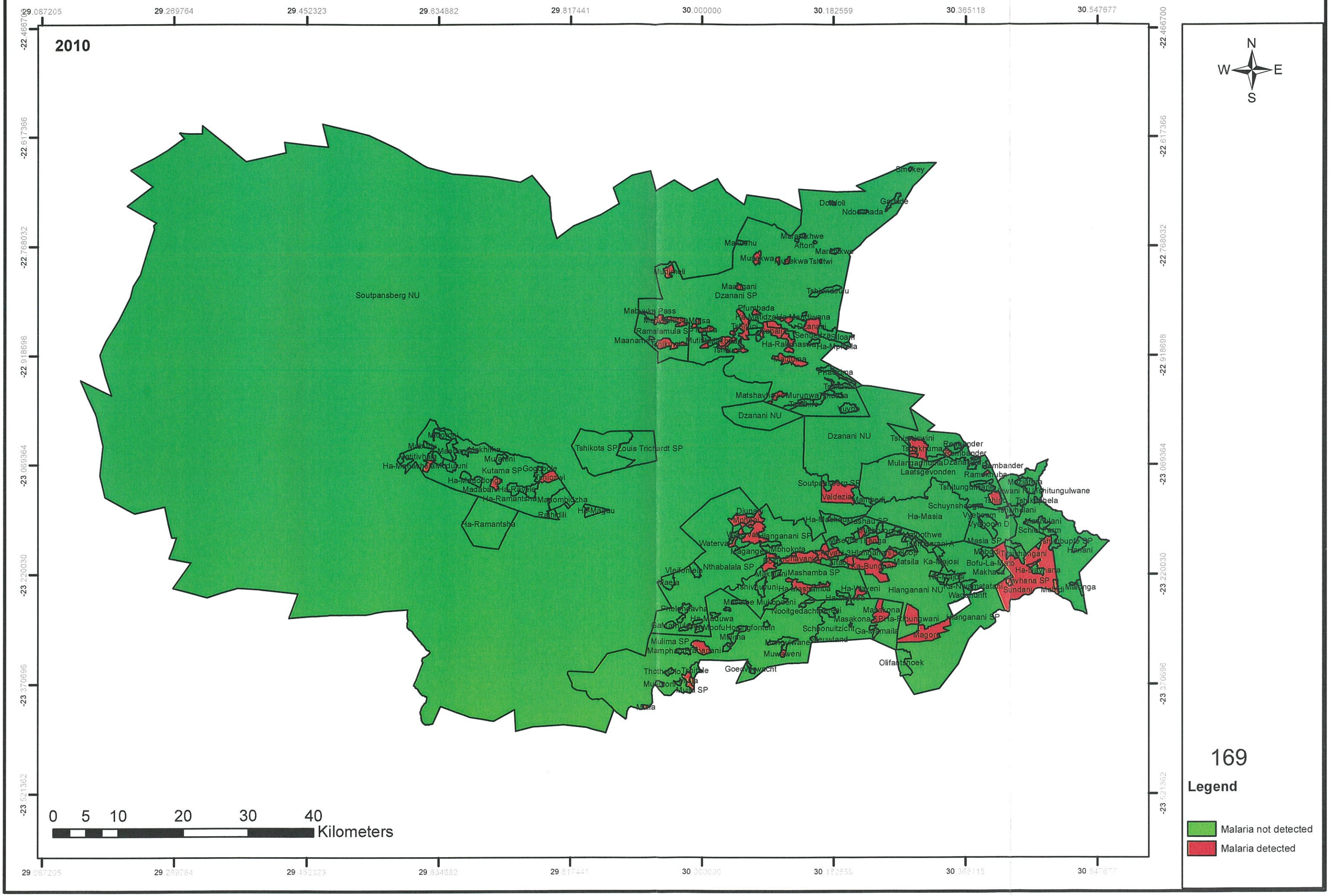
168

Legend

- Malaria not detected
- Malaria detected

Figure 7.21:

Spatial Distribution of Malaria in Makhado Local Municipality (2010)


2010
29.087205
29.269764
29.452323
29.634882
29.817441
30.000000
30.182559
30.365118
30.547677
-22.466700
-22.617366
-22.768032
-22.918698
-23.069364
-23.220030
-23.370696
-23.521362
N
W
E
S
Soutpansberg NU
Dzanani NU
Hlanganani NU
Tshikota SP
Louis Trichardt SP
Soutpansberg SP
Dzanani SP
Hlanganani SP
Masisi SP
Mashau SP
Mashamba SP
Nthabalala SP
Ramalamula SP
Smokey
Gertside
Afton
Laatsgevonden
Olifantshoek
Goedgewacht
Schoonuitzicht
Ha-Ramantsha
Kutama SP
Madaban
Ha-Ravele
Ha-Masisi
Ha-Mashamba
Ha-Maseloni
Ha-Makuya
Ha-Ramabulana
Ha-Mphaphuli
Ha-Mutshaeni
Ha-Matidza
Ha-Mphephu
Ha-Rabali
Ha-Raluswiha
Ha-Mpfumela
Ha-Maduwa
Ha-Mbulungwani
Ha-Masakona
Ha-Mulima
Ha-Mutele
Ha-Mutsila
Ha-Mutsetse
Ha-Mutsila
Ha-Nwamatatani
Ha-Vhuthu
Ha-Vhuvha
Ha-Waveni
Ha-Wavhana
Ha-Wavhana SP
Ha-Wavhana
Ha-Wavhana
Ha-Wavhana

In 2005 a cluster of malaria cases was observed in the south eastern part around Muila, Muumoni, Thothololo, Muwaweni, Mukondeni and immediate surrounding settlements. Malaria cases gradually increased in the municipality from 2005 to 2010. This may be attributed to increase in temperatures within the municipality (Figures 6.7 – 6.9). From 2006 (Figure 7.20) to 2010 (Figure 7.21), a similar situation to that observed in previous years ensued; malaria cases continued to be detected in the municipality's central and eastern settlements. A notable fact is that, though, is that it can be observed that from 2008 to 2010 malaria cases were not detected in the village of Ha-Masia which is quite large. A scattering of malaria cases in various human settlements is clearly observed in the municipality.

7.3.2 Makhado Malaria Distribution Based on a Digital Elevation Model

Makhado Local Municipality has altitudes which range between 479 MASL and 1735 MASL. The maps in Figure 7.22 maps indicate that in 1998 and 2001, malaria was detected in areas below 912 MASL. No malaria cases were detected on the north western part, which is the part bordering with Musina Local Municipality which is between 479 and 750masl. Most of the settlements which detected malaria are below 648masl and on the eastern side of the municipality. These areas are also close to water bodies. Between 2002 and 2004, most of the malaria cases were detected in areas below 648 MASL and very few areas between 648 and 912 MASL had malaria as indicated in Figure 7.23. However, in 2005 malaria was detected on the southern side around Thothololo and Matla which are between 985 and 1176 MASL. In 1999, 2000, 2002, 2003, 2005, 2007, 2008 and 2010, malaria cases were also detected in the areas of Matshavawe, Tshifhire and Vuvha which are enclaved within the valleys of the Soutpansberg mountain range at 912-1735 MASL.

From 2006 to 2010, malaria continued to be occur in locations below 912 MASL (and a few isolated cases above 912 MASL) in Makhado Local Municipality (Figures 7.24 and 7.25). It can be observed from these maps of malaria cases between 1998 and 2010 is that malaria cases were detected in valley locations between mountains in Makhado Local Municipality. These areas also happen to have water bodies and rivers crossing through them (Figure 1.5), which serve as mosquito breeding habitats.

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Figure 7.22

Spatial distribution of Malaria in relation to Altitude in Makhado Municipality (1998 to 2001)

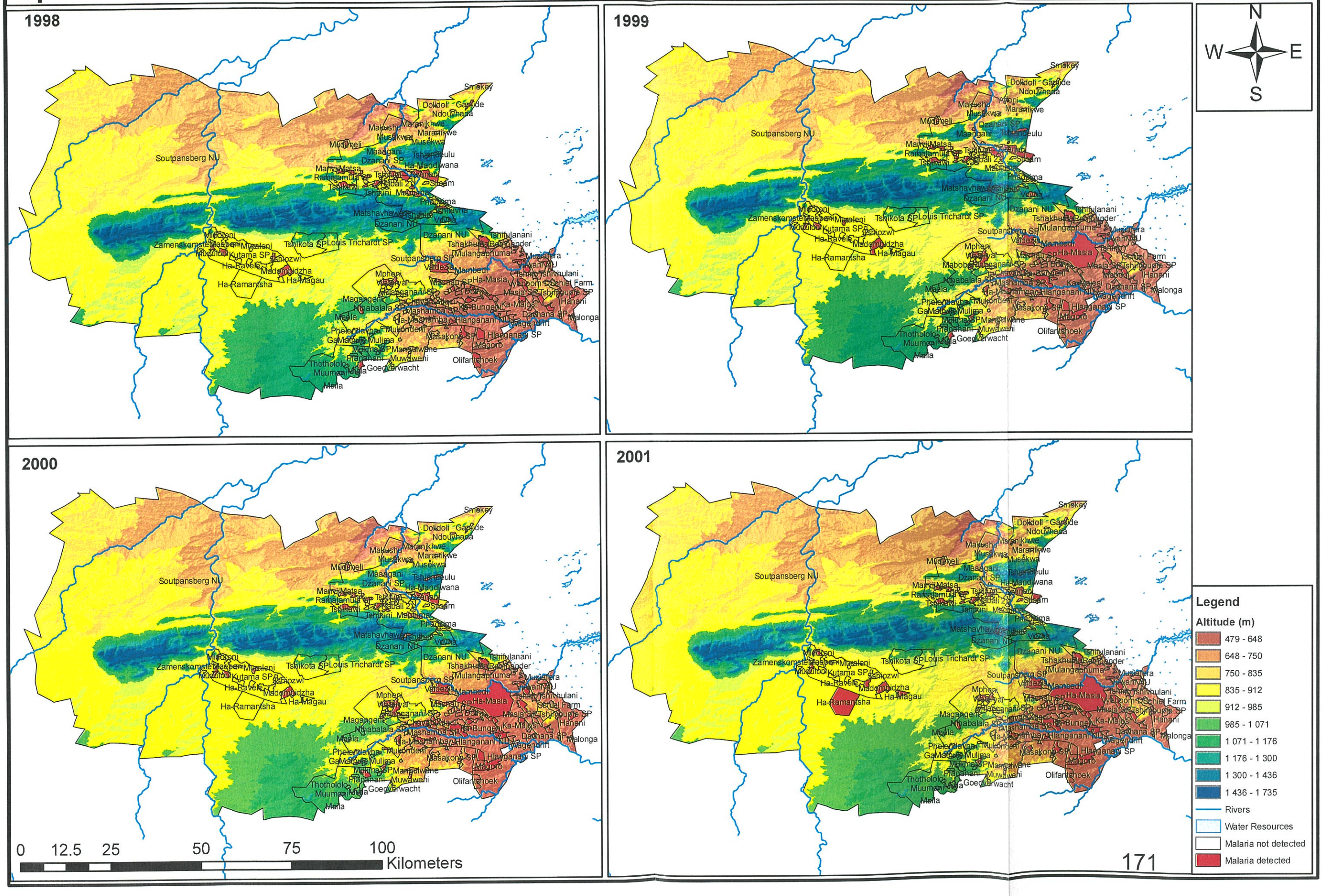


Figure 7.23

Spatial distribution of Malaria in relation to Altitude in Makhado Municipality (2002 to 2005)

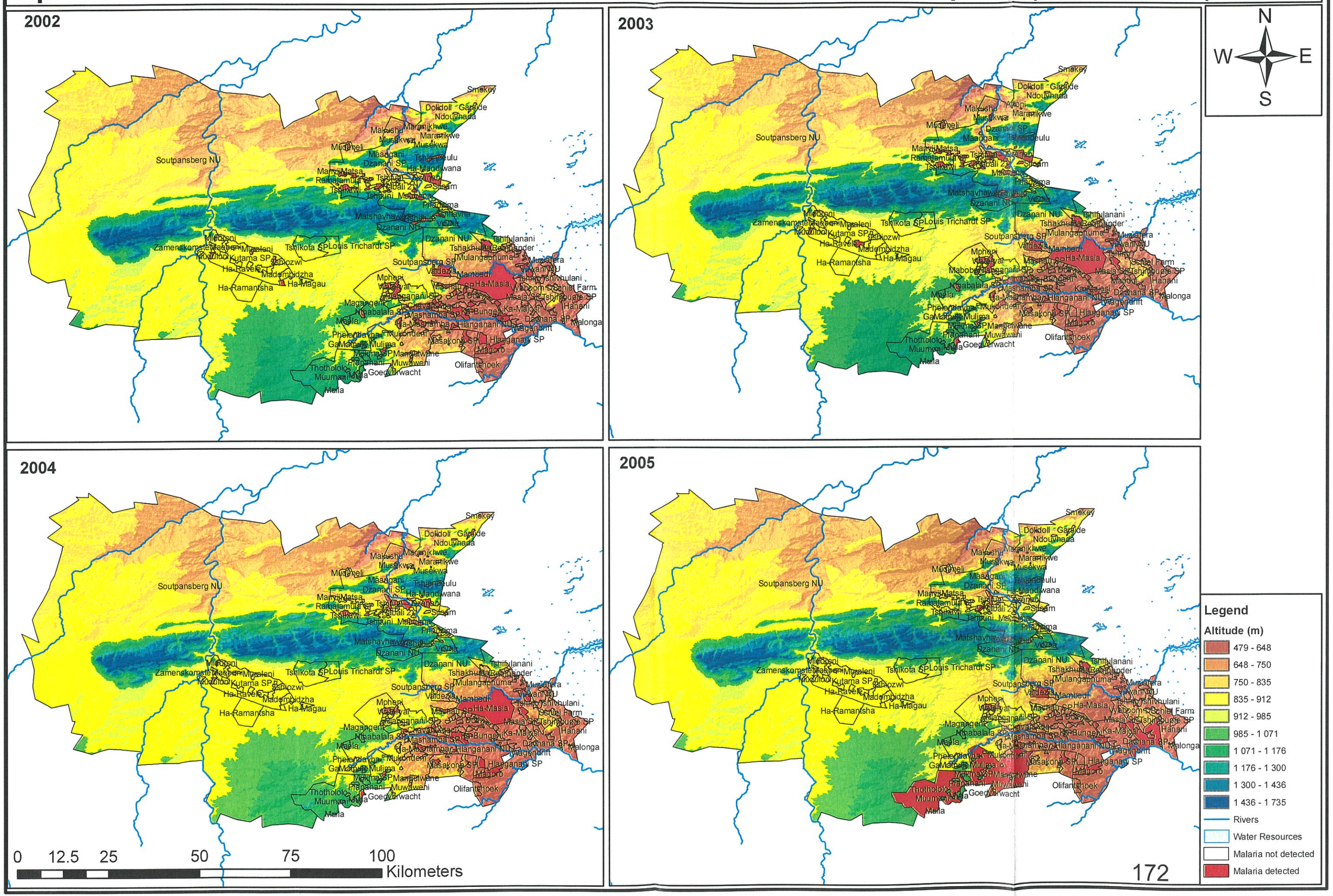


Figure 7.24

Spatial distribution of Malaria in relation to Altitude in Makhado Municipality (2006 to 2009)

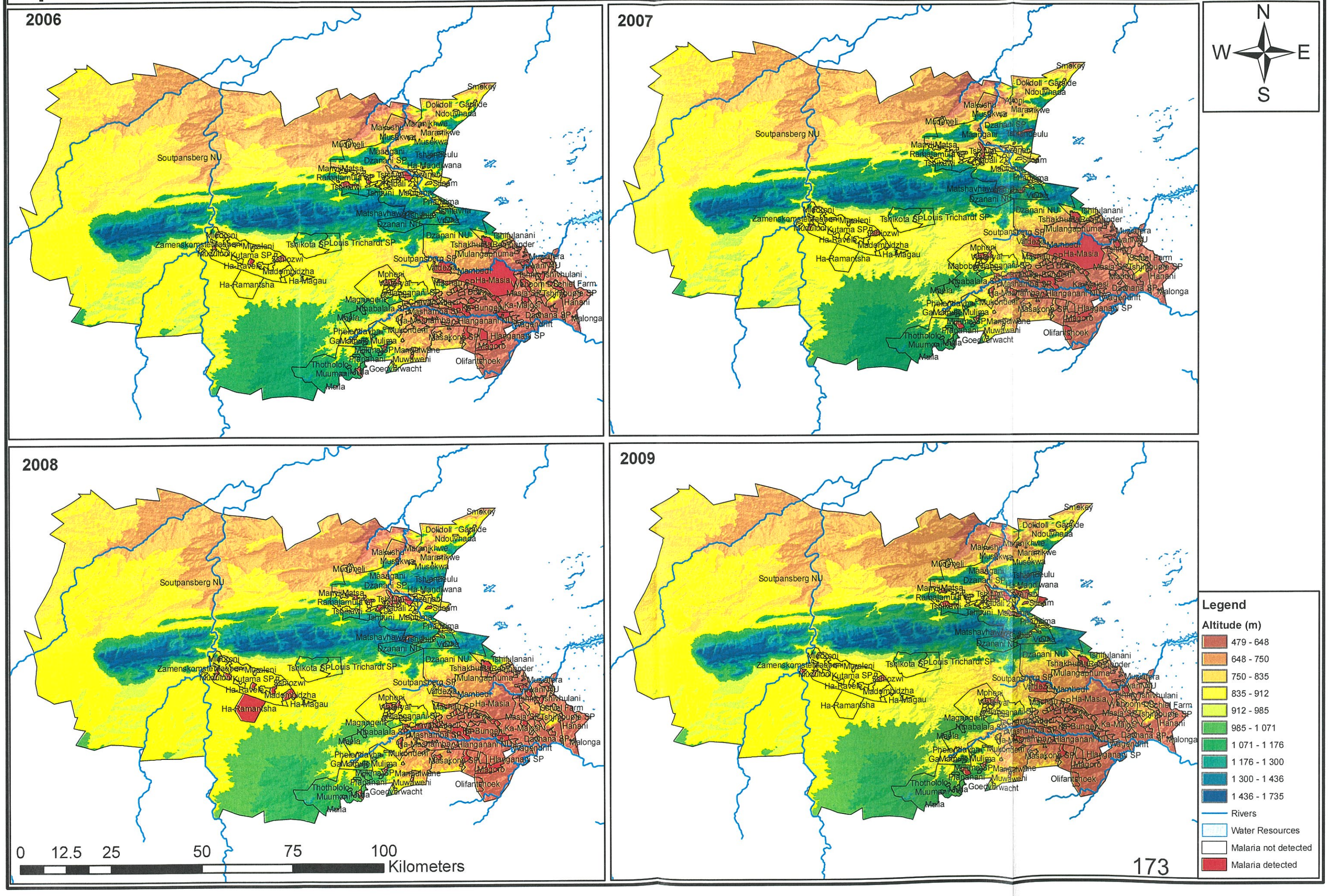


Figure 7.25

Spatial distribution of Malaria in relation to Altitude in Makhado Municipality (2010)

2010

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Altitude (m)

- 479 - 648
- 648 - 750
- 750 - 835
- 835 - 912
- 912 - 985
- 985 - 1 071
- 1 071 - 1 176
- 1 176 - 1 300
- 1 300 - 1 436
- 1 436 - 1 735
- Rivers
- Water Resources
- Malaria not detected
- Malaria detected

0 10 20 40 60 80 Kilometers

7.4 Malaria Distribution in Thulamela Local Municipality

Thulamela Local Municipality is located in the south of Vhembe District (Figure 1.3a). It is mostly constituted of village settlements and a few growth points or urban centres, notably Thohoyandou (Figure 1.5).

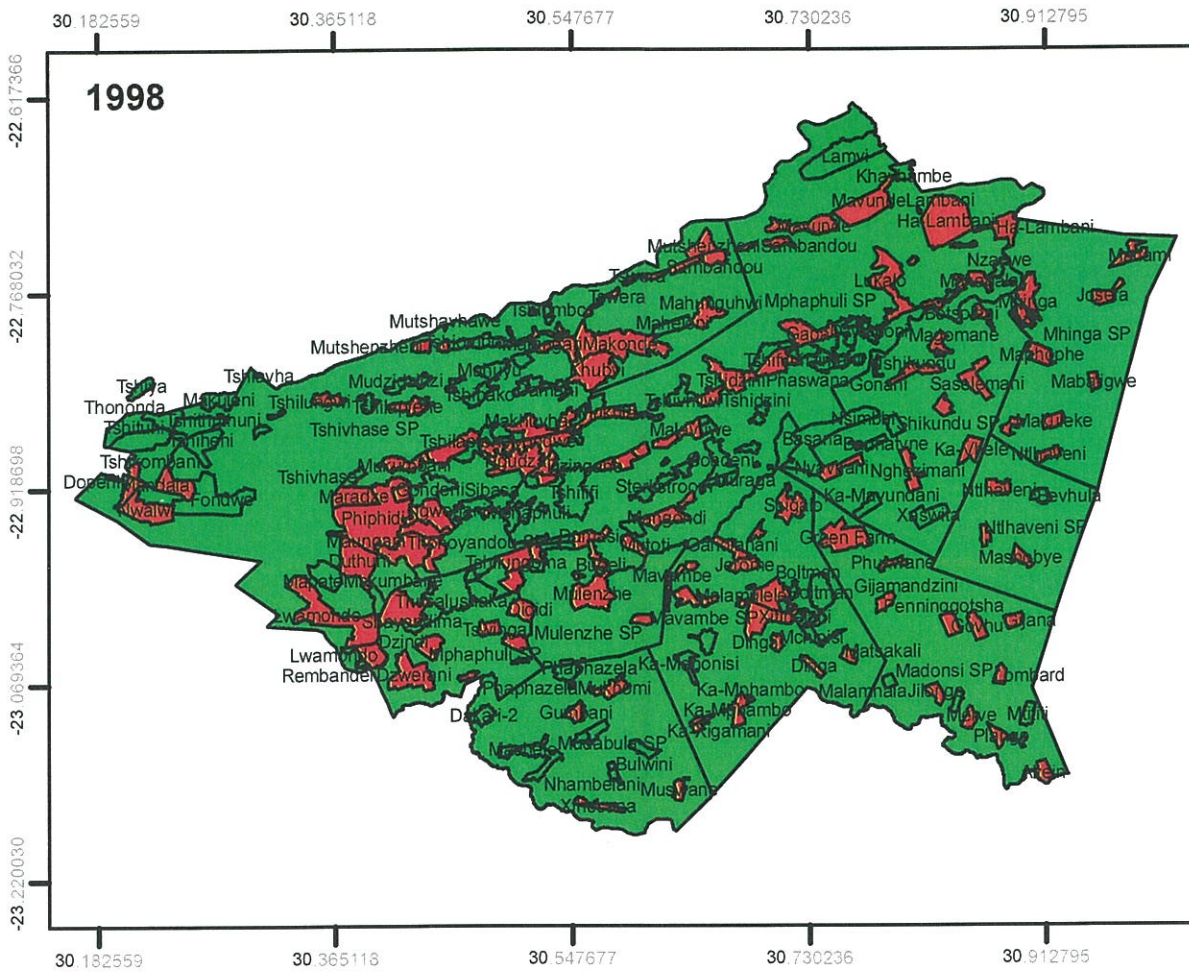
7.4.1 Spatial distribution

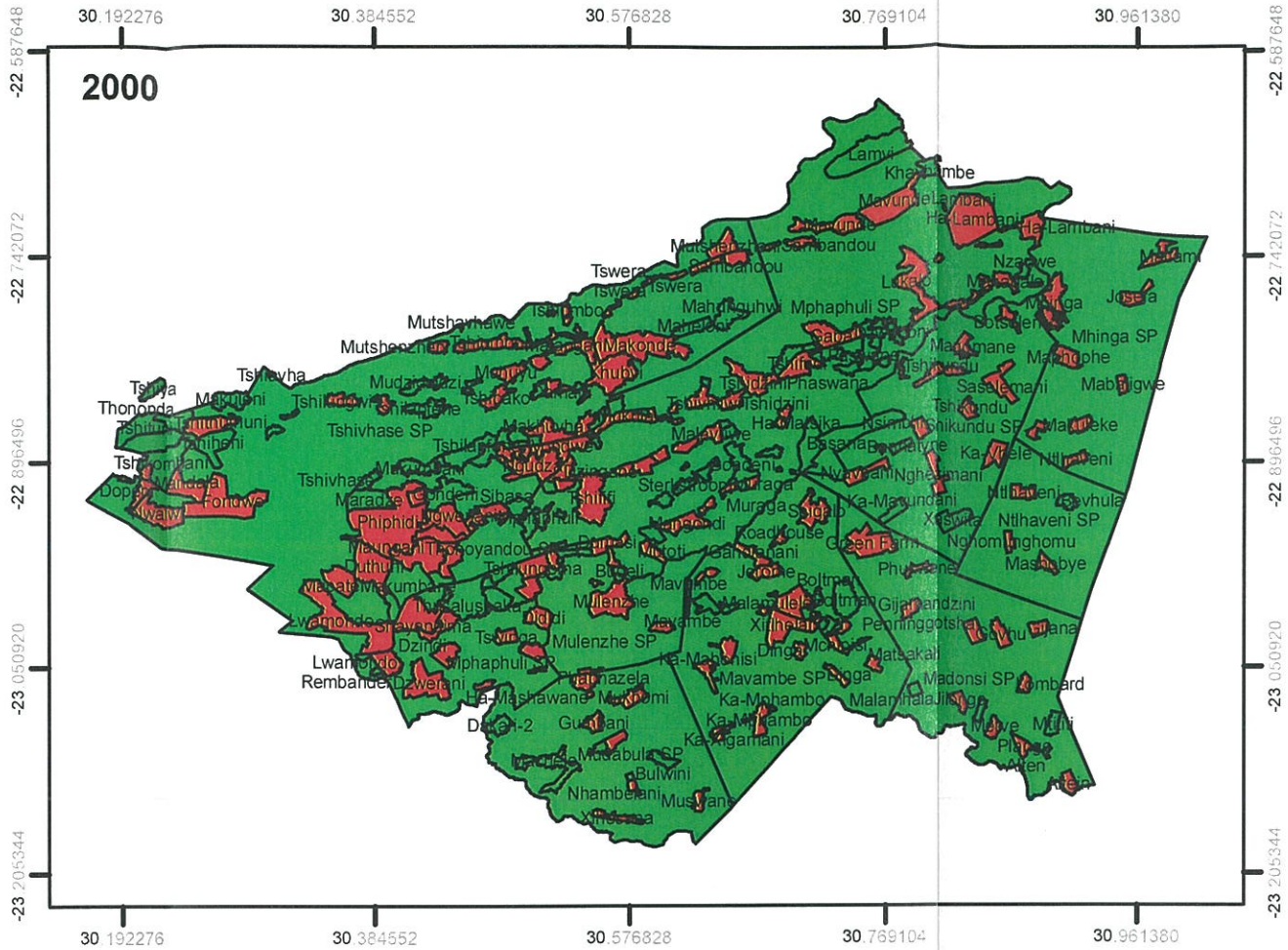
Malaria was scattered throughout Thulamela in the period 1998 to 2010 (Figures 7.26 - 7.29). In most instances, malaria cases were detected in the same settlements every year from 1998 to 2010. There were malaria cases in the northern part of Thulamela in settlements like Ha-Lambani, Mavunde, Mutshenzheni, Gaba, Lukalo and surrounding settlements. On the eastern side it occurred in Mhinga, Tshikundu, Ntlaveni, Ka-Vhele, Altein, Mashobye and surrounding areas; and in southern parts in Malamulele, Mavambe, Mukhomi, Xikosana and surrounding settlements. To the west side it occurred in Phiphidi, Lwamondo, Duthuni, Fondwe, Tshikomani, Thononda Dopeni, and the urban centres of Thohoyandou, Shayandima and surrounding areas also reported malaria during the period. The central part of Thulamela which includes Mangondi, Mutoti, Dumasi, Mukula, Khubvi, Makonde, Green Farm and surrounding settlements, also had malaria annually from 1998 to 2010.

