

**The Use of Geographic Information Systems to Identify
the Winter Breeding Sites of the *Anopheles* Mosquitoes
in Northern KwaZulu-Natal**

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Abstract

Malaria incidence in the province of KwaZulu-Natal is influenced by seasonal climatic variations, drug and insecticide resistance, and population mobility within the region. Current control methods are directed at the malaria vector, the *Anopheles arabiensis* mosquito, through indoor residual spraying. Control of the dominant malaria parasite, *Plasmodium falciparum*, is done by treating the symptomatic and asymptomatic parasite carriers with prophylactic medications. A ceiling of effectiveness with current control efforts have been reached, necessitating the search for supplementary methods.

The study area is located in the Ingwavuma District of northern KwaZulu-Natal which adjoins the Mozambique border to the north, and includes the malaria areas of Ndumu and Mkanisdrift. Homestead location coordinates were obtained with Global Positioning System (GPS) receivers and linked to malaria case records through homestead numbers which have been allocated to all homes in the area. The study includes the cases reported during 1993 and 1994 as this was the only data available when the project commenced in 1995.

A geographic information system was used to undertake the spatial analysis to test the hypothesis that the malaria vector, *Anopheles arabiensis*, is localised to certain breeding sites during the winter months in northern KwaZulu-Natal. Identification of these winter 'seed point' breeding sites from which the onset of transmission spreads during the following malaria season, will allow them to be targeted for winter larval control measures. This will contribute to limiting the distribution and lowering the levels of malaria intensity in the region as a whole. The analysis also provided evidence of the maximum likely flight distance of the female mosquito given an adequate host supply in close proximity, thereby identifying those areas requiring additional prevention and control activities. Understanding the local epidemiology of the disease was necessary to determine which monthly malaria cases to include in order to identify the winter breeding sites, due to seasonal variations in the length of the mosquitoes life cycle.

Medical geography, as a sub-discipline of geography, combines investigating spatial patterns with the epidemiological principles of medicine and zoology through scientific methods. It is traditionally divided into two approaches, the first being the geography of disease, under which this research falls, and the second being the geography of health care. The integration of the two

disciplines allowed the results of the analysis to be presented in maps, graphs and tables in order to describe, interpret, test and explain possible associations between the location of the potential breeding sites and the homesteads at which the malaria cases were reported. The potential breeding sites consisted of the perennial pans, non-perennial pans and dams. Zones were created in the GIS at one kilometre intervals from these sites up to a distance of four kilometres, and the number of cases within each zone determined and corrected for the population at risk per 1000 people for comparative purposes. This spatial analysis was followed by the statistical analysis of the results to verify the findings.

The results of the spatial and statistical analysis indicated that the perennial pans were used as the winter 'seed point' breeding sites, and that the maximum likely flight distance of the female mosquito, given an adequate host supply in close proximity, is 4 kilometres. The results will be made available to the local malaria research and control community who will assess the feasibility of implementing supplementary control measures.

Preface

This study represents original work done by the author, and has not been submitted in any form to any University. The work of people who have contributed to this research have been duly acknowledged in the text.

The work was carried out under the supervision Dr Dianne Scott, School of Life and Environmental Sciences (Geography), University of Natal, Durban, and in its early stages, by Dr Dave Le Sueur, Malaria Research Programme, Medical Research Council, Durban.

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List of Acronyms

CAD	Computer Aided Drawing
DBMS	Data Base Management System
DDT	Dichloro-diphenyl-trichloroethylene
GIS	Geographic Information Systems
GPS	Global Positioning Systems
MIS	Malaria Information System
MCP	Malaria Control Programme
MRC	Medical Research Council
MRP	Malaria Research Programme
PHC	Primary Health Care
PIN	Permanent Identity Number
SA	South Africa
UN	United Nations
WHO	World Health Organisation

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaria affects more people than does any other vector-borne disease, its continuation being dependant on the presence of malaria parasites, mosquitos, human hosts and suitable environmental conditions (Brêtas, 1994). Africa has the highest levels of malaria in the world, as 400 of the 500 million people at risk live in sub-Saharan Africa (Nevill, 1990). The World Health Organisation (WHO) estimates that between 270 and 480 million clinical malaria cases occur each year, which includes more than one attack per person, 140 - 280 million of whom are children under the age of five. Of the estimated 1.4 to 2.6 million deaths caused by malaria each year, approximately one million are children under the age of five. Studies have indicated that there has been little change in these figures in recent years, highlighting the need to continue investigating additional ways to control and manage the disease (Nevill, 1990; Hempel, 1995a). The WHO's budget of US\$ 118 million (R600 million) for the control and prevention of malaria during 1994-95 indicates the perceived severity of the problem (WHO, 1993a).

The environmental conditions necessary for the continued transmission of malaria are high temperatures and extended periods of rainfall in order to form pools of surface water that provide suitable breeding sites for the mosquitos. The eastern and northern region of South Africa experience seasonal malaria due to the climatic conditions, with the dry and cooler winter months resulting in a reduction in the number and distribution of breeding sites until the arrival of the spring and summer rains (le Sueur and Sharp, 1988). The area of northern KwaZulu-Natal province was selected for this study as it experiences the highest malaria incidence in the province. The availability of potential breeding sites throughout the year and the continued reintroduction of the malaria parasite through the movement of people from neighbouring Mozambique provide ideal conditions for continuing transmission.

The Malaria Research Programme (MRP) of the Medical Research Council (MRC) in Durban, South Africa, has a mandate to conduct relevant malaria research; undertake collaborative projects and training programmes in order to establish links with other southern African authorities; and to facilitate information exchange between policy makers, researchers and health workers (MRC, NMRP pamphlet, undated). Its close working relationship with the provincial Department of Health's Malaria Control Programme (MCP) in northern KwaZulu-Natal over the years, has resulted in an exchange of information that has benefited both organisations, the data from the MCP being pivotal to the work of the MRP. This project aims to provide a contribution to the research of the MRP and to assist the efforts of the MCP in reducing the number of people afflicted by the disease.

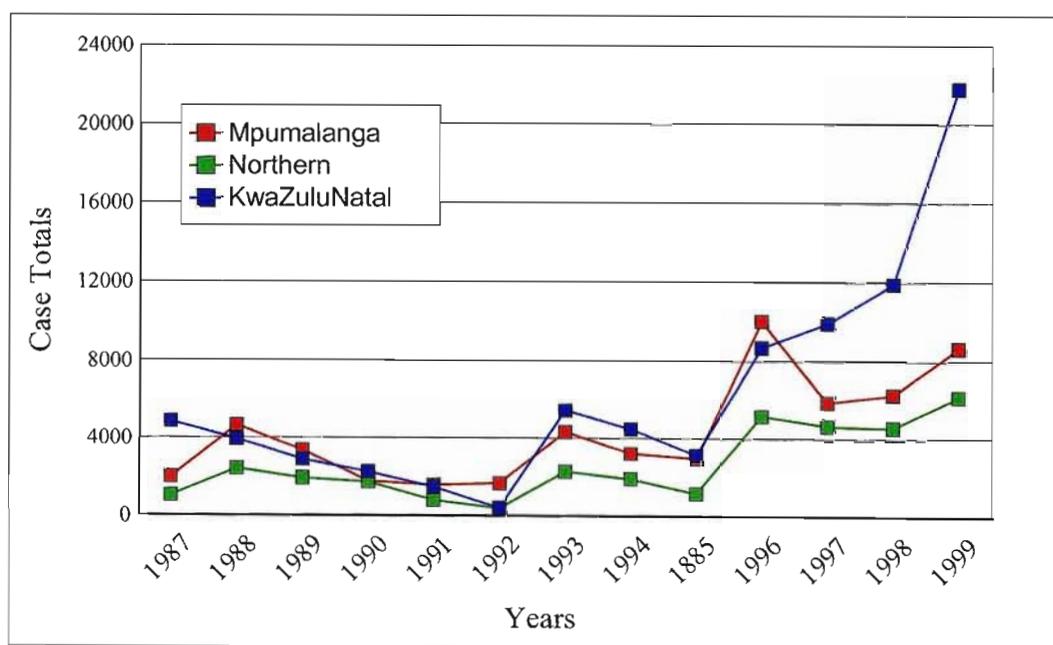
Medical Geography is a sub-discipline of geography, with the spatial investigation of diseases and health care being undertaken by a wide range of disciplines, particularly medical practitioners. The application of Geographic Information Systems (GIS) to investigating the spatial relationships associated with the distribution of environmental diseases is a recent but growing field. GIS has been used for this study due to its ability to manipulate and display geographical features and statistical (tabular) data in a manner that simulates reality and reduces time and space to manageable proportions.

The research undertaken for this thesis aims to provide an additional tool with which to control and manage malaria by identifying the winter breeding sites to which larvicides can be applied. Reducing the number of larvae that reach adulthood will limit the number of mosquitoes that survive into summer and thereby delay the onset of the peak malaria season (April and May) which will be truncated by the onset of the cooler winter months (late May, June). This will prevent the current high number of cases presenting during April and May due to fewer mosquitoes being available to transmit the disease. Reducing the effects of malaria has implications for the health of the local population, rationalising the resources spent on malaria control, and encouraging tourism and investment in the area.

1.2 The Nature of the Problem

Despite continuous and costly efforts to combat malaria in the three malarious provinces of South Africa, namely KwaZulu-Natal, Mpumalanga and Northern Province, the number of reported malaria cases has not stabilised at a consistently low level, but tends to fluctuate with annual climatic variations (Figure 1.1). For the 2000/2001 malaria season, R90 million (\$12 million) will be spent on malaria control in South Africa (pers comm. Maharaj, 2000). A ceiling of effectiveness with current control methods would therefore seem to have been reached (Sharp *et al*, 1988). Provincial control efforts are hindered by the annual re-infestation of the malaria parasite due to cross-border movement by asymptomatic immune Mozambicans and non-immune South Africans (Ngxongo, 1993; Freese *et al*, 1994). Parasite drug resistance and changes in the vectors' resting behaviour in response to indoor residual spraying have prompted the renewed search for supplementary methods of control (Sharp and le Sueur, 1991; Freese *et al*, 1994).

Figure 1.1 Malaria Case Totals for Mpumalanga, KwaZulu-Natal and Northern Province (Source: MRP. 2000)



While it is acknowledged that the breeding sites during the dryer winter are localised to more marginal sites in the region, these have not all been identified. The blanket application of larvicides to all potential breeding sites during winter would be costly and labour-intensive,

highlighting the need to identify those sites which can be targeted for additional control efforts. The availability of many possible breeding sites during the remainder of the year makes the application of larvicides unfeasible during the months of November to June. The continuous cross-border movement of people between northern KwaZulu-Natal and southern Mozambique, in which no malaria control activities occur, results in localised immunity due to increased exposure to the malaria parasite and the availability of a reservoir of parasites throughout the year. This effects the reporting of the disease in that relatively few people present with malaria symptoms at clinics in what should be a high risk area. This has the potential to provide an inaccurate impression of the nature of the disease and resulted in both the symptomatic and asymptomatic parasite carriers being included in this study.

1.3 Aim

This study used GIS to assist in testing the hypothesis that the malaria vector (*Anopheles arabiensis*) is localised to certain breeding sites during winter in northern KwaZulu-Natal, and that these can be identified by mapping them in relation to the July to December malaria cases. Undertaking a statistical analyses of the proximity of these breeding sites to the malaria cases will (1) substantiate the spatial analysis of these sites, and (2) provide evidence of the maximum likely distance that female mosquitoes will fly for a blood meal given an adequate host population in close proximity.

The implications of this hypothesis are that:

1. Localised winter breeding sites act as 'seed points' from which the onset of transmission spreads in the area during the following malaria season.
2. Should the hypothesis be valid, these sites can be targeted for winter larval control measures.
3. Reducing malaria in this high incidence area will contribute to limiting the distribution and lowering the levels of malaria intensity in the region.
4. Establishing the likely maximum flight distances of mosquitoes to blood meals will identify those people most at risk as well as those areas requiring additional prevention and control activities.

1.4 Objectives

The objectives of the study are :

1. To understand the role of the participants in malaria life cycle (parasite, mosquito, human host) in order to take the local epidemiology of the disease into account in determining the methodology.
2. To review the development of malaria control both globally and locally in order to establish the viability of applying larvicides to winter breeding sites, and to provide an overview of the current situation in the study area.
3. To identify the location of all the potential breeding sites within the study area.
4. To determine the population at risk in one kilometre intervals zones up to and beyond a distance of four kilometres from the potential breeding sites.
5. To determine whether it is possible to identify, through spatial analysis, those breeding sites around which malaria cases are reported at the start of the malaria season.
6. To statistically compare the number of passive and active cases within the one kilometre zones up to and beyond a distance of four kilometres, corrected for the population at risk, in relation to their proximity to the potential breeding sites.

1.5 Study Outline

Understanding the role of the malaria parasite and mosquito vector in perpetuating malaria has formed the basis of the current methods of control. While efforts have been made for many centuries to prevent and control its harmful effects, those currently used need to be continually re-evaluated in the light of increasing incidence of drug and insecticide resistance as well as changes in the mosquitoes behaviour.

The background to this research is presented in Chapters 2 and 3, the former reviewing the epidemiology of malaria, and the latter reviewing the global malaria history and control efforts. The effects of malaria on society are outlined in Chapter 2 as well as the life cycle of the malaria parasite and vector, the conditions necessary for their survival, and some of the human influences

on the distribution of the disease. These factors are important in determining which monthly case data should be used to identify the winter breeding sites, given the variations between the summer and winter duration of the mosquitoes life which affects the length of time from when the eggs are laid until the disease symptoms present in the host. The characteristics of the potential winter breeding sites are identified and the studies that have been undertaken to establish maximum likely flight distances reviewed. Malaria is an environmental disease, its distribution and level of intensity being dependant on factors such as rainfall, temperature, altitude, the availability of suitable breeding conditions and the presence of mosquito vectors and human hosts (Molineaux, 1988).

An overview of the use of larvicides and role of the WHO and the milestones that have been achieved in combatting the disease are outlined in Chapter 3 in order to place the current local situation in its historical perspective. A history of the control efforts and the and current control initiatives in the province of KwaZulu-Natal which fall within the broader global framework of efforts to limit the distribution and effects of the disease are reviewed. The chapter outlines the geographical location of the study areas and describes the environmental conditions that effects the transmission of malaria in the area. Case detection and data collection methods are outlined as well as their limitations. The data for 1993 and 1994 was used for this project due to the relevant data needed to undertake this study only being available for these two years when the project started in 1995.

The dispersed nature of the rural homesteads (a number of structures in which an extended family usually lives as a unit) that fall under the jurisdiction of the MCP, and the lack of an address system in the region, has necessitated the development of a homestead numbering system (le Sueur *et al*, 1997). The use of Global Positioning Systems (GPS) and GIS has allowed the coordinate locations of the most likely place of infection (the homestead) and the potential breeding sites to be obtained and displayed, and for relationships between the two to be explored. The availability of 'seed point' breeding sites during the winter months to which the mosquitoes are localised, results in the seasonal spread of the disease to the more numerous and dispersed sites further south with the onset of the spring rains (Stuttaford, 1992; le Sueur *et al*, 1997). Accurate and reliable information forms the basis of the control strategy, the data being collected by the field and support staff of the MCP at the Department of Health's regional office in the

northern town of Jozini. Malaria is a notifiable disease in South Africa, necessitating each case to be reported to the Department of Health. This data is made available to the MRP and forms the basis of their Malaria Information System which is housed in their Durban office (le Sueur *et al*, 1997).

Medical geography is reviewed in Chapter 4 as well as the relevant literature in which GIS and satellite technology have been used to investigate the spatial patterns of diseases, particularly malaria. Medical geography combines the traditional methods of geography, namely, to describe and interpret, largely through the use of maps to display spatial relationships, with the scientific principles and methods of epidemiology, which aim to test and explain, in an order to find proof of causal relationships. This thesis falls within the traditional geography of disease approach of medical geography. This approach tends to be divided between describing disease patterns and their diffusion, and finding causal relationships between variables and spatial patterns, the latter being the focus of investigation for this research. GPS and GIS have been used since the early 1990's by the MRP to assist with their research and the work of the MCP, an overview of which is provided (le Sueur *et al*, 1995; le Sueur *et al*, 1997).

The methodology is presented in Chapter 5, with GIS being used to integrate spatial and statistical data which were stored, managed, modelled, displayed and the results analysed. The analysis consisted firstly of a spatial investigation of relationship between the proximity of the potential breeding sites and the location of the reported cases, and was followed by a statistical analysis of the results to establish a causal relationship between them. For the purposes of this study, the calendar year was divided into two halves, a low season (July to December) and a high season (January to June). This was done due to the extended life cycle of the mosquito during the dryer, cooler winter months (May to September) which results in a delay of approximately two months from the time an egg is laid until an infected person presents with the symptoms of the disease. Understanding the local epidemiology of the disease is therefore important to determine the variables that need to be included in the modelling as well as for establishing the most appropriate methodology. The results of the spatial and statistical analysis to describe, interpret, test and explain the resulting relationships, are presented on maps, graphs and tables. Wilken (1992, 55) states that "GIS technology represents the technological underpinnings for achieving environmentally responsible decision making". Ensuring the reliability of the analysis

will result in sound management decisions being made which will reduce mortality and morbidity in the province.

The results of the analysis are presented in Chapter 6 followed by the conclusion and recommendations in Chapter. The validity of the findings and the stated hypothesis is assessed, as well as the suitability of using the GIS and the described methodology. Recommendations are made regarding which breeding sites should be targeted for larval control due to them acting 'seed point' breeding sites during winter, as well as other research issues that may have arisen in the course of this thesis. The findings will be made available to the MCP, the scientists of the MRP and the broader scientific community.