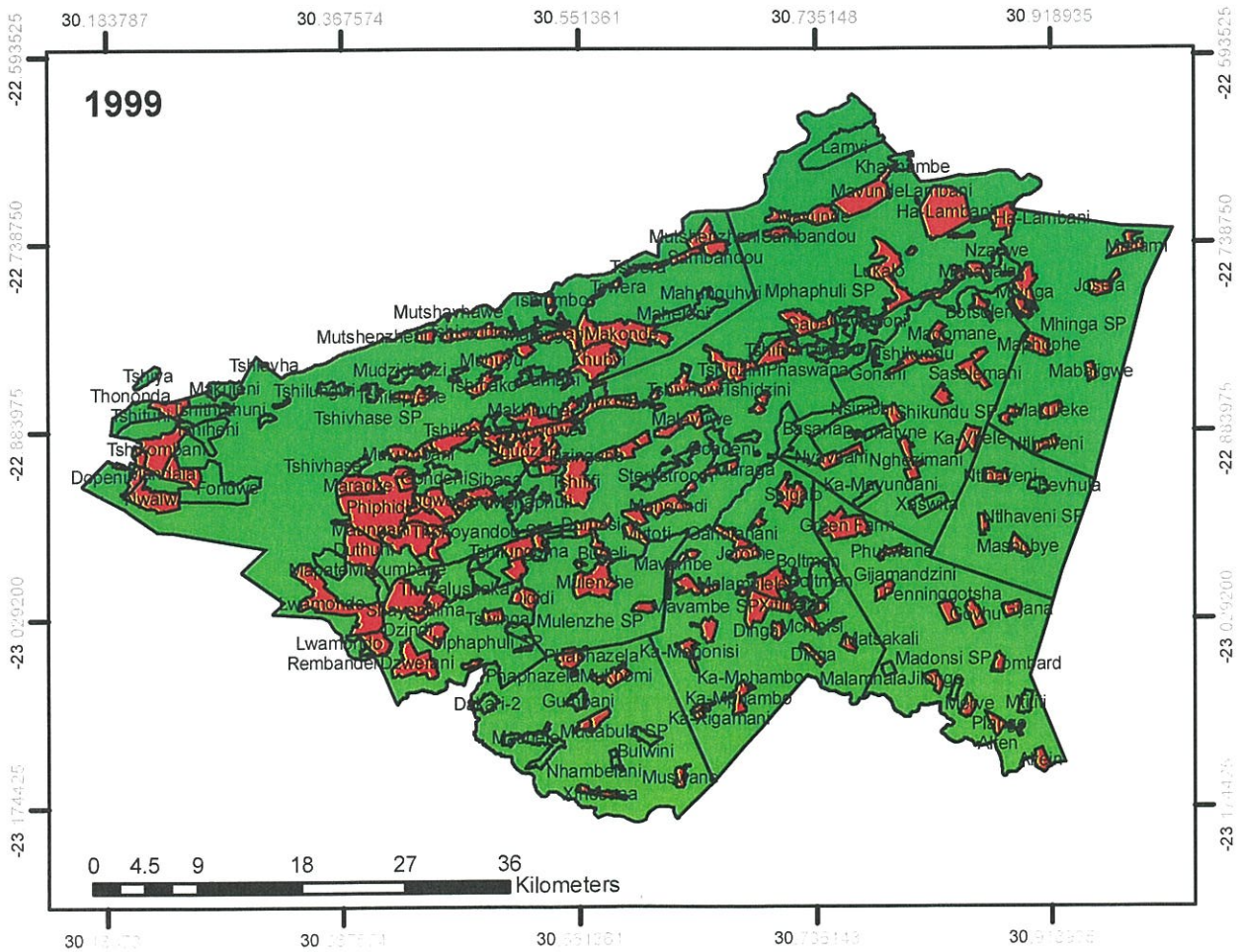
7.4.2 Thulamela Malaria Distribution Based on a Digital Elevation Model

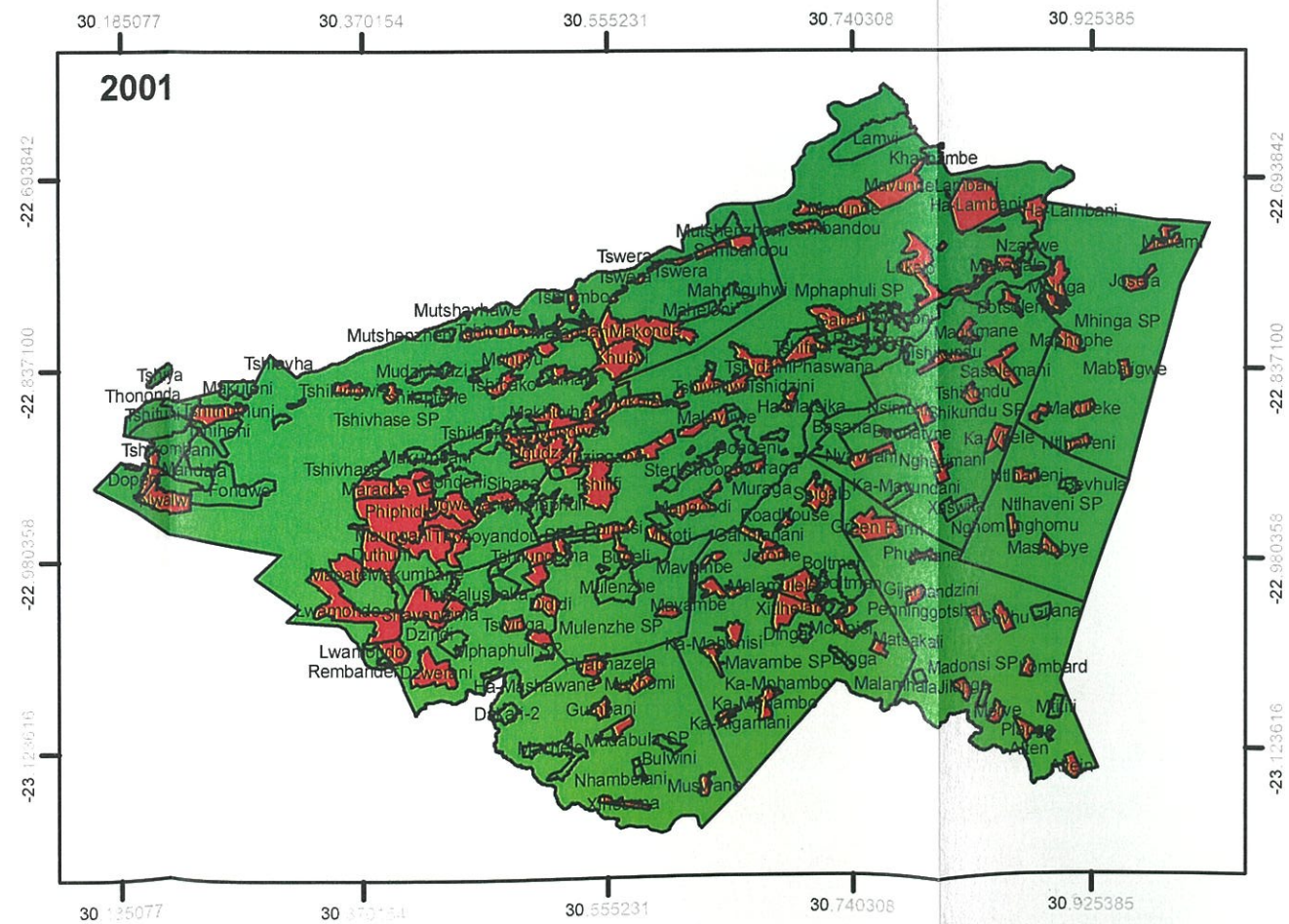
Thulamela has altitudes ranging between 385 and 1507 meters above sea level (MASL). Figures 7.30 to 7.33 show that settlements in Thulamela Local Municipality are located mostly below 673 MASL, and this is where malaria cases are predominant. The western tip of the Soutpansberg mountain range, which has valleys with altitudes between 764 and 971 MASL detects malaria frequently. Most of the areas where malaria was reported have water bodies nearby. There were belts of malaria cases on either side of the Soutpansberg mountain range as it levels towards the Limpopo River valley, between 764 and 971 MASL. Malaria cases in this area occurred in locations that are mostly below 764 MASL.

Figure 7.26: **Spatial Distribution of Malaria in Thulamela Local Municipality (1998 to 2001)**









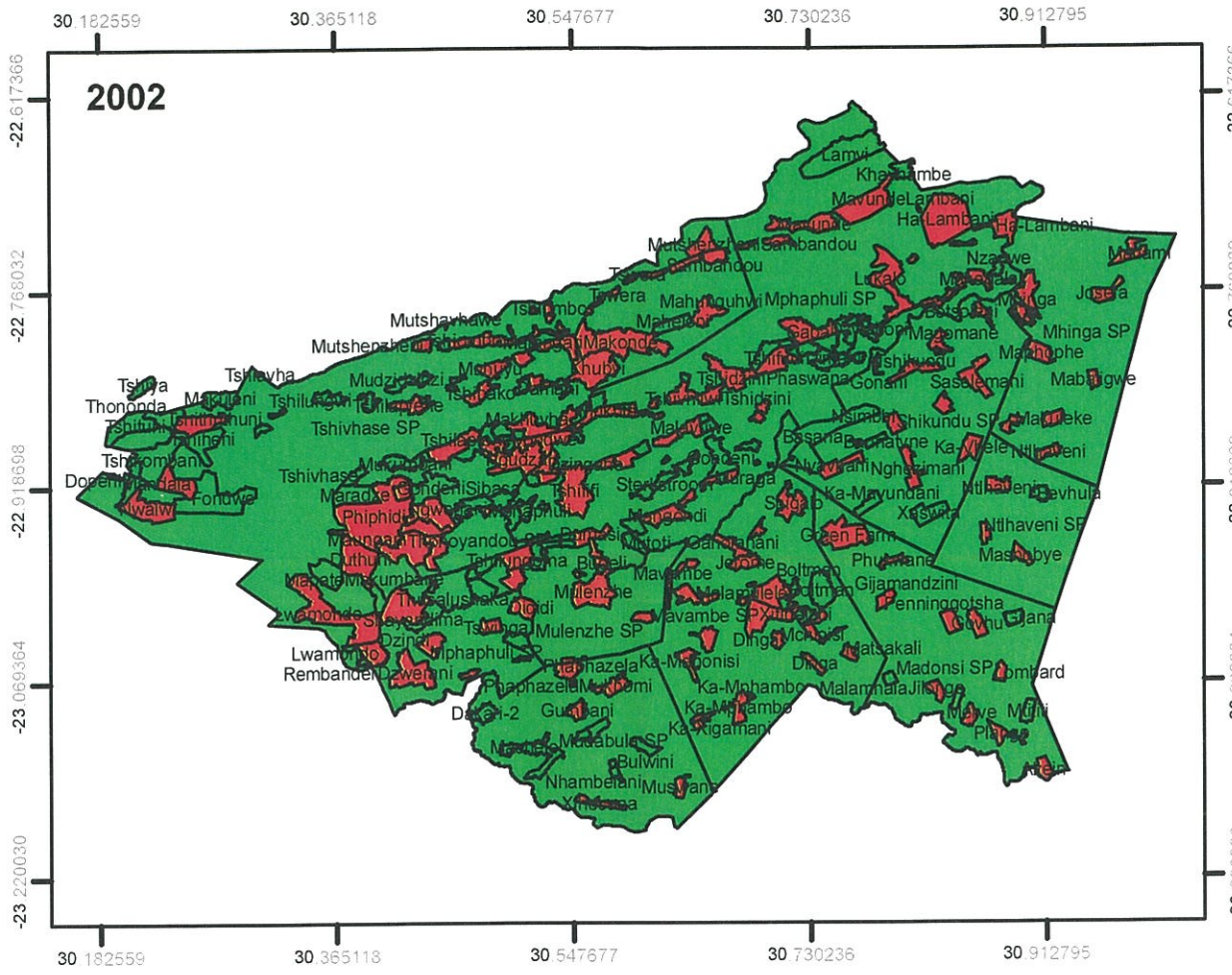
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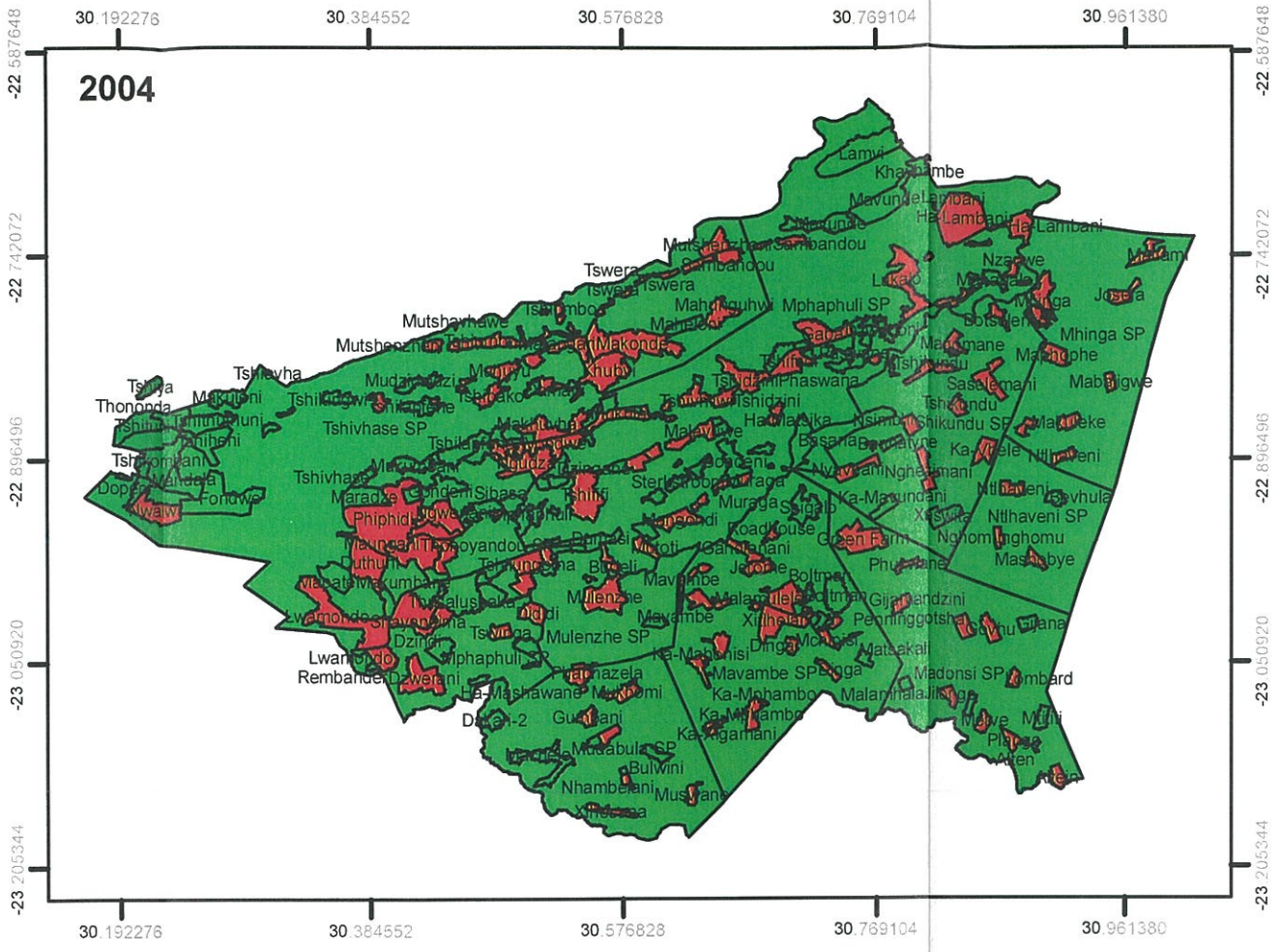
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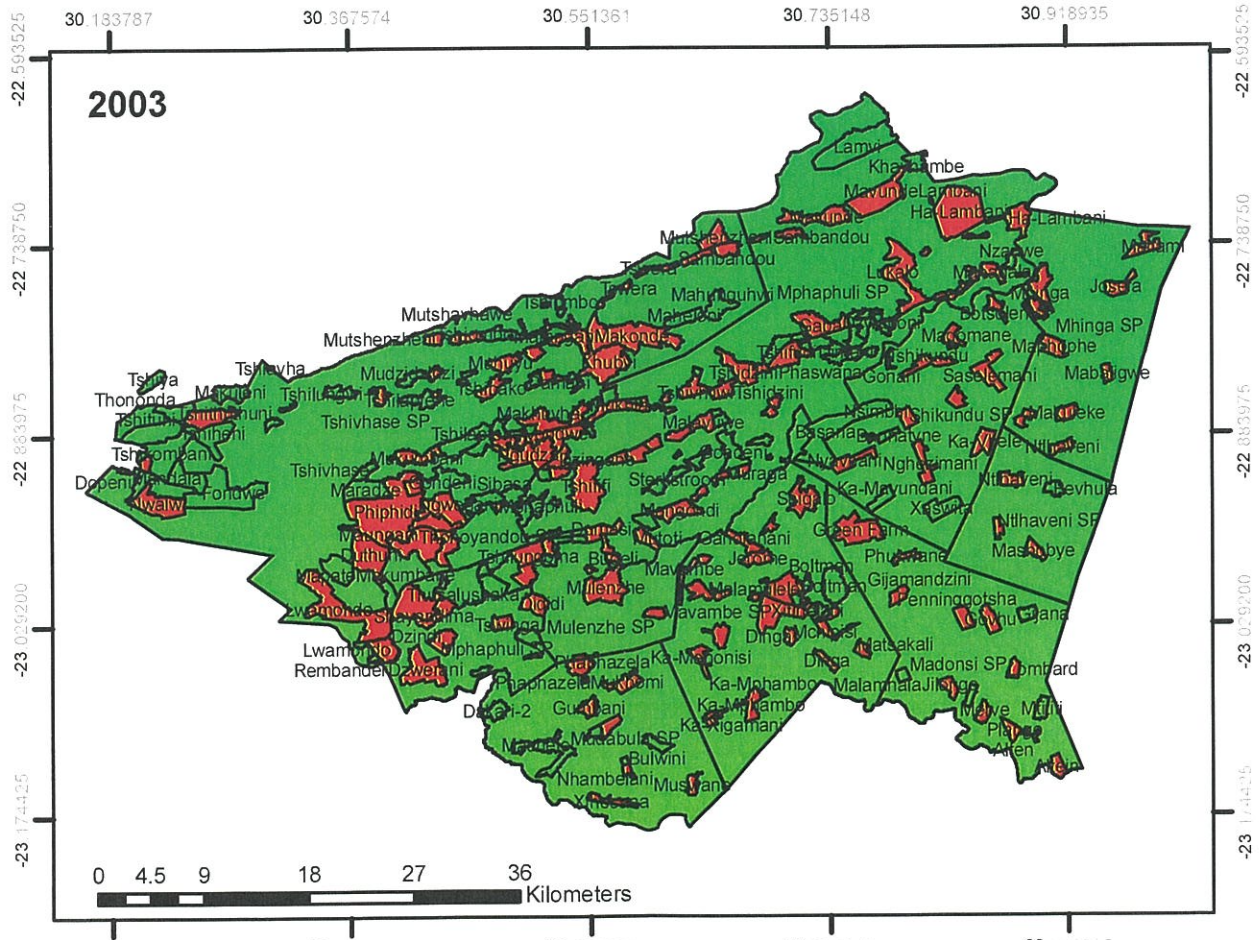
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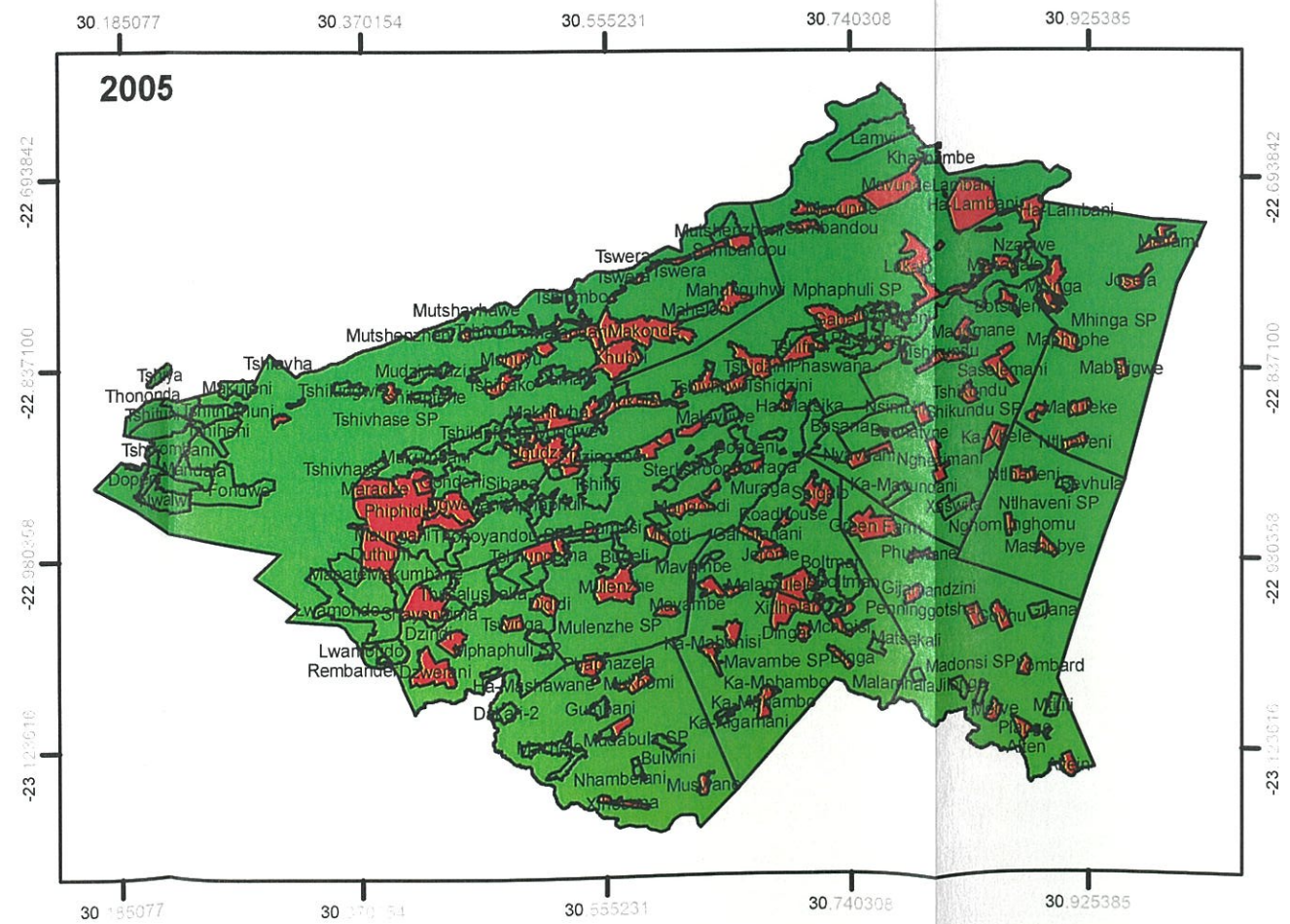
- Malaria not detected
- Malaria detected

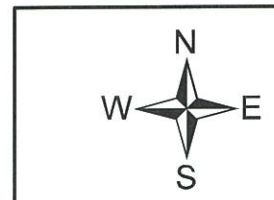
Figure 7.27: **Spatial Distribution of Malaria in Thulamela Local Municipality (2002 to 2005)**









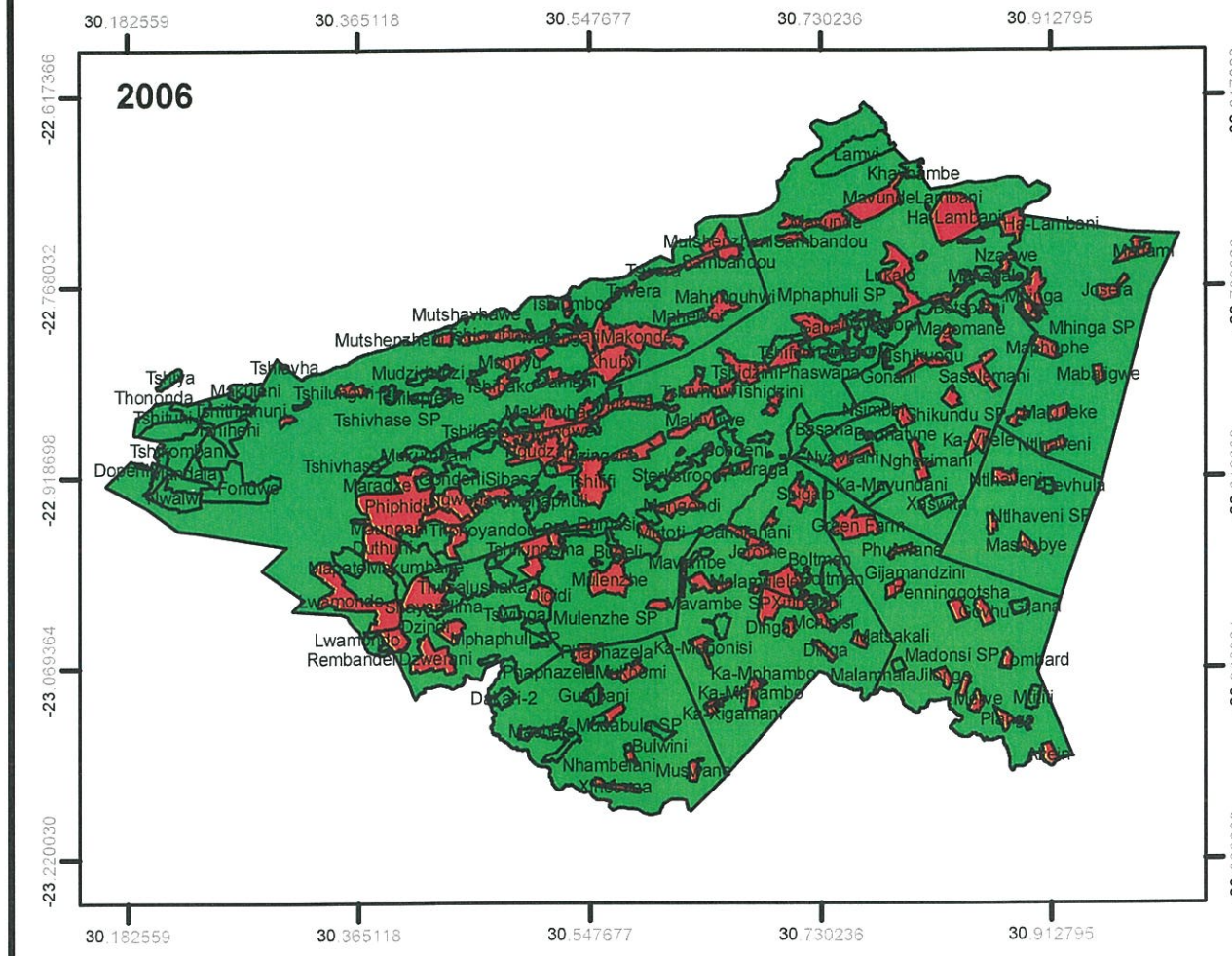


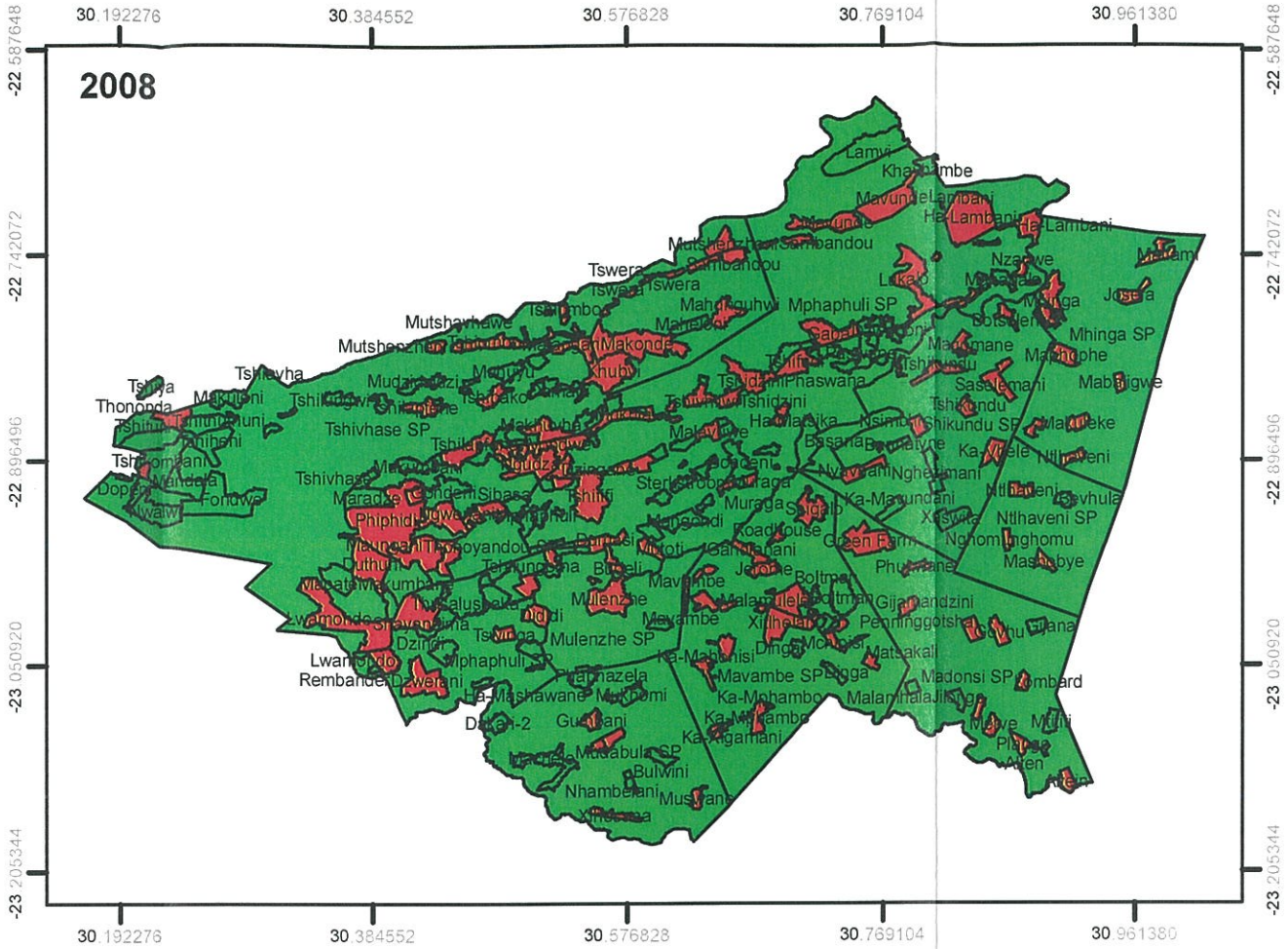
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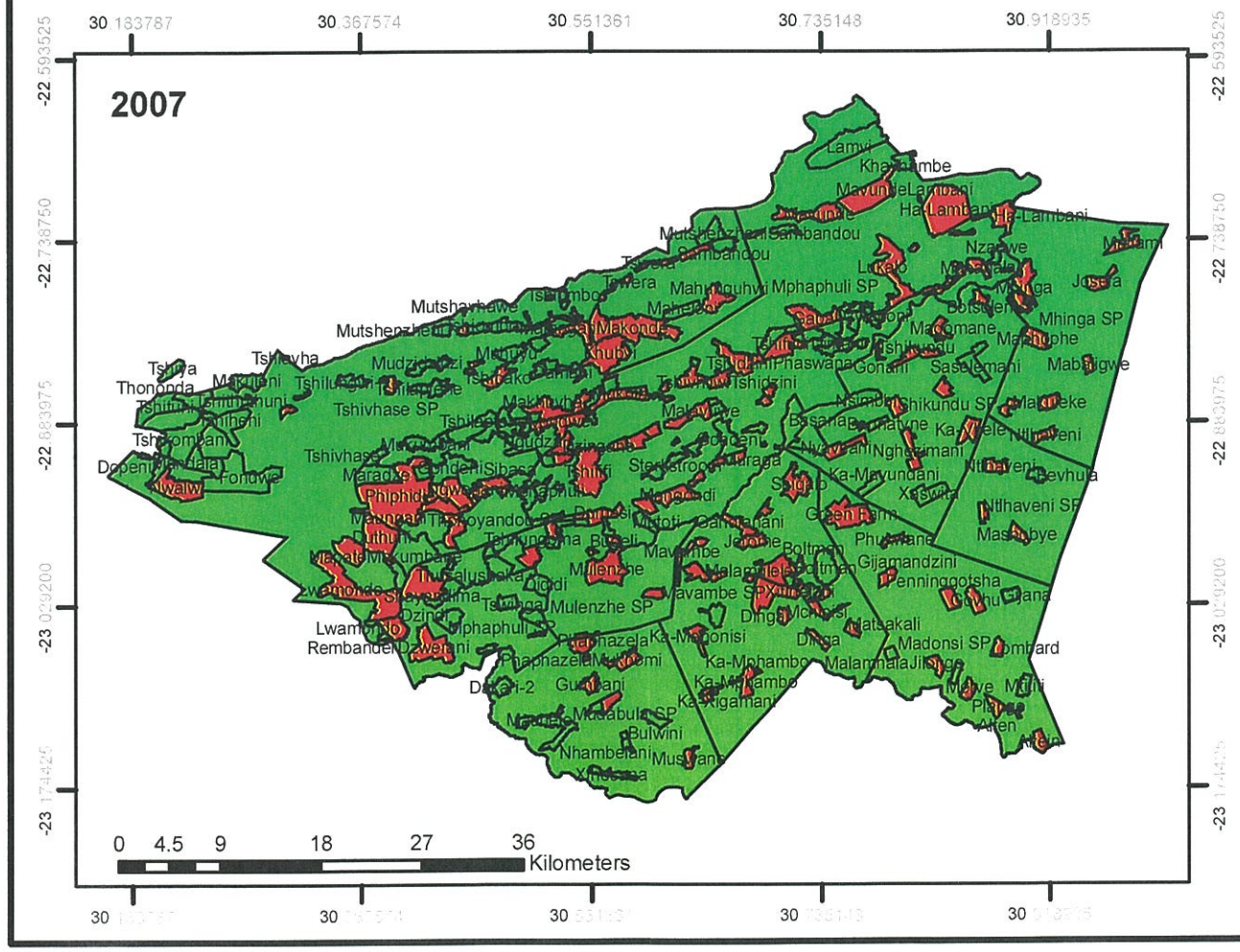
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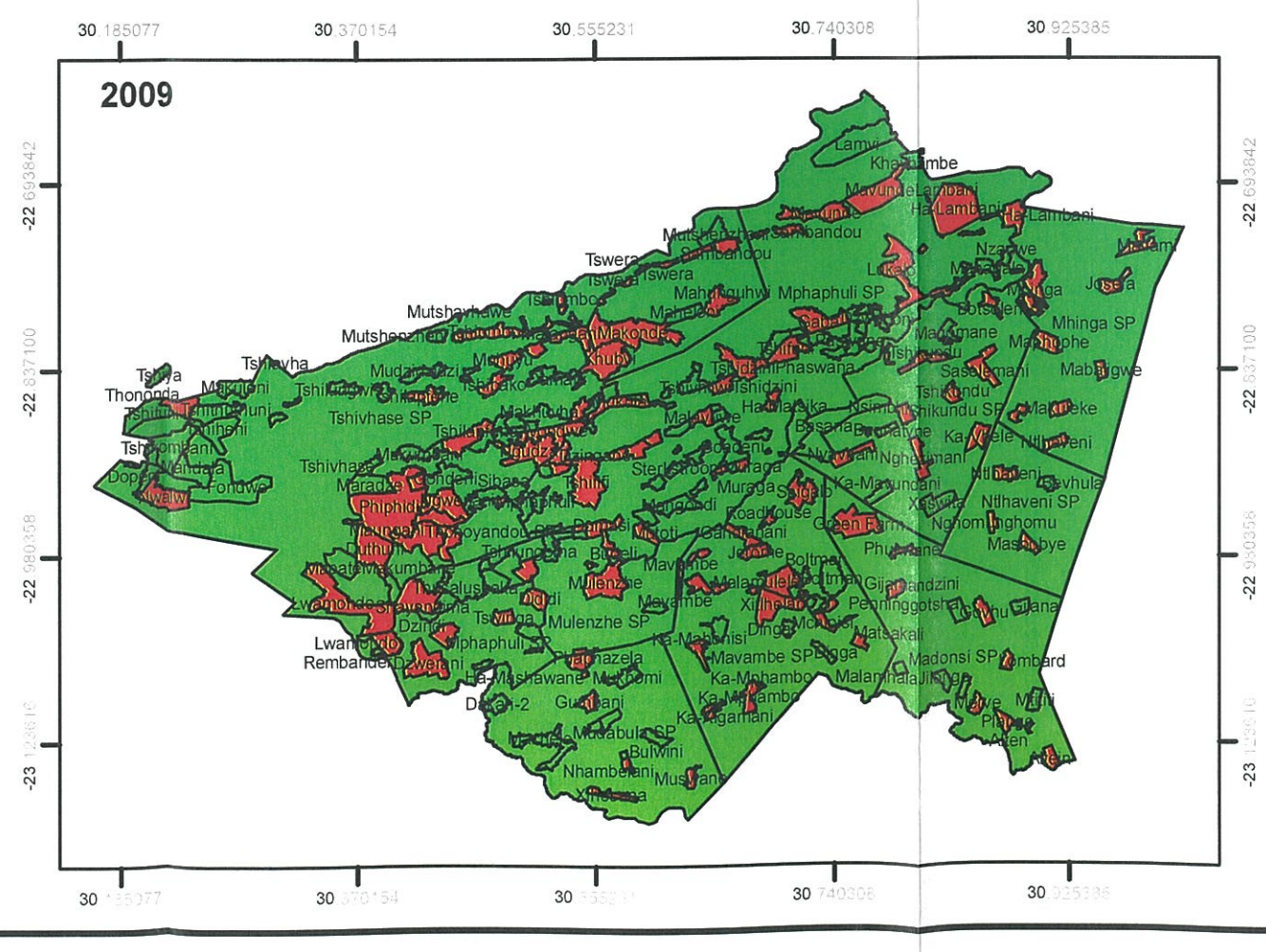
- Malaria not detected
- Malaria detected

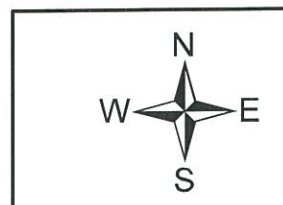
Figure 7.28: **Spatial Distribution of Malaria in Thulamela Local Municipality (2006 to 2009)**









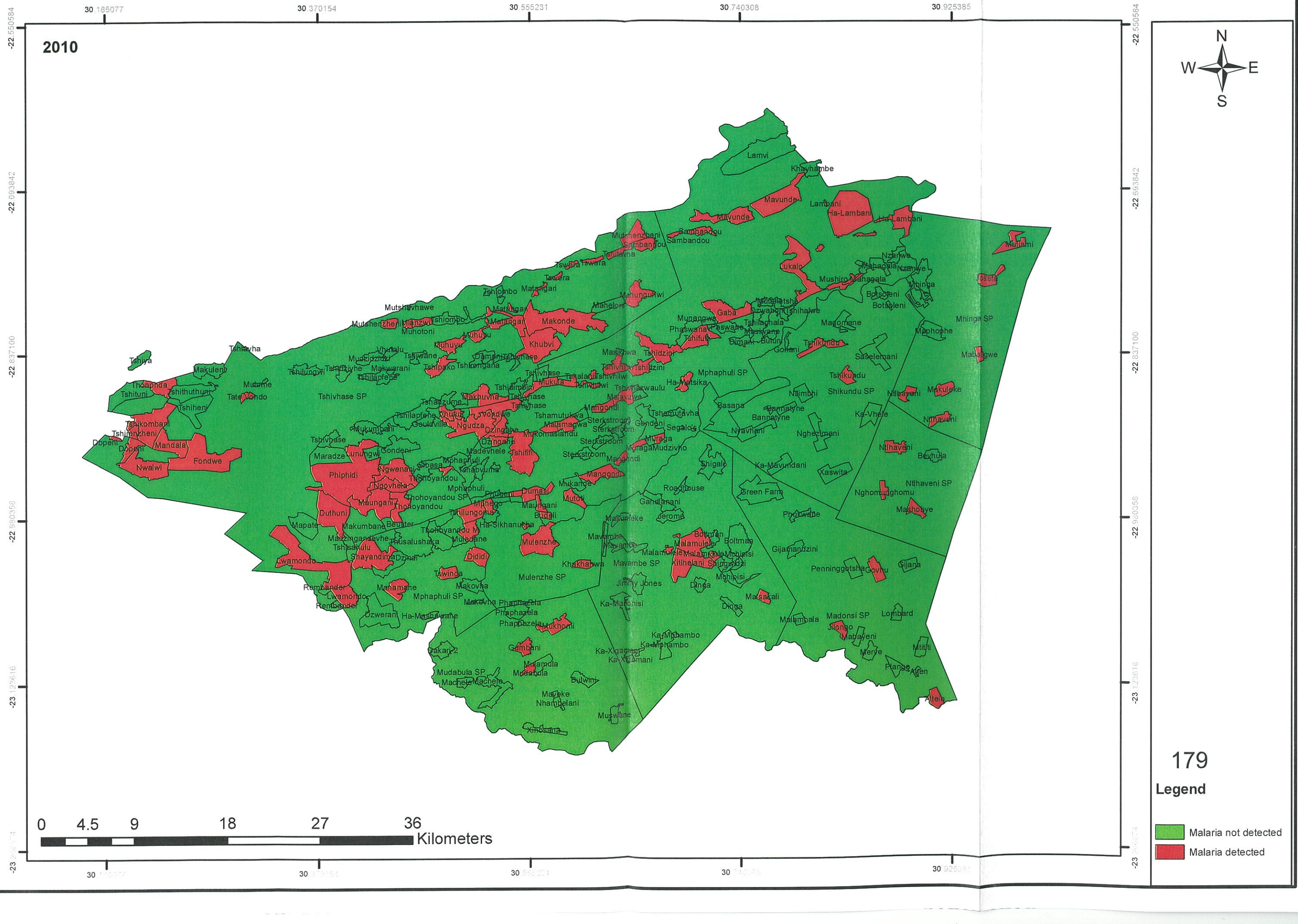


178

Legend

- Malaria not detected
- Malaria detected

Figure 7.29: **Spatial Distribution of Malaria in Thulamela Local Municipality (2010)**


2010
30.185077
30.370154
30.555231
30.740308
30.925385
-22.550584
-22.693842
-22.837100
-22.980358
-23.123616
-23.266874
N
W
E
S
Lamvi
Khayhambe
Mavunde
Lambani
Ha-Lambani
Sambandou
Tshulavha
Tswera
Matangari
Maheloni
Mahungululwi
Mutshavhawe
Tshiombo
Makonde
Muhotoni
Khubvi
Tshitavha
Tshiya
Makuleni
Mudzidzidzi
Tshilungwi
Tshilapfene
Mutale
Thononda
Tshituni
Tshithuthuni
Tshiheni
Tate Vondo
Tshivhase SP
Tshikombani
Tshienzheni
Dopeni
Mandala
Fondwe
Nwalwi
Maradze
Ngwenani
Phiphidi
Ngovhela
Thohoyandou
Thohoyandou SP
Maungani
Duthuni
Mapate
Makumbane
Beuster
Tshisakulu
Shayandima
Dzindi
Lwamondo
Rembander
Dzwerani
Ha-Mashavhane
Mahamane
Mphaphuli SP
Tshivhase
Tshilimbini
Mukula
Tshiungani
Tshaulu
Makuvha
Tshaguma
Tshilapfene
Vhudule
Geuldville
Ngudza
Mukumbani
Dzinganie
Mphaphuli
Thohoyandou
Mukaneke
Mutoti
Dumasi
Maungani
Bungeli
Tshilungoma
Ha-Sikhanuna
Mulenzhe
Mulenzhe SP
Tshinwa
Makuvha Phaphazela
Phaphazela
Mukhomi
Gambani
Dakari 2
Mudabula SP
Mudabula
Machele
Bulwini
Mavheke
Nhambelani
Muswane
Xihosane
Ka-Maphisi
Ka-Mphambo
Ka-Xigamani
Ka-Xigamani
Mavambe
Mavambe SP
Khakhalwa
Jimmy Jones
Dinga
Masakali
Mavunde
Mavunde
Sambandou
Mutshenzheni
Tshulavha
Tswera
Lukalo
Mushiro Mahasala
Botsoleni
Gaba
Ndzwabon Tshihalwe
Tshilaphala
Phaswana
Tshifudi
Dumani Budeli
Gohani
Tshikundu
Masiphwa
Tshidzini
Tshivhilwi
Tshidzini
Mphaphuli SP
Ha-Matsika
Tshaswaulu
Malavuwa
Mangondi
Tshamutukwa
Malamagwa
Sterkstroom
Mukomasandu
Sterkstroom
Madevhele
Tshifiri
Sterkstroom
Mangondi
Mangondi
Mukaneke
Roadhouse
Gandlanani
Jeroma
Makuneke
Mavambe
Malamulele
Malamulele
Xitlhelani Shigwadi
Boltman
Boltman
Malamulele
Vhobirisi
Mphinisi
Gijamandzini
Penninggotsha
Govhu
Gijana
Shigalo
Basana
Bannatyne
Bannatyne
Nravhani
Nghezimani
Ka-Mavundani
Kaswita
Green Farm
Pfukwane
Ka-Vhele
Ntlhaveni
Nghomunghomu
Ntlhaveni SP
Mashobye
Beyhula
Ntlharoni
Makuleke
Naimbhi
Shikundu SP
Mhinga SP
Maphophe
Mabalingwe
Saselemani
Mahonisi
Dinga
Malamhala
Madonsi SP
Jilongo
Lombard
Mabayeni
Merye
Mutuli
Plange
Alten
Atteiu
Mhinga
Matlami
Nzanwe
Nzanwe
Tshaulu
Tshivhase
Tshivhase
Tshivhase

Thulamela Local Municipality has a lot of malaria patches scattered throughout the whole municipality. The settlements further on the eastern side near the border between the municipality and the Kruger National Park are the most prone to malaria, with some having recorded over 200 cases between 1998 and 2010. These included villages like Ha-Lambani, Mhinga, Mabililigwe, Maphophe, Makuleke, Ntlavheni, Mashobye and the immediate surrounds, as well as farther south east in Altein. In the north there were pockets of malaria in Makonde and Khubvi, which reported over 200 cases during the period under study.

Other hotspot areas included Tshikundu, Madonsi in the east, Thohoyandou in the western side and Mpambo in the south east which also recorded over 200 cases between 1998 and 2010. The villages of Muledane, Mavambe, Lwamondo, Mulenzhe and Xigamani in the south western part recorded between 50 and 100 cases. On the northern side villages like Lukalo and Sambandou recorded between 50 and 100 cases in the period 1998-2010.

There are several streams and rivers within Thulamela (Figure 1.5) which could have contributed to the high number of malaria cases. The stream and rivers then provided mosquito breeding habitats, thereby contributing to the availability of a number of breeding areas for the mosquitoes. However, further discussion on the availability of breeding areas is beyond the scope of the current study.

7.5 Malaria Distribution in Mutale Local Municipality

Mutale Local Municipality is mostly constituted of villages. The very few urban centres include Mutele, Tshandama, Nwanedzi and Tshikondeni mine. The municipality is located mostly at low altitudes and has a lot of potential mosquito breeding areas, as was observed on a digital elevation model (DEM).

Mutale Local Municipality had no statistically significant relationship between the prevalence of malaria and rainfall (Table 5.4). Rainfall was the only variable that could be statistically tested in this study.

Figure 7.30

Spatial distribution of Malaria in relation to Altitude in Thulamela Municipality (1998 to 2001)

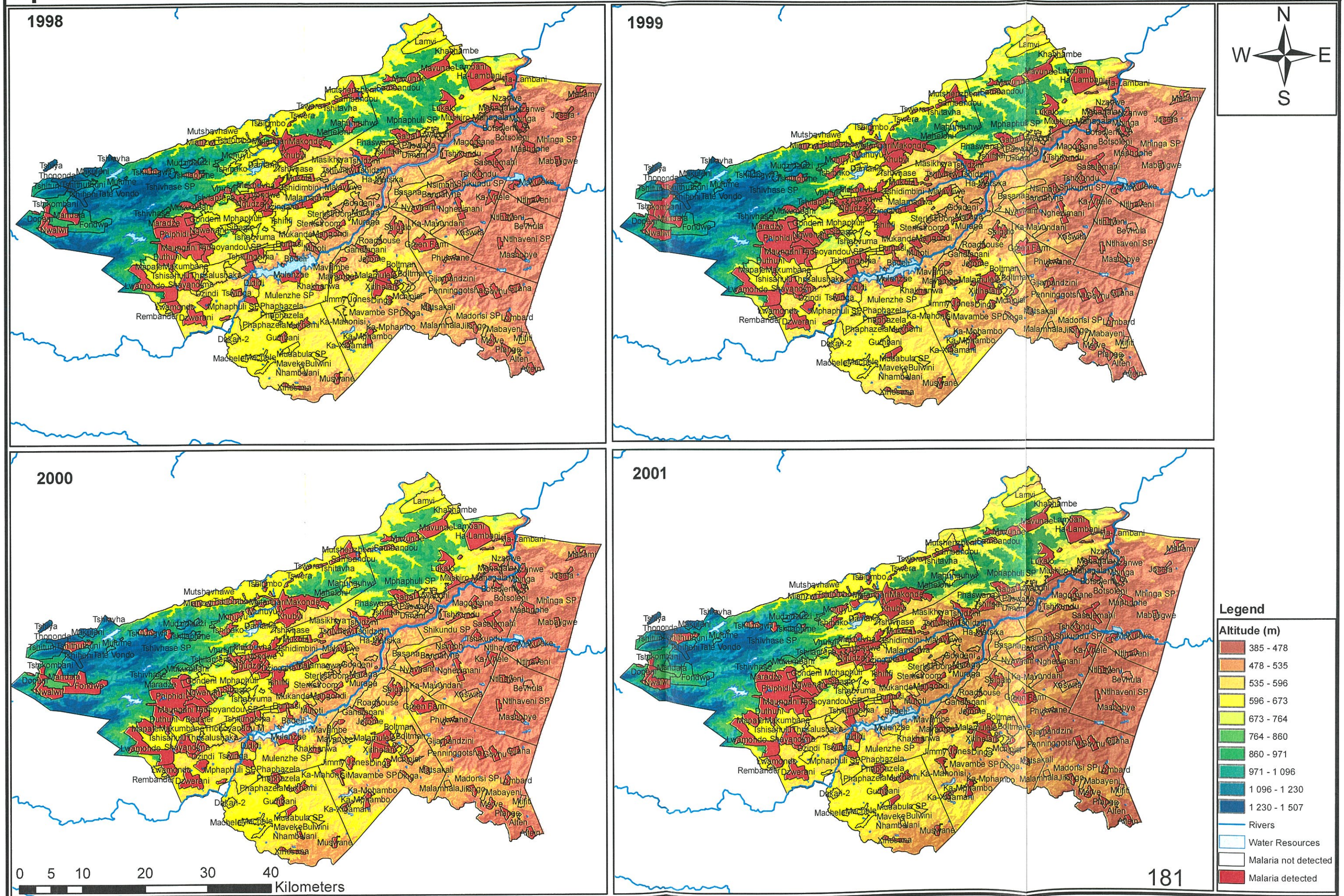


Figure 7.31

Spatial distribution of Malaria in relation to Altitude in Thulamela Municipality (2002 to 2005)

2002

2003

2004

2005

N
W E
S

0 5 10 20 30 40
Kilometers

Legend

Altitude (m)
- 385 - 478
- 478 - 535
- 535 - 596
- 596 - 673
- 673 - 764
- 764 - 860
- 860 - 971
- 971 - 1 096
- 1 096 - 1 230
- 1 230 - 1 507

Rivers
Water Resources
Malaria not detected
Malaria detected

Figure 7.32

Spatial distribution of Malaria in relation to Altitude in Thulamela Municipality (2006 to 2009)

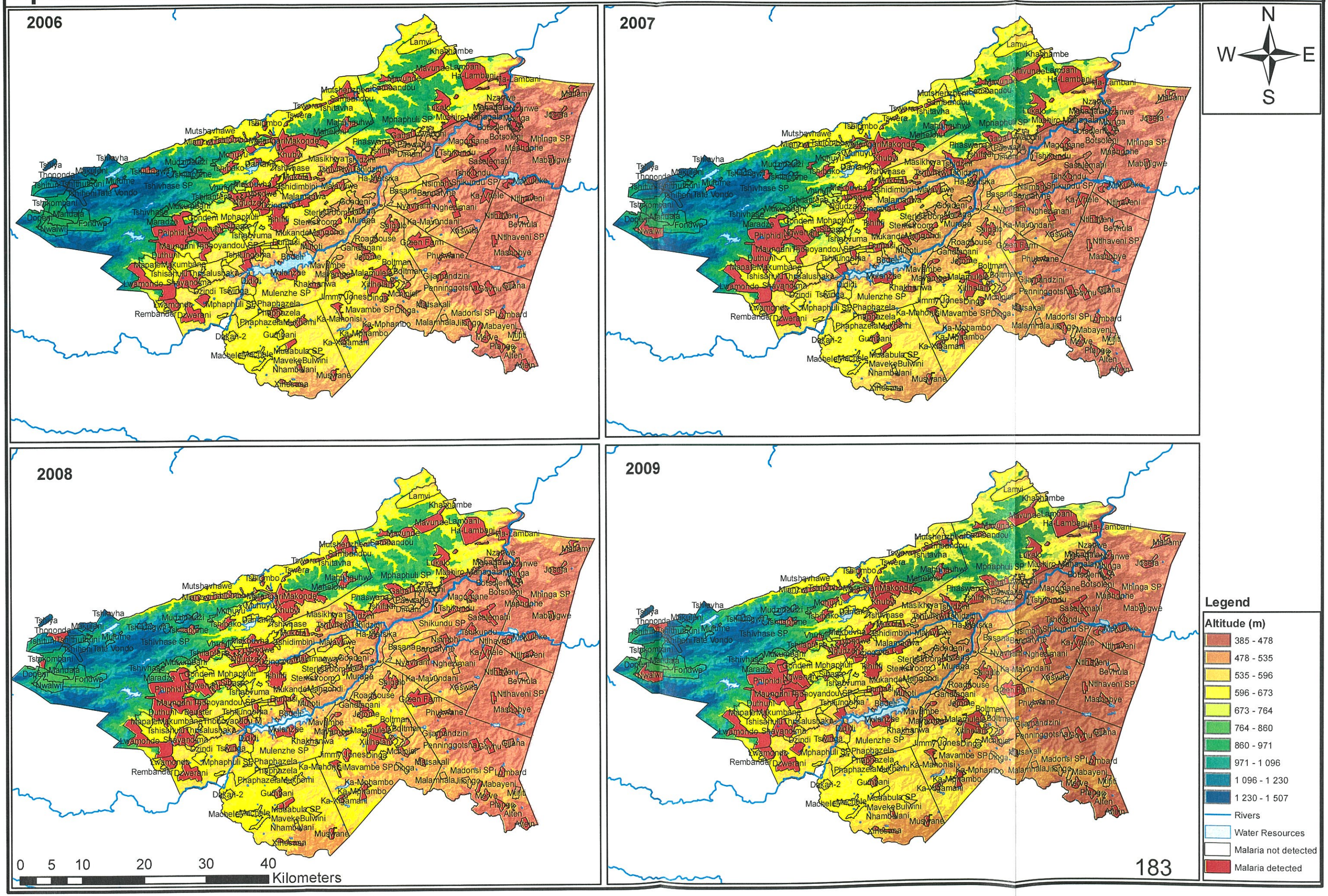
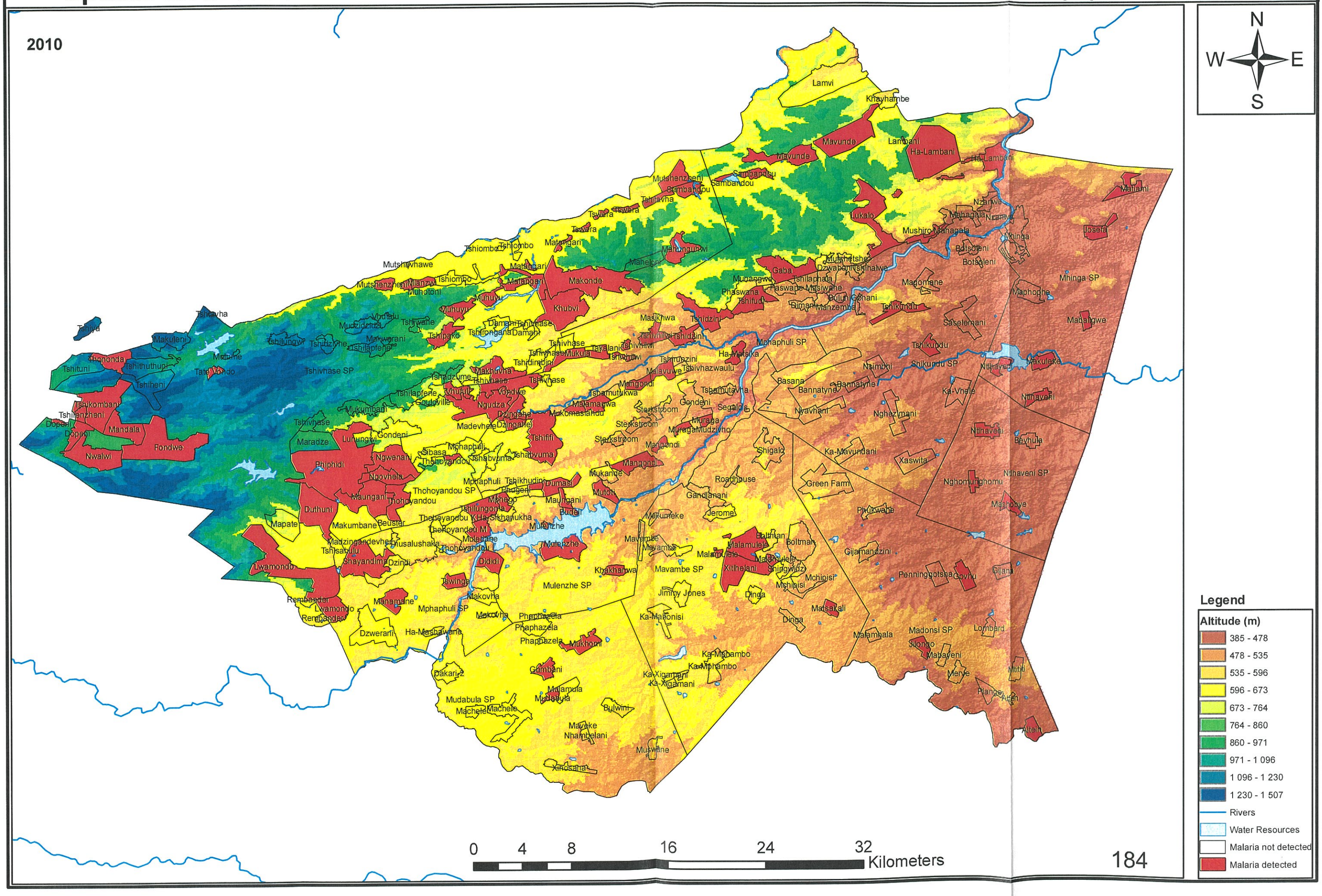


Figure 7.33

Spatial distribution of Malaria in relation to Altitude in Thulamela Municipality (2010)



7.5.1 Spatial distribution

The malaria maps in Figures 7.34 - 7.37 show a malaria spatial distribution pattern similar to that in Thulamela Local Municipality, with malaria cases being scattered throughout the local municipality. The villages in central Mutale which reported malaria in the period 1998-2010 included Mulaluwe, Tshipise, Shakadza, Mbodi, Dambale, Domboli and other isolated surrounding villages.

The malaria cases that were reported in the northern part of Mutale Local Municipality occurred in Gumbu, Sigonde, Dovho, Tshikuyu, Mutele, Bende Mutale and Bale. In the eastern part the settlements included, Guyuni, Lamvi, Hamakuya, Domboni, Thengwe, Tshamndama, Lukau, Vuvha and Maheni. In the South, malaria cases occurred in Gogogo, Khakhu, Gombani, Fefe and surrounding settlements. On the western side of the municipality, the settlements that were affected by malaria every year from 1998 to 2010 included Nwanedzi, Folovhodwe, Dipeni, Tshiungani and isolated settlements surrounding these highly prone areas.

Of particular note is the belt of settlements which border with Thulamela on the southern part of the municipality where malaria was detected. This belt or cluster, includes settlements like Tshanzhe, Mangaya, Makwilidza, Maheni, Thengwe, Tshihlavulu, Tshandama, Lukau, Madzivhanani, Mulodi, Vuvha, Pile and Tshapasha. Malaria cases were being reported almost every year along this belt, which makes the area a malaria risk. It was, therefore, important to detect what altitude these settlements are positioned in order to establish whether altitude had an influence.

7.5.2 Mutale Malaria Distribution Based on a Digital Elevation Model

Mutale has the lowest altitudes in Vhembe District, which range between 249 and 1547 meters above sea level (MASL). The higher ground at 1547 MASL occurs on the south western side, which is part of the Soutpansberg mountain range. The municipality has three distinct altitude zones: the north eastern part with altitude ranges between 249 and 453 MASL, the central part which ranges between 453 and 728 MASL and the south western part with altitude ranges between 728 and 1547 MASL.