The analysis is presented on the following assumptions:

1. The number of cases is incomplete due to missing area, sector and homestead information. However, the effect of the missing data on the results cannot be determined.
2. The rivers were not taken into consideration as a source of potential breeding sites but it is acknowledged that temporary pools along their banks may provide suitable sites.
3. The effect of wind direction and speed on the distribution of the cases could not be taken into account. While mosquitoes tend not to fly when it is windy, it is difficult to determine to what extent their flight direction and distance are affected by the wind.
4. The classification of the water bodies was based on the categorisation from the 1:10 000 orthophotos, 1:50 000 and 1:250 000 topocadastral maps from the Surveyor General and are assumed to be correct.
5. The distribution of the water bodies was assumed to be the same over both years as was their classification into the different categories e.g. perennial pans.
6. Malaria was assumed to have been contracted at the homesteads at which people reside.
7. Water bodies in Mozambique that are in close proximity to the border with South Africa were not included in the study, but may well have provided breeding sites for mosquitoes that infected people in the Mbagweni Corridor
8. The borrow-pit along the road were not included in the study as they were not visible on the maps from which the spatial data was obtained.

1.6 Conclusion

Integrating the spatial concepts of geography with the scientific methods of epidemiology will allow a description of the likely winter breeding sites, through an interpretation of the spatial analysis undertaken using GIS. This will be followed by a statistical analysis of the results in order to test and explain any possible association between the location of the breeding sites and those of the malaria cases. Identifying the winter breeding sites will not only reduce the number of local cases, but also lower the malaria incidence in the surrounding region to the south. Reducing the incidence of malaria in the province will prevent unnecessary deaths, reduce the suffering caused by the disease and the expenditure on treating the infected, lower the budgetary requirements of the MCP, and generally improve the quality of life of those living in the malarious areas.

CHAPTER 2

MALARIA EPIDEMIOLOGY : PARASITE, VECTOR AND HOST

2.1 Introduction

In order to investigate the spatial relationships between the locations of the potential winter breeding sites and the homesteads at which malaria cases were reported, it is necessary to understand the factors that affect these patterns. This falls in the field of epidemiology which is the study of the distribution and causes of disease in groups of people, an understanding of which is required if appropriate control measures are to be implemented at the correct time and place (Glass *et al*, 1992). While both the parasite and the mosquito are found extensively throughout Africa, understanding their local environmental preferences is important to assess the potential use of larvicides. The relevance of epidemiology in the field of medical geography will be discussed further in Chapter 4.

This chapter outlines the consequences of the disease at the individual and societal levels, to highlight the need to continue exploring new control methods. The epidemiology of the disease is discussed, with the role of each of the three players in the malaria life cycle being reviewed; namely the parasite, mosquito and the human host. Particular emphasis is given to the environmental prerequisites and other factors that effect the distribution and levels of intensity of the disease in the study area. These include the breeding requirements, flight range, resting habits and seasonal variations in the duration of the different components of the mosquitos' life cycle, with special reference being made to factors that relate to the study area.

2.2 Malaria : Signs and Symptoms

Malaria is a parasitic infection, its transmission being dependent on the presence of a host (people), a vector (mosquitoes), and environmental conditions (Nevill, 1990; WHO 1993c; Brêtas, 1994). Malaria symptoms present themselves within a set time of a person being bitten and infected, this being dependent on the parasite species, and is characterised by bouts of fever

(WHO, 1994). Malaria epidemics occur when new strains of the parasite are introduced into a region or where suitable carriers are available and conditions are conducive to the survival and spread of existing parasites (Learmonth, 1978). Epidemic infections tend to cause severe illness in all age groups while endemic infections cause severe illness and death in children and the elderly, and milder illness in adults (Learmonth, 1978; WHO, 1988).

The detrimental effects of malaria highlights the need to continually investigate new methods to reduce the resulting deaths and suffering. Reducing the effects however requires an understanding of its cause, namely the roles of the parasite, mosquito and human hosts in the perpetuation of the disease.

2.3 The Malaria Parasite

Human malaria is caused by an intercellular protozoa of the genus *Plasmodium*, and of the 120 species, four are important for the spread of malaria in humans: *P. falciparum*, *P. vivax*, *P. malariae* and *P. ovale* (Nevill, 1990). *Plasmodium falciparum* is responsible for approximately 90% of cases worldwide, and occurs mainly in Africa, where the prevalence rate among children is higher than 50% in some areas. It causes the most dangerous form of the disease although this also depends on the immunological status of the person at the time of infection (Johnson, 1993). It seldom survives longer than a year and generally causes a severe illness of short duration (Nevill, 1990).

The malaria parasite is transmitted by the female *Anopheles* mosquito mainly during nocturnal feeding (Nevill, 1990). The life cycle occurs in both the vector and the host, both stages being essential for the continued survival of the parasite and the continuation of the disease. The distribution of malaria parasites is determined by environmental constraints, with *Plasmodium falciparum* generally requiring ambient temperatures of above 19°C for at least one month in order for it to complete its life cycle in the mosquito (MacDonald, 1957; Molineaux, 1988). Its survival in the mosquito also drops when the temperature exceeds approximately 30°C (WHO, 1988). *Plasmodium falciparum* accounts for over 95% of the parasites in the South Africa, but a few cases of *Plasmodium ovale* and *Plasmodium vivax* have been reported (Annual Malaria Report, 1994).

The life cycle of the human malaria parasite consists of a sexual stage in mosquitoes (primary host), known as the extrinsic incubation period, and an asexual stage in humans (secondary host) (WHO, 1982). The female mosquito injects the malaria parasite from an infected human host which it bites to obtain amino acids that are necessary for the development of its eggs (Bruce-Chwatt, 1980). Inside the mosquito, the parasite takes between 14 and 21 days to mature into an infectious parasite, changing from an ookinete stage which escapes into the body cavity from which sporozoites are released. These are then introduced into a human host when the female mosquito bites a person, after which they migrate to the liver where they multiply, resulting in the release of merozoites into the blood stream (Desowitz, 1993; Nevill, 1990). Here they enter the red blood cells where they again multiply and are released when the red blood cells rupture. This occurs approximately 14 days after infection, and results in bouts of fever that corresponds with the eruption of successive crops of parasites from the blood cells where the haemoglobin is digested, resulting in anaemia as the cells are destroyed. At this stage, the injection of the gametocytes by the female mosquito starts the sexual stage of the parasite (Nevill, 1990).

2.4 The Vector

The malaria vector is the mosquitoes, and of the approximately 3 200 known mosquito species, the most important are *Anopheles* (*An.*), *Aedes* and *Culex*. Of the 400 Anopheline species, approximately 60 transmit malaria, with 30 being important worldwide but only two or three being important in any one area (Nevill, 1990). Mosquitoes can be part of a species complex whereby they are all closely related, as is the case with the *An. gambia* complex in the study area, which is divided into *An. arabiensis* (fresh water), *An. quadriannulatus* (fresh water), *An. melas* (salt water), *An. merus* (salt water) and *An. gambiae* (fresh water). Each subspecies has its own behaviour as well as host and environmental preferences (Nielson, 1979). Sharp (1990) found that of the *An. gambiae* species that occur in the region, the three most common were *An. arabiensis*, *An. merus* and *An. quadriannulatus*, with the former being the most dominant. and therefore considered to be the major malaria vector. *An. merus* could not be implicated in malaria transmission as it was found to favour animals rather than humans for blood meals (Sharp, 1990).

Mosquitoes undergo a complete change of form during their life cycle in which the first three

stages (egg, larvae and pupae) occur in water and the final adult stage is spent above the water surface. Once the mosquito hatches from the egg it is known as larvae and passes through four larval stages after which it becomes a pupae. The adult mosquito emerges from the pupae, and after waiting approximately 24 hours for the wings to harden, it flies off in search of food and to mate (WHO, 1982). The female mosquitoes' blood-meal requirements of amino acids for egg production results in their seeking humans who are bitten and infected with the malaria parasite. The eggs are laid on the surface of suitable water bodies where only a small percentage will survive (Nevill, 1990). Mosquitoes survive where the environmental conditions are suitable for the completion of their life cycle, both in and out of the water. Its distribution and survival are determined by local environmental conditions, breeding site requirements, seasonal variations in the mosquitoes life cycle, flight range, its ability to locate a human host and its biting and resting habits. These will be discussed in order to establish the viability of using larvicides in the study area and to establish the most appropriate time during which they could be applied.

2.4.1 Environmental Prerequisites

While mosquitoes of the same species are distributed extensively across Africa, their adaptation to local conditions prevents a blanket approach to the application of vector control measures (le Sueur, 1991). *Anopheline* mosquitoes occur throughout the world except in cold and hot deserts and at least 75% live in the tropics or subtropics with the remainder living mainly in warm temperate regions (Nielson, 1979). Most of sub-Saharan Africa is plagued by malaria to varying degrees, particularly where the climatic conditions provide breeding sites and suitable conditions for transmission, such as in eastern South Africa (MacDonald, 1957; Sharp, 1990).

Adequate rainfall, high relative humidity and appropriate temperatures are necessary for mosquitoes to complete their life cycle and produce another generation. Optimal mean temperatures for malaria transmission are between 20° C and 30°C in combination with an average relative humidity of 63% or more. The relative humidity is not collected in the study area and can therefore not be included (The Wellcome Trust, 1963; Bruce-Chwatt, 1980; Molineaux, 1988). Rainfall in the study area generally occurs between September and April/May, and is not only adequate for filling depressions in the ground which provide breeding sites, but also fills the local rivers, the banks of which are surrounded by natural water bodies with varying amounts of vegetation. The number and distribution of malaria cases in the study

area are reduced in years of drought and in winter when there are fewer breeding sites (Sharp *et al*, 1988).

Adult female mosquitoes are able to distinguish between suitable and unsuitable breeding sites (Johnson, 1993). The potential breeding sites for mosquitoes change with seasonal climatic conditions, an understanding of which is important in order to apply larvicides at the appropriate time to the correct sites. Factors that determine breeding place preference are sun or shade, calm or flowing water, temperature, salinity, oxygen content, surface vegetation, organic pollution, algae for the larva to feed on and pool durability (MacDonald, 1957; WHO, 1982).

The main vector in the study area, *An. arabiensis*, favours fresh-water breeding sites that are shallow, calm, generally unshaded, vegetation free and small, although larvae have also been reported at the edges of larger pools (Sharp *et al*, 1988; le Sueur, 1991). In areas that experience seasonal fluctuations in the disease, marginal breeding sites are used during the dry months from where the mosquitoes expand to the preferred sites during the wetter months, affecting the distribution of the disease (Molineaux, 1988).

Borrow-pits (road construction material extraction sites) and hoof-prints next to the rivers and water bodies were excluded from this study due to their geographic locations not being known. The water bodies that had suitable characteristics and contain water long enough for the aquatic stage of the *An. arabiensis* mosquitoes life cycle to be completed during winter, are those classified as the dams, the naturally occurring perennial (permanent) pans as well non-perennial (seasonal) pans. These were included in the study to establish any possibility of their being used as winter breeding sites, and to determine if they could assist in determining the maximum likely flight distance of mosquitoes. Marshes (highly vegetated naturally occurring water bodies) were excluded from the study due to their over-abundance of vegetation which results in suitable breeding conditions (le sueur, 1991).

While the air temperature in the study area tends not to exceed 37° C, higher summer water temperatures have been recorded which results in a raised evaporation rate, resulting in the reduced durability of the pool of water and increased larval deaths once the temperatures exceeded 40° (le Sueur, 1991). Winter water temperatures tend not to fall below 13° C, providing an environment in which larvae can still grow (le Sueur, 1991).

Due to the preference of *An. arabiensis* for fresh water bodies with no salt content, le Sueur (1991) suggests that the application of 12 grams of sodium chloride per litre of pool volume would be adequate to adversely affect conditions to the extent that they would no longer be suitable for larval breeding. This method could only be used where intensive breeding by *An. arabiensis* was occurring, and would require field assistance in identifying the breeding sites and applying the salt. The merits of salt applications would need to be weighed against the short and long term effects of other larvicides as well as their associated costs (le Sueur, 1991). Le Sueur (1991) maintains that salination of the soil would be limited due to the low concentration that would be applied, and to the dilution that would occur with the onset of the heavy summer rains. The application of salt to fresh water sites has not been undertaken, and should it be possible to identify the winter breeding sites of the mosquitoes, the merits of applying salt against the other larvicides currently available would need to be determined by the MCP. The larvicides currently available are discussed further in Appendix 1.

2.4.2 Seasonal Variations in the Length of the Life Cycle

The rate of development of mosquitoes is dependant on the climate, with insects growing slower and bigger at lower temperatures when food is not a limiting factor. High summer temperatures may result in a growth rate which exceeds the rate at which food can be consumed by larvae (Bussvine, 1975; WHO, 1982; le Sueur, 1991). The shorter life-span can increase transmission due to increased feeding frequencies of the adult mosquito, but can also reduce transmission by shortening the life of the vector which is unable to live long enough for the parasite within it to complete its life cycle (Molineaux, 1988). Understanding these changes will indicate the most appropriate time of year to apply the larvicide. The changes in the duration of the immature aquatic stages of *An. gambiae* in the winter life-cycle and therefore the survival of the mosquito in northern KwaZulu-Natal was investigated by Le Sueur (1991). *An. merus* was used as the sample group due to its availability in terms of population numbers and breeding sites. No studies of a similar nature have been undertaken on *An. arabiensis*, resulting in the reference to *An. merus* as it is a member of the same species.

The peak transmission season in northern KwaZulu-Natal is in autumn (April/May), and although mosquito population numbers are highest in summer, the insects are small and weak due to rapid growth rate and live no more than a approximately three weeks. The increase in autumn

transmission is the result of an optimum balance between population size and longevity at cooler temperatures (le Sueur, 1991). A drop in temperature in May/June results in an increase in the duration of the larval lifespan with an accumulation of larvae, which in turn reduces the number of adults (see Appendix 2) (le Sueur, 1991). The number of larvae per pool drops by July as they mature into adults or die, but the number of adults is still fairly low due to the low number of eggs that are laid from the reduced number of adults. The temperature begins to rise in August, resulting in a shorter larval stage due to a faster growth rate. A low egg-input from the few adults results in a large number of larvae that are in the later part of their cycle in August. The increasing adult population results in larger number of eggs and a subsequent rise in the number of initial phase larvae in September/October (le Sueur, 1991).

The summer duration of the aquatic stage of the life-cycle has been shown to last between six and 12 days in summer, and between 25 and 42 days in winter (Holstein, 1954 in le Sueur, 1991; Le Sueur, 1991). The life span of the female vector in summer is typically about three weeks while the males live for only one week. During winter, the females can live for three to four months (Muir, 1988; le Sueur, 1991). The duration of the larval stage increases during winter due to reduced metabolic rates, and results in an accumulation of larvae (le Sueur, 1991). The increase in larval density results in the food becoming limited, further extending the larval stage. This is important for the later stages of the aquatic phase when the larvae are larger and therefore have greater nutritional requirements (le Sueur, 1991). Larval densities depend on competition for food, space, the presence of toxic substances (possibly excretory in origin), predators, and levels of pH and salinity (le Sueur, 1991). The pupal stage does not feed but is temperature dependant, lower temperatures resulting in a longer duration in the water (le Sueur, 1991).

Larval mortalities for the aquatic stages have been recorded at above 90%, this figure rising with increased time in the water (Service, 1973; le Sueur, 1991). This may be due to the density of the larvae, food availability, a presence of predators, larval nematodes, the durability of the breeding site and fungal infections (MacDonald, 1957; Service, 1973). High summer temperatures result in the drying up of pools of water due to high water evaporation rates which can prevent the completion of the life cycle in marginal sites. These pools may have a high toxic content (excretory), a large food demand due to high larval densities, and an increased risk from predation (le Sueur, 1991).

The growth and survival rate of the larval stages of the mosquito are responsible for fluctuations in the adult populations, with the life-span and number of larvae determining the efficiency with which malaria is transmitted (le Sueur, 1991). With the bulk of the mosquito population in the larval stage in June/July, the larval density per pool high and the adult population low, le Sueur (1991) proposes winter larviciding towards the end of July in the high risk areas. This would assist with controlling the vector population before the August increase in the adult numbers by further reducing the number of larvae that reached adulthood. A reduction in the mosquito population before the height of the malaria season would shorten the transmission season due to there being insufficient time to reach peak numbers (le Sueur, 1991). The number of summer vectors will only be significantly reduced if there is a marked reduction in the number of winter vectors, or if the summer season is short in relation to the time it takes for the population to build up to its maximum size (Molineaux, 1988).

2.4.3 Flight Range

Mosquitoes that feed on humans are attracted to airborne factors such as carbon dioxide, moisture, body odours, body temperature, convective heat and visual factors such as movement, non-reflectivity and contour. Newlands (1989) maintains that a female mosquito will fly upwind and follow a scent once it has been detected, provided that the wind is not too strong. The capacity to transmit malaria therefore depends on the flight range of the mosquito, its individual characteristics, as well as the wind direction and velocity (Nielson, 1979).

Since the 1930's, researchers have undertaken a number of studies to determine the flight range of mosquitoes. A distance of half a mile (0.8 km) was thought to be adequate until the 1930's, when some MCPs extended their control measures to two miles (3.2 km) (Adams, 1940). Symes (1930) recorded the flight of *An. gambiae* at over three miles (4.8 km) in Kenya although this was not conducted under test conditions.