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Figure 7.34: **Spatial Distribution of Malaria in Mutale Local Municipality (1998 to 2001)**

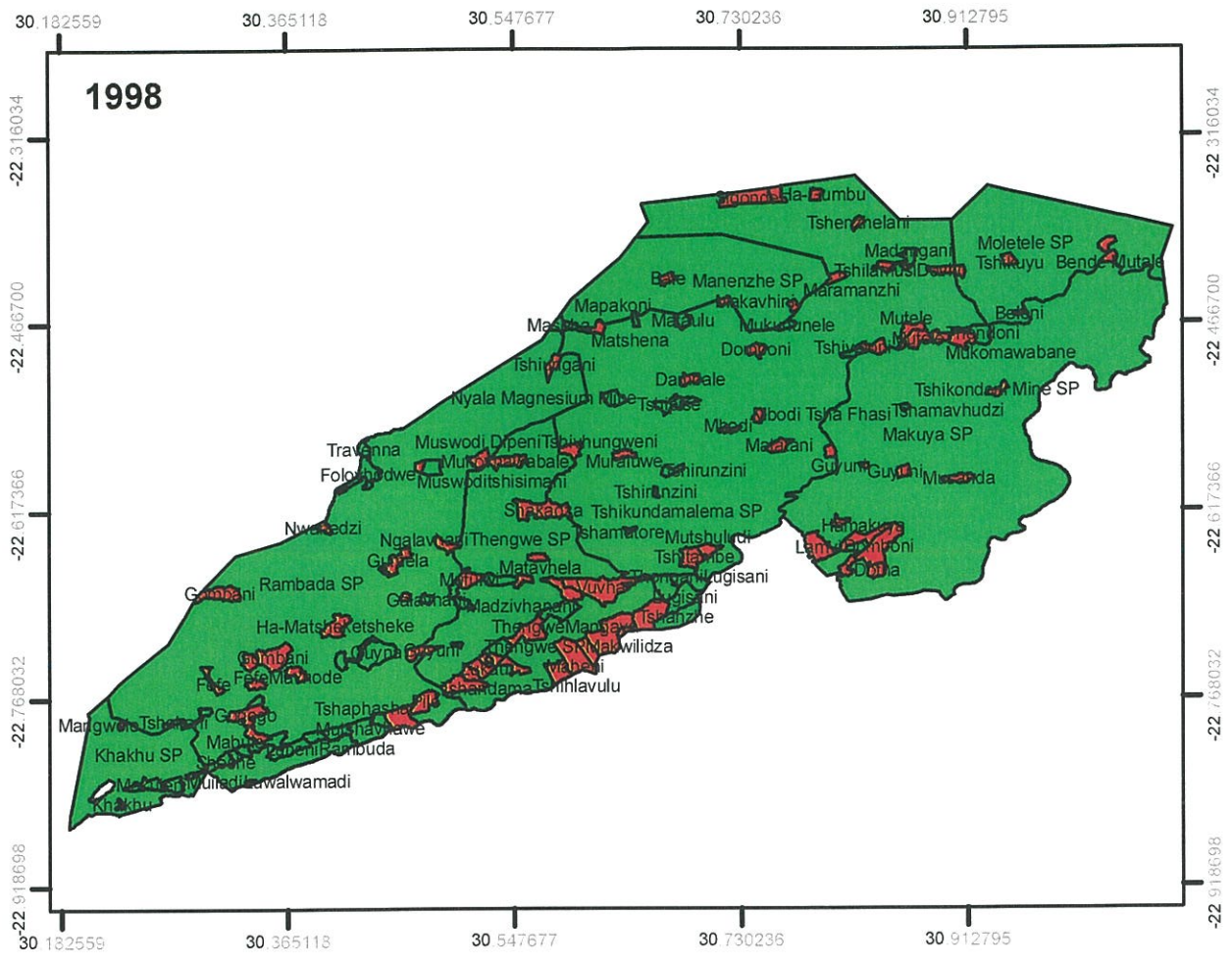
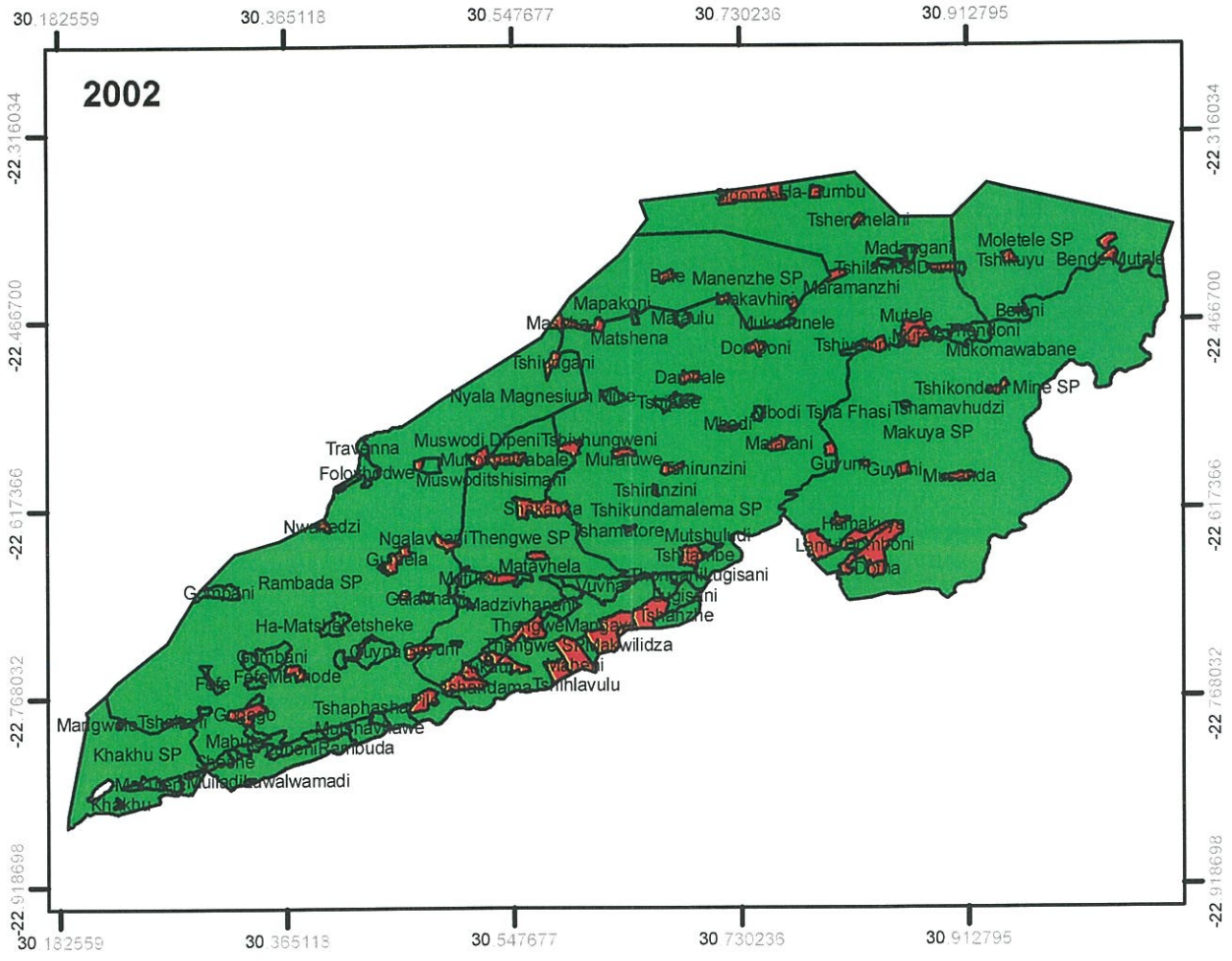
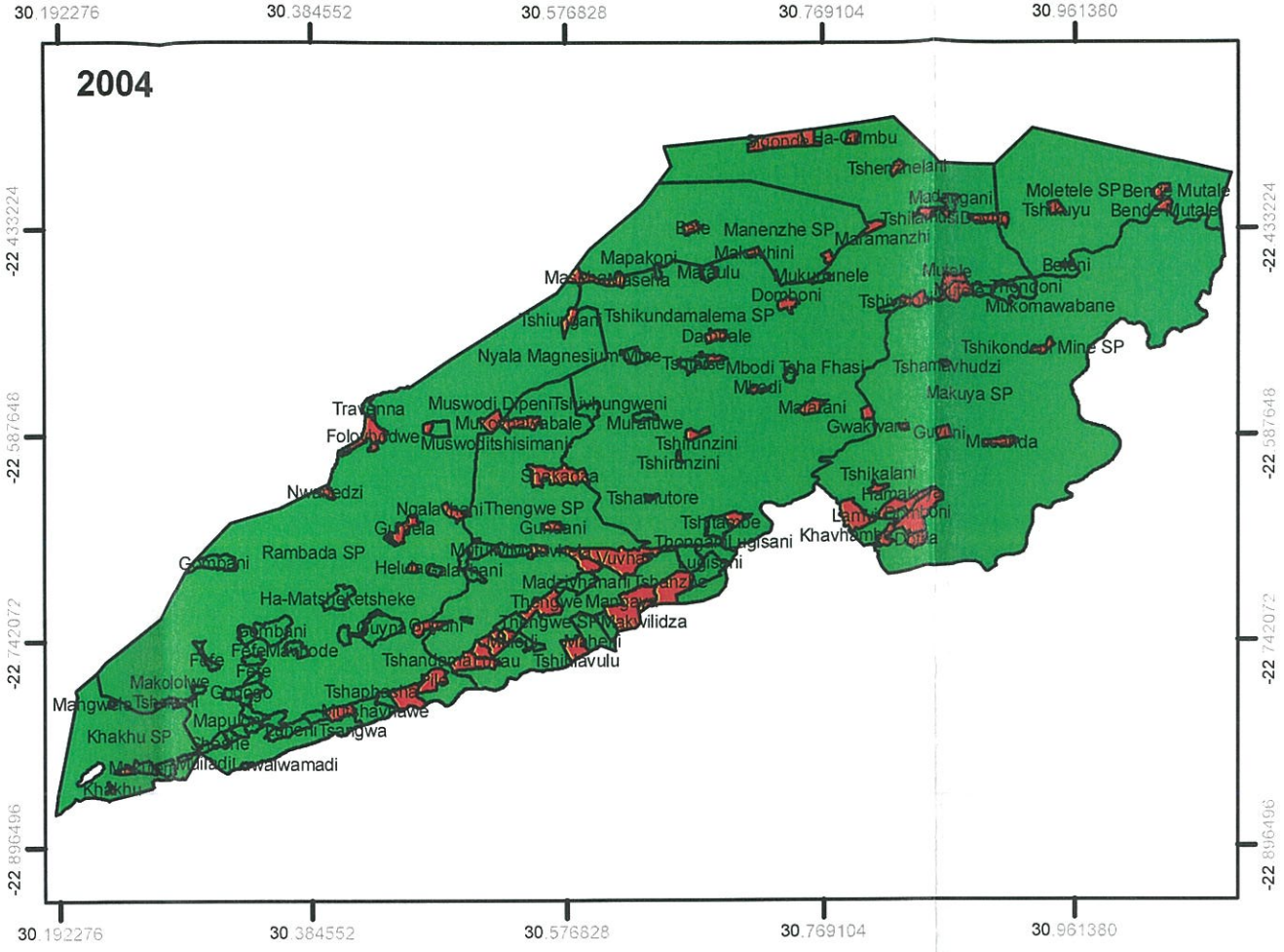
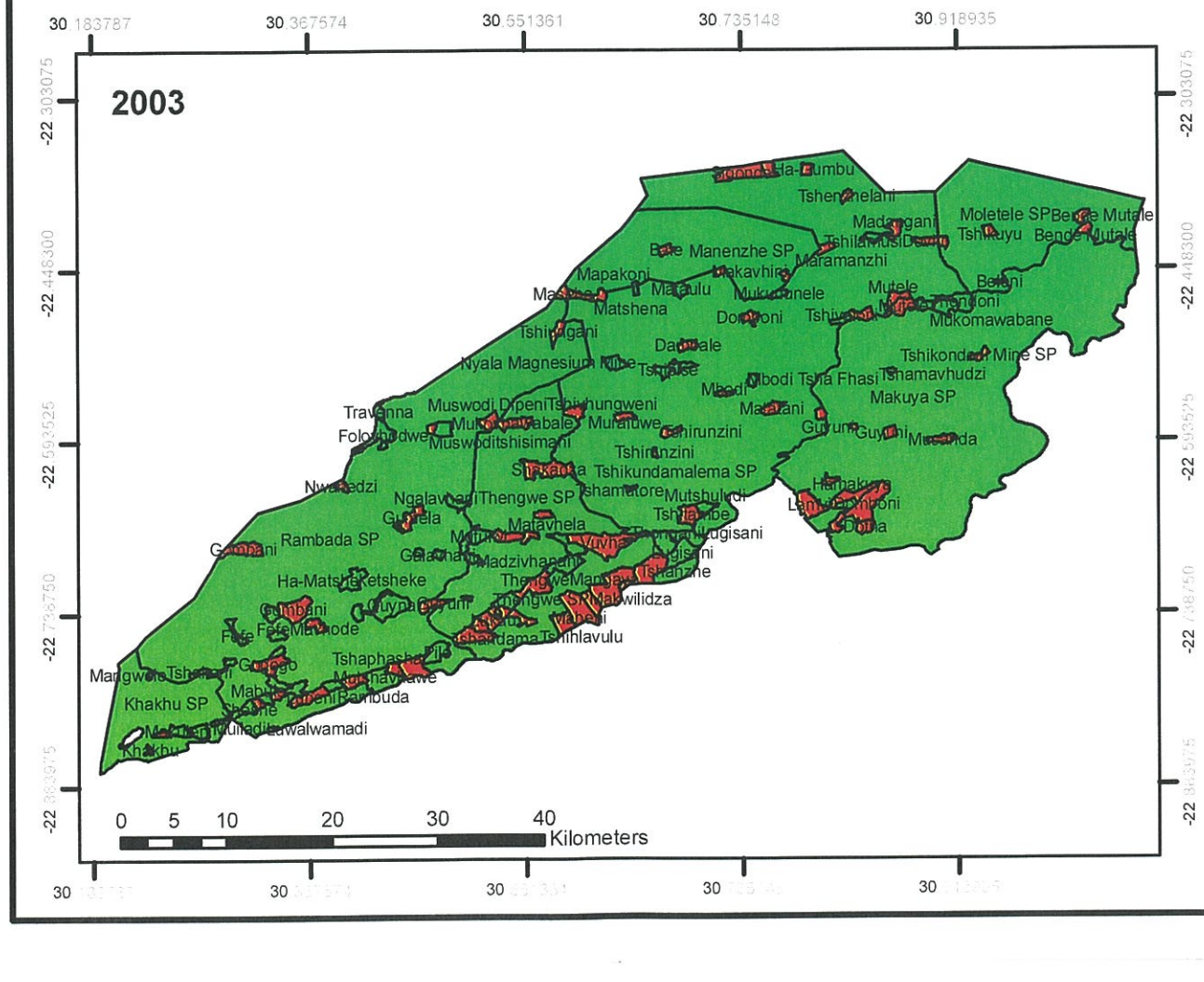


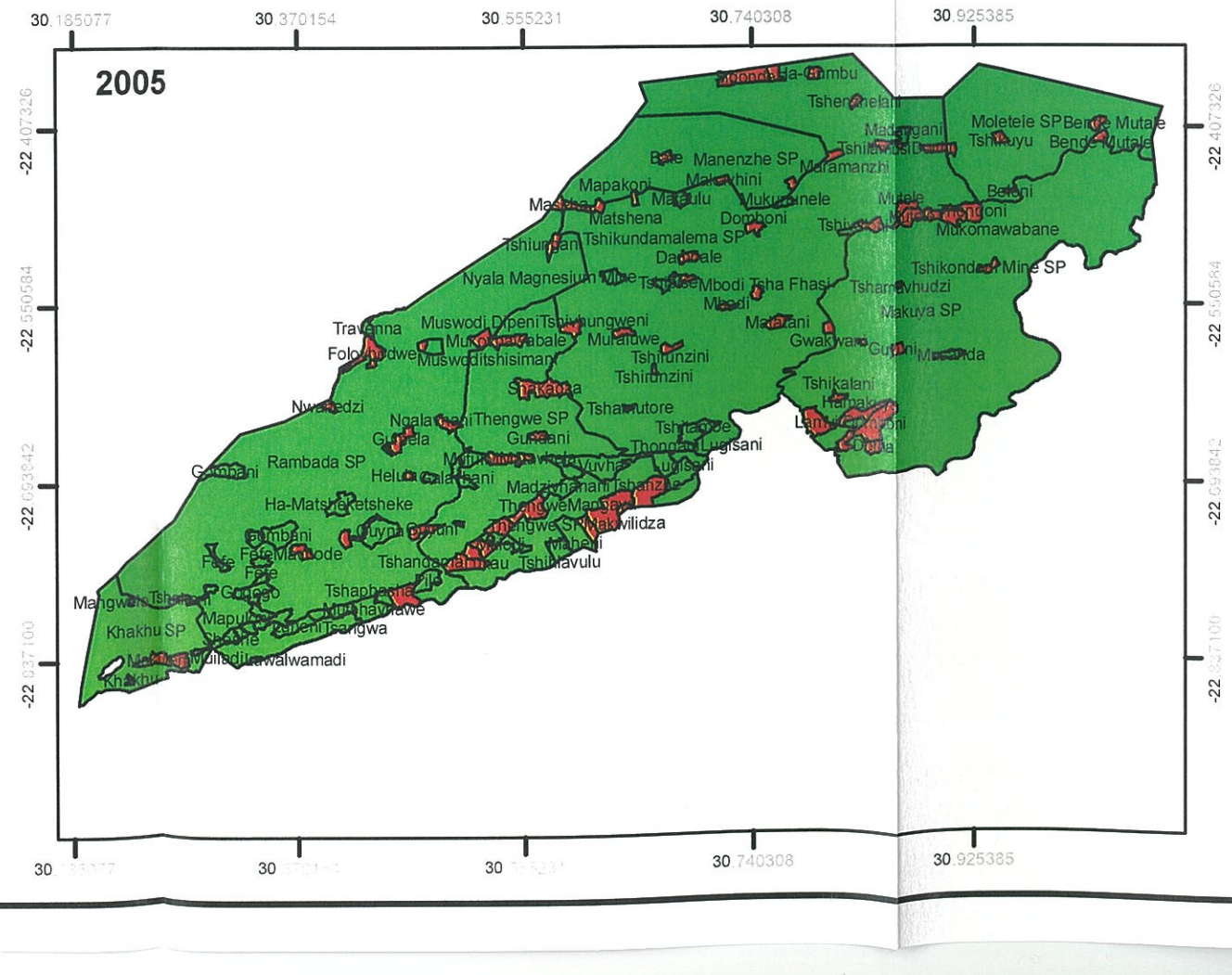
Figure 7.35:

Spatial Distribution of Malaria in Mutale Local Municipality (2002 to 2005)









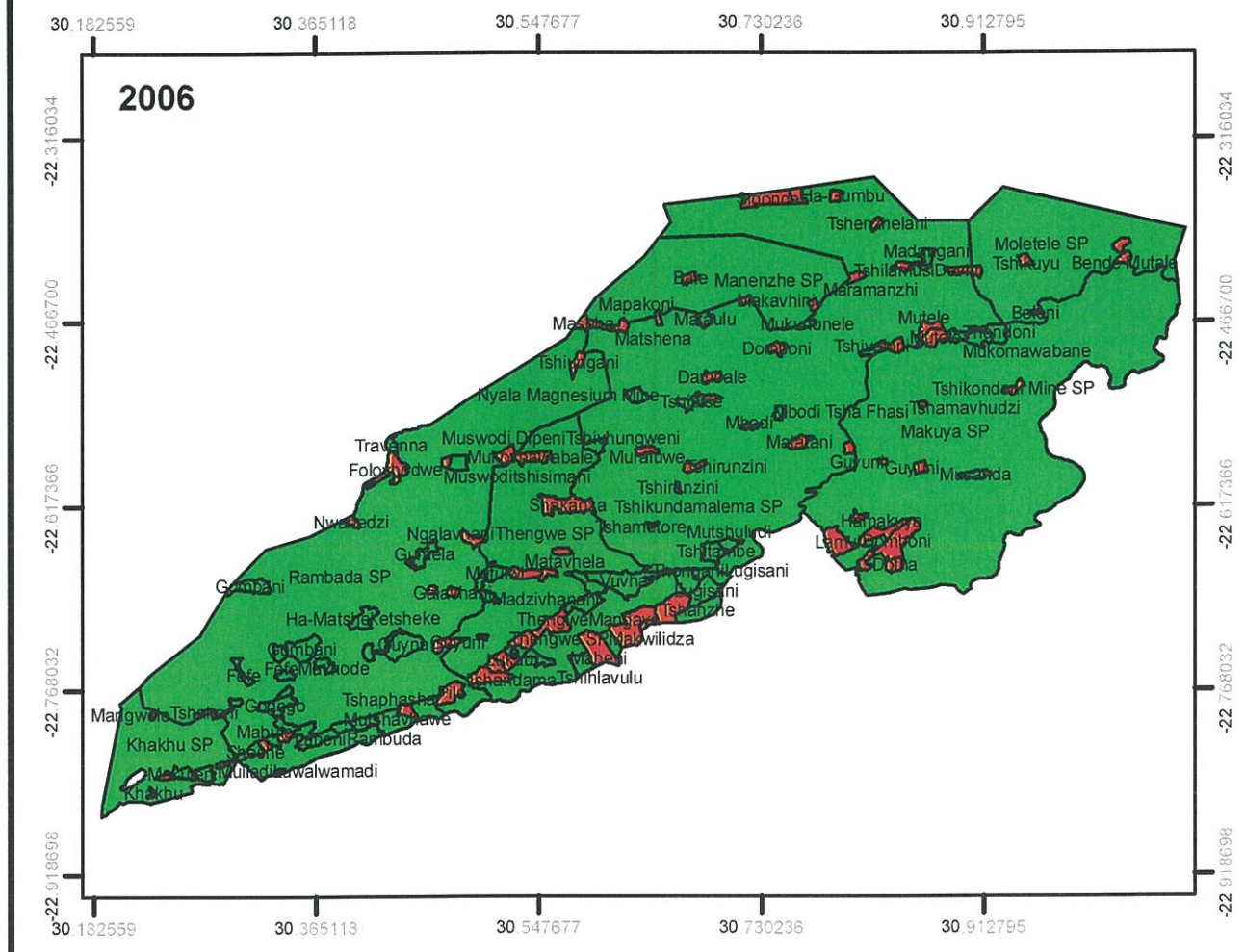
N
W E
S

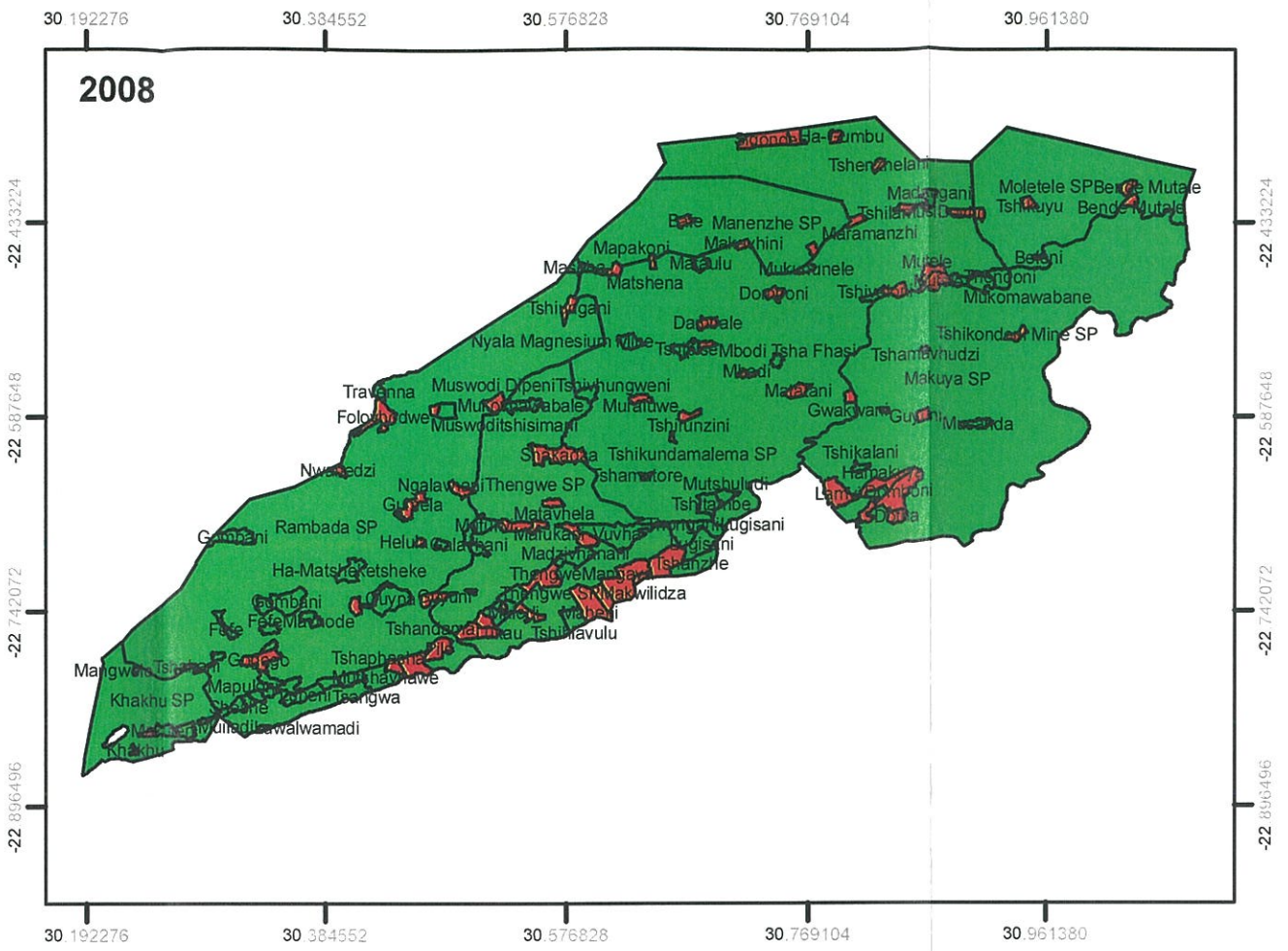
187

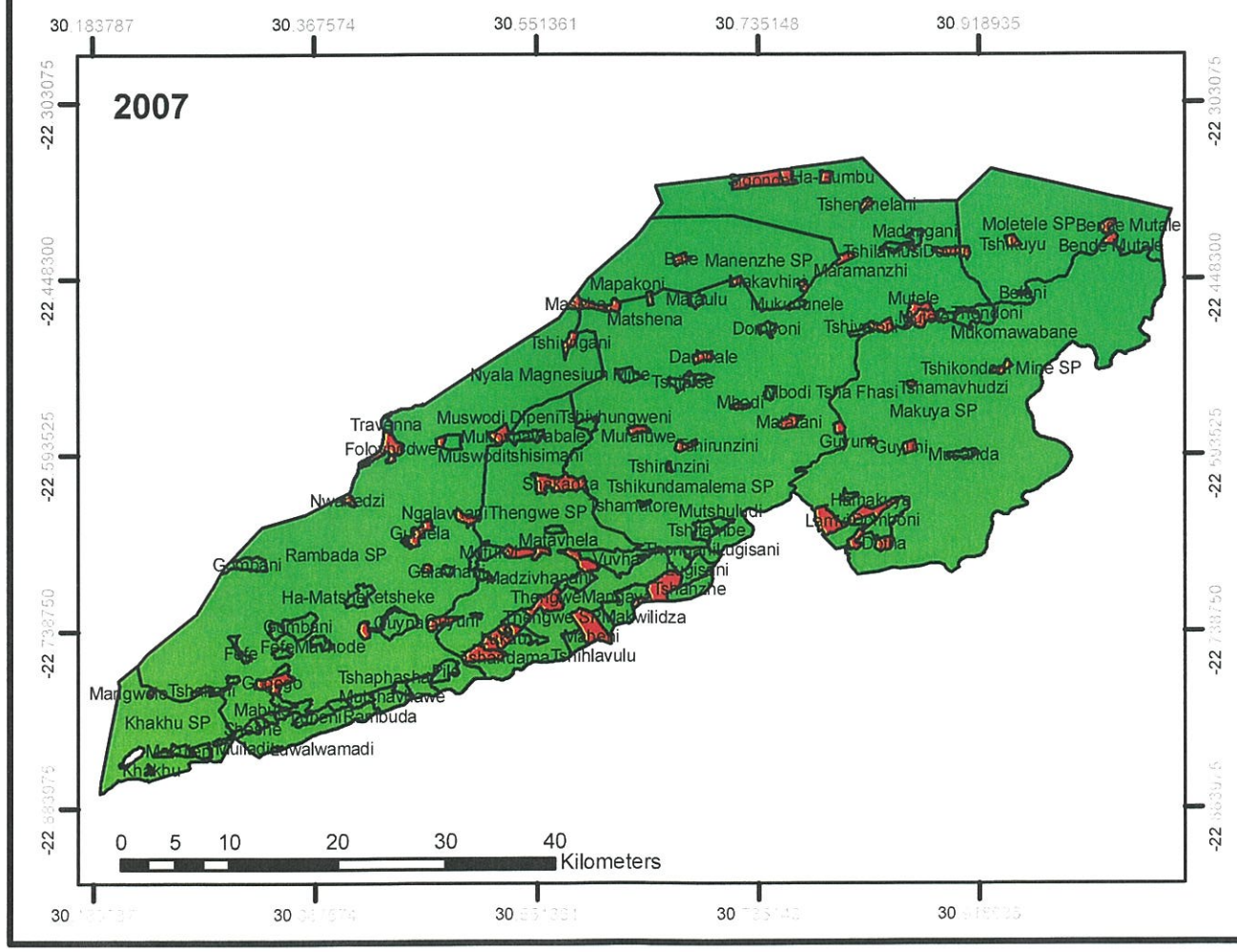
Legend

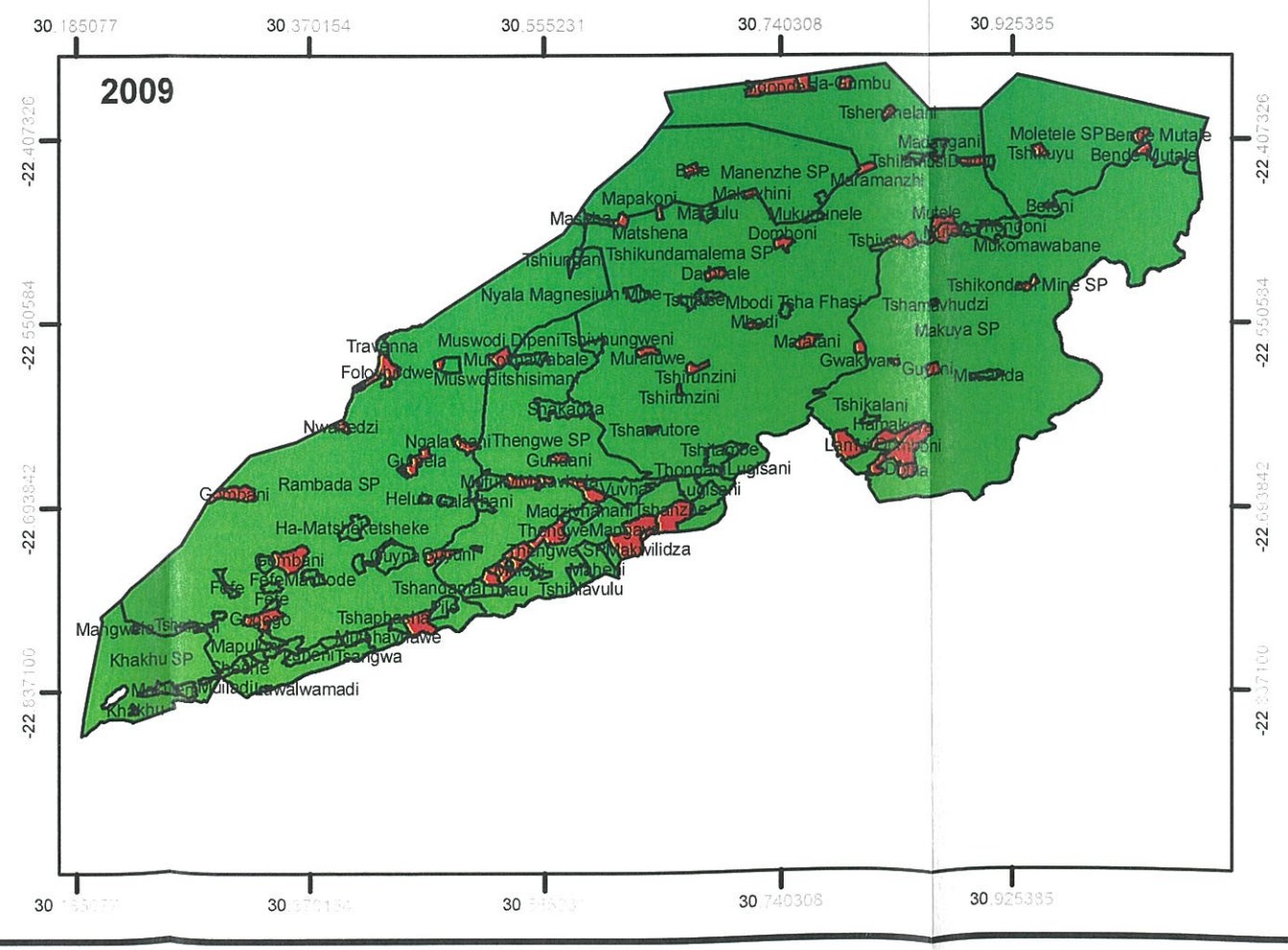
- Malaria not detected
- Malaria detected

Figure 7.36: **Spatial Distribution of Malaria in Mutale Local Municipality (2006 to 2009)**