The majority of mosquitoes, both *An. funestus* and *An. gambiae*, were thought to fly to distances of inside one mile (1.6 km) in KwaZulu-Natal during the 1930's, this distance then being the limit to which control measures were extended (Hopkins, 1941). Mosquitoes have been recorded at distances of four and a half miles (7.2 km) from their breeding place, however this distance is not considered to be the range at which there might be sufficient numbers of mosquitos to cause

an outbreak of malaria. A study done in Uganda showed that mosquitos can transmit the disease quite effectively with a flight distance of two miles (3.2 km) (Hopkins, 1941).

The WHO (1982) reported that under normal atmospheric conditions, most mosquitos fly up to three kilometres from their breeding site. Omer and Cloudsley-Thompson (1970) maintain that the maximum flight range is generally lower than 3.6 km although a distance of 6.5 km was once recorded. Field studies indicate that most *Anopheline* mosquitoes do not fly more than four or five kilometres but can travel further if there is a gentle, humid wind to carry them (Rafatjah, 1988). Learmonth (1978) and Corbley (1996) estimated the flight range of a mosquito being approximately four kilometres. Rafatjah (1988) reported that the highest concentration seem to occur in the vicinity of the breeding site with most not travelling more than two kilometres.

The presence or absence of a breeze is important for the direction and distance that the mosquitoes fly with strong down-winds carrying them further than they would travel under calm or mild conditions (WHO, 1982; Hopkins, 1941). De Meillon (1937) in Kenya reached the conclusion that *An. gambiae* mosquitoes tend to fly with the wind rather than against it, and can then fly at least two miles (3.2 km). De Meillon (1937) and Adams (1940) showed that mosquitoes travel greater distances if they fly down-wind (4.25 miles or 6.8 km) than if they fly at right-angles to the wind (1.5 miles or 2.4 km). Mosquitos were observed to fly to a height of approximately 20 to 30 feet (6 to 9 metres) in order to avoid vegetation before taking a direction which is partly determined by the wind (De Meillon, 1937).

As no studies on the flight range of mosquitoes have been undertaken in the study area, this study aims to establish the maximum likely distance that the female *Anopheles* mosquito will fly in sufficient numbers to be able to cause a substantial outbreak of the malaria. As different methods of case detection are used in this study due to varying degrees of immunity to the malaria parasite, a brief overview of the factors affecting susceptibility to the disease will be given

2.5 The Host

There are important human factors which affect the degree of malaria transmission, particularly those governing human/vector contact (Wernsdorfer and Wernsdorfer, 1988). Three of the

transmission dynamics which are important for this study are human behaviour, immunity and migration each of which will be outlined briefly and discussed later in Chapter 3 in the context of the study area.

Human behaviour factors influencing human/vector contact are affected by the location of settlements in relation to water bodies, house design, sleeping arrangements, clothing traditions, occupation, nocturnal habits, deforestation, animal husbandry practices, irrigation schemes and water related projects (Molineaux, 1988; Wernsdorfer and Wernsdorfer, 1988). These activities provide opportunities for more breeding sites and greater contact between humans and mosquitos.

People develop levels of immunity to malaria after repeated encounters with the parasite found in the area in which they live. The development of immunity does not preclude people from being parasite carriers and acting as asymptomatic hosts (Bruce-Chwatt, 1980). People living in endemic areas generally develop a high degree of immunity and display milder symptoms in attacks with the same number of parasites in the blood as would cause severe attacks in those living in epidemic areas who are not immune (Bruce-Chwatt, 1980; Cohen and Deans, 1988).

The migration of people to and from malarious regions pose problems in areas of little or low risk where the introduction of parasites into non-immune populations via in-migrations can result in suffering and death. Annual re-infestation of the parasite highlight the need to continually search for and implement new control methods, particularly in fringe areas which could experience major epidemics or return to endemic conditions (Prothero, 1962, 1983).

2.6 Conclusion

Northern KwaZulu-Natal is defined as malarious area due to its climatic conditions, the presence of suitable breeding sites, malaria parasites, vectors and human hosts. *Plasmodium falciparum*, as the main parasite, can cause severe illness and death when not treated in time, and affects societies in a number of ways. The female *Anopheles arabiensis* mosquito is the main malaria vector in the study area and survives due to the favourable environmental conditions and the

presence of suitable breeding sites. Being able to identify these winter breeding sites to which larvicides can be applied will provide the malaria control programme with a supplementary measure to combat the disease by reducing the number of larvae that mature into adulthood.

Understanding the changes in the duration of the different stages of the life cycle has important consequences for the time at which the larvicides need to be applied. The optimal time for their application being July and August when the majority of the mosquitoes are in the larval stage of their life-cycle (le Sueur, 1991). This research follows that of le Sueur (1991), who recommended the application of a larvicide, namely salt, during July and August in order to lower the larval population that would mature into adult mosquitoes. He recommended that the larvicide be applied to winter breeding sites, the locations of which need to be identified for the optimal allocation of resources.

Understanding the seasonal changes in the life cycle of the mosquito was important in order to determine which months to include in this research. According to current literature, the maximum distance that female mosquitoes will fly under normal climatic conditions, given the presence of an adequate host supply in close proximity to breeding sites, is 4 km. This research aims to establish whether this distance is correct in the study area and thereby assist the MCP in determining the areas that require additional malaria intervention methods.

CHAPTER 3

GLOBAL AND LOCAL MALARIA - ITS HISTORY AND CONTROL

3.1 Introduction

This chapter provides the second part of the background to this thesis, giving firstly an overview of the global history of malaria and its control with an emphasis on larvicides, and secondly, an overview of the historical and current malaria situation in the study area. The first section provides a brief history of the milestones in malaria research and global efforts to control malaria in general, and more specifically, traces the use and effectiveness of larvicides in order to establish the viability of applying them to the winter breeding sites in the study area. The second section reviews the local malaria conditions in the province of KwaZulu-Natal, tracing the history of the disease and resulting control efforts, as well as the factors that have resulted in the need to investigate alternative intervention methods. Current control efforts are aimed at the *Anopheles arabiensis* mosquito vector through indoor residual house spraying, and at the *Plasmodium falciparum* parasite through the treatment with prophylaxis of symptomatic and asymptomatic parasite carriers.

The objectives of malaria control are to reduce vector density, the vector life-span, human-vector contact, malaria transmission, and prevent and reduce malaria mortality and morbidity (WHO, 1999). Many of the important discoveries with regard to the cause and transmission of malaria have occurred during the last 150 years and form the basis of the control methods that have been used this century. The World Health Organisation (WHO) has played an important role in promoting and directing global malaria control efforts with varying levels of success in different parts of the world. Their policies have contributed to the establishment and gains made by the Malaria Control Programme (MCP) of KwaZulu-Natal, and this historical outline serves as a backdrop against which to understand the current strategy. The use of larvicides and present infrastructure of the MCP are outlined as well as the methods of case detection and the seasonality of the disease. The effects of the proximity of the Mozambique border are discussed as well as the resulting levels of immunity and disease incidence in the study area.

3.2 Global History of Malaria and its Control

Early writings from ancient China, Samaria and Greece, notably those of Plato, Homer and Aristotle, all describe the intermittent fevers associated with malaria. Their texts refer to settlements and armies suffering heavy losses due to recurrent fevers contracted in swampy regions (Desowitz, 1993). Swamps and stagnant waters were drained by the Greeks and Romans in the 6th Century BC, and marshes outside Rome were drained with varying degrees of success by the Popes from the 10th to the 19th century AD due to an awareness of their association with fevers (Bruce-Chwatt, 1980; Gramiccia and Beales, 1988). The word 'Malaria' originates from the mid 18th Century Italian phrase 'Mal' aire' which means 'bad air', as it was commonly believed that the disease was associated with the foul air found near marshy places (Bruce-Chwatt, 1980; Johnson, 1993).

Malaria parasites were first discovered in human red blood cells in Algeria in 1880 by Dr Charles Lavern, a French pathologist working in Algeria (Newlands, 1989). This was followed by the discovery by Drs Marchiafava and Celli in 1885, that malaria parasites were passed between people by infected blood. Sir Patrick Manson, in Scotland, in 1894 announced the possible role of the *Anopheles* mosquito in the spread of the disease, and in 1895, this was demonstrated by Sir Ronald Ross in India (Desowitz, 1993). During the early 1900's Sir Ross also showed that malaria tends to disappear when the vector density is below a threshold level, and he contended that malaria could only be controlled by attacking the mosquito where it bred (Bruce-Chwatt, 1988; Desowitz, 1993). These findings were important as they provided insight into the transmission of the disease, and assisted in developing prevention and control measures.

Prevention and control measures used include bednets, the screening of openings, repellents, larvicides and the use of appropriate clothing (Bruce-Chwatt, 1988; Newlands, 1989). The first reported use of larvicide as a means of controlling mosquitoes was in 1793 in the United States of America, where it was recommended that oil (probably whale oil) be poured on water to kill the larvae that were found in rain barrels (Herms and James, 1961; Newlands, 1989). Approximately 100 years later, the application of paraffin and kerosene as larvicides were recommended for treating mosquito-infested waters. The discovery in 1912 of the effectiveness of Paris Green (copper acetoarsenite) as a larvicide revolutionised malaria control and became the standard procedure throughout malaria-infested territories until the advent of dichloro-

diphenyl-trichloroethylene (DDT) (Herms and James, 1961; Newlands, 1989). The use of pyrethrum-oil emulsion as a larvicide began in the 1930's and remained an important compound due to its safety and efficacy (Herms and James, 1961).

Research undertaken in the malarious rural areas of South Africa during the 1930s showed that the female *Anopheles* mosquito preferred resting on the inner walls of dwellings at night (Annual Report, 1932 in le Sueur *et al*, 1993a). This resulted in initial experiments with fumigants, and the use of the indoor residual spraying of Pyagra (liquid pyrethrum and kerosene) in Natal. It was to be so successful that its application was requested outside of the test region and later used globally in malarious areas (Le Sueur, 1993a). This method of control gradually supplemented, then replaced larviciding around the world in the 1940's and 1950's, with twice yearly applications of dichloro-diphenyltrichloroethylene (DDT) eventually replacing Pyagra (Gish, 1992) due to the former's long-lasting effectiveness and low cost. However, the ceiling of effectiveness that has been reached with current control measures has necessitated the search for supplementary efforts to reduce the increasing mortality and morbidity caused by malaria.

3.3 The Role of the World Health Organisation in Malaria Control

The problems associated with malaria were addressed by a number of organisations before the founding of the WHO in 1948 as a specialized agency of the United Nations, with the primary responsibility of attending to international health matters (Najera, 1989; WHO, 1993c). The establishment of committees to address the problems associated with malaria highlighted the realisation of the global extent of the problems associated with the disease. The world food shortage and slow pace of industrial and agricultural development in the post-war period were partly attributed to malaria and the WHO therefore established an Expert Committee on Malaria in 1947. Expert committee reports outlined scientific developments, policies and management guidelines for assisting governments to accomplish effective malaria control (Najera, 1989).

Four approaches have been adopted by the WHO for addressing the problems associated with malaria. These are malaria control (1946-54); malaria eradication (1955-1969); malaria control with the ultimate goal of eradication (1969-1978); and from 1978 to 1991, malaria control as part of primary health care (Najera, 1989). A Global Strategy on Malaria Control was developed in

1991 and 1992 by a consultative group of scientists who adopted the new strategy of promoting early diagnosis and treatment, preventing epidemics and initiating community based efforts to combat the disease (Johnson, 1993). Member States were urged to strengthen their malaria control efforts and develop programmes that were cost-effective, flexible, sustainable and adapted to local conditions and needs (WHO, 1993c).

During the initial years of the WHO's efforts (1946-54), successes in controlling malaria in relatively marginal areas such as in the southern parts of America and Europe as well as parts of Venezuela, led to the assumption that eradication could be achieved elsewhere with the same techniques (Gish, 1992). DDT was recommended as an indoor residual spray but warnings were issued regarding its excessive use as an outdoor spray and as a larvicide due to the possible harmful effects to beneficial insects and wild life (Najera, 1989).

The coincidental development towards the end of World War *II* of residual insecticides (such as DDT) and synthetic anti-malarial drugs, resulted in the Eighth World Health Assembly in 1955 which accepted and endorsed the concept of *global malaria eradication*, and marked the start of the second WHO approach (1955-69) (Gish, 1992). Eradication was justified by the argument that case treatment accompanied by sufficient spraying would interrupt transmission of the malaria parasite and result in the disappearance of the disease (Gish, 1992). The WHO recommended as the basis for future policy, the establishment of national malaria control schemes and the implementation of surveillance systems to detect the presence of parasites (Bruce-Chwatt, 1988). The WHO also endorsed a policy of internationally coordinated campaigns to stimulate inter-country cooperation in order to minimize the importation of sources of infection (Bruce-Chwatt, 1988). This proved to be highly successful over several years with some countries, such as India, almost eradicating the problem (Gish, 1992). At the time when the eradication programme was proposed, many of the developing countries, where malaria was a far more serious problem than in the developed countries, were not yet members or had only recently become members of the WHO. This resulted in the extent of their malaria problems not being fully appreciated and therefore being underestimated (Gish, 1992).

The effects of drug resistance by both the vector and the parasite as well as the effects of population movement were realised during the 1960s (Najera, 1989). The implications of population movement on the spread of diseases was highlighted by Mr. R Prothero in east Africa

during the 1950s and 1960s. His research contributed to planning the WHO's eradication programmes (Prothero, 1962, 1977). He stressed the need for interdisciplinary collaboration within countries and for regional cooperation in order to combat malaria (Prothero, 1968).

The resurgence of malaria during the early 1960s was a result of the inability to control it as well as a lack of understanding of the epidemiological dynamics on which to plan eradication strategies (Najera, 1989). By the mid 1960's the WHO's Expert Committee realised that malaria could not be eradicated in the developing countries despite the success achieved in the more developed parts of the world (Gish, 1992). Their poorly developed industrial sectors, lack of resources and infrastructure, and the largely rural nature and sometimes unknown location of their inhabitants, prevented the extent of the problem being fully understood and made the implementation of control efforts difficult (Woodcock, 1989). The WHO acknowledged that it was not possible to establish effective surveillance without a solid health infrastructure, and these countries were encouraged to develop rural health services in parallel to or before establishing eradication programmes (Najera, 1989).

A re-evaluation of the global strategy of malaria eradication in the late 1960s reaffirmed that control of malaria was to be encouraged, with the ultimate goal being eradication, this becoming the WHO's third approach (1969-78) (Najera, 1989). This would require a shift in planning from routine intervention to problem identification and solving (Najera, 1989). The anticipated short-term investment into eradication was to be replaced by a new long-term expenditure for control, and resulted in the withdrawal of financial support by a number of national and international organisations. Attempts were made to integrate the eradication programmes into poorly developed primary health care services which in some instances, led to an increase in malaria cases (Najera, 1989).

The failure of the eradication programme contributed to the formulation of an integrated strategy for health improvement in general, and provided the basis of the Primary Health Care (PHC) concept in the late 1970s, resulting in the fourth approach in the post 1978 period (Gish, 1992). PHC was based on the principles of equity, prevention, appropriate technology, intersectoral action and community participation, and stressed among other things, that intervention should not be limited to medical aspects but encompass a holistic approach which included adequate water and food supplies (Streefland and Chabot, 1990; MacGregor, 1991). The Primary Health

Care Conference held in Alma-Ata in 1978 resulted in the formalisation of a change in policy strategy from vertical disease control programs to one which included local participation for improving health and health care systems (Gish, 1992). This new strategy aimed at reducing mortality and the negative effects of the disease, controlling or preventing epidemics, and protecting malaria-free areas, with control methods being selected based on the local ecological, biological, social and economic determinants of the problem (Najera, 1989). It was also anticipated that control and eventual eradication would come with economic development and an improvement in the quality of life (Learmonth, 1978).

An epidemiological approach for designing control interventions was developed by the Expert Committee in 1985. The emphasis was on designing appropriate intervention strategies based on the type of malaria problem (Najera, 1989). The two main objectives for any anti-malaria action were identified as:

1. Providing people in malarious areas with accessible and appropriate diagnostic and treatment facilities including promoting the use of personal protection methods;
2. Interrupt or controlling malaria transmission, guided by local epidemiological considerations (Najera, 1989).

The WHO has played an important role in directing malaria research and control efforts. The first enthusiastic efforts to eradicate the disease were later tempered with the realisation that local complexities, population movement and drug resistance made eradication a difficult target to meet. The focus therefore changes to one of control, with an emphasis on providing diagnostic and treatment facilities, and interrupting malaria transmission based on an understanding of local epidemiological conditions. Malaria control methods have therefore been divided into a number of categories, with the MCP's within each country deciding which to use.

3.4 Malaria Control Methods

Control programmes have been established around the world with varying degrees of success but all use similar control methods. These are based on a thorough understanding of the mosquito, parasite, relevant social, economic, ecological and environmental factors as well as the provision of an adequate health infrastructure (WHO, 1993c). In malaria-free areas, the aim is to maintain

that freedom from the disease, while in endemic areas, it is to prevent mortality and reduce morbidity and the accompanying socio-economic losses (WHO, 1993c). The circumstances within each country will determine the way control is implemented, with successful intervention depending on local competency and the scientific knowledge regarding the habits and epidemiology of the mosquito (WHO, 1982).

The WHO Malaria Unit has outlined four basic technical elements for a Global Control Strategy (WHO, 1993c):

1. To provide early diagnosis and prompt treatment.
2. To plan and implement selective and sustainable preventive measures, including vector control.
3. To detect, contain or prevent epidemics.
4. To strengthen local capacities in basic and applied research to permit and promote the regular assessment of a country's malaria situation, in particular the ecological, social and economic determinants of the disease.

The WHO divides the control methods into the following categories (WHO, 1993c):

1. Indoor Residual Spraying : the spraying of long-lasting chemicals on the inner surfaces of buildings in order to kill the adult mosquito.
2. Chemoprophylaxis and Chemotherapy : respectively, the use of medication to prevent and cure the disease by interfering with the parasite once it has entered the host.
3. Personal Protection Methods : the use by individuals of repellents, sprays, creams and bednets.
4. Larval Control and Environmental Management : interfering with the aquatic stage of the mosquito life cycle

Reducing malaria morbidity and mortality by lowering the transmission rate through the application of site-specific, targeted control methods are the main objectives of mosquito control. This depends on the ability to reduce successive generations to a level where the disease will die out due to an insufficient number of mosquitoes being able to sustain transmission effectively (MacDonald, 1957). Controlling the mosquito population can occur at two locations, the breeding sites or the biting sites. Outdoor resting places during the day of male and female mosquitoes are many and varied, and therefore not ideal for targeting for environmental control

(WHO, 1982). Although residual spraying is the dominant form of control in South Africa, a WHO report on environmental management as a means of vector control in Malaysia (1988) states that insecticides should supplement and not substitute source eradication. Altering the breeding sites should take precedence over the control of the vector itself although this may not always be attainable for economic or practical reasons. Where this is not possible, destroying the aquatic stage of the vector should take precedence over the control of the adults (Sing and Tham, 1988). For the purposes of this study, only larval control and environmental management will be outlined as the aim of this research is to identify the winter breeding sites to be targeted for larval control measures. The results of this research will be made available to the MCP in the province who will then decide on the most appropriate method of control to use.

3.4.1 Larval Control and Environmental Management

Larval control and environmental management were the main method of controlling disease vectors before the advent of synthetic residual insecticides and in many instances proved to be very effective. However, problems of drug and insecticide resistance and the environmental implications of insecticides necessitated a search for alternatives (WHO, 1988). The purpose of these methods is to reduce mosquito density to a point where the transmission of malaria is minimal or totally interrupted. This point will vary depending on the mosquito species, its flight range, the level of endemicity, environmental factors such as temperature, rainfall, humidity and the intensity level of transmission (Gratz and Pal, 1988). As the exact level to which mosquitoes must be reduced to ensure interruption of transmission is not known, the highest levels of control need to be aimed for. The use of larviciding as a control method requires fairly specific knowledge of the biology and ecology of the target species and of their distribution. The choice of larvicide will be determined by the mosquito species, the cost of application and its equipment and transport requirements. The toxicity of the material to non-target life forms also needs to be considered (Gratz and Pal, 1988).

Anti-larval measures need to be considered under the following circumstances:

1. When the breeding sites are identifiable resulting in the appropriate use of transport, manpower, and materials, and when environmental management would be inappropriate.
2. When the use of indoor residual spraying is impractical, uneconomical, unwanted by the home owner or has resulted in behavioural changes in the mosquito.

3. When the adult mosquitoes are resistant to the residual spray.
4. When house spraying is not feasible and chemotherapy or chemoprophylaxis is impractical due to the nomadic movements of people (Gratz and Pal, 1988).

Larval control methods tend to be labour intensive and expensive when applied indiscriminately over water bodies which may not have been identified as breeding sites. There are six broad categories of larvicides, each with a unique effect and therefore applicable under differing circumstances (Gratz and Pal, 1988). These are larvicidal oils, arsenicals, chlorinated hydrocarbons, organophosphorus insecticides, pyrethrum and synthetic pyrethroids and development inhibitors all of which are briefly outlined in Appendix 1.

The objective of this strategy is to reduce the mosquito population by modifying and/or manipulating environmental factors so as to reduce or prevent the continuation of the species. Such measures should supplement and not replace existing control methods, and can include modification of the environment such as water course changes, manipulation of environmental conditions through salination, and interfering with the behaviour or living conditions of humans (WHO, 1982). Any changes require an understanding by the community that the alteration of their or their livestock's water source is to their advantage and appropriate alternatives will be provided where necessary (Muir, 1988; Ministry of Health and Child Welfare, 1994).

The disadvantages of larvicides are the possible ecological impacts on other organisms. The advantages include their effectiveness, long term viability, low cost of small-scale schemes, contribution to social and economic and social upliftment, limited environmental impacts, limiting other vector-borne and water associated diseases, and the minimal safety precautions that need to be applied (Nielson, 1979; WHO, 1982).

This global perspective serves to situate the province of KwaZulu-Natal, and more specifically the study area, within the broader context of malaria initiatives. Malaria research and control efforts in all malarious countries are, to a greater or lesser degree, influenced by the initiatives of the WHO. South Africa is no exception, with control efforts taking direction from, and in some instances provided new direction to, global attempts to reduce the burden of disease caused by malaria. An overview of the study area and the factors that affect the current malaria situation will now be reviewed.

3.5 The Study Area

The province of KwaZulu-Natal is situated on the east coast of South Africa and shares a border with Mozambique to the north. The northern malarious part of the province is characterised by a coastal belt, a low lying coastal plain that rises to approximately 350m to the west. The study area is situated in the northern most magisterial district, Ingwavuma, which borders the Ubombo magisterial district to the south, Swaziland to the west and Mozambique to the north (Figure 3.1).

The study area includes the malaria areas of Mkanis Drift (Mkanis) and Ndumu, an explanation of which will be given in describing the current MCP (Section 3.7). It is situated between 32°09' and 32°24' east, and 26°50' and 27°07' south, covers an area of 446 square kilometres (km), and is approximately 20 km across and 25 km in length at its longest point (Figure 3.2). The area borders with Mozambique and the Ndumu Game Reserve to the north, the Tembe Elephant Park to the east, the Pongolo River flood plain to the south and the Lebombo Mountains to the west. The water bodies in the area consist of dams, marshes, perennial and non-perennial pans. The two main rivers are the northward-flowing Ngwavuma and the Pongolo. From the flood plain altitude of 50 to 150 metres, the Lebombo Mountains rise to over 600 metres. The flood plain is characterised by coastal bush to the east, and temperate forest and open bush to the west, known as 'thornveld'. It is characterised by a variety of *Acacia* tree species reaching heights of up to ten metres (Shuter & Shooter, 1981; Mr Ntuli, pers. com. 1997).

This region is inhabited by people of the Tembe Tribe who were divided by the boundary between Mozambique and South Africa, resulting in a considerable amount of cross border movement (Stuttaford, 1994). Road infrastructure in the area is limited and the Ndumu Residential Health Clinic and a few schools support the local population. The area is characterised by scattered patriarchal homesteads which consist mainly of groupings of individual buildings made largely of traditional materials, mainly mud walls with thatched roves. There is some aggregation of settlements around roads, water sources and other infrastructural features. Subsistence farming of cattle, goats and various crops are the main form of land use, while fish from the rivers provide a source of protein (Mr Ntuli, Pers Com, 1997).

Figure 3.1 Ingwavuma and Ubombo Magisterial District in the Province of KwaZulu-Natal, South Africa

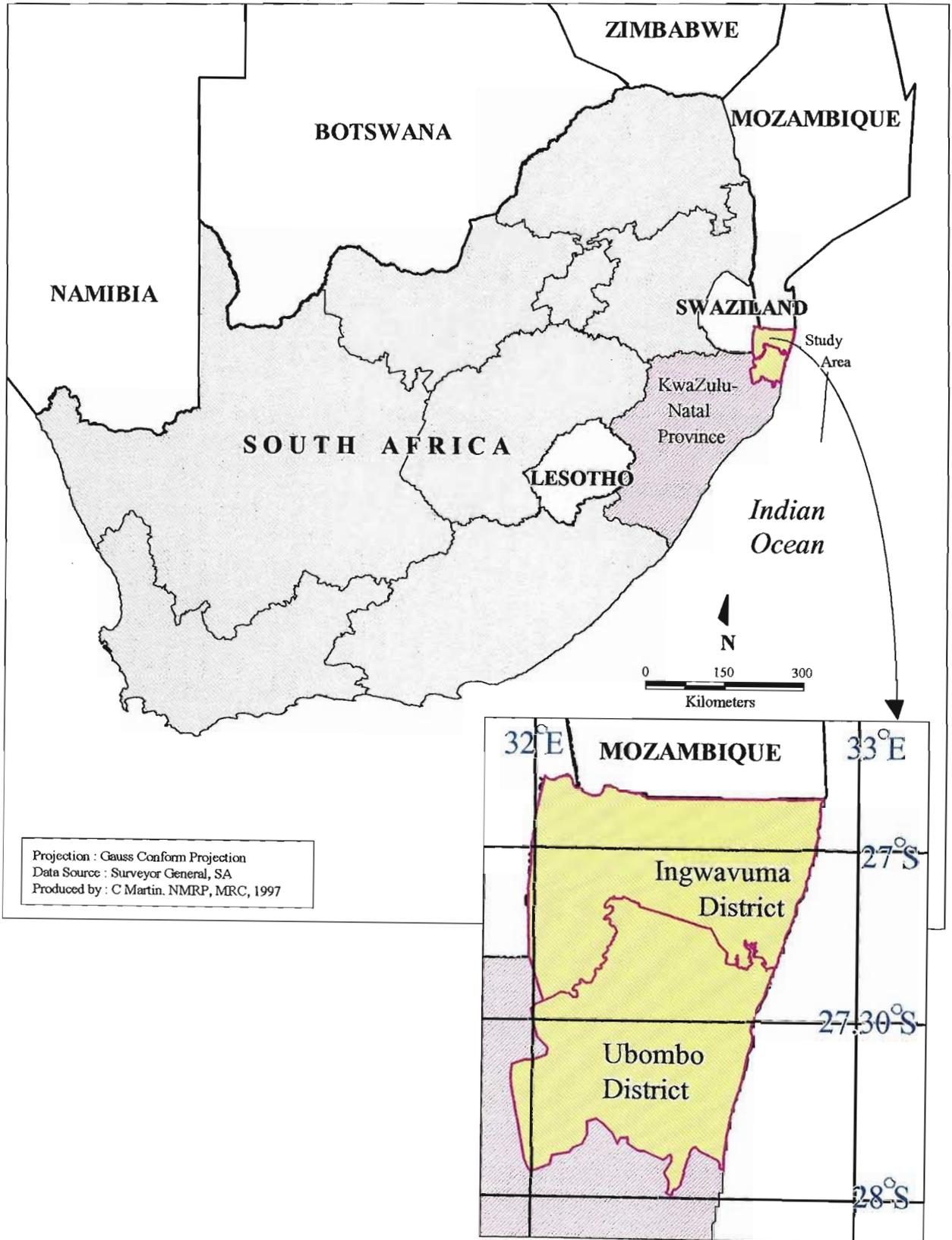
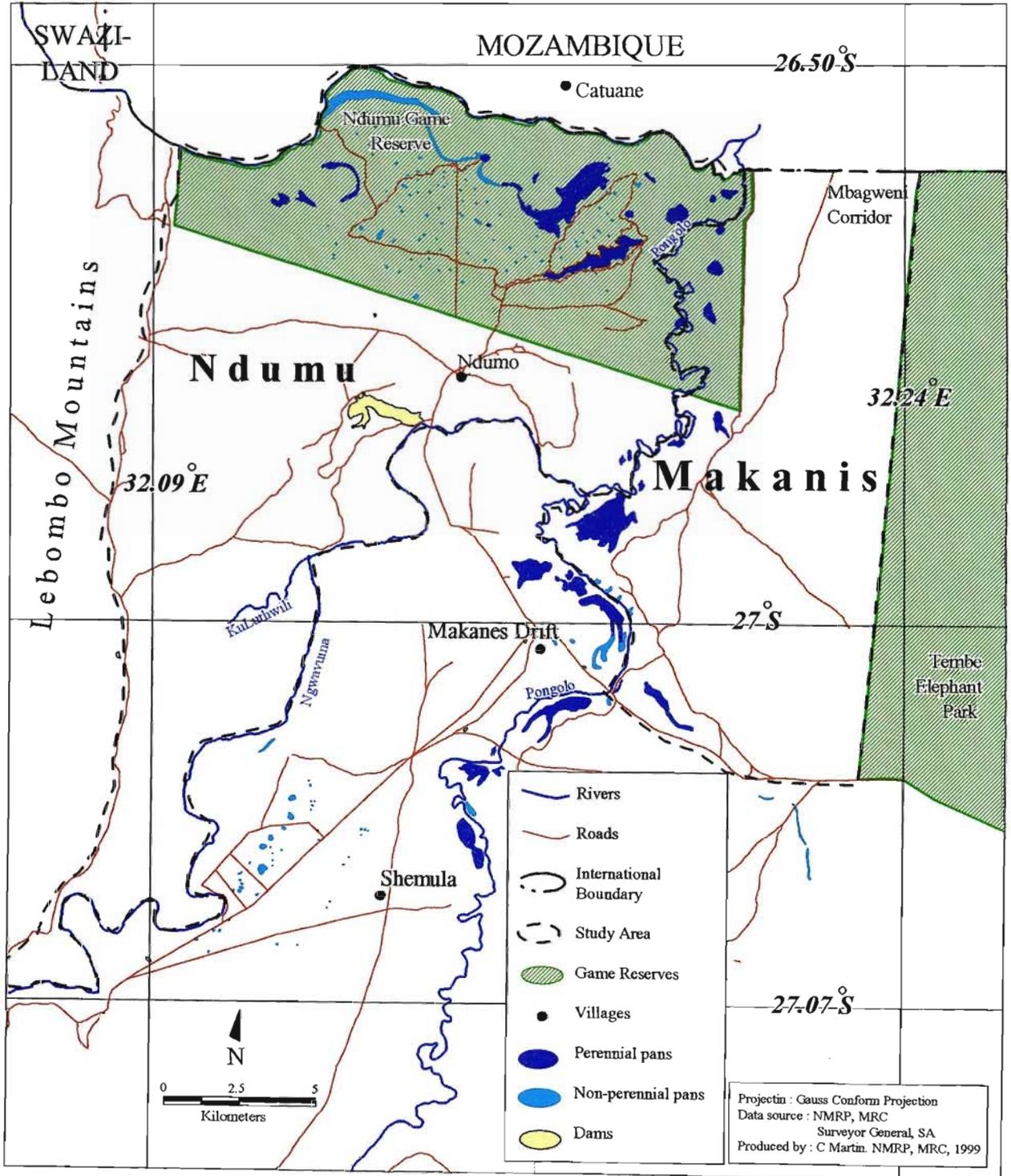


Figure 3.2 The Study Area of Makanis and Ndumu in the Ingwavuma District of Northern KwaZulu-Natal



The area experiences a mild sub-tropical climate with hot, wet summers and mild, dry winters. Rainfall is seasonal, with most falling between November and April. Rainfall for 1993 and 1994 varies from a maximum of over 100 millimetres (mm) in February 1993 to minimum of 4 mm in July 1994. Temperatures ranges are between 19° and 35° Centigrade (C) in summer (December to March) and between 10° C and 25° C in winter (June to August) (SA Weather Bureau, 1996) (Appendix 2).

3.6 History of Malaria in KwaZulu-Natal and its Control

Superstitions about the cause of malaria flourished in southern Africa before the role of parasites and mosquitoes were discovered, with night mists and evil spirits being held responsible (Plus File, 1995). The *Acacia xanthophloea* (fever tree) was thought to be associated with the disease by white settlers as it was found in the same geographical location in which malaria occurred. Many early settlements were located in mountainous areas as it was noticed that people who stayed at higher altitudes did not succumb to malaria to the same extent as those who lived at lower altitudes (Newlands, 1989).

Sporadic malaria epidemics have been recorded, extending along the coastal plain as far south as Port St Johns (31°38' S and 29°33' E) (Hill and Haydon, 1905). An epidemic in Natal in the first half of 1902 resulted in 9,106 cases (107 deaths) being reported, of which 4,177 (42 deaths) occurred in Durban (30°50'S and 31°E). This resulted in malaria became a compulsory notifiable disease in Durban during the same year (Pratt-Johnson, 1918). It was thought that the opening of the new railway line to the highly endemic northern areas of the province had resulted in a movement of immune people bringing the parasite to the city of Durban (Hill and Haydon, 1905). Research in the early part of the century indicated that rainfall did have an effect on the incidence of malaria, with the rate increasing from the rainy season in early summer through into April/May when it reached its peak, after which it dropped off as the availability of suitable water bodies diminished (Lamborn, 1925; Ingram and De Meillon, 1927; Park Ross, 1929). Papers at the time acknowledged that information was required on the life-history and the habits of mosquitoes if an organised effort was to be made to control the disease. It was also noted that the low malaria incidence figures in the northern part of the province indicated a high degree of immunity amongst the local black population (Ingram and De Meillon, 1927).

Epidemics in 1929 and 1930 resulted in many deaths and a vast drop in sugar production due to the ill-health of the cane workers in the coastal areas of northern Natal which seriously affected the and the local economy (le Sueur *et al*, 1993a). Figure 3.3 shows the distribution of the malaria risk in 1938 prior to the introduction of malaria control, as well as that of 1998/99, indicating the gains that have been made in limiting its occurrence through the implementation of control strategies. The high risk area KwaZulu-Natal in 1938 was along the coast (Figure 3.3), while the current high risk area is now situated inland (Figure 3.4), with the coastal area falling being classified as medium and low risk.