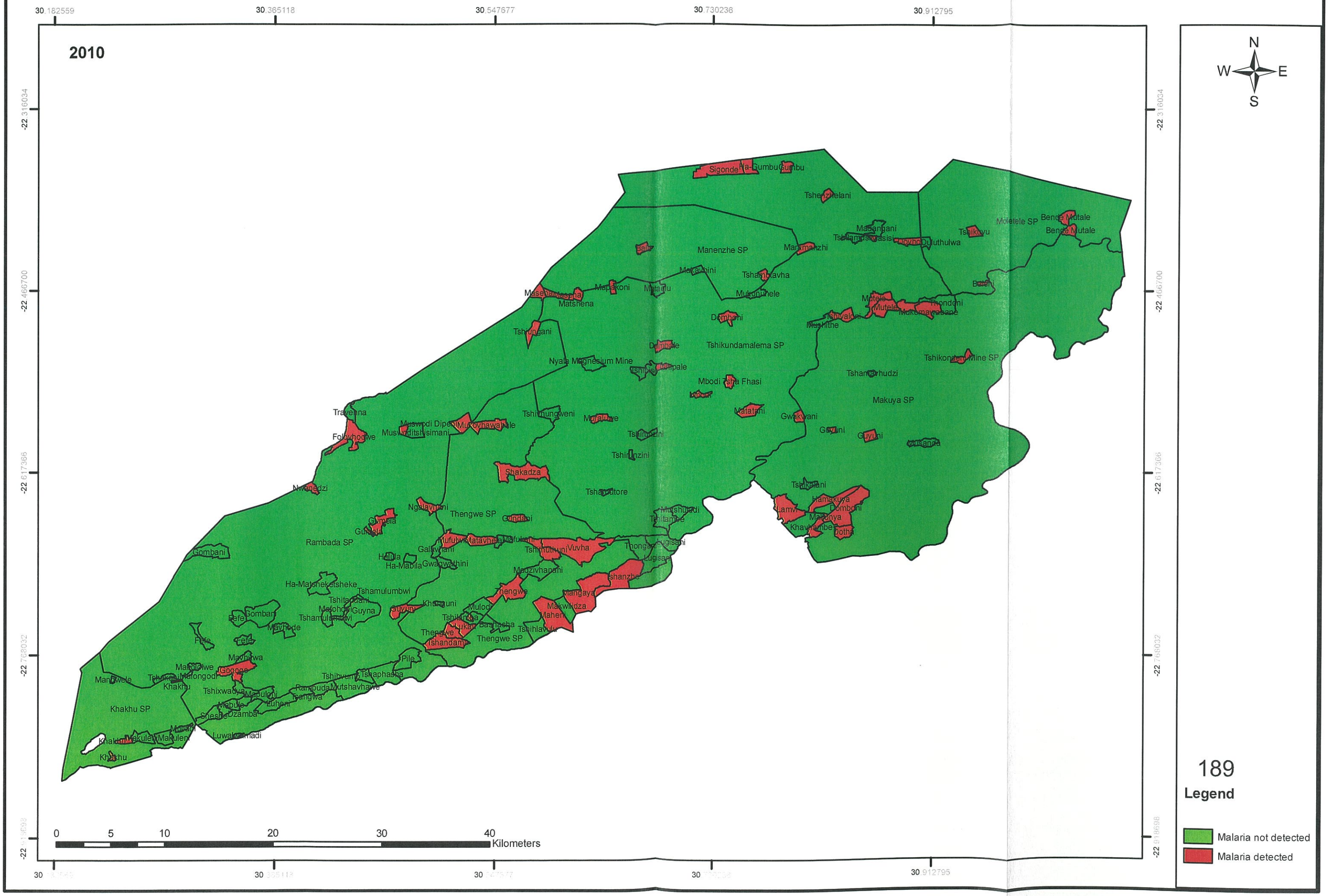
N
W E
S

188

Legend

- Malaria not detected
- Malaria detected

Figure 7.37: **Spatial Distribution of Malaria in Mutale Local Municipality (2010)**


2010
30.182559
30.365118
30.547677
30.730236
30.912795
-22.316034
-22.466700
-22.617366
-22.768032
-22.918698
N
W
E
S
Sigonde
Na-Gumbu Gumbu
Tshenzhelani
Masangani
Tshilamulenzhe
Tshikovhi Duluthulwa
Tshikovhi
Moletele SP
Bende Mutale
Bende Mutale
Manenzhe SP
Maxmanzhi
Mekaubini
Tshambavha
Matshena
Maphakoni
Mutandu
Mukumbhele
Dzimbini
Mutele
Mutele
Mukomawabane
Tshondoni
Tshivaloni
Mashithe
Tshungani
Dzimbale
Tshikundamalema SP
Nyala Magnesium Mine
Tshikongoni Mine SP
Tshandama
Mbodi Tsha Fhasi
Makuya SP
Matatani
Gwakwani
Gevuni
Guyuni
Tshikhani
Hamakuya
Domboni
Makonya
Khavhambeni
Lamvi
Tshitambe
Mudzuludi
Tshiungani
Tshiozwi
Tshiozwi
Tshiungweni
Murahuwe
Tshimbupfe
Tshinzini
Tshaulutore
Shakadza
Nwamedzi
Ngulavhani
Thengwe SP
Gundani
Rambada SP
Gombani
Ha-Mabila
Gwadzulhini
Galisvhani
Mufuluwa
Matavhela
Mafukani
Tshimbupfuni
Vuvha
Thongani
Lugisani
Lugisani
Madzivhapani
Shanzhe
Mangaya
Makwikiza
Maheni
Thengwe
Mulodi
Tshilamba
Tshikani
Basitsha
Tshihlavulu
Thengwe SP
Tshandama
Thengwe
Ha-Matshekatsheke
Tshamulumbwi
Tshitandani
Mafhohoni
Guyna
Tshamulumbwi
Gombani
Fefe
Mavhode
Fefe
Fefe
Madzhiwa
Pile
Tshaphasha
Tshibvumo
Rambuda
Mutshavhawe
Tshengwa
Mabulohi
Luheni
Mabule
Shesha
Dzamba
Luwalani
Mudadi
Makuleni
Makuleni
Khakhu
Khakhu
Khakhu SP
Manyiwele
Tshikalanga
Matongodi
Tshixwadza
Mavhungo
Mavhungo
Mavhungo

Mutale has low lying areas that run from the north eastern side to the central part. These low lying areas had between 100 and 200 cases of malaria in the period 1998 to 2010. The belt includes villages like Tshenzhelani, Manenzhe, Mukondeni, Tshikondeni, Dovho, Tshikundamalema, Domboni, Guyuni, Shakadza, Thengwe and Lamvi. On the western side of this belt are scattered areas like Nwanedi, Gumbu and Folovhodwe, while on the eastern side of the belt areas like Hamakuya and Bend Mutale, amongst others, which recorded more than 200 malaria cases during the analysis period 1998-2010. Figures 7.38-7.41 illustrate the distribution of malaria in relation to altitude in Mutale Local Municipality for the period 1998-2010.

As observed for Makhado Local Municipality, cases of malaria occurred in settlements that are autoclaved within the valleys of the Soutpansberg Mountains. These settlements are found in the Southern tip of the municipality, and include settlements like Gogogo, Khakhu, Gombani and Fefe.

Table 7.1 summarises the altitudes for the four local municipalities in Vhembe District, as well as the predominant malaria altitude range for each. The table shows that in Musina Local Municipality, malaria predominantly occurs below 500 MASL, below 648 MASL in Makhado, below 673 MASL Thulamela and below 624 MASL in Mutale. Isolated cases of malaria are detected between 698MASL and 1300MASL across the municipalities.

Table 7.1: Summary of altitude characteristics and malaria in the local municipalities in Vhembe District.

Municipality	Minimum altitude (MASL)	Maximum altitude (MASL)	Predominant malaria altitude (MASL)	Isolated malaria cases altitude (MASL)
Musina	320	1150	Below 500	689 maximum
Makhado	479	1735	Below 648	1300 maximum
Thulamela	385	1507	Below 673	971 maximum
Mutale	249	1547	Below 624	1093 maximum

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Figure 7.38

Spatial distribution of Malaria in relation to Altitude in Mutale Municipality (1998 to 2001)

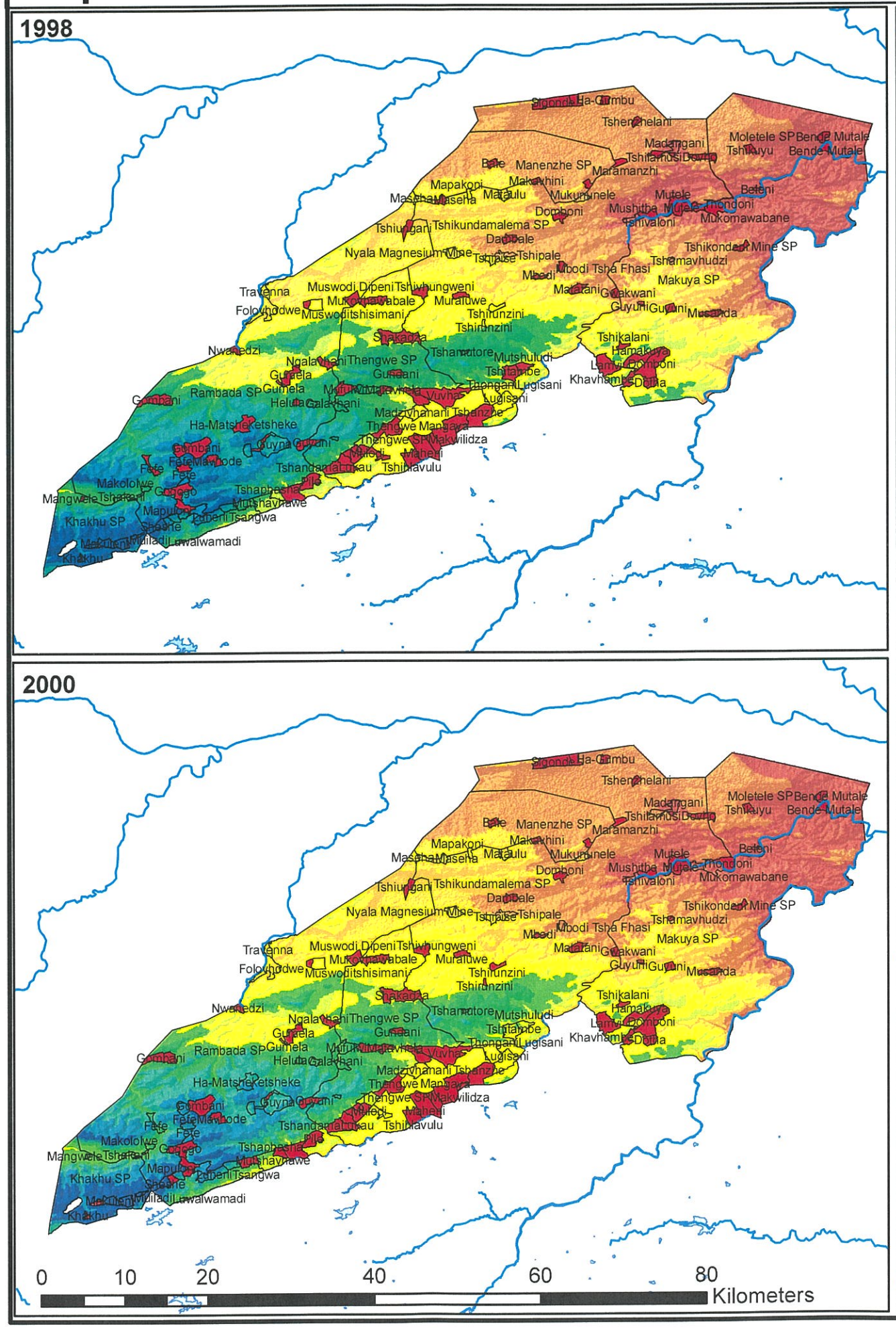
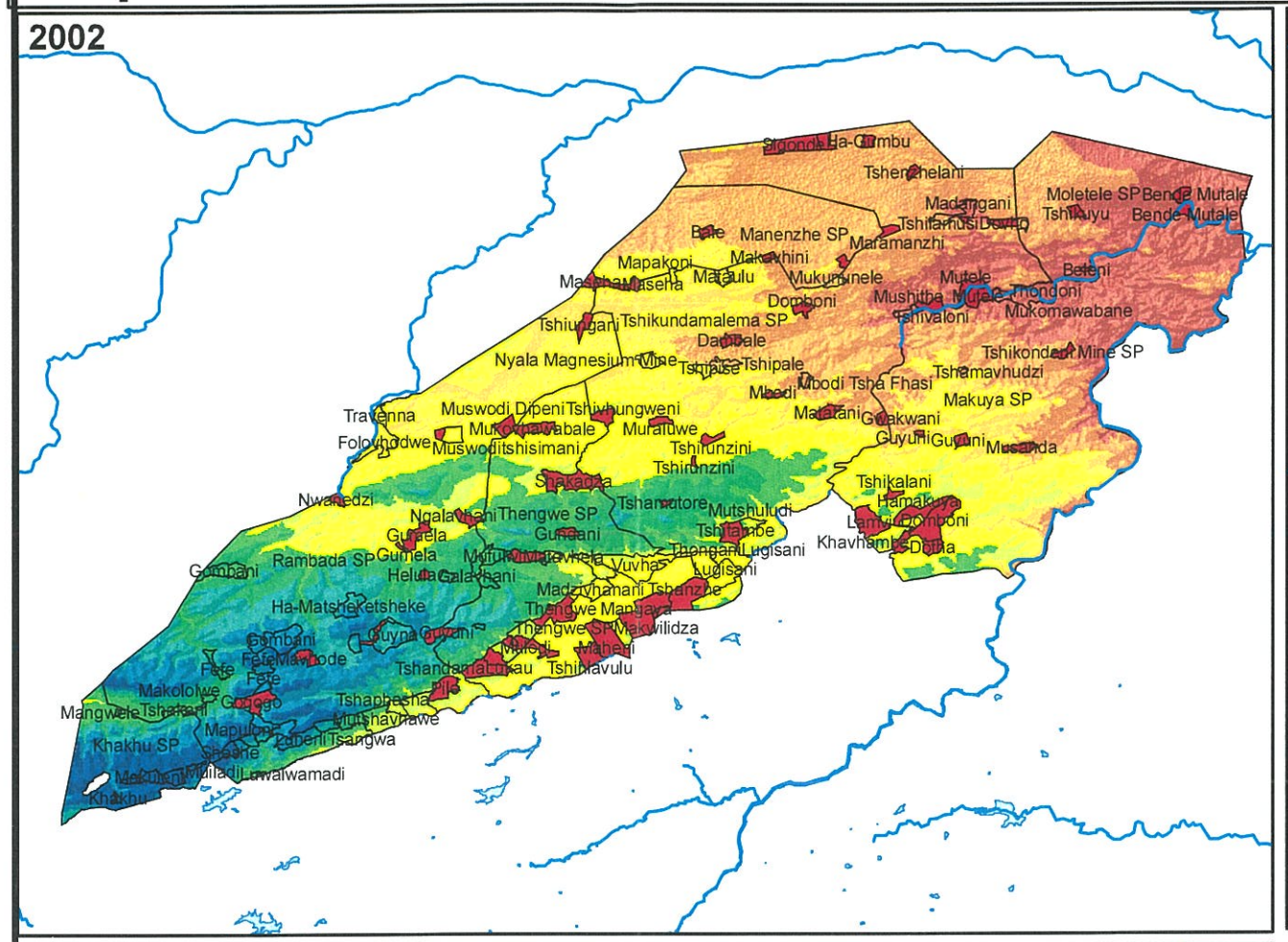
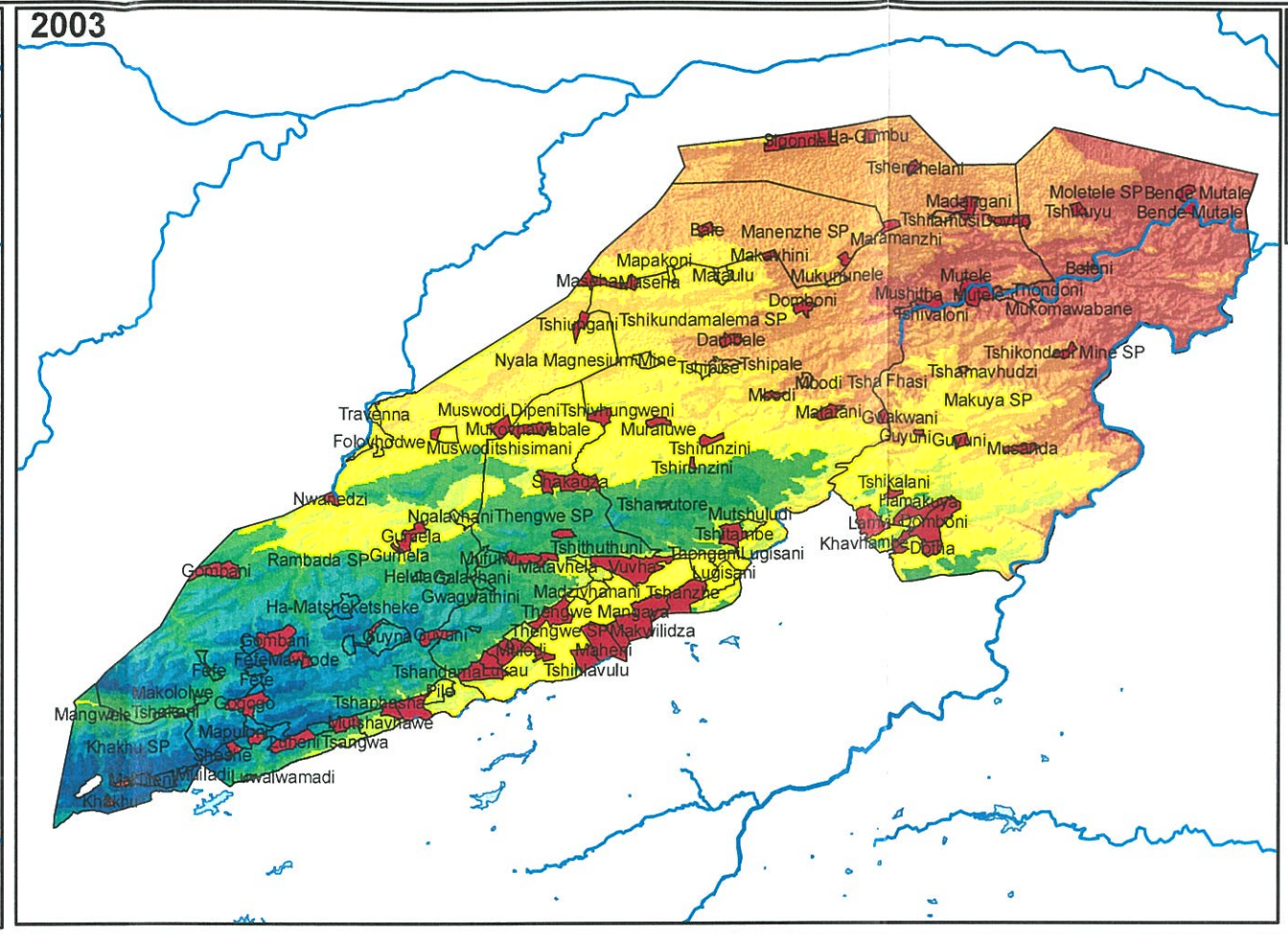
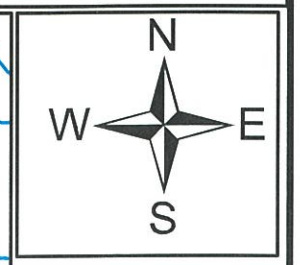


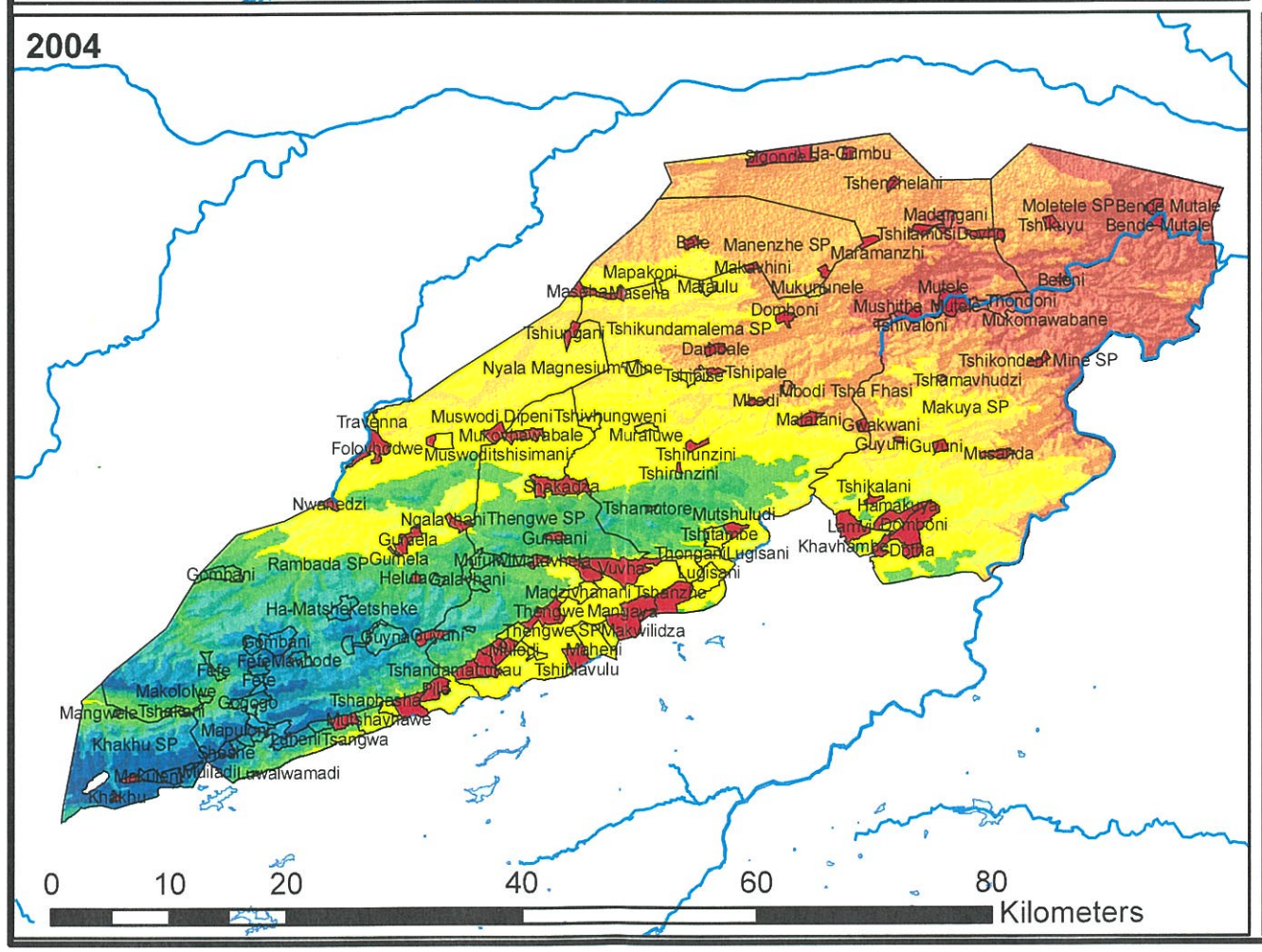
Figure 7.39

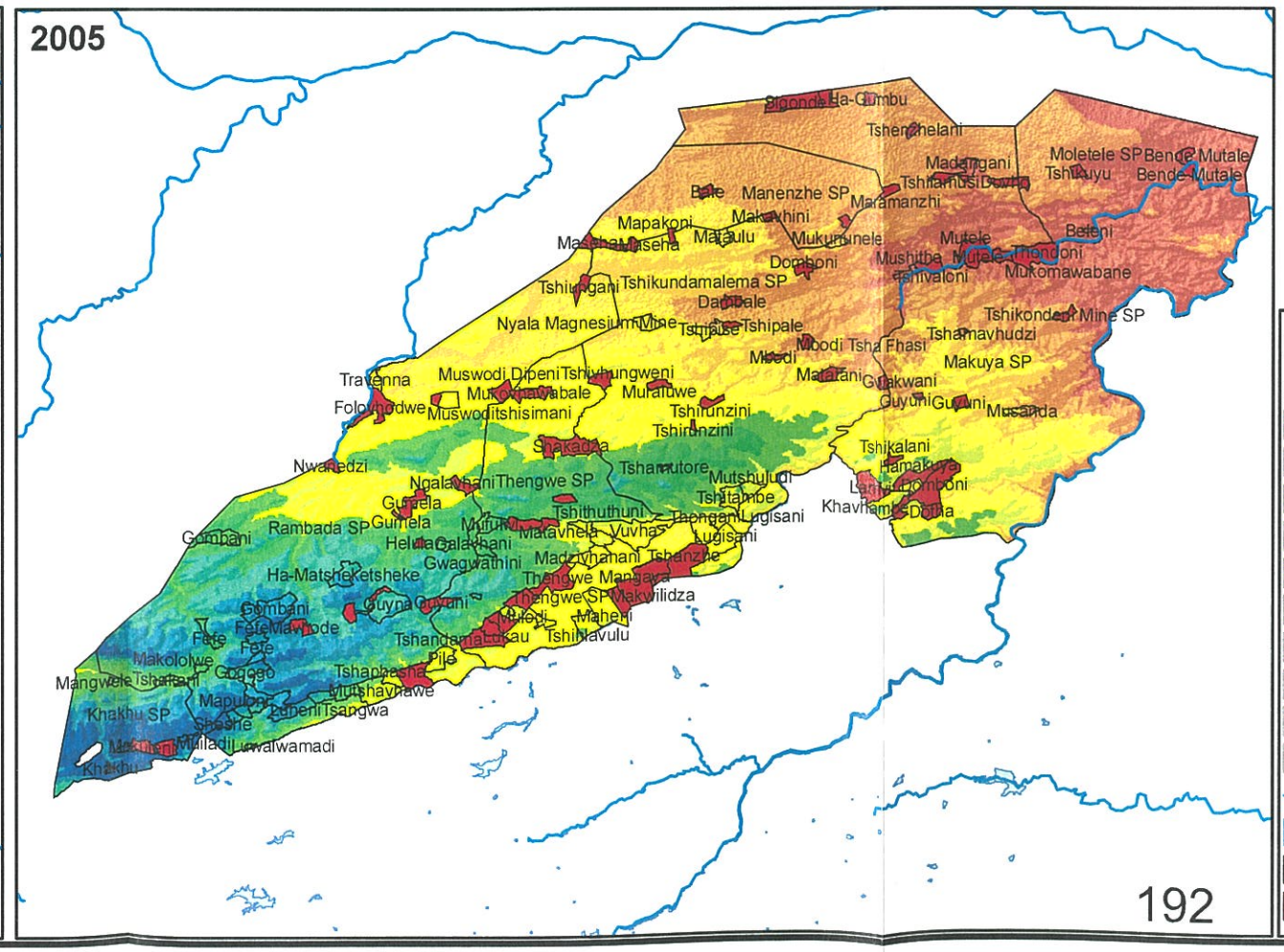
Spatial distribution of Malaria in relation to Altitude in Mutale Municipality (2002 to 2005)











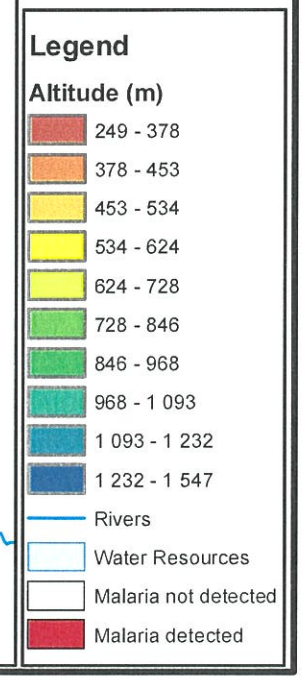
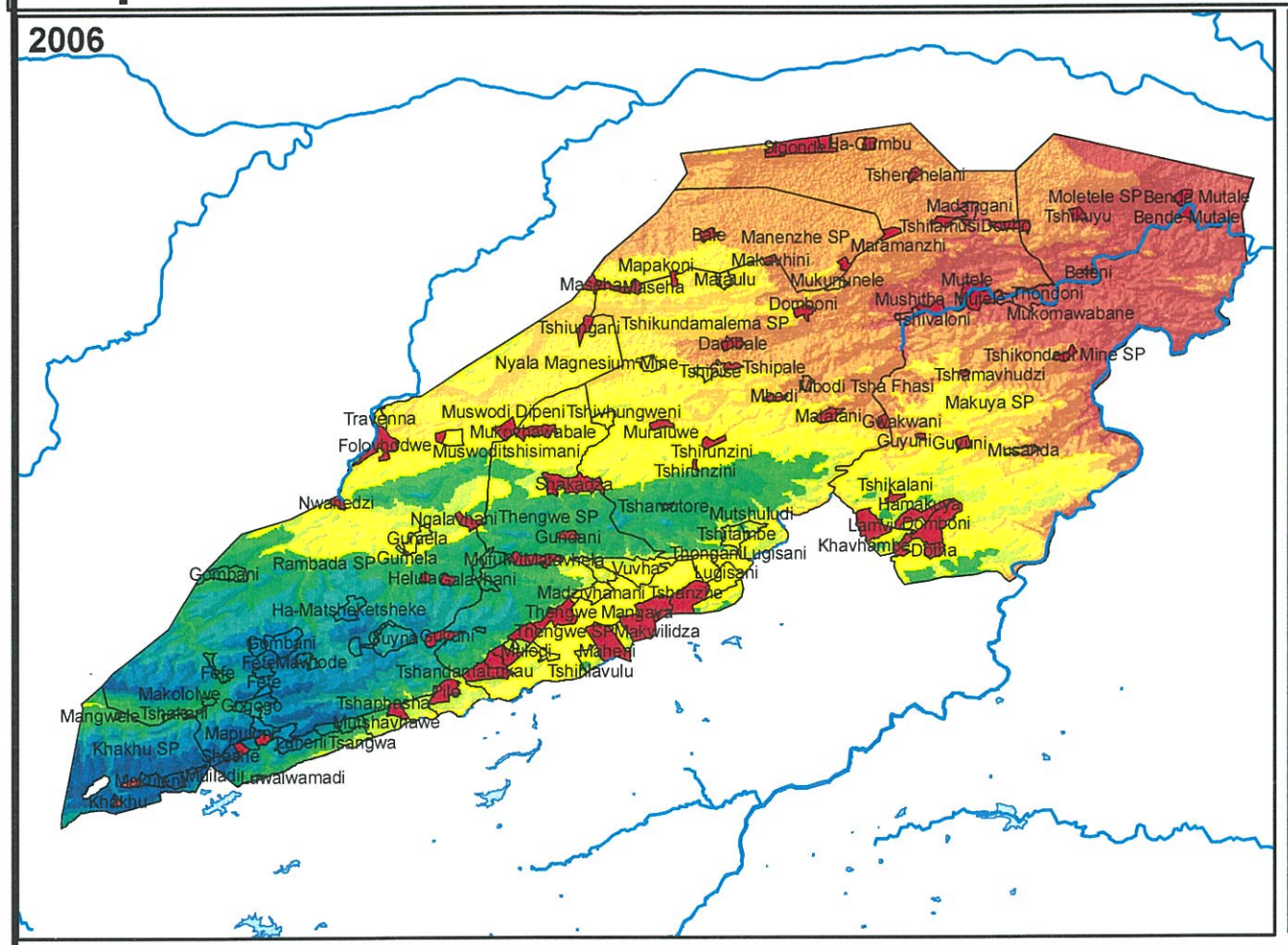
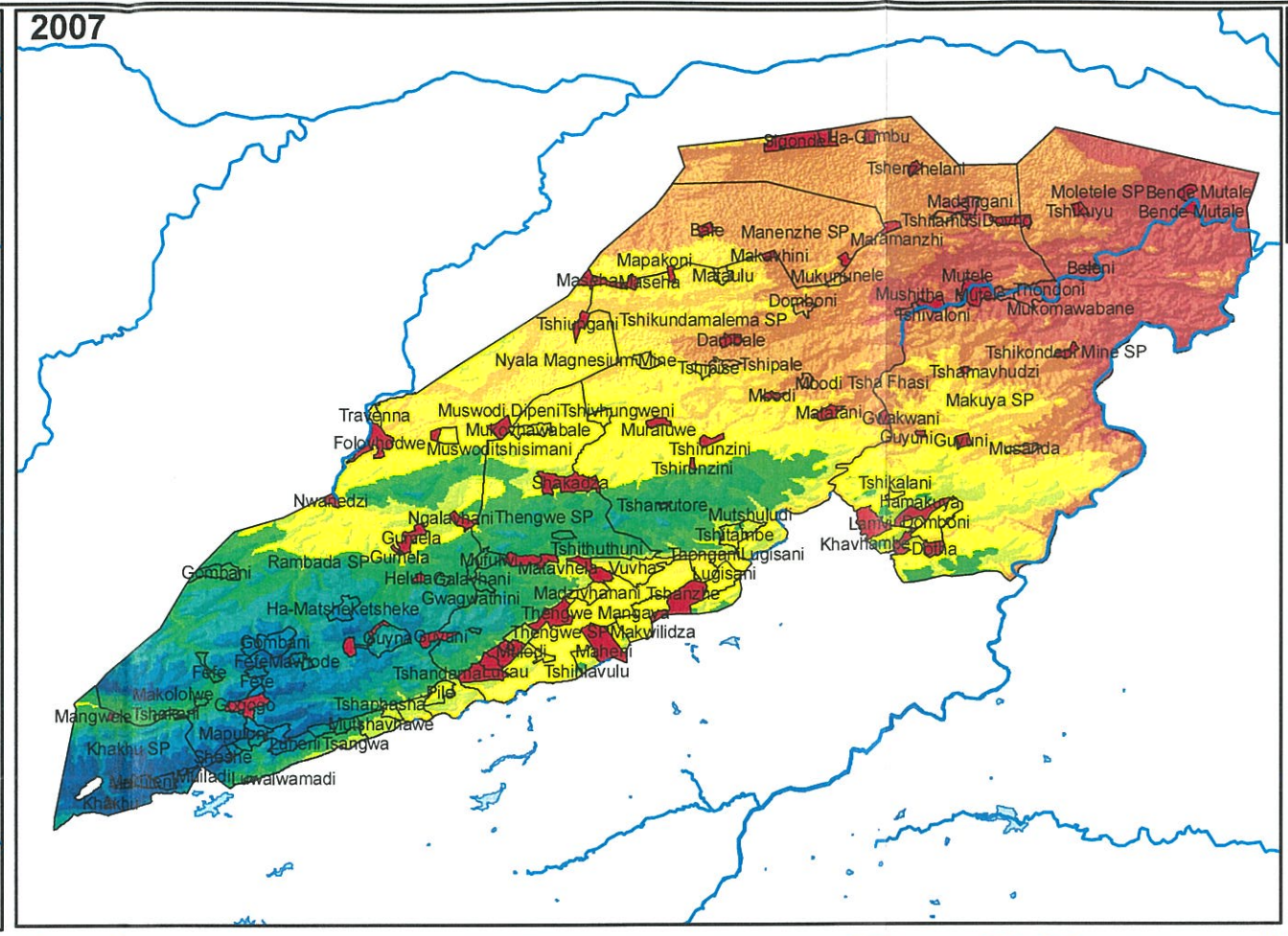
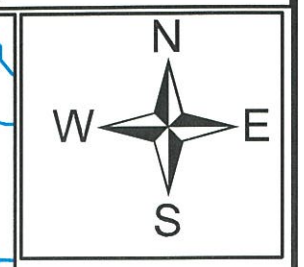