The anti-malarial drug quinine was used to treat those infected, and people were encouraged to use preventative methods such as bednets and protective clothing (le Sueur *et al*, 1993a). The larvicide Paris Green was introduced during 1930 with great success in a test area, but was not applied over a large enough area to halt the epidemic (le Sueur *et al*, 1993a). It was used to kill the mosquito larvae during winter in order to reduce the number that could mature into adults and in this way lower the summer malaria case numbers (Lamborn, 1925; le Sueur *et al*, 1993a). This epidemic resulted in the South African Government inviting some noted malariologists to the country during the 1930's to assess the malaria situation and advise on its control. Professor N.H Swellengrebel, a member of the Malaria Committee of the Health Organisation of the League of Nations, of Amsterdam University was one such visitor (Department of Public Health, 1930; le Sueur *et al*, 1993a).

Swellengrebel (1931) worked in the coastal area and identified *An. funestus* (Giles) and *An. gambiae* (Giles) as the two major malaria vectors, both with fairly specific breeding site requirements. He maintained that breeding sites were reduced to a few local foci during the dry months to which anti-larval measures could be limited. He reported that epidemics were caused by a rise in the number of mosquitoes due to an increase in the availability of breeding sites as a result of consistent rainy periods. His investigation also led him to the conclusion that people were bitten by mosquitoes inside their dwellings and not outside as it was then assumed. Swellengrebel (1931) recognised the role played by migrant labour in the transmission of the disease, many of whom came from Ingwavuma and Ubombo districts as well as from Mozambique. He suggested that people living in the three northern malaria endemic districts of Ingwavuma and Ubombo, be excluded from malaria control efforts for fear of tampering with their immunity (le Sueur *et al*, 1993a).

Figure 3.3 Malaria Risk in South Africa 1938

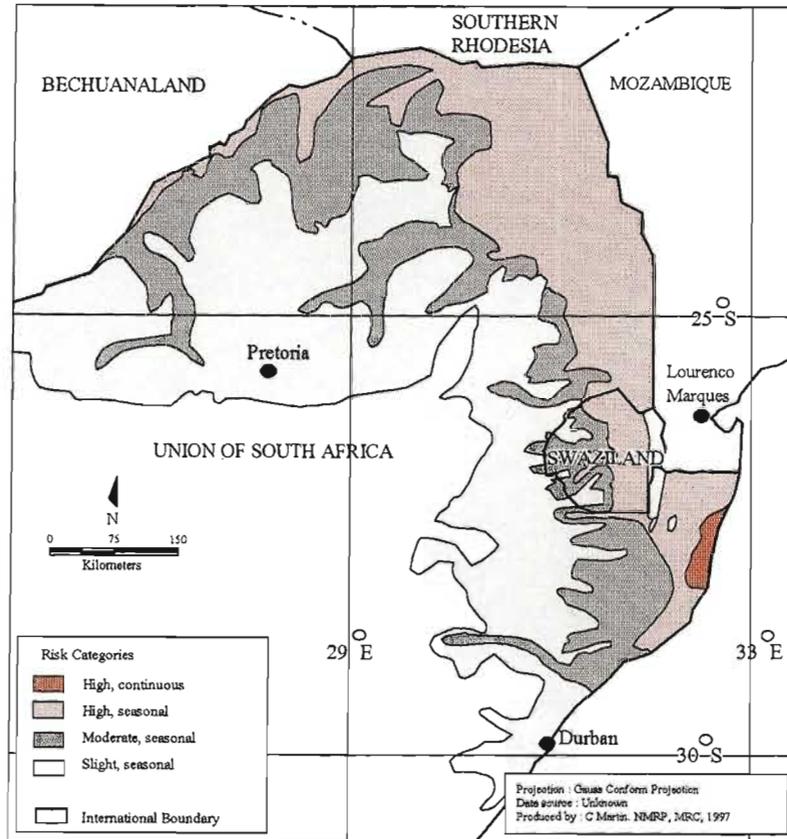
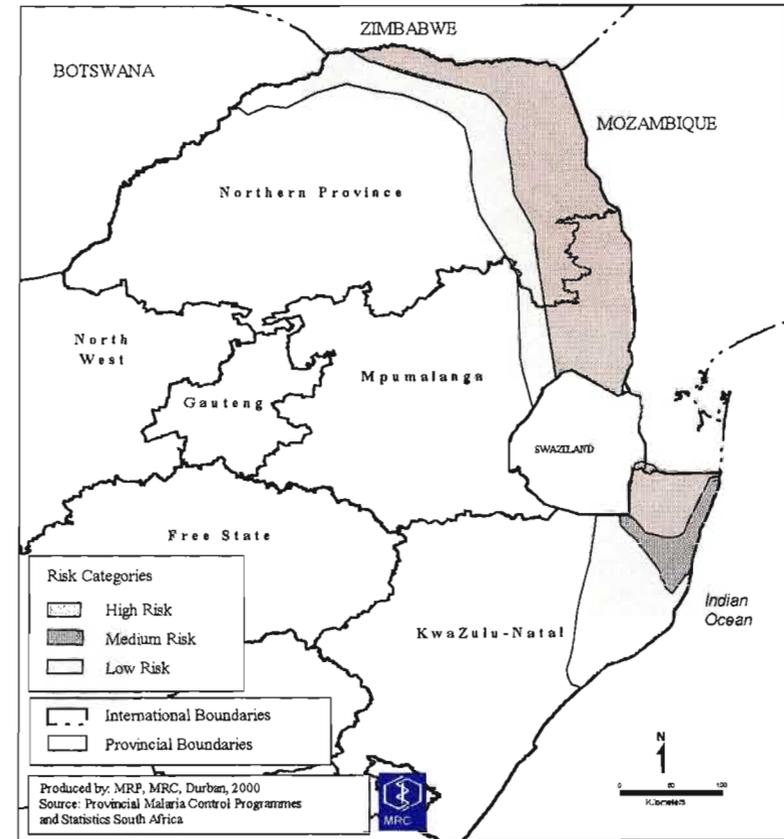


Figure 3.4 Malaria Incidence and Risk Levels in South Africa : 1998/99



He recognised the benefits of using immune labour in semi-malarious areas but he also realised the potential danger of spreading the disease by employing asymptomatic infected migrant labour in non-malarious areas.

Swellengrebel (1931) advocated a system of preventive and curative measures which included the identification and treatment with quinine of those who carried the parasite, as well as applying larvicides to potential breeding sites (le Sueur *et al*, 1993a). The location of the identified and treated breeding sites were mapped, and later revisited to establish the effectiveness of the larvicide (Swellengrebel, 1931). These methods were, however, fairly labour intensive and expensive due to their wide-spread application but did result in a reduction in the number of mosquitoes (Busvine, 1975).

The 1932 malaria season was the worst in recorded history where, out of a population at risk of one million people, an estimated 22 000 died, resulting in the implementation of the MCP in 1933 (le Sueur *et al*, 1993a). Evidence of the indoor biting and resting habits of the mosquito resulted in the first experiments being conducted with Pyagra (liquid pyrethrum and kerosene) as a residual insecticide in the province of Natal. The success of these tests resulted in its widespread application, bringing the epidemic under control (le Sueur *et al*, 1993a). In 1936 it was recommended that the inner walls of every building in the affected areas be sprayed with Pyagra, and although it gradually replaced larval control as the main control method, it was recorded in 1938 that controlling the winter breeding sites of the vector had sharply decreased the summer incidence of the disease (le Sueur *et al*, 1993a).

DDT replaced Pyagra in 1946 and was used as both a larvicide and for indoor spraying, resulting in a dramatic drop in the incidence of malaria (Busvine, 1975; le Sueur *et al*, 1993a). Control measures were extended to the three northern endemic districts by 1958, with the realisation that this exclusion provided a parasite reservoir to areas further south. Their inclusion into the control programme resulted in these districts then experiencing epidemic rather than endemic transmission (le Sueur *et al*, 1993a). Anti-larval measures were abandoned in 1956 and malaria became a notifiable disease in South Africa (Sharp *et al*, 1988). A limited amount of larviciding was re-introduced in the 1970's in areas where the use of malaria had not been adequately controlled (le Sueur *et al*, 1993a). Although DDT is banned for agriculture and domestic uses, it remained the primary means of mosquito control in KwaZulu-Natal until the introduction of

Deltamethrin in 1995 (le Sueur and Sharp, 1996). A Primary Health Care system is being introduced which will broaden the support infrastructure for preventing and controlling malaria, and place more emphasis on community based programmes which will include the use of treated bednets in the high risk areas (Mnzava *et al*, 1997).

3.7 The KwaZulu-Natal Malaria Control Programme

The KwaZulu administration was established in 1972 to administer the former KwaZulu homeland as a separate entity from that of the province of Natal, each administration being responsible for their own MCP. The northern districts of Ingwavuma and Ubombo fell within the KwaZulu jurisdiction (Ngxongo, 1993). Political change in South Africa in the early 1990s resulted in the amalgamation of the administrative units of KwaZulu and Natal into the current province of KwaZulu-Natal, resulting in the merging of the two MCP's. The headquarter of the Department of Health's MCP is in the northern town of Jozini and has a staff compliment of over 400 which includes staff involved in administration, statistics, laboratory work and field operations. Eighteen malaria teams operate these two northern districts, each consisting of a health field officer, four to six surveillance agents and 10 spray men. The spray men are responsible for applying the indoor residual insecticides to the buildings in their region. The surveillance agents traverse their areas on bicycles, each being responsible for approximately 400 homesteads in which they detect, through blood smear analysis, and presumptively treat people suspected of carrying the malaria parasite (Ngxongo, 1993).

3.7.1 Current Control Methods

Malaria intervention strategies as carried out by the MCP currently consist of a two-pronged approach; one which targets the vector (indoor spraying) and the other the parasite (chemotherapy). These will be outlined briefly to indicate the problems associated with their use thereby highlighting the need to investigate supplementary control measures.

Indoor Spraying

The use of DDT as the main vector control measure has been replaced with the synthetic

pyrethroid Deltamethrin which has been laboratory and field tested by the National Malaria Research Programme. Currently, spraying of the homesteads begins in September/October so as to be completed in the high risk areas by the time the transmission season starts in November (Sharp *et al*, 1988; le Sueur *et al*, 1993b; Ngxongo, 1993; Sharp *et al*, 1993).

The change to Deltamethrin was as a result of studies which indicated a number of problems relating to the use of DDT (le Sueur and Sharp, 1996). This included slightly raised levels of DDT in fish which form an important part of the protein diet of the local people, as well as in other birds and animals in the region (Bouwman *et al*, 1990). Levels of DDT in human serum and breast milk in the sprayed areas were slightly higher than those not under spraying control (Bouwman *et al*, 1990; Bouwman *et al*, 1992). Studies in 1990 showed that many mosquitoes, which had previously rested on the DDT sprayed internal walls before exiting, exited without resting due, partly, it is thought, to an irritational effect of the insecticide (Sharp, 1990; Sharp and le Sueur, 1991).

The walls of some homesteads are annually replastered by the women in the local households in order to cover the habitats of the bedbugs which burrow into the inner walls of the houses; to hide the discolouration of the walls caused by DDT, and for decorative purposes during the festive season. Replastering covers the insecticide sprayed surfaces and reduces or negates the effect of the insecticide (Sharp *et al*, 1988; Sharp *et al*, 1990; Ngxongo, 1993). A reduction in the number of bedbugs as well as the number of homesteads being replastered has been reported due to the use of Deltamethrin (Sharp, 1990). However, the loss of effectiveness of the insecticides that are applied to the inner walls of homes highlights the need to find supplementary control methods.

Chemotherapy

Chemotherapeutic medicines are administered presumptively to those who present with the symptoms of malaria at health facilities, or who are presumed by the surveillance agents to have the disease. Medication is continued once the presence of the parasite has been positively identified by microscopic detection (Ngxongo, 1993). Chloroquine and Pyrimethamine were used in combination until February 1988. Due to reports of Chloroquine resistance in 1987, this was changed to Pyrimethamine-sulphadoxine (Fansidar) to treat the asexual stage, and

Primaquine to treat the sexual stage of the parasite (Sharp, 1990). Resistance to Fansidar has been reported in South East Asia but not yet in South Africa (Freese *et al*, 1993; Ngxongo, 1993; Freese *et al*, 1994).

3.7.2 Data Collection and Malaria Case Detection Methods

The area between the border with Mozambique (26°50'S) and Lake St Lucia (28°S) is divided into two magisterial districts, Ingwavuma to the north and Ubombo to the south. These two districts account for 88% of the malaria cases in the province, with 69% of these occurring in the northern-most district of Ingwavuma (Sharp *et al*, 1988). A number of cases do occur south of the Ingwavuma and Ubombo districts but due to the on-going efforts of the MCP, major epidemics are uncommon (Ngxongo, 1993). The two districts have been divided into smaller units for administrative purposes by the Control Programme called 'areas', each of which is named. These areas are further sub-divided into 'sections' which are numbered, and range in size from five to 30 square kilometres, depending on the density of settlements. These administrative units are presented in Figure 3.5 as well as the town of Jozini, the regional head office of the MCP. These subdivisions were necessary due to the dispersed nature of the homesteads and the absence of villages as identifiable units. The patriarchal homesteads of the area usually consist of several individual dwellings and are home to extended family units. Figure 3.6 presents the subdivision of Nakanis and Ndumu areas into their 10 malaria sections, with Ndumu section 1 being the Ndumu Game Reserve which is uninhabited. Due to its proximity to high risk areas, tourists are however advised to take preventative measures when staying overnight.

Every homestead in this region has been numbered by the MCP field staff according to the area and section within which it falls. The numbers are recorded on green cards which are stored under the eaves of the roof of each homestead. On each is recorded the visits of the surveillance agents or spray team members as well as the date and reason for their visit. A record of the homestead number, homestead head, wall surface type and population per homestead is also kept by the spray teams on forms which they complete and return to the MCP (le Sueur *et al*, 1995). This homestead number is also recorded on the surveillance agents case incidence sheet when blood slides are taken so as to ensure that follow-up visits can be made if the presence of parasites has been confirmed at the laboratory (le Sueur *et al*, 1995).