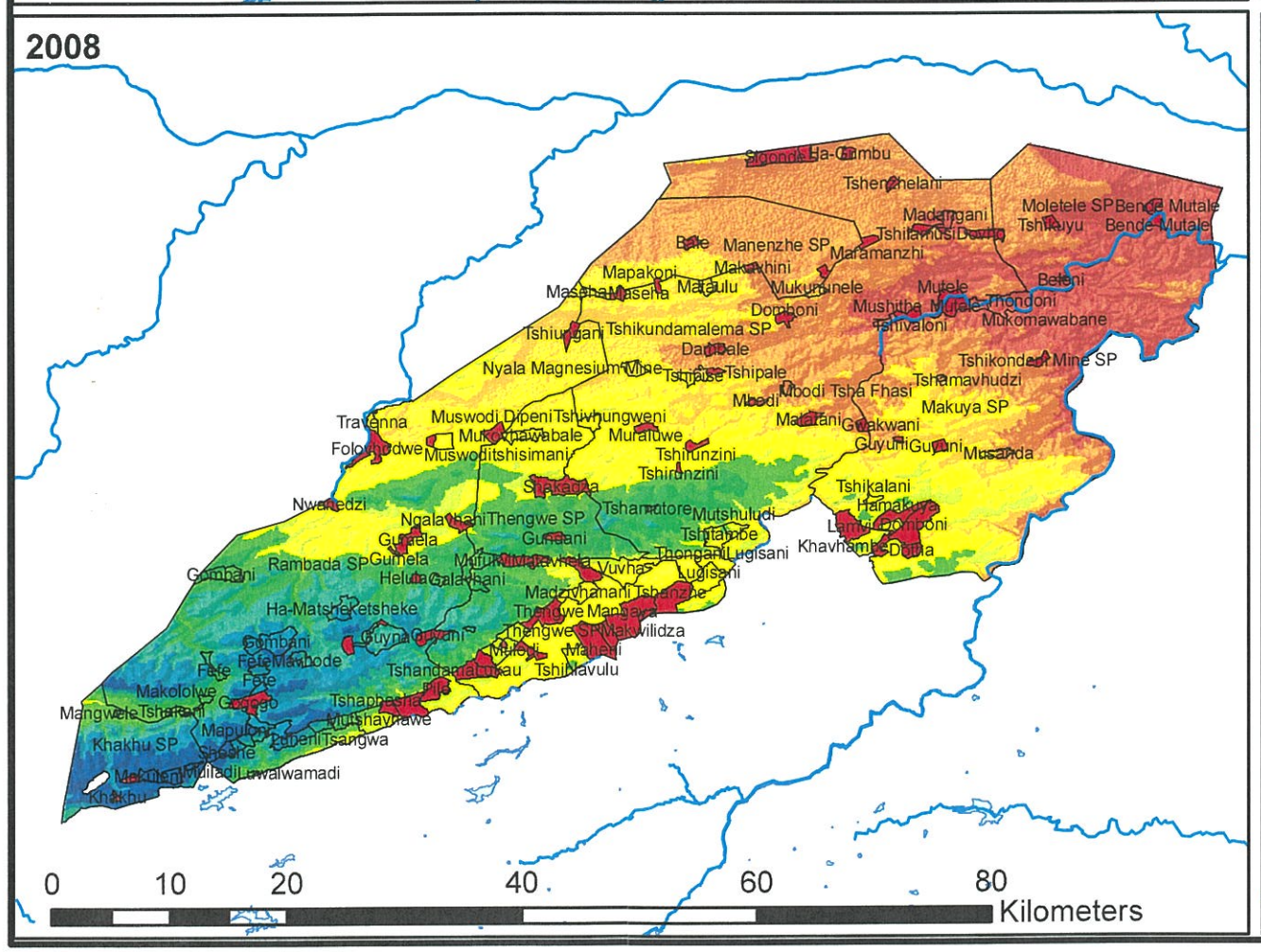
Figure 7.40

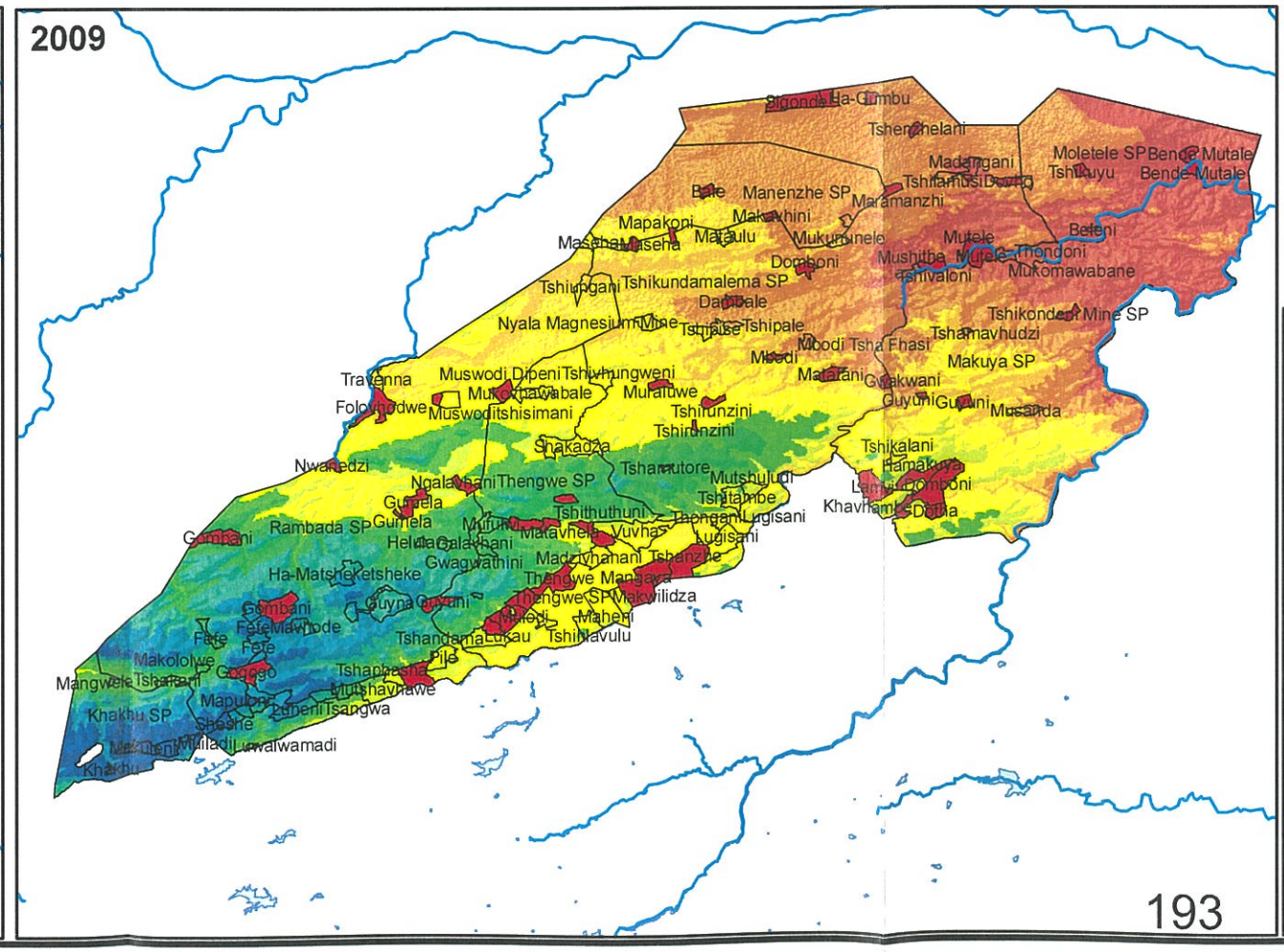
Spatial distribution of Malaria in relation to Altitude in Mutale Municipality (2006 to 2009)











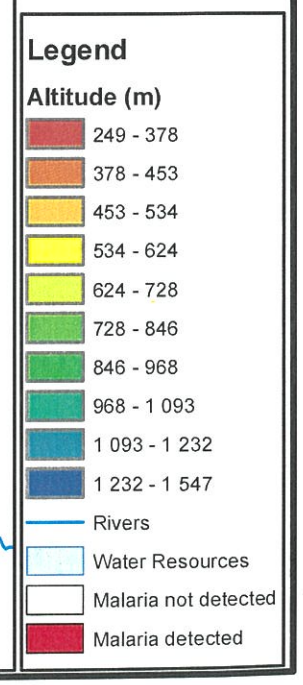


Figure 7.41

Spatial distribution of Malaria in relation to Altitude in Mutale Municipality (2010)

2010

N
W E
S

Legend

Altitude (m)

- 249 - 378
- 378 - 453
- 453 - 534
- 534 - 624
- 624 - 728
- 728 - 846
- 846 - 968
- 968 - 1 093
- 1 093 - 1 232
- 1 232 - 1 547
- Rivers
- Water Resources
- Malaria not detected
- Malaria detected

0 5 10 20 30 40 Kilometers

194

7.6 Summary and Discussion

The spatial distribution of malaria in Musina Local Municipality, as in the map in Figure 7.1, shows that the northern and eastern parts are prone to malaria infection. It can be suggested that this is due to their proximity to the Limpopo River. Since altitudes in Musina Local Municipality range between 327 and 1144 MASL, it would be expected that there would be a lot more malaria cases in Musina than in the other municipalities as suggested by Cox *et al.* (1999) and Baker *et al.* (2009) that areas below 1000 MASL are prone to a high rate of malaria transmission. However, fewer cases are reported in Musina and most of them in locations below 582 MASL. Other environmental conditions, notably the low amount of rainfall in Musina and quite high temperatures (Figures 6.22 and 6.23), may be a hindrance to mosquito breeding and hence transmission. Additionally Musina Local Municipality has a low population density (Table 5.1), which also makes the area less likely to have an upsurge in malaria. Another aspect observed from the DEM maps (Figures 7.14-7.17) is that malaria cases were detected in settlements that are close to a water resource. This underscores the influence that the availability of mosquito breeding areas has in the transmission of malaria. The areas that stood out in terms of malaria infection in Musina include the cluster farm areas of Joan, Doreen, Tshipise, Alicedale and Weipe; Musina town; River, Pontdrift, Folorodwe, Vryheid and Esmofour farms.

In Makhado Local Municipality the malaria spatial distribution maps in Figures 7.18 to 7.21 show that the central and eastern parts are prone to malaria infection. The likely reason why the eastern part is malaria prone is its proximity to Mutale and Thulamela Local Municipalities which have high malaria cases. The settlements in the south eastern part (e.g. Muwaweni and Masakona) are being affected due to their proximity to rivers and streams (e.g. the Luvhuvhu River, Figure 1.5) where mosquitoes breed. Since most of Makhado Local Municipality is at altitudes above 750MASL, it would be expected that there would be fewer malaria cases. However, the environmental conditions suppress mosquito breeding as already discussed in Chapter 6. The areas that are of concern include Ha-Masia, Tshiozwi, Tshikuwi, Mudimeli, Musekwa, Dzanani, Valdezia, Tshakhuma, Moheni, Chavani, Muila, Masakona, Sundani, Davhana, Tshimbufe, Magoro and Muwaweni.

The "pocket" trait of malaria infection can be clearly observed in Makhado. Figures 7.18 to 7.21 show how detected cases are scattered around the villages. Some settlements within the

same area are not being affected whereas other villages are affected. This clearly illustrates the importance of localising malaria investigations to enable the Department of Health to determine the malaria prone settlements instead of using national or regional interpolated data. The DEM maps in Figures 7.22 to 7.25 show that malaria cases are being detected in Makhado in the high altitude areas of Matshavawe, Tshifhire and Vuvha which are enclaved within the Soutpansberg mountain range at 912 to 1735 MASL. This could be explained by the fact that the low lying areas are getting drier and hence mosquitoes are moving up into high humidity areas for breeding, hence the high infection numbers.

The malaria spatial distribution maps for Thulamela Local Municipality (Figures 7.26 to 7.29) show that the whole municipality is prone to malaria infection. This is probably due to the closeness of settlements and high population density within the municipality. The bulk of Thulamela Municipality is located below 764 MASL and in the whole municipality altitudes range between 385 and 1507 MASL. Based on the climate and environmental conditions prevailing in the municipality and the high population density, an upsurge of malaria within the municipality is likely unless the conditions become unfavourable. The low lying (below 535 MASL) eastern parts of Thulamela reported the highest number of malaria cases within the Vhembe District between 1998 and 2010. Once again, the "pocket" distribution nature of the malaria infections can clearly be observed in Thulamela as well, as depicted in Figures 7.26 to 7.29. Some villages within the same area are not being affected by malaria whereas other villages are. This clearly emphasises the importance of localising malaria investigations instead of using national or regional interpolated data.

In Mutale Local Municipality the malaria spatial distribution maps in Figures 7.34 to 7.37 show that the central and north eastern parts of the municipality are prone to malaria infection. It can be suggested that this is because the central and north eastern parts of Mutale are low lying areas, mostly below 729 MASL. The conditions in these areas are conducive for mosquito breeding and human settlement. The area is constituted of several rivers and streams as observed on the DEM maps (Figures 7.38 - 7.41). Mutale is close to the Limpopo River and its tributaries, some of which are large rivers themselves (e.g. the Mutale River). The altitudes in Mutale range between 249 and 1547 MASL. Most of Mutale's settlements are below 700 MASL and highly populated, hence an upsurge in the number of malaria infections is likely as a result of the conducive climate and human population density factors

prevailing in the area. The changes in population in these settlements over time imply a change in the environmental system around the settlements as they increase in size and the people clear the area to make room for houses and cultivation fields. This in turn will affect the local climate conditions by bringing about localised climate conditions. This aspect of ecological change may affect malaria disease transmission through the mosquito vector since it can result in rapid evolutionary change even though the rate of change may not be easy to predict and varies among species (Erickson *et al.*, 2012).

It was observed in Chapter 6 that following a low rains in 2002 and 2005, there were increases in malaria in 2003 and 2006, respectively. An analysis of the spatial distribution of malaria during these years highlights that there was no change in terms of the spatial distribution. Almost all the areas that reported malaria in 2002 and 2005 also detected malaria in 2003 and 2006, respectively. The difference was the increase in the number of malaria cases in some of these areas. This then suggests the notion of lack of immunity or lack of preparedness from individuals and government in terms of malaria prevention and control measures.

In line with Nenwiini (2011) who divided Vhembe District into three rainfall zones (namely humid, sub-humid and semi-arid), it is observed that most of the malaria cases are found within the humid zone, followed by the sub-humid zone with very few malaria cases detected in the semi-arid zone. The humid zone is found along the border of Makhado with Thulamela and Mutale towards the east. The sub-humid zone is mostly around the central part where the four local municipalities meet (Figure 1.3a), with the western part of Makhado and the rest of Musina being the semi-arid zone. This explains why Relative Humidity had a significant correlation with malaria in Vhembe District.

Chapter 8

DISCUSSION

8.1 Introduction

This Chapter discusses the results presented in Chapters 4, 5, 6 and 7 in relation to Objectives 1, 2, 3 and 4, respectively, which are stated in Section 1.5. The Discussion is also in the context of the research hypothesis, which is stated in Section 1.6.

8.2 Climate Variability

This section focuses on addressing *Objective 1*, which was "to determine long-term (30 year, 1981-2010) climate trends in Vhembe District in terms of rainfall, temperature and relative humidity". Chapter 4 (and parts of Chapter 6) present results addressing this objective. It was noted that Vhembe district was experiencing climate variability, considering the disparity in the magnitude of anomalies identified for each of the climate elements analysed for each of the four local municipalities constituting the district. The extent of deviations (anomalies) for the various climate elements ranged from -3 to +4, and some of the pattern observed in the anomalies may be attributed to natural climate variability through phenomena like ENSO. For example, the two seasons centered on 1996 and 2000 are found to coincide with La Niña events, where 1996 fell under a weak La Niña while 2000 was in a strong La Niña episode; 2002 and 2005 being identified as moderate El Niño and weak El Niño years, respectively (Null, 2015). The influence of these La Niña and El Niño events was detected in this study through the climate data.

The years under study (1981-2010) belong to the dry part of a complete cycle of wet and dry (rainfall reduction) spells that constitute 18 to 20 years (Kabanda, 2004; Makarau, 1995; Mason, 2001; Tyson, 1990; Preston-Whyte and Tyson, 1988). From the 25 trend analysis tests conducted for long-term (1981-2010) period and 21 trend tests for medium-term (1998-2010) period, only 6 statistically significant trends could be established on long-term analysis and only 2 for medium-term analysis. This highlights the extent of climate variability in Vhembe District, since few statistically significant trends were detected. A number of other important findings are notable for Vhembe District and its four local municipalities:

1. Musina Local Municipality has the least annual rainfall, but highest annual air temperature, maximum temperature and minimum temperature. The lowest level of Relative Humidity is reported in the municipality as well. A statistically significant increase in long-term (1981-2010) maximum temperatures was detected.

2. Mutale Local Municipality has the second lowest amount of rainfall which is, however, double the amount of rainfall in Musina. It experiences the lowest air temperature, has the second highest maximum temperature, the lowest minimum temperature and the highest Relative Humidity. A statistically significant decreasing trend on long-term Relative Humidity and medium-term (1998-2010) rainfall was established for the municipality.

3. Makhado receives the second highest amount of rainfall, which is just above Mutale. It has the second lowest air temperature and experiences the lowest maximum temperatures. The area experiences the second lowest minimum temperature and Relative Humidity. A statistically significant increasing trend on long-term minimum temperature and medium-term maximum temperature was established.

4. Thulamela receives the highest rainfall in Vhembe District, and has the second highest Relative Humidity. The area has the second highest air temperatures, comes third on maximum temperatures and second highest on minimum temperatures. A statistically significant decreasing trend on long-term air temperature was established for Thulamela.

5. A composite climate analysis of Vhembe District highlighted statistically significant increasing trends of the long-term minimum temperatures and long-term maximum temperatures.

Therefore, the results obtained from this study established statistically significant increasing trends in temperature in the different local municipalities in Vhembe District, with only Thulamela Local Municipality showing a decrease in air temperature. Increasing temperatures have established by other studies. For example, Enfield *et al.* (1999), Kandji *et al.* (2006) and Hansen *et al.* (2011) have all highlighted the upward shifting of global temperatures and in the southern African region. Increasing temperatures are, however, a

major concern since they affect the ecological and biological systems in an area. With regards to malaria, higher temperatures reduce the mosquito vector breeding time (Section 2.3) and hence increase mosquito reproduction drastically. However, excessively higher temperatures may also result in the rapid drying off of pools and ponds after the rains, which then reduces the number of possible breeding areas for mosquitoes and, consequently, lead to a reduction in the number of malaria cases. This finding may be contributing towards the reduction in malaria cases in the district and as discussed further in Section 8.4.

Varying trends on rainfall were also noted, and of particular note was the slight rainfall increase trend in the long-term but a reduction in the medium term in most parts of the district. Studies by Tshiala *et al.* (2010) and Kabanda (2011) identified a decrease in rainfall in the study area, but the current study could not detect statistically significant decreasing trends except in Mutale Local Municipality. The reason for the reduction in rainfall in the study area, according to Tshiala *et al.* (2010), is the shortening of the rainfall season. Egbe (2014), in a similar study in Nigeria, also detected a shortening of the rainfall season. This may imply that there has been a reduction in rainfall in recent years throughout the Southern and West African regions. Kabanda (2011) detected a reduction of rainfall in zones within the Vhembe District. These decreasing rainfall trends affect mosquito breeding sites and, therefore, mosquito proliferation. Olwoch (2008) also indicated that an increase in rainfall normally results in an increase in malaria due to the formation of water pools (mosquito breeding areas). It follows then that a decrease in rainfall should result in a decrease in malaria prevalence. This reduction in rainfall in recent years may be contributing further towards the reduction in malaria cases within the district. It should, however, be noted that the availability or non-availability of rainfall does not equate to the availability or non-availability of suitable mosquito habitats and breeding sites (Ermert *et al.*, 2011). The relationship between the two cannot be represented as a simple linear function since other factors bear influence.

Another notable result from Chapter 4 was the statistically significant decreasing trend in Relative Humidity in the long-term that was detected in Mutale Local Municipality only, with most municipalities revealing non-statistically significant decreasing trends. Relative Humidity plays a big role in providing suitable biting conditions for the adult mosquitoes.

This decreasing trend in Relative Humidity may also be contributing towards the reduction of malaria cases in the district.

Based on the analysis done in Chapters 4 and 6, climate normals can be summarised for Vhembe District as in Table 8.1. These values will be taken as the normal climate for the area as derived by this study and will be the basis for a proposed climate-malaria management framework.

Table 8.1: Summary of long-term (30-year) and medium-term (13-year) climate parameter normal values in the local municipalities of Vhembe District.

Municipality	Period	Climate parameter				
		Rainfall (mm)	Air temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Relative Humidity (%)
Musina	Long-term	313	22.9	30.3	15.7	69.2
	Medium-term	351	23.1	30.7	15.8	71.7
Makhado	Long-term	796	20.8	27	14.9	78.2
	Medium-term	865	20.9	26.9	15.2	79.3
Thulamela	Long-term	1089	21.1	27.7	15.6	78.9
	Medium-term	1189	21.0	27.7	15.8	81.7
Mutale	Long-term	726	20.7	28.2	13.5	81
	Medium-term	779	xxx	xxx	xxx	xxx
Vhembe	**Long-term**	**789**	**21.4**	**28.2**	**15.2**	**75.7**
	Medium-term	**859**	**21.6**	**28.5**	**15.6**	**75.2**

xxx = no data available

As identified in Chapters 4 and 6, the long-term and medium-term climate parameter values are normally different. This explains why long-term interpolated data will not give the same result as medium/short-term localised data in malaria control, which was observed in this study. Cox *et al.* (1999), in the MARA project report, stress the same point and caution that their conclusions are useful as a basic static stratification which may mask temporal variations and fluctuations or long-term variations.

8.3 Malaria and Population Dynamics

The second objective of the study was "to analyse malaria and demographic trends in the Vhembe District between 1998 and 2010". The results for this objective are presented in Chapter 5. It was important to understand malaria trends in the district and how the spatial distribution of the human population influences the prevalence of malaria in the district. Key findings from Chapter 5 were:

1. In the period of analysis (1998-2010), the number of malaria cases reduced significantly in all municipalities in Vhembe District.

2. Higher cases of malaria were recorded from 1999 to 2003 in all the municipalities in Vhembe District.

3. The point of significant change in malaria trends for Musina and Makhado Local Municipalities occurred in 2005, while for Vhembe District as a whole it occurred between 2005 and 2006. The other municipalities do not have clear cut points (year) of change.

4. Population density affects malaria prevalence. A high population density results in high prevalence and a low density in lower prevalence. Population density, therefore, plays a crucial role in the transmission of malaria within Vhembe district.

5. Mutale Local Municipality showed higher malaria prevalence than the other municipalities in the analysis period (1998-2010), with prevalence values ranging between 34.7 and 211.3 (Table 5.9), followed by Musina (ranging 2.6 - 87.6) then Thulamela and Vhembe District (ranging 7 - 39). The least prevalence was in Makhado Local Municipality, with a range between 1.1 and 6.7.

It was noted that non-climate conditions like human settlements contribute to the prevalence of malaria as highlighted in the maps in Chapter 7. Areas with more settlements had higher malaria infections compared to areas with less settlements and population. Hence, even when the current study did not delve into the investigation of other non-climate conditions, their effect is noted. One of the assumptions of this study (Section 3.6) was that the non-climate conditions are being taken care of by the Department of Health of South Africa in accordance with the *Guidelines for the Prevention of Malaria in South Africa* (Baker *et al.*, 2009).

8.4 Climate Variability and Malaria

This section focuses on the interactions between malaria and climate elements, as presented in Chapter 6, in addressing the third objective of the study which was "to determine the relationship between climate trends and malaria patterns in Vhembe District between 1998 and 2010". In terms of medium-term trends (1998-2010), there was no statistically significant

relationship between the number of malaria cases and any of the annual climate variables in Musina and Mutale Local Municipalities. Associations between malaria and annual air temperature and maximum temperature were established for Makhado Local Municipality and between malaria and Relative Humidity at the aggregated scale of Vhembe District as a whole. There was also association between malaria and rainfall, and between malaria and Relative Humidity in Thulamela Local Municipality. Linear regression analysis showed that the annual Relative Humidity (RH) explained 82.88% of the variation in malaria in Thulamela, 50.3% in Vhembe District and 44.44% in Makhado, with Mutale recording low dependency of malaria on RH and Musina having no data. Malaria showed some dependency on rainfall, with R^2 values of 23.56% for Vhembe, 25.76% for Makhado, 24.54% for Mutale and 36.01% for Thulamela. Relative Humidity seemed to have a higher influence on malaria from a medium-term perspective since monthly data indicated weak associations.

The number of malaria cases was strongly correlated with monthly climatic data. The minimum and monthly air temperatures had the most influence on malaria based on monthly data. This is observed in the various Pearson correlation tables in Chapter 6. Linear regression analysis indicated that the lowest dependency of malaria on minimum temperature was for Musina Local Municipality at 63.18% of the variation in malaria, followed by Makhado at 87.53%, then Thulamela at 91.34%. At the aggregated scale of the whole Vhembe District 87.86% of the variation in the number of malaria cases could be explained by minimum temperature. Therefore, the results indicate that although conducive medium- and long-term conditions like Relative Humidity are required, the prevalence of malaria is influenced mostly by the immediate short-term conditions more than the long-term. Hence long-term data is useful in giving a basic understanding of the area, but short-term data appears to be more useful for decision making. It should be stressed, though, that the medium- and long-term influence of Relative Humidity on malaria compared to the short-term (monthly) influences should not be disregarded completely. Relative Humidity still has an influence on malaria at the medium- to long-term scale, but not in the same time scale as the other climate variables. The Relative Humidity in the study area is above 60% nearly all year long including during winter, which brings a permanent conducive humid environment for mosquitoes.

The finding that malaria is strongly dependent on temperature is quite crucial in managing malaria in the study area. In general, Vhembe District showed statistically significant

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increasing trends on annual minimum and annual maximum temperature (Table 4.4). Musina Local Municipality showed an increase in annual maximum temperature and Makhado an increase in annual minimum temperature, with only Thulamela showing a decrease in air temperature. The decrease in air temperature in Thulamela may also be of no effect since the main driving climate element is the minimum temperature, which was established to be increasing in Vhembe District. Of concern is the fact that previous studies (e.g. Basurko *et al.*, 2011) have established that increases in temperature affect the mosquito vector's behaviour and ultimately cause an increase in malaria through the acceleration of the gonotrophic cycle (Figure 2.1) of the *Anopheles* mosquito by decreasing the interval between egg-laying episodes and increasing vector abundance. The higher temperatures can also lead to acceleration of the development cycle of the parasite (Basurko *et al.*, 2011). A positive consequence of the temperature increases, especially increases in the maximum temperature, is that the high temperatures may quickly dry off any small pools of water, thereby reducing breeding areas. Moreover, if the temperature becomes too high, this may jeopardies the survival of adult mosquitoes, thereby suppressing an explosion of malaria. Evidence of this is the sharp fall in the number of malaria cases in Cacao, French Guiana, that between 2003 and 2004 even when the temperatures were particularly high (Basurko *et al.*, 2011). This is appears to be similar to what is happening to Vhembe District at the aggregated scale (and in Makhado, Thulamela and Musina Local Municipalities separately) where in 2005 maximum temperatures increased, but malaria cases declined. In fact, 2005 recorded the highest maximum temperature in Vhembe District for the period of analysis (1981-2010) and trend analysis on malaria cases showed that the significant point of change for Musina, Makhado and Vhembe District was around 2005.

Two significant points are of note with regard to the climate versus malaria analysis for Musina and Makhado Local Municipalities. Firstly, analysis for the period under study highlighted a statistically significant decrease in malaria as observed in chapter 4; and increasing trends in the annual temperature variables in two municipalities as observed in chapter 4 trend analysis. This seems to be in agreement with the findings by Basurko *et al.* (2011) that when temperatures become too high, malaria transmission becomes negatively affected. Secondly, however, an analysis on Musina and Makhado for the period 2005 to 2010 reveals a generally increasing trend in malaria prevalence. This revelation may then support how increasing temperatures may result in the increase in malaria.

The results showed identical increasing peaks of malaria at the aggregated scale of Vhembe District and at the scale of the local municipalities in 1999/2000, 2003, 2006, and 2008. On the other hand the similar decreasing peaks of malaria observed in 2002, 2005, 2007 and 2009 are linked to climate elements either above +0.5 anomaly or -0.5, anomaly especially temperature variables. For example in 2000, there was a high number of malaria cases in all the local municipalities, with the rainfall anomaly peak above +3, the maximum temperatures below -1, the minimum temperature almost -1, the air temperature below -1 and Relative Humidity above +1.5 anomaly. In 2003, Makhado, Thulamela, and the Vhembe District aggregated scale had rainfall peaks below -0.5 anomaly, maximum temperature was above +0.5 anomaly in all the local municipalities, the minimum temperature above +0.5 at the Vhembe District aggregated scale and at the local scale of Makhado Local Municipality, the air temperatures were above +0.5 in all the municipalities and the result was an increase in the number of malaria cases. In 2006, the rainfall was almost normal, but the maximum temperature was above +0.5 anomaly in all municipalities except Makhado, the minimum temperature above +0.5 including in Makhado, and the air temperature was at +0.5 excluding Musina. The result was another high peak in malaria which excluded Musina and Makhado though. In 2005, the rainfall was below -0.5 anomaly in all municipalities, the maximum temperature above +1, the minimum temperature above +1 in all municipalities except Thulamela, the air temperature at $\geq +1$, and the Relative Humidity for Vhembe District as a whole was below -1. The result was low malaria prevalence in all municipalities, with Makhado and Musina showing the lowest for the period under study.

According to Thomson and Connor (2001) drought periods, which in the case of malaria may reduce malaria prevalence drastically, are normally followed by high malaria prevalence when rainfall gets back to normal. The reason for the increase in malaria is that people are at lower immunity levels and are caught unprepared, including government. This is observed in 2003 and 2006. The years 2002 and 2005 were drier as seen in Figure 4.41 rainfall anomalies which resulted in a drop in malaria cases in all the areas. However, in 2003 and 2006, there was an increase in malaria cases in all the municipalities possibly due to lack of preparedness or lack of immunity. In South America (Colombia, Venezuela) studies also discovered that dry conditions such as those caused by ENSO are followed by increases in the incidence of malaria (Githeko *et al.*, 2000). This consequence of dry periods is of concern because, for the

study area, trend analysis showed that rainfall is declining; hence chances of more frequent droughts are possible. Moreover the economic outlook and environmental degradation in the study area may exacerbate the disease. Hence, closer monitoring and management is required in future when such anomalies occur. Therefore, whether variables indicate a negative or positive anomaly, as long as one of the variables is above +0.5 or below -0.5, an early warning system should be set into motion. This threshold has been taken forward to the management framework.

Based on the scattering and pocket nature in terms of the spatial distribution of malaria in Vhembe District, it can be inferred that the climate within this region is currently conducive enough for vector breeding, habitation and transmission of malaria. It is essential that climate data be examined regularly to determine changes in the suitability of the habitats for malaria transmission. Traditionally such activities would not be undertaken by National Malaria Control Programs (NMCP) but this may need to be done so as to increase the network on climate data within the district. A policy change requiring the inclusion of climate data by NMCPs may be required for these activities to be undertaken (Githeko, 2009). More weather stations are required in the area (especially in western and northern sections, Figure 3.1) in order to refine the findings for future studies. However, the use of local area climate conditions minimises a lot of discrepancies and errors to the study.

This study has shown that climate variability affects malaria infection and transmission due to the differences in climate conditions in the different local municipalities of Vhembe District, which in turn results in a different response from the mosquitoes and ultimately malaria prevalence. Human population issues are also important in that the different climate conditions trigger different behaviours which in turn either expose the person to mosquito bites or not. For example, when it is raining, people have the tendency to stay indoors and wear warm long clothes which protect them from mosquitoes, however when it is sunny and warm, they walk outside in less protective clothes which allow for mosquito bites and probably malaria infection. Hence immediate climate conditions affect the whole malaria cycle (Figure 2.1), resulting in the variability of malaria prevalence and relationships with climate from area to area.

The key highlights from Chapter 6 were:

1. Musina Local Municipality had no statistically significant relationship with all the annual climate variables. However, there were very high correlations between the number of malaria cases and all climate variables except the Relative Humidity. The monthly minimum temperature drives malaria in Musina, followed by the air temperature, then maximum temperature and rainfall at lag -1 month.

2. Makhado Local Municipality had a statistically significant negative correlation between malaria and the annual air temperature and maximum temperature. The air monthly temperatures drives malaria prevalence most strongly followed by the minimum temperature, maximum temperature, rainfall and to some extent Relative Humidity at lag 0 followed by lag -1 month.

3. Thulamela Local Municipality had a statistically significant positive correlation between malaria and annual relative humidity and rainfall. The minimum monthly temperature drives malaria prevalence most strongly followed by the air temperature, the maximum temperature and rainfall at lag 0 followed by lag -1 month.

4. Malaria in Mutale Local Municipality had no statistically significant correlation with annual rainfall. However, there was a strong correlation with the monthly rainfall at lag 0 followed by lag -1 month.

5. Vhembe district had a statistically significant correlation between malaria and the annual Relative Humidity. The minimum monthly temperatures drive malaria prevalence most strongly in the district at lag 0 month, followed by lag -1 month, then the monthly air temperature, the maximum temperature, and then rainfall.

6. Malaria cases were found to be still high at the start of winter in May in all the local municipalities making up Vhembe District. The cases only dropped sharply in June.

7. Relative humidity remained high even during winter, sometimes even higher than it was in some summer months.

8. Musina Local Municipality experienced a -1 month lag effect between the onset of a climate effect and the response in the number malaria of malaria cases. On the other hand Vhembe District, Makhado Local Municipality, Thulamela Local Municipality and Mutale Local Municipality had 0-month lags, highlighting how quickly the mosquito reproduction cycle went in the areas.

9. February had the highest rainfall in the study area. However, there was a drop in the number of cases in malaria in all the local municipalities in February. This suggests that each municipality had a rainfall threshold beyond which negative effects on the malaria cycle began to be experienced.

10. At the aggregated level of Vhembe District as a whole, the drop in malaria cases occurred when the February rainfall was above 150 mm, above 200 mm for Thulamela Local Municipality, and above 150 mm and 140 mm, respectively, for Mutale and Makhado Local Municipalities. Musina Local Municipality did not show any such trend, and its monthly rainfall amount was below 70 mm on average even in summer.

11. A high number of malaria cases occurred in January in the majority of the local municipalities and Vhembe District.

12. The number of malaria cases in Thulamela Local Municipality, and Vhembe District as a whole, had a positive statistically significant trend with annual Relative Humidity data. Thulamela also had a statistically significant trend with rainfall. Makhado malaria cases showed a negative statistically significant trend with annual air temperature and annual maximum temperature.

13. In Musina and Thulamela Local Municipalities, and at the aggregated level of Vhembe District, among the climate parameters the monthly minimum temperature had the highest correlation with the number of malaria cases, followed by the air temperature. On the other hand in Makhado malaria is driven most strongly by the air temperature, followed by the minimum temperature.

14. Although not statistically significant at the annual level, the minimum temperature influenced the decrease or escalation of malaria cases especially in Makhado and

Thulamela Local Municipalities, and at the aggregated level of Vhembe District. When the minimum temperatures dropped, the number of malaria cases also declined and when there was an increase in minimum temperatures, mostly the number of malaria cases would also escalate.

15. The Relative Humidity seemed to have a long-term influence on malaria since statistically significant trends could only be identified at annual level. Moreover, the fact that in all the local municipalities making up Vhembe District the Relative Humidity was always above 60% on average, even in winter, means that conditions will always be favourable for malaria, and hence its effects may not always be statistically detected.

16. A dry year was followed by an increase in malaria cases when the rainfall got back to normal. This could have been due to lack of immunity in human individuals or unpreparedness by the community and government authorities, since the dryness would have suppressed malaria prevalence to some extent, as observed in 2003 and 2006 following dry years in 2002 and 2005, respectively.

17. An analysis of significantly correlated climatological elements indicated that rainfall was mostly negatively correlated with temperature, Relative Humidity was also negatively correlated with temperature, Relative Humidity and rainfall were positively correlated, and all temperature variables were also positively correlated.

It can be noted that malaria showed a statistically significant decreasing trend in Vhembe District between 1998 and 2010. Similar decreasing trends are observed on the amount of rainfall, but with a rise in temperatures. This may work in the favour of the District in that less rainfall implies few breeding places and high temperatures mean any small ponds of water that form after rains are quickly dried off. Ultimately natural phenomena may help in the reduction of malaria. However, it can also be inferred that the current decrease in malaria is also being influenced by variability in climate conditions and may not necessarily be due to management strategies since these have not changed between 1998 and 2010. The current strategies are not pro-active but reactive. Treatment of a particular area or village is based on the number of malaria cases detected in that village or area in the previous year. On the other hand, climate conditions as observed in the study area are not static but variable, hence malaria prevalence will then rise drastically in a different area or village in which it would

not have been treated and/or managed. Since the increasing or declining peaks of malaria observed in Vhembe District are linked to one or more of the climate elements being either above +0.5 or below -0.5 anomaly, and with knowledge of the leading climate elements that influence malaria, focused management of malaria which takes into consideration the climate will, therefore, be a step closer to the elimination of elimination. The same information if obtained timeously can be used for malaria prediction in an early warning system, which then enhances pro-active treatment and /or control of malaria.

8.5 Spatial Distribution of Malaria

This section focuses on the key findings determined from Chapter 7. It answers the fourth objective of the study, which was "to determine the spatial influence of the prevailing climate on the distribution of malaria in Vhembe District, between 1998 and 2010". Altitude plays a very important role in the distribution of malaria in Vhembe District, as can be observed from the spatial distribution and DEM maps. Most malaria cases are reported in areas below 700 MASL, in accordance with similar studies (Cox *et al.*, 1999; Githeko *et al.*, 2000) which indicated that malaria transmission is most predominant below 1000 MASL. Isolated cases of malaria in places that are above 700 MASL are a possibility in this region based on the prevailing climate conditions. Huang *et al.* (2011) found out that commercial farms in Motou County of Tibet, which lies between 700 and 2100 MASL, had malaria due to the availability of breeding areas.

The pocket distribution nature of malaria infection in Vhembe District is clear from the malaria distribution maps in Chapter 7 (Figures 7.1 – 7.41) in that some settlements within the same geographic area are not being affected whereas others are. The cause of this is a result of varying altitudes, varying climate conditions and population density contributions within the area of study. In work in the same study area Nenwiini (2011) established that the rainfall is highly variable in the local settings, with two major rainfall areas (humid and semi-arid) and pockets of intermediate rainfall characteristics like those in the two rainfall areas were also identified. This clearly illustrates the importance of localising malaria investigations instead of using national or regional interpolated data if the critical malaria pockets are to be identified so that proper management of malaria is achieved.

The DEM maps of sections of Vhembe District showed that that malaria cases occurred in low altitude areas below 700 MASL. Very few cases were detected in high altitude areas above 1200 MASL except in settlements that are enclaved between the Soutpansberg mountain ranges or on the slopes of the mountains. This could be explained by the high humidity levels experienced in these areas due to changes in pressure systems and hence mosquitoes are moving up into high humidity areas for breeding. This explanation is supported by Erickson *et al.* (2012), whose study supported the hypothesis that changes in climate tend to shift, rather than expand, the spatial distribution of some diseases. Erickson *et al.* (2012) go on to highlight the differences that can occur by studying malaria at different spatial scales. For example, regional MARA studies versus this localised study may give conflicting conclusions because most of the available maps from the MARA studies are modelled and hence do not represent the actual data. This will in turn affect management plans.

8.6 Topography and Land Use Influences on Malaria in Vhembe District

The hypothesis of the research was that there is spatial climate, topographic and land use variation which influences malaria and its distribution in Vhembe District. This was proven correct in that there were pockets of malaria in Vhembe District. This pocket distribution trend manifested through the number of malaria cases being different in contiguous (neighbouring) villages. This anomalous spatial pattern of malaria can be attributed to microclimate variations induced by land use and topography. The influence of topography manifested through the occurrence of malaria in villages that were at high altitude in the Soutpansberg Mountains, but in valley enclaves. The valley enclaves then had their own microclimates, which then could have had influences in the number of malaria cases.

Land use factors that could have contributed to microclimate anomalies include irrigation and the construction of water supply dams. There are a number of large dams in Vhembe District (Figure 1.5), examples of which are Albasini, Nzhelele, Nandoni (at Thohoyandou), Luphephe, and Vondo. Irrigation has been shown by some studies (e.g. Lee *et al.*, 2016) to influence malaria. This is possibly through providing mosquito breeding areas in the irrigation water reservoirs and through increasing Relative Humidity. Further research needs to address the influence of water bodies and irrigation on malaria in Vhembe District. Musina and Mutale Local Municipalities have a number of commercial farms where crops are

irrigated as a supplement to the low rainfall. The water bodies and irrigation systems have a bearing on the Relative Humidity of that particular area which will affect that zone, making it conducive for mosquito breeding and thereby creating a malaria pocket if all the other conditions are met.

Another land use factor that could have caused the anomalous pocket distribution of malaria in the study area is arable farming. The crops grown on the farms can harbour the mosquito vectors. Areas in Vhembe District in eastern sections of Makhado Local Municipality have a lot of banana plantations along the Luvhuvhu River (Figure 1.5). These areas also have a dense distribution of settlements, making the inhabitants vulnerable to malaria. In addition to harbouring the mosquitoes these plantations can also have a microclimate anomaly (for example slightly lower temperatures) in favour of mosquitoes and, consequently, malaria.

8.7 Malaria Management Conceptual Framework for Vhembe District

Having established that there is climate variability in Vhembe District which affects malaria prevalence and its spatial distribution, it is important to add to existing conceptual frameworks the aspect of management of malaria climate that incorporates climate. In Chapter 9, the design of a Climate-Malaria Management Framework (CliMM) proposed for Vhembe District is discussed. CliMM will be used as part of the malaria Early Warning System (EWS) measures put in place for the district.

However, before detailing the proposed CliMM, it is necessary to highlight the contemporary setting of Vhembe District based with regard to the findings in this study. Figure 8.1 shows a context-specific conceptual framework on climate and malaria interactions in Vhembe District and its local municipalities. The conceptual framework has been developed based on the findings in this study. The framework has been divided into three block steps as follows;

i. Intrinsic Linkages between Climate Elements and Topographic Element,
ii. Vector Cycle, and
iii. Human Population Density and Malaria Prevalence.

The framework only uses the elements that were investigated in this study but is based on Figure 1.4. It is important to note that there are other external factors which form part of the conceptual framework as discussed in Section 1.3 that have not been investigated. This study,

therefore, contributes towards the understanding of climate, topographic and demographic factors in the prevalence of malaria.

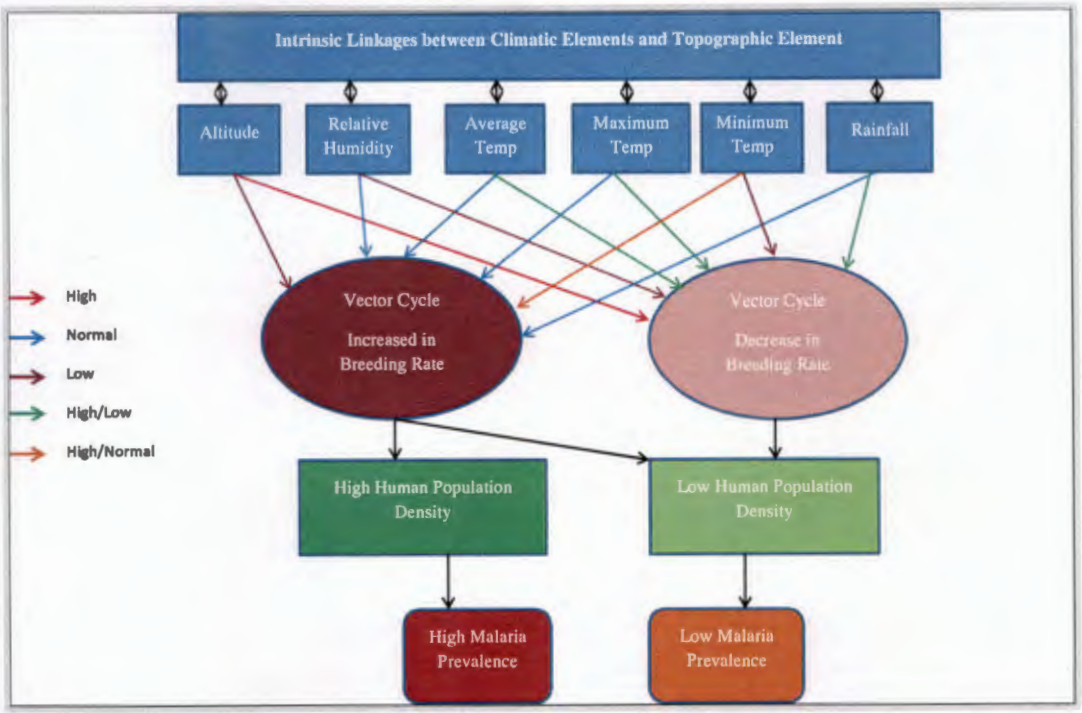


Figure 8.1: A climate-malaria conceptual framework developed for Vhembe District based on results from the study.

8.7.1 Intrinsic Linkages between Climate Elements and Topographic Element

The first block in Figure 8.1 (*Intrinsic Linkages between Climate Elements and Topographic Elements*) shows how the various climatic elements are related with each other. The relationship between the elements might be weak but in some cases quite strong. Statistically significant relationships between the elements were established in this study. For example, an analysis of data on the climate elements at the aggregated scale of Vhembe district established statistically significant associations between rainfall and minimum temperature; rainfall and air temperature; air temperature, maximum temperature and minimum temperature; Relative Humidity and minimum temperature, and between all the other temperature variables and Relative Humidity.

Away from the aggregated scale of Vhembe District, for Makhado Local Municipality some of the statistically significant relationships included rainfall and air temperature, maximum

temperature and minimum temperature. For the Makhado data all the temperature variables were strongly correlated, and there were associations between maximum temperature, rainfall, air temperature, minimum temperature and Relative Humidity. The years 1988, 1996 and 2000 had extreme events, which affected two or more of the parameters under study. This underscores the intrinsic relationships among the climate elements. These climate elements will then influence malaria prevalence based on the altitude as well; most malaria cases were detected in areas below 689 MASL.

8.7.2 Malaria Vector Cycle in Vhembe District

The second block in Figure 8.1 (*Vector Cycle*) highlights the influence of the climate and topographic elements on the malaria vector reproduction cycle. Climate conditions affect the vector reproduction cycle as opposed to having a direct linear relationship with the number of malaria cases. This is in line with literature, and is stated as an assumption in Section 3.6 (as *Assumption 5*). Results from this study showed how increases in temperature and rainfall did not directly result in an increase in the number of cases, but actually a decrease. For example, most municipalities showed a high rainfall amount in February, but there was a drop in malaria cases. Vhembe District showed lower maximum temperatures from 2003 to 2006, but this did not affect malaria cases, highlighting how the different climate elements affect the malaria vector cycle.

For example, if we look at an area with a high altitude of 800 MASL (red arrow), it is expected that the breeding rate of the mosquitoes will be low or non-existent since an analysis of the spatial distribution of malaria in this study showed this. However, low altitude areas will most likely have malaria cases. On the other hand altitude alone cannot explain suppressed vector breeding, as already highlighted in the first block that most of these climate elements and topography are linked. Therefore, going back to the high altitude example and looking at Relative Humidity, it can be observed that for us to have a low breeding rate, the Relative Humidity should be low (brown arrow), the minimum temperatures should be lower than normal (brown arrow) and the rainfall should be lower/higher than normal (green arrow). The explanations in terms of high, low and normal have been discussed in this study. As an example, high rainfall or flash floods will tend to wash away breeding areas, thereby reducing the rate of mosquito reproduction. High or low temperatures will tend to affect the

survival of the adult mosquito (high) and inhibit the sporogonic cycle (low), thereby affecting the reproduction rate.

8.7.3 Human Population Density and Malaria Prevalence in Vhembe District

The third block in Figure 8.1 (*Human Population Density Malaria Prevalence*) highlights the effect of population density on the prevalence of malaria. This is where we have the vector biting the host (human beings). In Chapter 5 the human population density of Vhembe District and its link with the number of malaria cases was analysed. It was established that areas with a high population density had higher malaria prevalence than areas with low population density, like Musina and Makhado Local Municipalities. The third block in Figure 8.1 then shows a division based on population density. The vector cycles will affect the population based on the density, which is a measure of the availability of a host. If the area has an increased amount of vectors and a high population density there is a high chance that malaria prevalence will be high. If an area has a high amount of vectors and a low population density, chances are that malaria prevalence will be low. Finally, if an area has a low vector population and a low human population density, it follows then that malaria prevalence will be low.

8.7.4 Malaria Management in Vhembe District

The conceptual framework in Figure 8.1 can, therefore, be applied in detecting villages in Vhembe District that are prone to high malaria prevalence. From a climate perspective, it has been established by this study that the climate parameters under study are interlinked, ultimately also in the way they affect malaria. Key climatic parameters will, therefore, need to be closely monitored per local municipality, with the understanding that the other non-key parameters still have an influence on malaria. The variables listed in Table 8.2 are, therefore, the main drivers (determinates) of malaria in each municipality as determined in this study based on annual and monthly data at either lag 0 or lag -1 month.

Using the malaria determinants in Table 8.2, monitoring of monthly data on the climate element malaria drivers can be conducted and a comparison for consolidation should be done every year. This will enable the improvement of the malaria EWS. Chapter 9 discusses the proposed EWS and management framework for Vhembe District, based on the key findings

obtained in this study. The chapter reviews previous frameworks, the missing links and how this study can complete such gaps with particular reference to the Vhembe District.

Table 8.2: The key climate drivers (determinants) of malaria in Vhembe District that are recommended for annual and monthly monitoring as part of an Early Warning System.

Municipality	Climate parameter determinants and time frame	
	Annual monitoring	Monthly monitoring
Musina	Relative Humidity *(at Vhembe District level)*	Minimum Temperature Air Temperature (Option)
Makhado	Maximum Temperature Air Temperature (Option)	Minimum Temperature Air Temperature (Option)
Thulamela	Relative Humidity Rainfall (Option)	Minimum Temperature Air Temperature (Option)
Mutale	Relative Humidity *(at Vhembe District level)*	Minimum Temperature Air Temperature (Option) *(At Vhembe District level)*
Vhembe District	Relative Humidity	Minimum Temperature Air Temperature (Option)

Chapter 9

CLIMATE-MALARIA MANAGEMENT FRAMEWORK AND CONCLUSION

9.1 Introduction

Though there is no ideal framework and different approaches are employed in coming up with management frameworks, the basis for developing this Climate-Malaria Management framework (CliMM) hinges on several authors including Martens and Thomas (2005) who indicated that for malaria models (and presumably frameworks), the more complicated they are, the higher the possibility of errors and bugs. Previous research has shown that small and transparent models or frameworks are often superior in that they provide similar results just like larger frameworks. In addition, the results from smaller models and frameworks will be obtained faster and offer ease of use (Martens and Thomas, 2005). In their concluding remarks in Early Warning System-Roll Back Malaria, Thompson and Connor (2001) allude to the fact that there is always a conflict between convenient simplicity and realistic complexity in developing models for epidemics. However, scientifically based approaches should submit to the principle of using the simplest models and seemingly management frameworks for approximations, especially where great care was taken during data collection and analysis as the case with this study. Hence management frameworks should be relatively simple and user friendly so that the decision makers, particularly medical institutions in this case, can use them without difficulties. In this study a good framework, as idealised by Frankel and Cage (2007), is supposed to:

- show where environmental factors fit into the wider context,
- clarify assumptions about causal relationships,
- show how environmental factors will influence outcomes,
- guide identification of outcomes, and
- guide the impact analysis (causal pathways).

CliMM will adopt an approach which helps identify and illustrate the causal relationships among the environmental factors (climate and altitude) and population density. This will be in line with the influence of the environmental factors (climate and altitude) on the malaria management programme and the successful achievement of the primary goal and objectives,

which is the elimination of malaria by 2030. The framework will help determine which factors will influence the programme and outline how each of these elements (altitude, population density, rainfall or Relative Humidity or temperature) might relate to and affect the outcomes. The assumptions and limitations during the design of the CliMM framework are stated and explained in Sections 9.5 and 9.6. Based on the work done, the CliMM framework is proposed for the management of malaria in the Vhembe District Municipality.

9.2 Current Climate-Malaria Frameworks

A number of climate-vector disease frameworks were under consideration at the time of this study by various organisations, which included the World Health Organisation (WHO) and institutions associated with it. The frameworks included those by Thompson and Connor (2001), Rodier *et al.* (2004), Senay and Verdin (2005), Connor and Matilla (2008), Gebreslasie (2010). No specific framework has been formally issued except for different parts within the whole malaria management and control system. Some of these frameworks are discussed in this section. The first framework is the one documented by Gebreslasie (2010), in a proposal on the development of an EWS for Swaziland using Earth Observations (EO). This framework is summarised in Figure 9.1.

The framework in Figure 9.1, as a conceptual framework, requires remote sensing data as input for the construction of a model to forecast epidemic risk. The forecasting is achieved through the use of predictive models to detect relationships with malaria. The main output of the framework in the assessment of malaria using remote sensing data is to give guidance on malaria control policies and decisions. This idea will be considered in setting up CliMM. However, the framework is a typical malaria mapping framework with not much consideration on what to do with the other outputs like malaria maps produced, or how the information obtained will be used within the EWS concept. For example, the mapping of malaria prone areas is an output which is stand alone and not an input into how the maps can be utilised to control the disease. There is no detail as to how the information will enhance malaria control. The framework is not clear on how climate data will be used within the EWS. For example, the climate thresholds which will trigger an action or a management response need to be known for a better and faster reaction.

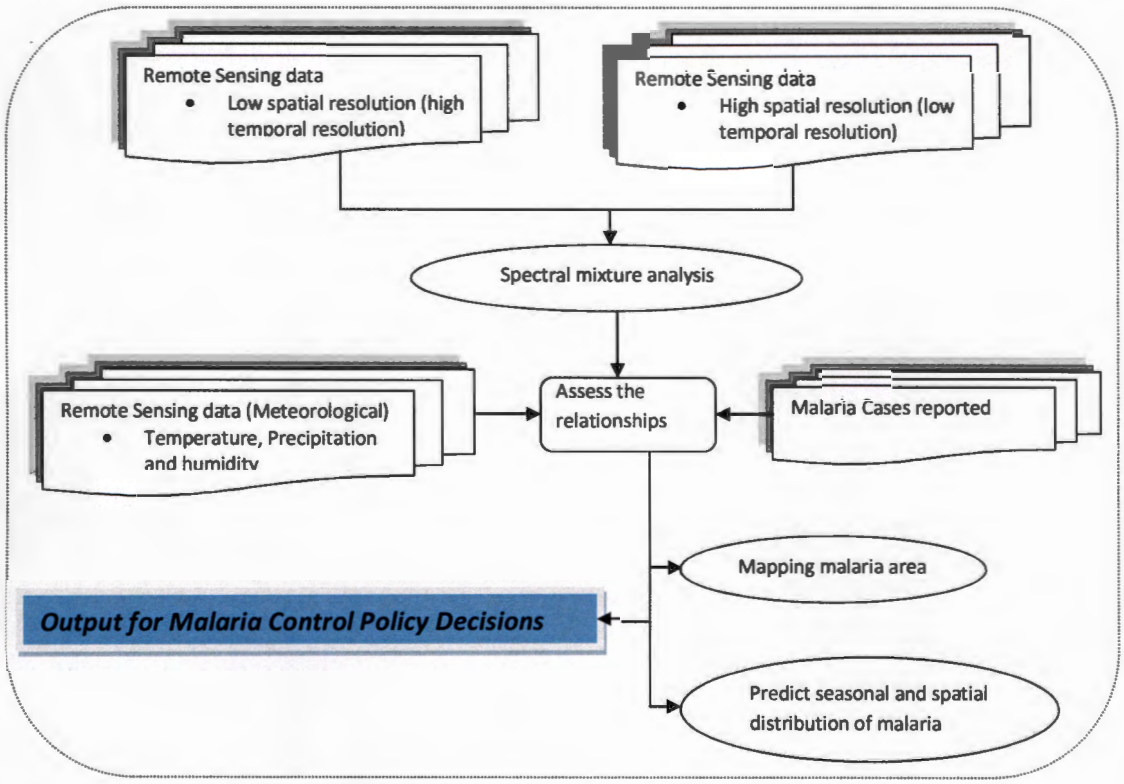


Figure 9.1: A malaria early warning system proposed framework for Swaziland (Gebreslasie, 2010).

Connor and Mantilla (2008) proposed an EWS framework for dengue, a disease that is similar to malaria since they are both vector borne diseases. Connor and Mantilla's proposed EWS is shown in Figure 9.2. Connor and Mantilla (2008) had ideas that support the findings of this current study in saying that climate variability plays a role in vector-borne diseases, pointing out that the abnormalities in these climate conditions trigger the epidemics. However, the study by Connor and Mantilla (2008) does not define the extent of the abnormality or anomaly which may trigger the epidemics. The current study has defined them for the Vhembe District. The critique on the epidemic EWS by Connor and Mantilla (2008) is based on a framework of five integrated components: (1) vulnerability assessment and monitoring, (2) seasonal climate forecasting, (3) environmental monitoring, (4) sentinel case surveillance, and (5) planning, preparedness and response. The framework starts from how the population is vulnerable to various diseases and how climate conditions contribute towards the vulnerability. Climate data used for forecasting the conditions is obtained from various sources and then considered in planning, preparedness, prevention and treatment response. The framework does not include the use of GIS mapping as a tool in malaria

management planning and/or preparedness as was the case in the current study. Most of the indicators on the framework were determined during the documentation of the Roll Back Malaria (RBM) Cabinet Project (Thompson and Connor, 2001) which makes them applicable in the current study. However, the framework is too generic and more detail is required to fit it into a specific area like Vhembe District.