Figure 3.5 Malaria Control Programme Boundaries in Northern KwaZulu-Natal

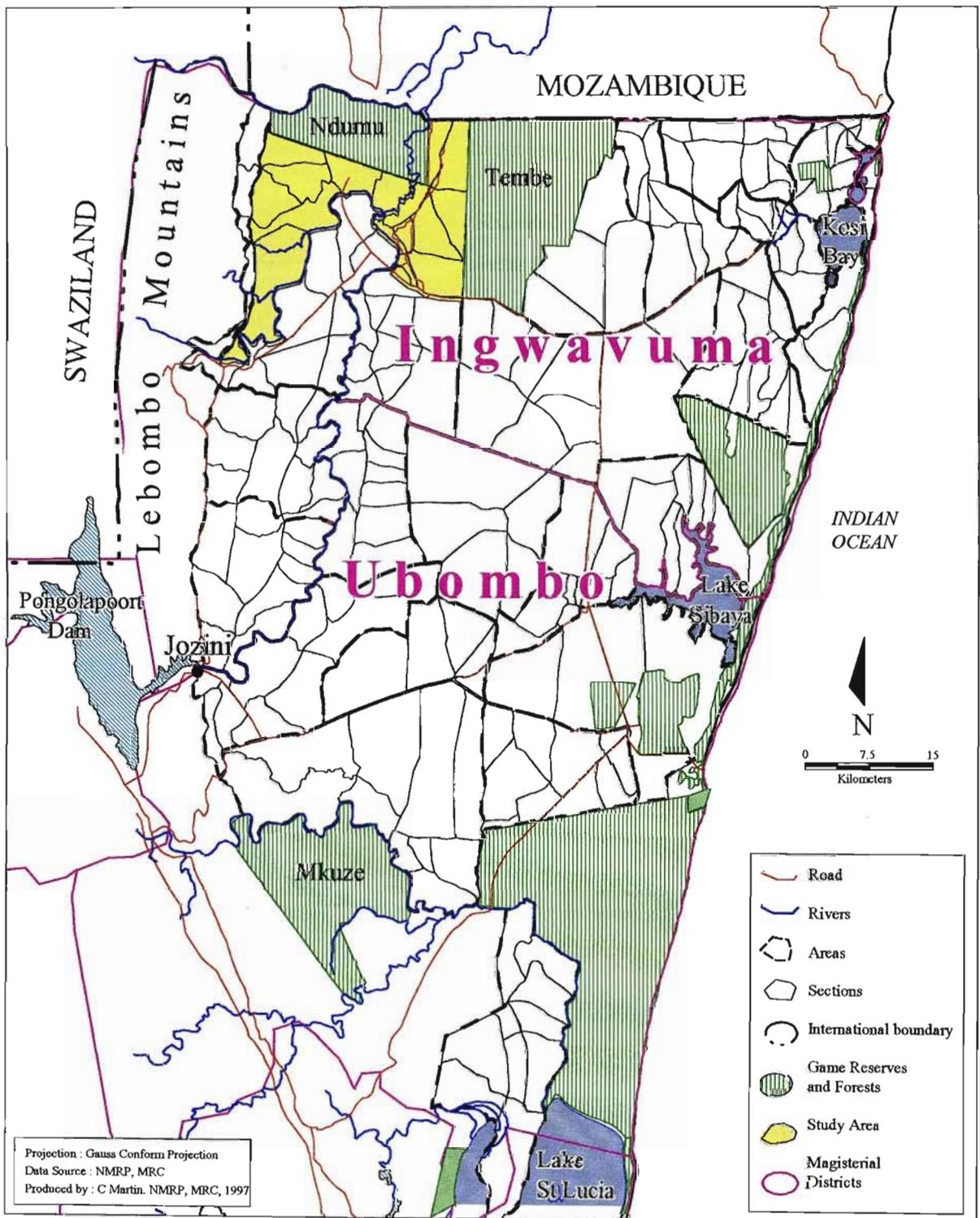
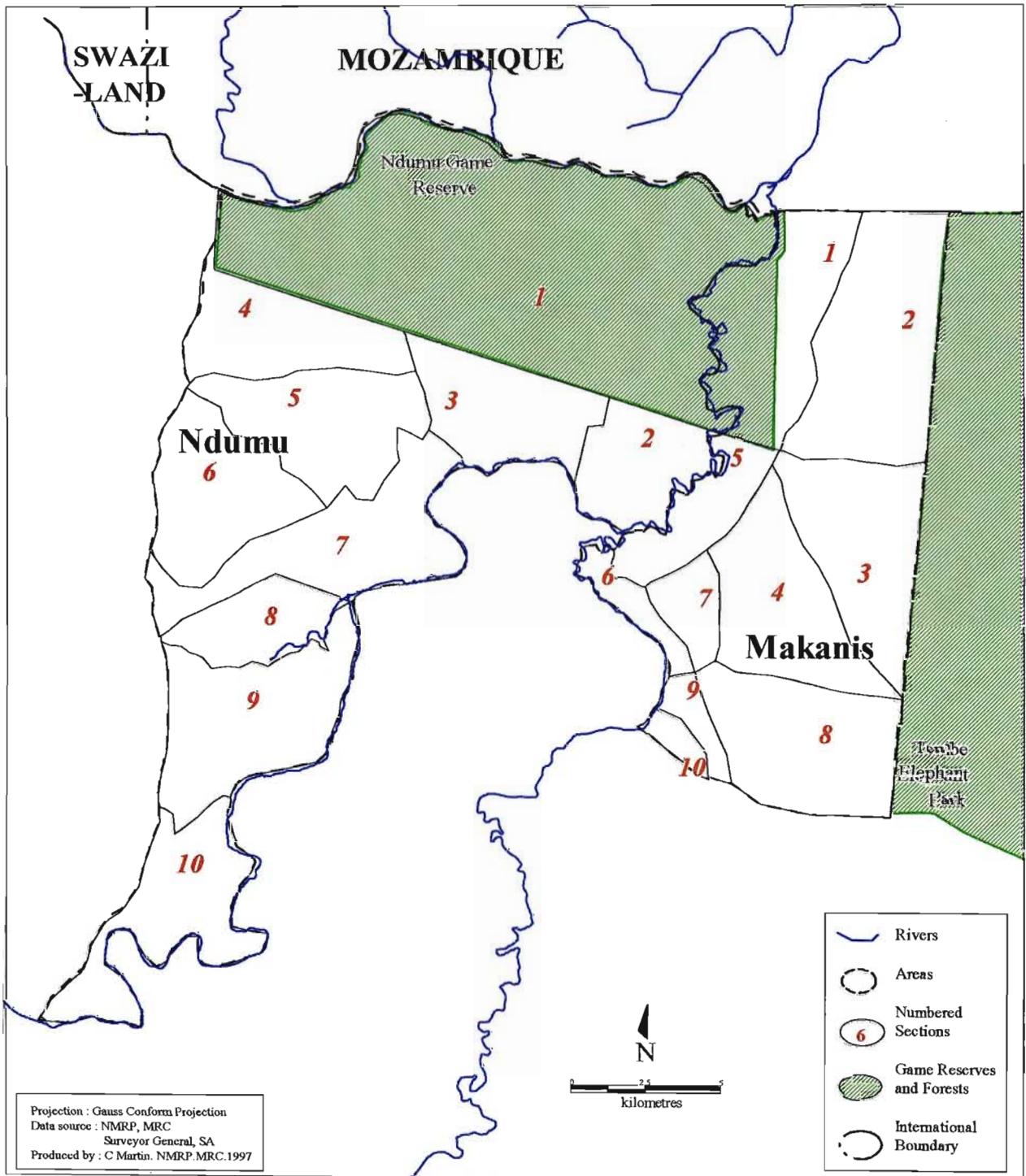


Figure 3.6 Malaria Section in the Study Areas of Makanis and Ndumu Malaria



The latitude and longitude coordinates of each homestead were obtained by the field staff during their routine activities in 1993 using Global Positioning System receivers. This provided the geographic reference for the Malaria Information System (MIS) as described in Chapter 5 (le Sueur *et al*, 1995). The location of the site of infection for this study was assumed to be the homestead of residence as it is not possible to trace the activities of all the inhabitants after sunset. The average number of people per homestead in the region, as determined by the information obtained on the spray forms, was calculated as seven. Based on figures obtained for the number of homesteads and population in a portion of the study area in 1994, an average population increase per year of approximately 2.2% was estimated (le Sueur *et al*, 1995). Appendix 3 presents the number of people in the malaria sections of Makanis and Ndumu and indicates the uneven distribution of people in the area.

The method of malaria case detection determines the classification of the disease, with cases being noted as either 'active' or 'passive'. People suffering from the disease who report ill to clinics or hospitals are classified as 'passive'. The malaria case incidence figures in the region are available due to malaria being a notifiable disease, and therefore requiring a record to be kept of every case that is positively diagnosed, both passively and actively (Sharp, 1990; Ngxongo, 1993). The malaria season traditionally lasts from December to June, and is reflected by an increase in the number of cases recorded by the passive method of case detection (Sharp, 1990). Raised levels of immunity in some areas due to an acquired tolerance of the parasite, results in immune people carrying the parasite asymptotically and therefore not reporting to the clinics for treatment. These cases are classified as 'active' and are detected by surveillance agents who visit homesteads and take random blood smears which are then screened for the presence of parasites (Sharp *et al*, 1988). The aim of 'active' case detection is to reduce the residual pool of parasites so as to prevent further transmission of the disease, with people in the high risk areas being screened prior to the transmission season (Ngxongo, 1993). The different methods of active case detection are briefly outlined in Appendix 4.

The number of migrants from Mozambique increased during the years of its civil war (mid 1970s - early 1990s) as many fled the strife. Malaria is endemic in Mozambique and malaria control activities in the form of an indoor residual spraying with an insecticide have only recently been reestablished in southern rural areas. This area has traditionally rely on the use of medication to treat those who report ill to clinics, and many of the citizens are asymptomatic

parasite carriers (Sharp *et al*, 1988). Of the imported cases reported in KwaZulu, 90% were from Mozambique, and of these, 97% occurred in the Ingwavuma district which adjoins the Mozambican border (Ngxongo, 1993). The reported active and passive cases for all 12 months of 1993 and 1994 in the malaria sections within Makanis and Ndumu are presented in Figure 3.7, with the size of each circle representing the total number of cases. The proportion of active cases is higher in all of the Makanis sections, however in Ndumu, most of the sections reported more passive cases. The 1994 maps indicates that the distribution of higher cases is similar to 1993, with more cases being reported in Makanis sections 2, 5 and 7, and in Ndumu sections 2, 3 and 7. Again there are more active cases in Makanis and more passive cases in Ndumu. This clear distinction between the proportion of active and passive cases in the two areas indicates raised levels of immunity in Makanis due to the availability of a reservoir of parasites in asymptomatic carriers. This resulted in the active and passive cases being analysed separately so as not to blur any results that may be due to the variation in their distribution.

Environmental conditions conducive to malaria transmissions are not homogeneous within each magisterial district, therefore displaying malaria incidence data at this spatial level does indicate the micro-level spatial distribution of the disease. Figure 3.8 indicates the malaria incidence at malaria area level for the two northern magisterial districts of Ingwavuma and Ubombo, for the years of 1987 to 1993 combine. The areas of highest incidence are in the north-eastern section of Ingwavuma District, after which the incidence drops with increasing distance from the Mozambican border. This level of display indicates the non-uniformity of malaria incidence that occur within a small area and may assist in appropriately allocating resources to where they are most needed (le Sueur *et al*, 1997).

The micro-level distribution of the disease for the combined cases of 1993 and 1994 is more correctly reflected when displayed at malaria section level and is presented in Figure 3.9 (le Sueur *et al*, 1995; Sharp and le Sueur, 1996). However, this only reflects the passive case incidence per 1000 people at risk and therefore does not take the actively detected cases into account. Figure 3.9 shows the highest incidence of between 151 and 300 cases (15-30%) in Makanis sections 2, 3, 6 and 10, followed by Makanis sections 1, 4, 9 and Ndumu section 4.

Figure 3.7 Reported Active and Passive Malaria Cases by Malaria Section for 1993 and 1994

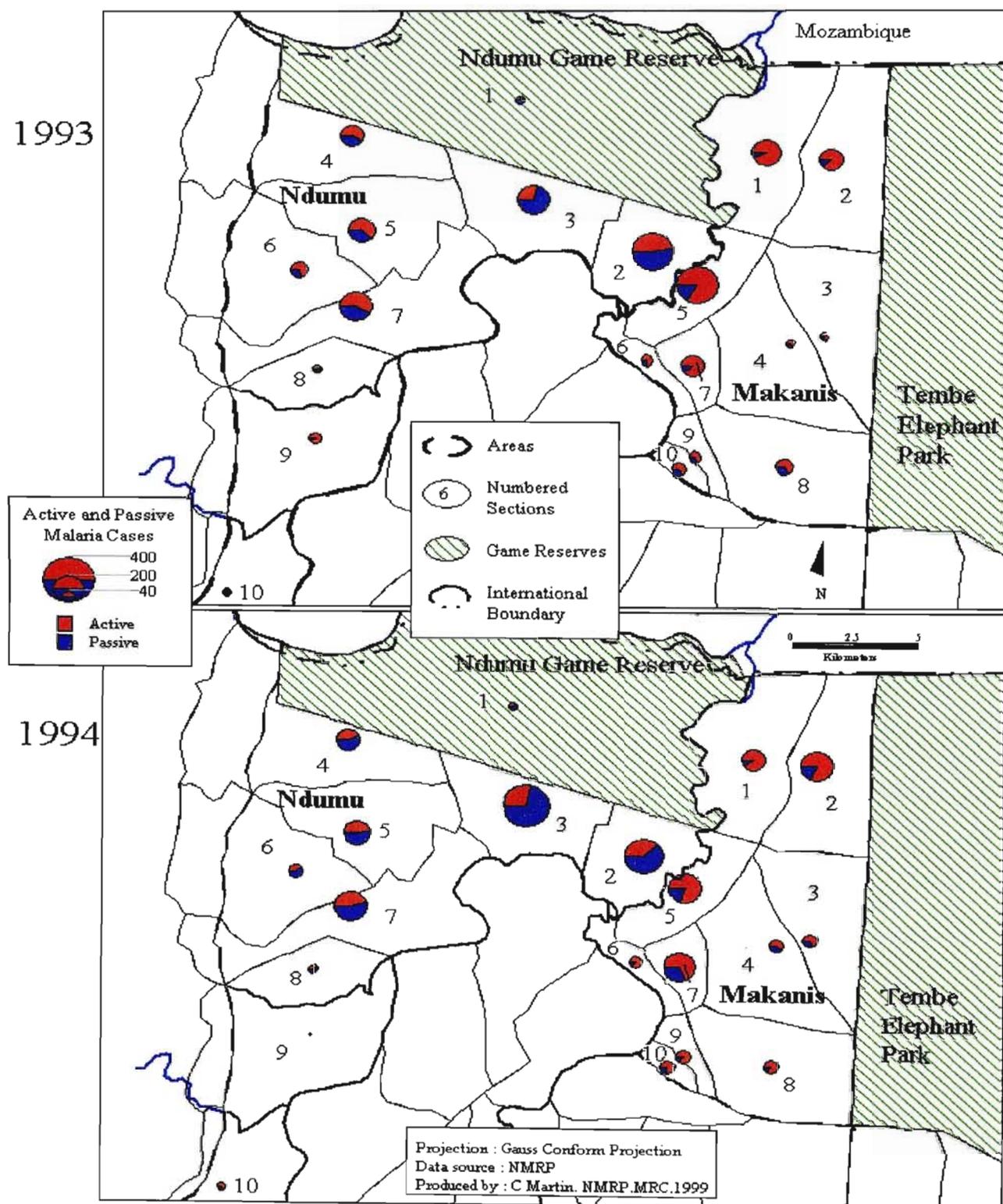


Figure 3.8. Average Malaria Cases Incidence in the Malaria Areas of Northern KwaZulu-Natal : 1987 - 1993 Cases Combined

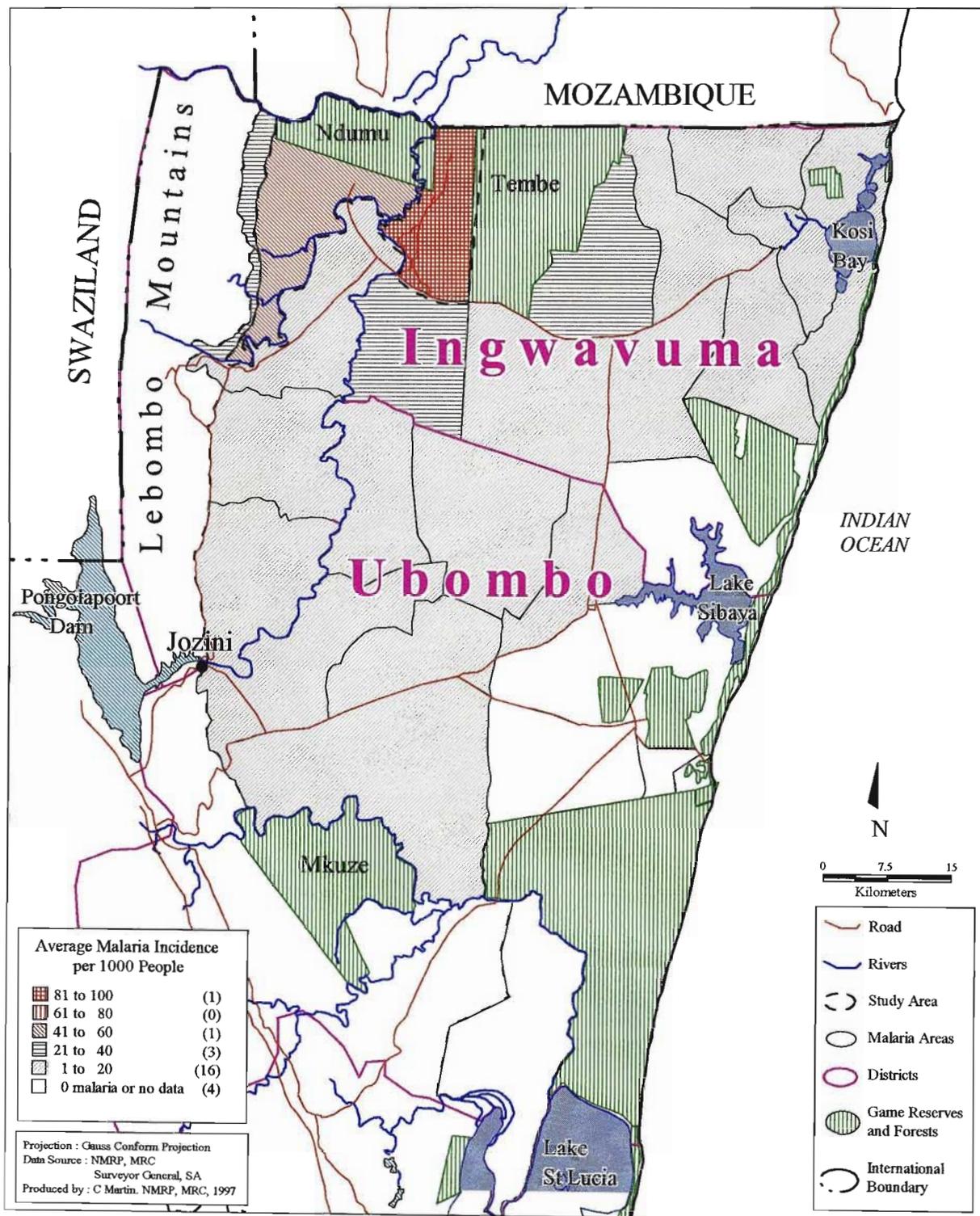
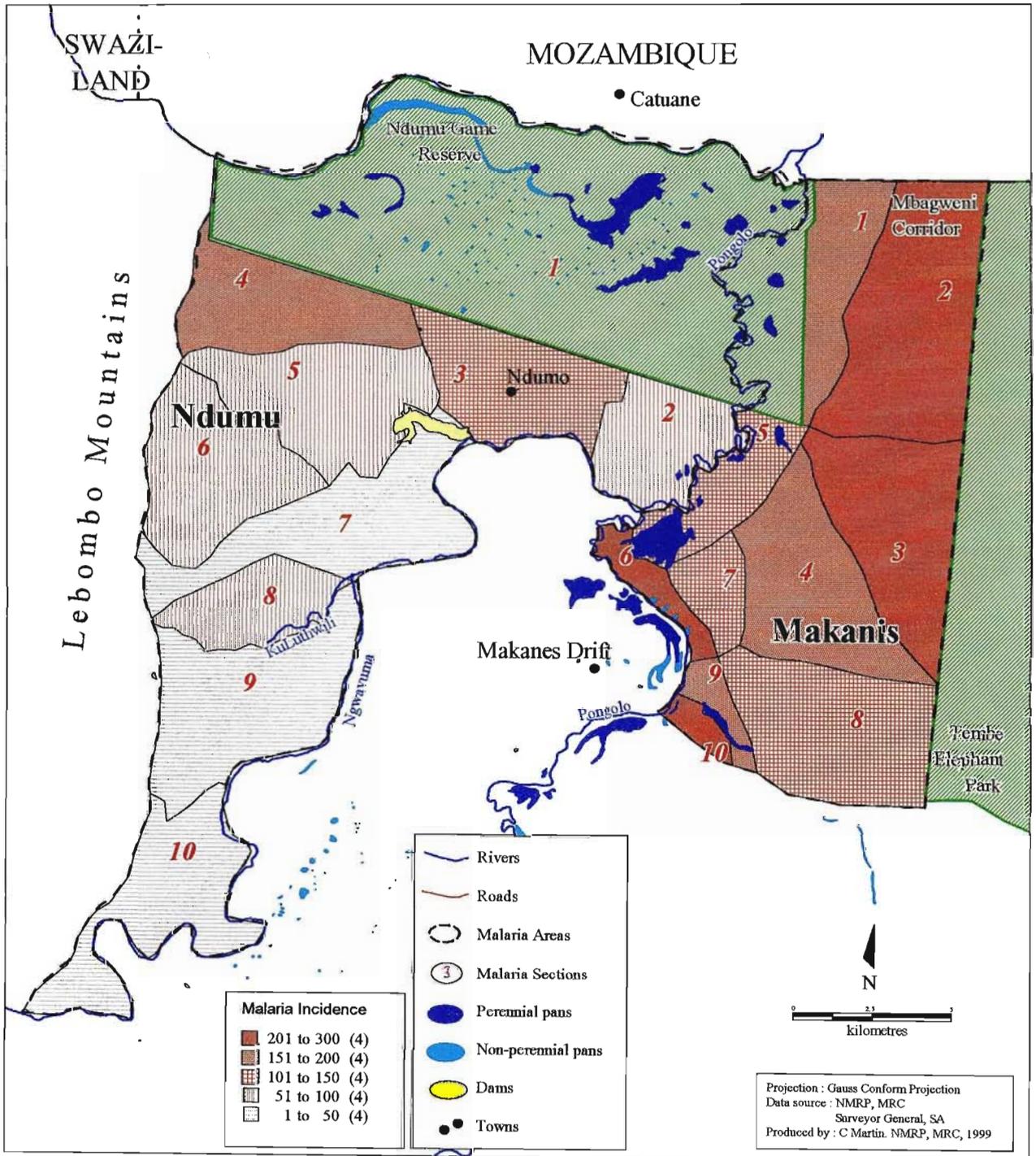


Figure 3.9 Malaria Incidence in Makanis and Ndumu per 1000 People at Risk :
1993 and 1994 Cases Combined



The remainder of the area experiences less than 150 cases (15%), with the lowest incidence being in Ndumu sections 7, 9 and 10. This map clearly shows the non-homogenous distribution of the disease at sub-district level, indicating that Makanis is the area of highest risk.

Details regarding monthly climatic conditions and the associated number of active and passive cases in Makanisdrift and Ndumu are provided in Appendix 2. The monthly active and passive cases that were recorded during 1993 are provided in Appendix 5, and those reported during 1994 in Appendix 6. The total number of passively detected cases for 1993 and 1994 respectively were Ingwavuma District 4 730 and 3 737, and Ubombo District 422 and 235. Within the Ingwavuma district, 635 (1993) were from Makanis and 749 (1994) from Ndumu. Epidemic indicators for the magisterial districts in the region are 75 cases per week per 1000 population, but due to the incidence within each district not being homogeneous, this would need to be refined to sub-district or malaria area and section levels (Mr Mthembu, pers comm, 1997).

Table 3.1 presents the total number of slides taken for both the active and passive methods of case detection during 1993 and 1994, and indicates the numbers that were positively identified, had missing address details and the resulting total number and percent used in this study.

Table 3.1 Active and Passive Malaria Case Details in the Study Area.

Case Detection Methods	Total Number of Slides Taken	Number Positively Identified	Number with Missing Address Details	Number of Usable Cases	% of Usable Cases
1993 Active Case	23 557	1 415	225	1190	84%
1993 Passive Cases	1 088	1 088	450	638	59%
1994 Active Cases	25 640	1 283	234	1 049	82%
1994 Passive Cases	1 170	1 170	421	749	64%

The percentage of actively detected cases is approximately 20% higher than the passively reported ones, with the missing information being due to the data not being collected by the field or clinic staff. Despite these limitations, the data was considered adequate for this study.

The cases reported as a result of the active and passive methods of case detection were analysed separately in this study so as not to diffuse any patterns that may have occurred due to the spatial variation in their distribution. The high number of cases detected by active case detection clearly

indicates the presence of immune parasite carriers who do not report ill to health facilities, their location being influenced by proximity to the Mozambican border. Varying spatial patterns as a result of the different methods of case detection will further be explored below as well as the diffusion of the disease through the study area.

3.8 Seasonality and Disease Diffusion

Northern KwaZulu-Natal experiences seasonal (epidemic) rather than continuous (endemic) malaria. Using malaria case data from 1976 to 1985, Sharp *et al* (1988) found that malaria transmission by passive case detection started to rise in January, peaked in April/May, and declined in June. Appendix 2 presents the monthly rainfall, minimum and maximum temperatures, and active and passive malaria cases for 1993 and 1994. As described in Chapter 2, optimal temperatures for malaria transmission are between 20° and 30° C. Appendix 2 shows that these conditions existed from January to March and again in December during 1993 and 1994, with the minimum temperature during the remaining months falling below 20° C. However, due to the mosquitoes being larger in size and living longer during the cooler autumn months, eggs that hatch into larvae and adults in April and May can survive into June and July (Chapter 2). There is only a marked drop in case numbers in July, indicating that the environmental conditions are no longer suitable for the continued transmission of malaria. The minimum temperatures drop to well below 20°C in June for both years (9.2°C and 9.3°C respectively) and with very little rain having fallen after May, the breeding sites that are available during wetter summer dry up due to the lack of surface water. Le Sueur (1991) described how this results in a reduction in the number and distribution of those sites that contain water through the dryer winter months and thereby act as 'seed points' from which the mosquitoes spread with the onset of the spring rains in October (Appendix 2). The gradual rise in the minimum temperatures from October onwards, accompanied by an increase in the amount of rainfall, results in increasingly suitable conditions for malaria transmission. However, the winter water bodies continue to be used for breeding during this time while the mosquitoes gradually spread to the newly available sites.

Since the start of the civil war in Mozambique in the 1970's, there has been cross border movement within the region as people for access to land, schools, health facilities, markets and

employment. Much of this movement takes place through the Mbagweni Corridor which is situated between the Ndumu Game Reserve and the Tembe Elephant Park (Figure 3.9).

People in South Africa living close to the Mozambican border tend to present with fewer passive cases than those living further away, as they have become semi-immune due to their continued exposure to the parasite (Ngxongo, 1993). Table 3.2 indicates the number and percentage of cases reported in the Mbagweni Corridor during the months of July to December for 1993 and 1994. While the total number of passive cases is considerably lower than the active cases, the percentage of active cases in the corridor is almost three times higher than the passive cases in 1993, and almost 5 times higher in 1994. This indicates the presence of asymptomatic parasite carriers with raised levels of immunity near the border with Mozambique. This provides a reservoir of parasites which are only detected through active surveillance methods, highlighting the importance of this method of detection in this high risk area.

Table 3.2 Active and Passive Malaria Cases in the Mbagweni Corridor as a Percentage of the Total Number of Cases in the Study Area for July to December, 1993/1994.

Case Detection Methods	Total Number of Cases	Number in the Mbagweni Corridor	% in the Mbagweni Corridor
Passive Cases 1993	41	3	7%
Active Cases 1993	265	49	18%
Passive Cases 1994	115	7	6%
Active Cases 1994	262	74	28%

The study area provides an ideal opportunity to study the diffusion of malaria as it has only one main parasite entry point, and is encapsulated by the Lebombo Mountains to the west, the Ndumu Game Reserve to the north and the Tembe Elephant Park to the east. The many water bodies, particularly the perennial pans, in Mozambican near the border, provide ideal breeding conditions, and the possibility of mosquitoes from these sites infecting people in Ndumu cannot be excluded due to their proximity to South Africa.

The water bodies in the study area consist of the perennial pans, non-perennial pans and dams, their distribution with respect to the location of the homesteads in the study area being presented in Figure 3.10. The scattered nature of the homesteads around the Mandlankunzi and Bumba

perennial pans are clearly evident as presented on Plates 3.1 and 3.2, with the homesteads identified by small clearings in the vegetation. The perennial pans are situated in the Ndumu Game Reserve and along the banks of the Pongolo River. The non-perennial pans are situated in the central and western section of the Ndumu Game Reserve, and along the lower sections of Makanis along the Pongolo River banks and below section 8. The dams consist of the Qotho Dam in Ndumu section 7, a small one on the western border of Ndumu between sections 3 and 4, one on the upper outside western edge of Ndumu section 9, and one on the outer eastern edge of Ndumu section 10. Although many of the water bodies fall outside of the study area, their zones of influence overlap it, resulting in their inclusion. The Qotho Dam is fed by non-perennial rivers at its western end and was originally a pan, with a dam wall being built at its eastern end.

The spread or diffusion of malaria through the study area is presented in Figure 3.11, with the monthly malaria cases for 1993 and 1994 combined and corrected for the population at risk in each malaria section. The cases were combined to give a general indication of the diffusion trend in the area with respect to the movement of the disease, more specifically, the start, peak and end months, and the number of cases in each month. It also presents the relationship between the active and passive cases. The malaria cases for each month are presented in their respective malaria section, with the upper portion of the bar graph representing the active cases, and the lower section representing the passive cases.

There are more active than passive cases in all the Makanis sections of each month, indicating raised levels of immunity due to repeated exposure to the malaria parasite. The reverse is true in Ndumu, where there are more passive than active cases, indicating more symptomatic cases of malaria and lower levels of immunity due to less exposure to the parasite. The number of active and passive malaria cases is highest near the Mozambique border (Makanis sections 1 and 2) and drops with increasing distance from the Mbagweni Corridor, with the case numbers being very low in the southern-most section 10 of Ndumu. Many of the Makanis sections present active cases during August to November indicating that malaria transmission continued during the dryer months of the year. While a few sections report increases in the number of December active cases, in general, the January and February cases are fairly low with the numbers increasing in March and April.

Figure 3.10 Distribution of Homesteads and Potential Breeding Sites in Makanis and Ndumu

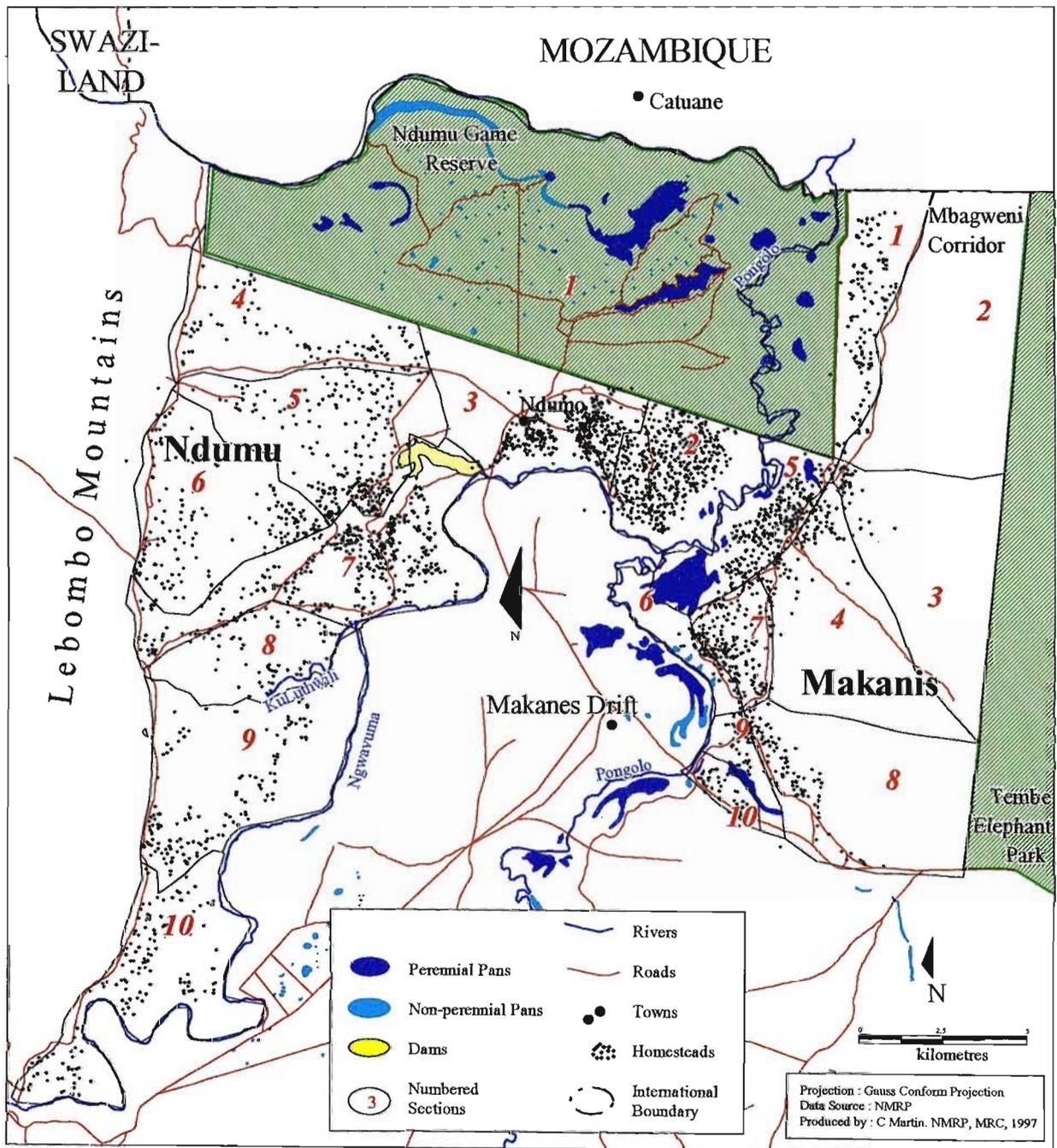


Plate 3.1 Scattered Homesteads around
Mandlankunzi Perennial Pan.
(C. Martin, 1997)

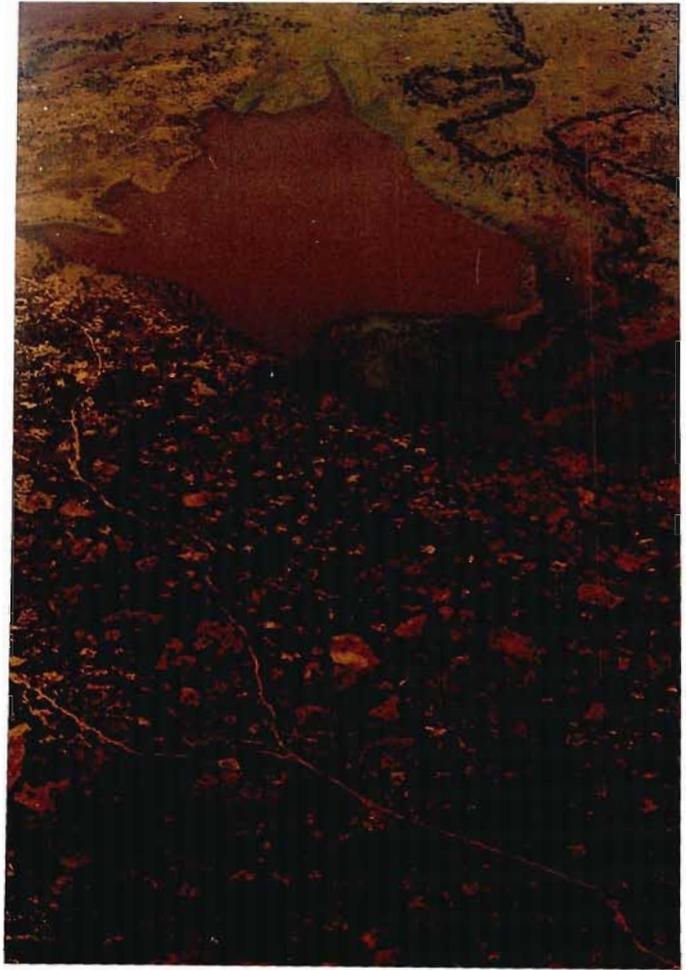


Plate 3.2 Scattered Homesteads around Bumbe Perennial Pan. (C. Martin, 1997)