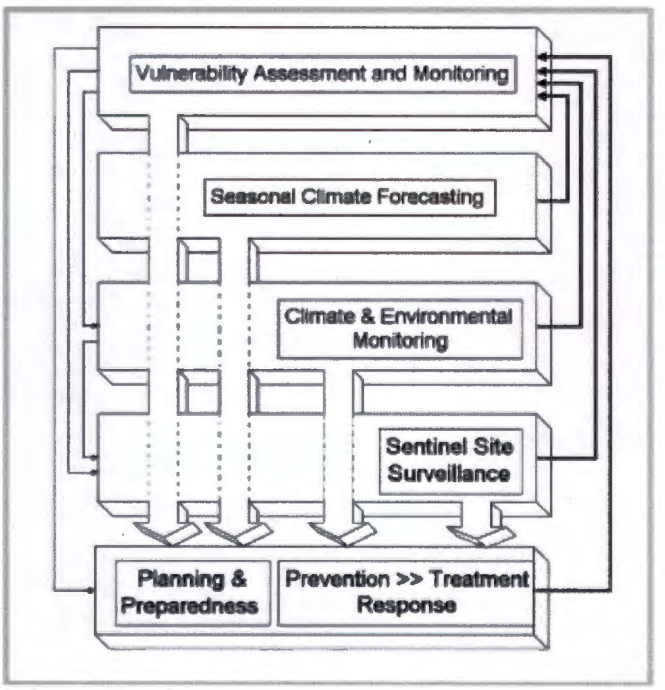


Figure 9.2: Conceptual framework for an integrated epidemic prediction, preparedness, prevention and response system for climate-sensitive diseases (Source: Connor and Mantilla, 2008).

The RBM project document gives an insight into some of the indicators and suggestions on designing district/country specific frameworks. It does not present clear, detailed and practical ready-to-use frameworks which can reliably be used for malaria predictions or decision making processes. One of the issues being emphasised in the report is the need to put in place thresholds specific to particular areas for EWS. This is why a climate management framework specific for Vhembe District is now being proposed in this current study, with climate anomaly thresholds for various climate indicators.

It is also necessary to review the WHO climate based early warning systems for infectious diseases report by Rodier *et al.* (2004). The report lays a foundation on the development of

disease EWS and also outlines how Famine Early Warning Systems (FEWS) can be used or referred to in the development of disease EWS by the health sector. Rodier *et al.* (2004), however, developed a guiding framework (shown in Figure 9.3) to be used as a foundation in future frameworks. The framework, though, appears incomplete in that some aspects are just hanging and not connected to any of the essential indicators. It merely lists the main determinants and indicators without defining the nature of response required when an epidemic is triggered, and even how the epidemic can be triggered.

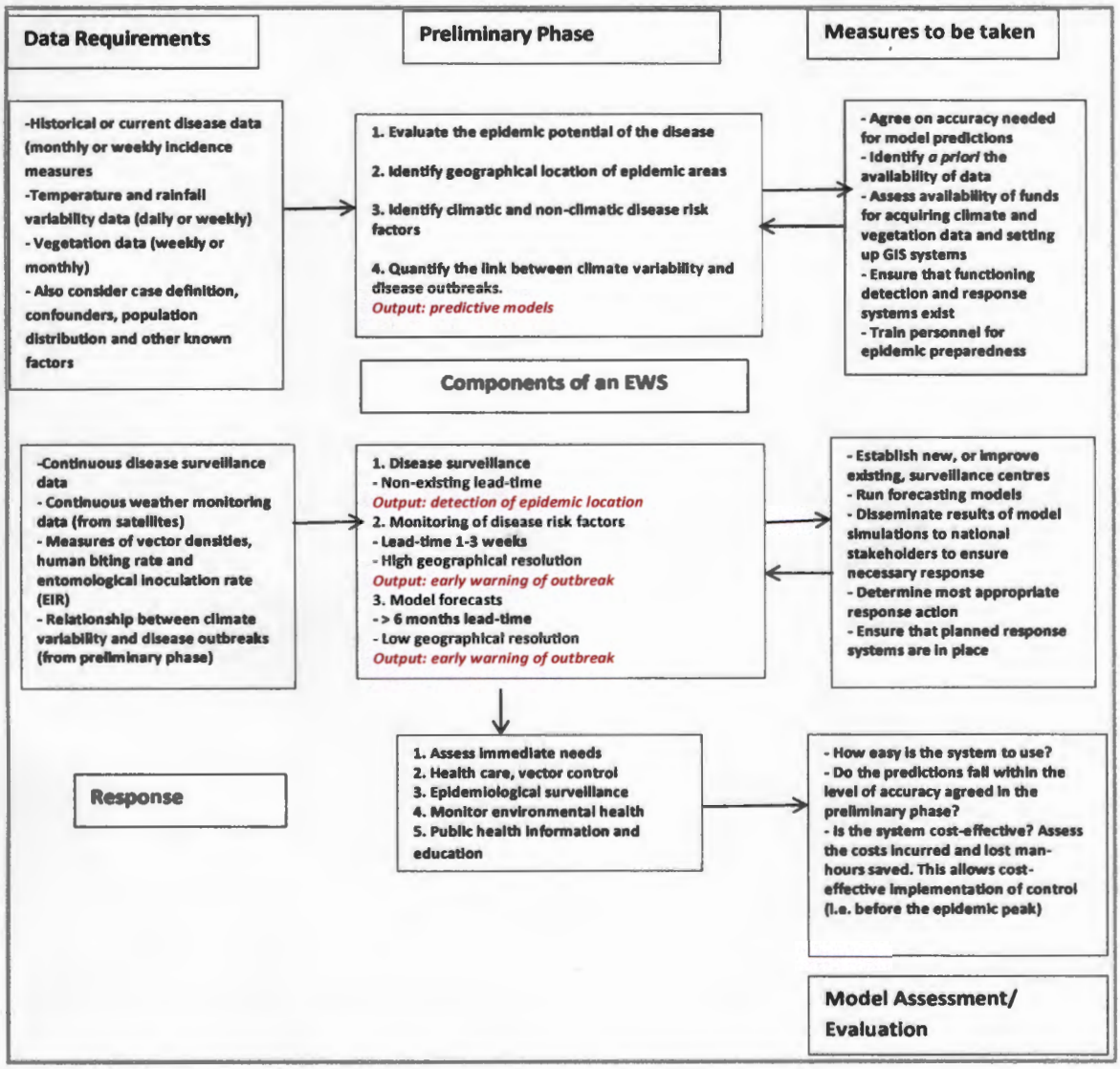


Figure 9.3: Guiding framework for developing climate-driven early warning systems for infectious diseases (Source: Rodier et al., 2004).

9.3 Proposed Climate-Malaria Management Framework (CliMM)

The Climate-Malaria Management Framework (CliMM) that is proposed for Vhembe District and its local municipalities is shown in Figure 9.4. The framework has been developed based on the findings in this study and the improved conceptual framework that is discussed in Section 8.6. The development of the CliMM framework also considered frameworks that were available at the time of the study and were being discussed in various institutions. Although there are other factors that may play a role in malaria prevalence, CliMM only considers those elements that were investigated in this study.

It is important to note that there are a number of other external factors which form part of the theoretical framework of malaria (shown in Figure 1.4) that were not investigated. This study, therefore, contributes towards the understanding of climate, topographic and demographic factors in how they fit into the existing malaria interventions, policies and procedures. Consideration has also been given to the existing frameworks so as to improve, refine and add on to what is currently in place. CliMM shows where environmental factors like climate and topography fit into the wider context, how the environmental factors influence the outcomes, and clear guidelines on the identification of outcomes and casual pathways are given. The assumptions about these causal relationships are clarified in Section 9.5.

9.4 Input Elements for CliMM

CliMM has been divided into three main sections, which are:

1. Data Capturing (climate data, malaria data, population data, GIS data),
2. Climate-Malaria Analysis (statistical analysis, relationships, interactions and mapping), and
3. Response (normal response and EWS response).

9.4.1 Data Capturing

Data capturing is the initial part of the CliMM and all subsequent steps rely on its accuracy. If inaccurate data is collected for processing, then erroneous predictions will be made, thereby leading to a flawed decision making processes. Three sets of data are required by CliMM as indicated in Figure 9.4. These are climate data, population data and malaria data.

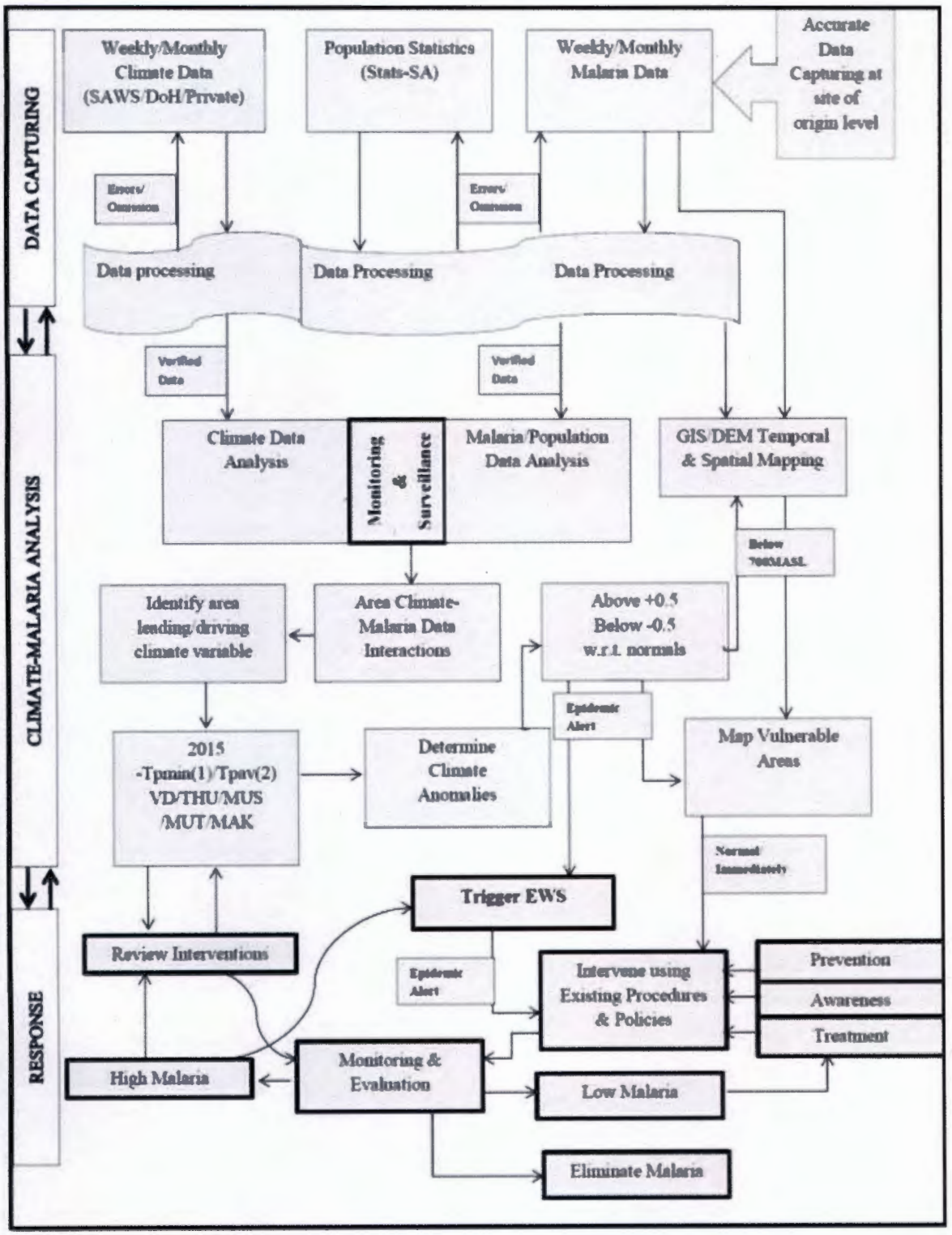


Figure 9.4: The proposed Climate-Malaria Management Framework (CliMM) for Vhembe District based on results from the study.

Climate data is obtained from the South African Weather Services (SAWS). There are also privately owned weather stations in Vhembe District, from where additional data can be obtained upon negotiation with the farmers who are responsible for them. The Department of Health can obtain portable measuring equipment to generate more weather data, which is proposed as one of the recommendations in this study. Population statistics data is obtained from Statistics South Africa (StatsSA). Ideally the population data should be at human settlement (village) level. Data on malaria cases is obtained from the various health facilities around Vhembe District and pooled at the Malaria Control Institute in Tzaneen. The place of origin of the infected individuals should be accurately noted to avoid allocating malaria cases to wrong places. The standard settlement names as documented by StatsSA or the Surveyor General should be strictly adhered to in capturing place names at the health facilities.

The next stage under data capturing is data processing. This involves quality control and validation of the raw data. Any omissions or mistakes should be referred back to the original documents received, and verified or clarified. If there are errors in the data they should be corrected before proceeding to the climate-malaria analysis step.

9.4.2 Climate-Malaria Analysis

The second step in CliMM involves the analysis of the processed data in determining the causal relationships and links between climate elements and malaria using statistical tools, and determining the leading climate variable. This has been done for Vhembe District in this study, using both monthly and annual data. It has been established that the minimum monthly temperature for all Municipalities and at Vhembe District level should be used as the option 1 determinant. If this information is not available, then the monthly air temperature (option 2) should be used. Monitoring for EWS should be done at lag -1 and lag 0.

For annual analyses reviews, the Relative Humidity should be used for Musina, Mutale, and Thulamela Local Municipality, and at the aggregated level of Vhembe District. The maximum temperature (option 1) or air temperature (option 2) can be used for Makhado. In using the climate determinants of malaria, what needs to be checked are the anomalies: whether they are above +0.5 or below -0.5 from the mean (normals). The normals for the area have also been established in this study. If the climate anomalies are still within allowable limits, the district can continue with their normal intervention processes. However, the

moment the limits are exceeded, an EWS is triggered which will then require extra resources to be mobilised. This is explained in step 3 (Response). The analysis stage also includes the mapping of areas reporting malaria so as to give information on the spatial distribution of the disease. The DoH should then set further limits and thresholds in the long-term that can trigger an EWS when malaria cases are consistently coming from the same place. When an EWS is triggered the latest plotted map available for the particular area (or local municipality) should then be retrieved and refined so as to identify the specific affected areas for management. This moves the framework process into Response mode.

9.4.3 Response

The response mode starts with triggering of the EWS. When this occurs, the malaria control units within the affected areas should be mobilised so as to intensify interventions. The interventions involve treatment, prevention and awareness campaigns (as documented in the guideline documents), processes and procedures (Baker *et al.*, 2009). Weekly monitoring and evaluating will need to be done. If, on monitoring and evaluation, it is found out that malaria has reduced to low, then the teams will get back to normal processes. If malaria is not detected over extended periods of time, then malaria has been eliminated. However, if malaria prevalence is still high, EWS will still be triggered and existing interventions continue until malaria is either eliminated or under control. On the other hand, if malaria cases remain high, intervention methods may then need to be reviewed in terms of policy and procedures. High numbers of cases may also require the review of the climate-malaria analysis to see if the leading determinants are still valid, otherwise re-analyse. The ultimate plan for the framework is that malaria gets eliminated from the area.

9.5 Justification of CliMM

Vhembe District and the southern Africa region have been grappling with malaria over the past decades. Millions of US dollars have been invested in malaria treatment, management and research. The aim is to eliminate malaria from the region by 2030, as stated in the Roll-Back-Malaria project document. Concerted efforts are required from everyone in order to achieve this feat. This study is, therefore, one of the many studies which have been carried out in the Southern Africa region as a way of contributing towards the body of knowledge that can be used to eliminate malaria. The CliMM framework has, therefore, been designed in a simple and user-friendly way to enable the people involved in malaria control and

management to be more focused and to quickly respond to the disease before it has affected a lot of people. Minimising the number of infected people will then make it easier to manage malaria and, in the short- to medium-term, eliminate the disease.

9.6 Assumptions for CliMM

A number of assumptions have been made in coming up with CliMM framework some of which were listed in Section 3.6. They include:

1. The current malaria control methods, which are based on the Department of Health's Guidelines for the Prevention of Malaria in South Africa (Baker *et al.*, 2009) and other related documents, are being followed and are effective in Vhembe District. Based on this assumption, therefore, the non-climate elements pertaining to the prevalence of malaria are assumed to be well managed in the study area.

2. The current malaria control and management processes will continue to be in place and applied effectively and efficiently.

3. Climate data for the area will continue to be captured accurately and more weather stations will be set up to enhance full coverage of the area.

4. Malaria data will be captured accurately and reported to the Malaria Control Institute in Tzaneen as soon as the cases are detected to enable a quick response before the disease spreads.

5. Other non-climate elements which have not been studied in this research will not have an excessive influence on malaria prevalence. In other words, the magnitude of influence by factors not analysed in this study should not be excessively altered.

9.7 Limitations of CliMM

The following limitations are noted in generating the CliMM framework:

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1. The weather stations are currently not uniformly distributed in the study area, and an improvement in the weather stations network can enhance the accuracy of the CliMM framework.

2. Consideration was not given to all the non-climate elements that can affect malaria except for the population density. This can affect the framework dynamics and response triggers.

3. The malaria cases that are reported are limited to cases of people who went to a medical facility for treatment. Some cases may not have been reported since some patients who have knowledge of the disease may have managed to treat themselves without reporting the case at a medical facility. Hence the threshold for triggering response may be altered if all cases, including self-medication, are reported.

4. The use of secondary data is also highly dependent on individual capturing accuracy. Hence, although quality control of the secondary data can be performed at the Malaria Control Institute, the assumption is that the original primary data was captured correctly.

5. At the time of the study, standardised baseline monthly 30-year normals for the various climate parameters (temperature, rainfall and Relative Humidity) for Vhembe District to give immediate monthly results were not available.

9.8 Suggestions for Further Research

Based on the parameters that were considered in this study and new extra information that was being collected in the study area at the time of the study, a multivariate mathematical model with best fit parameters may be generated. The model can be used to accurately predict the number of malaria cases per month under varying climate conditions and other related environmental factors in malaria hotspot villages. This will be a good extra tool for use in pro-active malaria management and control. Statistical modelling is used for the understanding and prediction of multi-factorial based events; as such, reproducibility, biological plausibility and robustness govern the applicability and effectiveness of each resultant model (Loha and Lindtjorn, 2010).

CliMM, as a malaria Early Warning System (EWS) framework, has been proposed to enable reliable predictions of malaria epidemics in Vhembe District using climate risk indicators like unusual increases or decreases in rainfall, temperature and Relative Humidity. However, producing accurate predictions using climate data remains a challenge (Loha Lindtjorn, 2010). This, according observations during this study, is mainly because of inadequate localised climate data. Availability of localised data eliminates errors caused by extrapolation. This is the main reason why there is need for a policy shift, as reiterated by Githeko (2009), to involve the DoH in the collection of climate data in their areas rather than always relying on SAWS. In the case of Vhembe District, portable multivariate equipment can be purchased for the measurement of temperature and Relative Humidity.

Additional research other related variables needs to be undertaken, like understanding the ecology of the area. It was noted during this research that there is a paucity of publications on two other interlinked factors that are key to malaria prevalence: the ecology and behaviour of humans, and the ecology and behaviour of vectors. Rieter (2008) noted this, and emphasised the importance of this kind of research. Ecological studies will include detailed investigations on relationships between malaria and water resources, as well as understanding relationships between malaria, human behaviour and human culture. Malaria vector behaviour in relation to ecological issues like hydrology, land cover, land use and the influence of changes in patterns of these will require further investigation as well.

The SAWS should establish the baseline monthly 30-year normals for the various climate parameters (temperature, rainfall and Relative Humidity) for Vhembe District and its local municipalities. This will enhance the immediate access and availability of data that can be used to establish monthly anomalies, which in turn can be used to detect climate anomalies for use in the Early Warning System and ultimately malaria control. Based on the current study, annual anomalies can be used for medium-term management.

9.9 Conclusion

It can be noted from the current study that malaria showed a statistically significant decreasing trend in the Vhembe District in the period 1998 to 2010. A similar decreasing trend was observed on the amount of rainfall, and in the Relative Humidity. Although there

are other factors contributing to the prevalence of malaria in Vhembe District, climatic conditions remain as one of the major factors. On the other hand, it can be inferred that the decrease in malaria that was determined in this study was being influenced by change and variability in climate conditions and may not necessarily be due to management strategies since these had not been changed between 1998 and 2010. The current strategies against malaria at the time of the study were not pro-active but reactive. Treatment of malaria in a particular area or village was based on the number of malaria cases detected in that village or area in the previous year. However, the climate conditions as observed in the study area were not static but variable, hence malaria would then emerge in a different area or village which would not have been treated and/or managed.

This study has managed to establish that climate change and variability plays a key role in influencing malaria in Vhembe District. Several findings in this study can be applied to support the medical efforts aimed at malaria, thereby helping towards minimizing and ultimately eliminating malaria from Vhembe District by 2030. In the circumstances at the time of this study, the weather patterns were helping the malaria control cause since there was a general decreasing trend in the amount of rainfall, a decreasing trend in Relative Humidity and a general increasing trend in air and maximum temperatures in the area under study. For the purposes of this study, Relative Humidity was found to be the climate determinant for malaria prevalence based on annual data, and the monthly minimum temperature was the leading determinant based on monthly data except in Makhado Local Municipality where the monthly air temperature should be considered. If the trends of a decrease in rainfall and Relative Humidity persist, an increase in temperature as observed may have a positive impact on the reduction of malaria by drying off pools rapidly and reducing the survival of adult mosquitoes.

It was established in this study that areas with a high population density had higher malaria cases than those with a lower population density. However, since people cannot be separated or eliminated from their settlements, the best way forward is to equip the people with information on how to deal with malaria. The people need to have an understanding of the current malaria management tools in detail, especially the people in the malaria hotspot villages.

Periods following a low rainfall (dry period) need very close monitoring. This is because it was in this study that the number of malaria cases in the study area increased immediately after such an event as soon as climate elements become suitable for breeding of mosquitoes. This was the case in 2003 and 2006 when the number of malaria shot up following a dry season. Based on other related studies performed in the area, it is expected that more dry years are coming and hence structures need to be put in place in order to manage *the-year-after-dry* period more effectively.

Two points are of note with regards to Musina and Makhado Local Municipalities. Firstly, analysis of the period under study highlighted a statistically significant decrease in malaria and mostly increasing trends in the annual temperature variables in Makhado and Musina. This seems to be in agreement with the findings by Basurko *et al.*, (2011) that when temperatures become too high, malaria transmission becomes negatively affected. Secondly however, an analysis of data for Musina and Makhado from 2005 to 2010 revealed a generally increasing trend in malaria prevalence. This revelation may then indicate how increasing temperatures may result in an increase in vector borne diseases.

CliMM should set a base for the development of specific frameworks for other malaria prone areas in the future, possibly in conjunction with different statistical tools like ARIMA. Such frameworks should be cognisant of the fact that the locality is not the same and hence each area should have its own specific framework for predicting malaria in an EWS.

9.10 General Recommendations on Malaria Management in Vhembe District

The following general recommendations can be made about the malaria situation in Vhembe District:

1. In order to effectively deal with malaria in Vhembe District, climate variability must be included as an important factor during the management of malaria, for example when and where to spray in the various villages. Hotspot villages should be identified based on this study, some of which have been identified in this study (Chapter 7). A systematic management programme which factors in climate conditions in those villages should then be established.

2. Based on the work in this research, malaria vulnerability mapping should be carried out to identify areas that malaria is likely to entrench itself in as the climate changes. The DoH, in collaboration with the SAWS, should set up more weather stations in Vhembe District in order to generate more climate data which can be used in used in identifying malaria-vulnerable areas. Alternatively, portable, multivariate and easy-to-use climate measurement equipment should be purchased for all medical centres in Vhembe District. This will improve the pool of climate data.

3. The SAWS needs to establish the baseline monthly 30-year normals for the various climate parameters (temperature, rainfall and Relative Humidity) in Vhembe District and its local municipalities. This will enhance the immediate access and availability of data that can be used to establish monthly anomalies, which in turn can be used to detect climate anomalies for use in the Early Warning System and, ultimately, in the control of malaria. Based on the current study, annual anomalies can be used for medium-term management of malaria.

4. Some of the village names captured by the Department of Health (DoH) when recording malaria cases are not the same as those on the national Surveyor General database or are captured slightly differently by the health institutions. The Department should, therefore, establish a coding system that is in line with the national system for all the villages in Vhembe District, so as to enable ease of reference and mapping in future. Training of all department personnel involved in data capturing should be done regularly.

5. This study can be used in furthering research on integrated malaria control with the intent of developing cost effective malaria control strategies, policies and procedures.

6. Using the linear regression models obtained in this study, further research using the latest data can help in refining the mathematical models and testing their validity if there are no time constraints.

7. It is recommended that ecologically sensitive areas around water bodies in locations identified as malaria hotspots be included in malaria control programmes for treatment at source during the malaria season for a period of time to avoid the inhabitants being reactive when malaria re-surfaces.

8. There is need for refined demographic data at the village level that is available at more frequent interval than the 5-year censuses, especially in malaria hotspot areas. This will enable the availability of enough information that will enhance the management of malaria.

9.11 Contribution of the Study to the Body of Knowledge

The study has made the following contributions to the body of knowledge:

1. A specific conceptual Climate-Malaria Management framework (CliMM) was designed, which takes into consideration area-climate factors in the management of malaria in Vhembe District. This could be useful in processes and methodologies used by the provincial malaria team. The framework can also be used by other nearby countries within Southern Africa that are prone to malaria.

2. This is one of very few comprehensive studies conducted in Vhembe District at a local municipal level which looks at the effect of climate elements and malaria. It is the first study to consider 5 different climate variables (rainfall, Relative Humidity, air temperature, maximum temperature and minimum temperature) at the same time in trying to understand malaria-climate relationships in Vhembe District.

3. The study established that malaria trends are associated with different climate parameters based on medium-term or short-term relationships. The strength of the relationships however differs from area to area and from one climate zone to another. Most of the malaria cases in Vhembe District are found within the humid zone, followed by the sub-humid zone with fewer malaria cases detected in the semi-arid zone.

4. At the monthly (short-term) data summary level for the period 1998-2010, most of the climate elements were highly correlated with malaria. However, the driving monthly level climate element for Musina and Makhado Local Municipalities was the air temperature; and the minimum temperature drives malaria in Thulamela Local Municipality and at the aggregated level of Vhembe District.

5. Significant monthly relationships between malaria and climate conditions, in order of relationship strength from the strongest, were identified in Musina Local Municipality at lag -1month as air temperature, minimum temperature, maximum temperature then rainfall; in Makhado Local Municipality at lag 0 month as air temperature, minimum temperature, maximum temperature, rainfall then Relative Humidity; in Thulamela Local Municipality at lag 0 month as minimum temperature, air temperature, maximum temperature then rainfall; in Mutale, rainfall; and as minimum temperature, air temperature, maximum temperature then rainfall at the aggregated level of Vhembe District at lag 0 month.

6. Using GIS techniques the study established that there was a pocket nature in the prevalence and distribution of malaria in Vhembe, thereby identifying some of the highly malaria prone areas in the district.

7. The study successfully applied various research techniques which included standardization, linear regression, Pearson correlation, cross-correlation, the Kolmogorov-Smirnov test corrected with the Lilliefors test and Shapiro-Wilk (SW) Test for normality, Mann-Kendall trend analysis and GIS.

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APPENDIX 1
List of Weather Stations in Vhembe District

Number in Figure 3.1	Local Municipality	Station Name	Latitude	Longitude
1	Musina	FOLONHODWE [R]	-22.575	30.4275
3	Musina	MESSINA MACUVELLE [TRH]	-22.27	29.9
4	Musina	MESSINA [TR]	-22.33	30.05
5	Musina	PONTDRIFT [R]	-22.22	29.15
6	Musina	TEBA PAFURI [R]	-22.45	30.32
7	Musina	TSHIPISE A [R]	-22.6	30.17
8	Musina	TSHIPISE B [TRH]	-22.62	30.15
9	Makhado	BANDELIERKOP [R]	-23.32	29.8
10	Makhado	DZANANI BIABA AGRIC [R]	-22.8944	30.0389
11	Makhado	ELIM – HOSP [R]	-23.1519	30.0586
12	Makhado	ENTABENI BOS [R]	-23	30.27
13	Makhado	GOEDEHOOP [R]	-23.0798	30.1
14	Makhado	HANGLIP [R]	-23.02	29.92
15	Makhado	JOUBERTSTROOM PLANTATION [R]	-22.9797	30.1497
16	Makhado	KLEINFONTEIN [R]	-23.3244	30.0303
17	Makhado	KLEIN AUSTRALIE [R]	-23.05	30.22
18	Makhado	LA-ROCHELLE-SAPEKOE [TRH]	-23.13	30.17
19	Makhado	LETABA WOODLANDS [R]	-23.217	30.217
20	Makhado	LEVUBU [TRH]	-23.0798	30.28
21	Makhado	LOUIS TRICHARDT [R]	-23.05	29.9
22	Makhado	MARA [TR]	-23.15	29.57
23	Makhado	MARA-POL [R]	-23.0799	29.38
24	Makhado	MATIWA [R]	-22.98	30.28
25	Makhado	MPHEFU [R]	-22.8728	30.1231
26	Makhado	NOOITGEDACHT [R]	-23.07	30.2
27	Makhado	ROODEWAL BOS ARS [R]	-23	30.02
28	Makhado	ROSSBACH [R]	-23.2114	30.0522
29	Makhado	SHEFEERA [R]	-23.03	30.12
30	Makhado	SILOAM HOSPITAL [TR]	-22.9	30.18
31	Makhado	THOHOYANDOU WO [TR]	-23.0872	30.3844
32	Makhado	TSIANDA [R]	-23.05	30.35

APPENDIX 1 (*Continued*)

List of Weather Stations in Vhembe District

Number in Figure 3.1	Local Municipality	Station Name	Latitude	Longitude
33	Makhado	UNA – AGR [R]	-23.12	29.67
34	Makhado	VREEMDELING [R]	-22.96	30.02
35	Makhado	VUWANI AGRICULTURE SERVICE CENTRE [R]	-23.1228	30.4231
36	Makhado	WATERPOORT [R]	-22.9	29.633
37	Makhado	WATERPOORT BRENHILDE [TRH]	-22.67	29.5
38	Makhado	ZWARTRANDJES [R]	-23.23	29.85
39	Thulamela	MUKUMBANI TEA – VENDA [TRH]	-22.92	30.4
40	Thulamela	PALMARYVILLE [R]	-22.983	30.433
41	Thulamela	PHASWANA-SAPEKOE [TRH]	-22.85	30.72
42	Thulamela	PHIPHIDI [R]	-22.95	30.4
43	Thulamela	SHINGWEDZI VLAKTEPLAAS [R]	-22.867	30.217
44	Thulamela	SIRHENI [TRH]	-22.95	30.22
45	Thulamela	THOHOYANDOU [TRH]	-22.97	30.5
46	Thulamela	TSHIVHASIE TEA VENDA [TR]	-22.97	30.35
47	Thulamela	VONDO – BOS [R]	-22.933	30.333
48	Mutale	RAMBUDA [R]	-22.78920	30.43440
49	Mutale	TSHANDAMA [TRH]	-22.77000	30.53000
50	Mutale	KRUGERWILD	-23.16690	30.95000