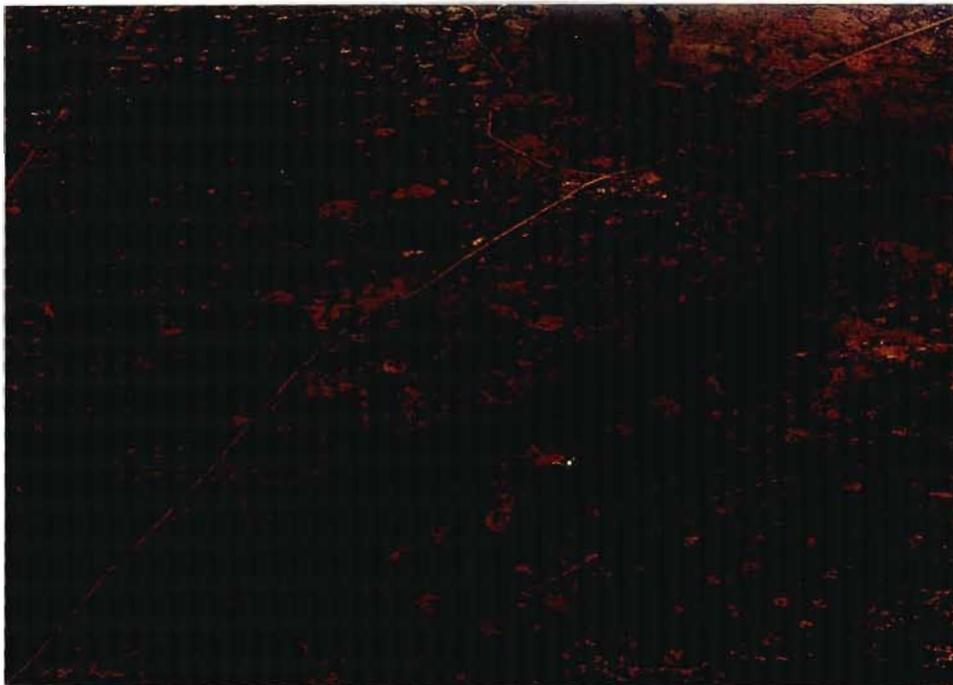
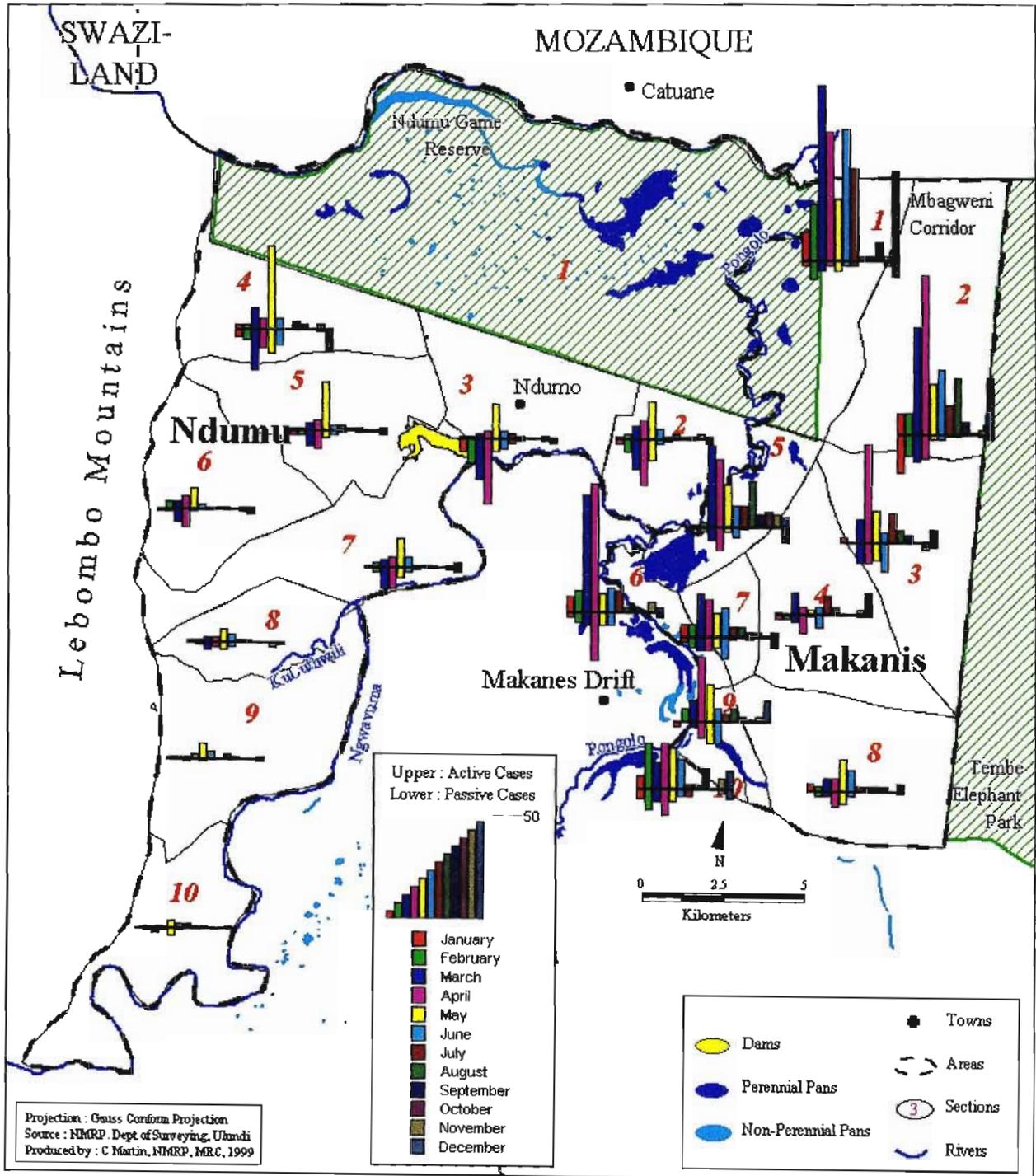


Figure 3.11 Monthly Distribution of Active and Passive Cases per 1000 People at Risk : 1993 and 1994 Cases Combined



The active cases peak during March in Makanis sections 1, 5 and 7, during April in sections 2, 3, 6 and 9, followed by a general downward trend towards August. The sections along the eastern bank of the Pongolo River experience transmission almost all year round, this being detected largely through active case reporting, indicating the presence of parasites that as a reservoir for the onset of the coming season. The passive malaria cases in Makanis peak during January and February in sections 1 and 2, during April in sections 4, 5, 6, 8 and 10, and during May and June in section 3, 7 and 9. The numbers drop sharply after June in all the sections indicating low transmission rates. The presence of cases between the months of July to December does however indicate the presence of suitable breeding, particularly in the Makanis area.

Most of the Ndumu sections indicate the presence of passive cases in December, with sections 4 and 7 peaking during March, and sections 2, 3, 5 and 6 peaking during April. The active cases tend to present in February with the peak month usually being May. The onset of the peak active month following that of the passive cases could be a result of repeated exposure resulting in immunity being developed during the latter part of the season. The relationships between the active and passive cases is not the focus of this research and requires further analysis.

The map indicates that malaria spreads through the area from the corridor southward along the Pongolo River and then westward into Ndumu. Both the month of initial transmission and the peak transmission months are delayed with increasing distance from the Mbagweni corridor. It is anticipated that being able to identify and apply larvicides to the breeding sites that exist during the dryer winter months will reduce the number of mosquitoes at the start of the malaria season and delay the onset of the peak season by reducing the number of malaria cases as described above. While every effort is made in KwaZulu-Natal to decrease the malaria incidence, eradication of the disease will not occur until a control programme is successfully implemented in Mozambique from where the malaria parasite is continually reintroduces as a result of population migration (Ngxongo, 1993).

3.9 Conclusion

The history of malaria prevention, control and treatment efforts has spanned several centuries, with major gains being made through larvicide applications. The WHO strategies on global

malaria control have changed from an optimism which assumed that eradicating of malaria was possible, to control leading to eradication with a PHC focus. This has shifted the emphasis from a unidirectional focus on malaria control, to an approach that integrates broader health aspects and involves the affected communities in the strategies. This resulted in a renewed interest in the use of bednets and other community based prevention and control strategies such as larviciding.

While larviciding was found to be an effective method of control mosquito numbers in the past, it is only financially viable and most effective when limited to those water bodies used for breeding, and when other intervention strategies have not been successful in reducing the adult female mosquito populations to required levels. Larvicides should supplement and not replace other existing methods, and with the likelihood of resistance being development to both drugs and insecticides over time, there is a need to find inexpensive and effective ways to compliment intervention strategies.

Mapping the extent of malaria epidemics that occurred in South Africa during the earlier part of last century indicates the area that could be affected should the malaria control measures not be effective. The gains that were made in limiting the southern extent of the disease were done through research efforts to understand the habits of the local epidemiology, and resulted in the use of larvicides and indoor sprays to reduce the mosquito population and medication to treat the infected. Maps were used to indicate the location of the water bodies to which larvicides were applied and scientific investigations revealed that the water bodies in the study area contracted during winter, limiting those that could be used as breeding sites until the onset of the summer rains. Despite extensive control measures aimed at the parasite and the adult vector in the area, the disease continues to persist.

The active and passive case detection methods used in KwaZulu-Natal indicate the presence of immune and non-immune parasite carriers, the former acting as a parasite reservoir from which the disease spreads with the onset of suitable environmental conditions. The malaria season is indicated by the presence of passively detected cases, however, the presence of a high number of actively detected cases, due to raised immunity in parts of the study area, necessitated their inclusion in this study to assist in identifying the potential low season breeding sites.

Le Sueur (1991) maintained that the perennial pans along the Pongolo River were the most likely breeding sites of the *An. arabiensis* mosquito in winter at which time the mosquito population is concentrated in the lengthened larval stage. The dams and non-perennial pans have been included in this research in order to substantiate this assertion and to ensure that their exclusion would not bias the results in any way. The application of salt, as recommended by le Sueur (1991), or alternative larvicides at the end of July would render the water bodies unsuitable for breeding and larval survival. This would reduce the number of larvae that would reach adulthood and thereby delay the onset of the distribution and intensity of malaria season in the region.

The MCP provided the locations of the homesteads as well as the active and passive case data for this research, these being considered suitable for this project despite the problems associated with their incompleteness. Malaria was shown to spread south and westwards from the Mbagweni Corridor, resulting in the delayed onset of the transmission season and peak months as well as a reduction in number of cases, with increasing distance from it. This indicated that the location and number of suitable breeding sites that are available during the dryer winter months are likely to be restricted to this northern area. The feasibility of identifying which breeding sites can be targeted for larviciding will be done by investigating their proximity to the active and passive malaria cases. Establishing the likely maximum flight distance of the female mosquito will assist in identifying the people who are most at risk and therefore areas that may benefit from additional intervention methods. This will not only contribute to the MRC's body of knowledge regarding malaria, but will also assist the MCP to rationalise its resources in a more cost-effective manner, and reduce the suffering and deaths caused by the disease.

CHAPTER 4

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

4.1 Introduction

The study of the spatial distribution of malaria incidence falls within the broader theoretical paradigm of 'medical geography'. This chapter aims to provide a brief overview of this field of literature in order to locate this thesis within a theoretical framework. Medical geography is a sub-discipline within geography and has focussed essentially on the relationship between health and space, developing out of a desire to understand and visualise the spatial dynamics and locations of environmental diseases. Traditionally however, this has not been a sub-discipline of geography, but rather of medicine and zoology, through the study of epidemiology. The essential characteristics of geography, as well as its methods and principles of description and interpretation, have combined with the scientific principles of testing and explaining that are associated with epidemiology. Medical geography is divided into the two major themes, the earliest to develop being referred to as 'the geography of disease' or 'geographical epidemiology', and the second later theme being referred to as 'the geography of health care' (Barrett, in Pacione, 1986; Rothman, 1986; Hayes, 1996).

Geographic Information Systems (GIS) in the field of health are being used by an increasing range of disciplines other than geography, providing a tool with which to visualise their subject matter, by condensing both time and space in order to find causal relationship between variables as a result of the spatial patterns. This chapter outlines the concepts associated with medical geography, and gives a brief introduction to GIS as the investigative tool for this project. A range of GIS projects in the field of health, and more particularly malaria, are reviewed in order to assess the use of GIS in medical geography.

4.2 Geography

For the purposes of this thesis, geography will be defined as the study of the portion of the earth's surface on which humans survive, through accurate, orderly and rational description and

interpretation of its variable characteristics, including the variations that occur between the characteristics of two locations (Hartshorne in Johnston *et al*, 1986). Variable characteristics refers to the spatial variations that can occur between two or more locations at any scale, from global to local. The term geography is derived from the Greek words 'geo' meaning the earth, and 'graphein' meaning to write. Halford J. Mackinder in the later 1980's (Mackinder, 1996) was the first to propose that geography be developed as a scientific discipline and not merely a "body of information" (Mackinder, 1996, 155). Until then, geographers had been largely concerned with exploring and observing the world, and describing and interpreting their findings with the aid of maps. Mackinder proposed including the analysis of science to look for causal relationships instead of simply undertaking superficial descriptive analysis which could lead to error. This resulted in the search for understanding processes through description, interpretation and the increasing use of theories and statistics as developed by the specialised sub-disciplines within human and physical geography, such as climatology, demography and medical geography. Theories provide a system of rules, procedures and assumptions that guide interpretations to produce logically valid results (Haggett, 1990; Collins, 1994). Unlike other sciences, the statistical emphasis in geography is on the spatial attributes and patterns of the data, and includes model building, probability theory and simulation techniques (Haggett, 1979; Mackinder 1996).

Geography's recent development as a distinct discipline resulted in it being required to fit within the already formalised academic faculties of the 'natural' and the 'human' sciences. This resulted in the splitting of geography into natural or 'physical geography' and 'human geography', with Mackinder proposing that geographical experiment hold the two together in an evolutionary perspective as they are not mutually exclusive (Johnstone *et al*, 1986; Mackinder, 1996). While they may have different subject matters, they both encompass the three essential characteristics of Geography; 1) *Spatial analysis - location, spatial concepts and patterns*; 2) *Ecological analysis - human/environment links*; and 3) *Regional analysis - spatial patterns of regional variations*, each of which will be outlined below (Haggett *et al*, 1977; Barrett in Pacione, 1986; Johnston *et al*, 1986; Haggett, 1979, 1990; Collins, 1994; Johnston *et al*, 1994).

1. *Spatial analysis - location, spatial concepts and patterns*

This approach emphasises location (site or position) and spatial concepts (ideas) with a focus on understanding the factors that lead to particular spatial patterns (detectable organisation of spatial units) and variations on the earth's surface in both physical and human phenomena over time.

Understanding the factors that cause spatial patterns can assist in modifying or changing them. The spatial concepts include: location, extent, dimension, density, proximity, distribution, distance, direction, speed, duration and frequency. This desire to accurately represent the location of the surface features of the earth in order to understand the factors that lead to particular spatial patterns, resulted in the field of cartography, the art and science of making maps. The advent of computers and Geographic Information Systems (GIS) have provided a tool that enable maps to be digitally created and spatial analysis to be undertaken in systematic and scientific manner (Haggett *et al*, 1977; Barrett in Pacione, 1986; Johnston *et al*, 1986; Haggett, 1979, 1990; Johnston *et al*, 1994).

Maps are a form of graphic communication designed to convey information about the environment in a scaled-down view of reality so that the viewer is able to see the whole earth, or a larger portion of it, than they would otherwise be able to do. A major function of maps is to assist in understanding and determining spatial relationships or patterns, and they are therefore structured to be similar to the territory they represent, with geographical features being located in ways that reflect their actual positions (Clark, 1984). Supplementary data that is not suited to being displayed on a map but which provides additional information can be presented as in the form of graphs and diagrams (Learmonth, 1978). Maps generally show a static situation with new maps being needed to reflect changes that occur over both space and time (Clark, 1984).

While statistical tables can display more attribute data than maps, they cannot easily convey the associated spatial patterns and are therefore less suitable for presenting geographical information. Data presented in tables may miss the less obvious spatial patterns due to relationships between populations being poorly represented (English in Elliot *et al*, 1996). Thematic maps are designed to emphasise a specific feature or theme and consist of a framework of features (roads, rivers, towns) which provide reference points against which the thematic data is displayed. The quality of the final product is determined by the quality and availability of relevant spatial and attribute data (Hodgkiss, 1981).

Maps with disease as their theme were first drawn to display yellow fever in the USA and later for cholera in Britain during the early part of the 19th Century (Howe in Pacione, 1986). Dr Robert Baker in 1833 produced a map with hatched areas to indicate the distribution of cholera at district level. In 1849 Dr T. Shapter published a dot map using different symbols to indicate

the locations of sites at which deaths took place as well as for important sites such as burial grounds, a different red shape representing the site of deaths for each of the years from 1832-1834. This was followed by further developments in thematic maps with symbols of graded colours being used to represent population density, and different coloured symbols to represent cholera cases over a number of years (Howe in Pacione, 1986).

Dr John Snow (1813-1858) was one of the most famous early users of maps in medical science. As an anaesthetist working in London (1854), he proposed that a cholera epidemic was caused by a water supply contaminated by leakage from a cesspool. By indicating on a map the location of the water pump and the deaths due to cholera in the Soho area, he was able to demonstrate the association between them (Johnston *et al*, 1986; Scolten and de Lepper, 1991). The spatial representation of the homes, water pumps and deaths in the area gave the clue to the possible cause of the deaths, and was followed by an epidemiological investigation which resulted in the contaminated pump being closed (Mayer in Pacione, 1986). His analysis of the cholera outbreak represents the beginning of modern epidemiology due to his use of “organising observations in order to verify a hypothesis” (Terracini, in Elliot *et al*, 1996, 257).

While an understanding of the relationship between diseases and the environment has had a long history, the use of maps to display their spatial relationships is fairly recent. “Maps provide an efficient and unique method of demonstrating distributions of phenomena in space” (Howe in Pacione, 1986, 35). Howe (in Pacione, 1986, 54) maintains that maps reveal the spatial variations and distribution patterns which may be suspected from tables but that “the disease map is a factual document, it proves nothing”. He states that proof of causation needs analytical investigations. Barrett (in Pacione, 1986, 27) states that “disclosure is the first step to analysis, and analysis is a pre-requisite to explanation”.

Maps were used to investigate the relationship (proximity) between the location of the potential breeding sites and that of the malaria cases for this project. A GIS was used to display the distribution of the malaria cases in relation to the potential breeding sites for the months of July to December of 1993 and 1994 in order to understand the factors that cause the spatial patterns. This will enable the application of a larvicide to the breeding sites which will reduce the number of mosquitoes that survive to transmit malaria during the following malaria season.

2. *Ecological analysis - human/environment links*

This approach considers the relationships between human and environmental variables in a defined geographic space. It consists of a number of interconnected systems - the impact of people on their environment and the impact of the environment on people. The emphasis is on understanding human-environment relations and systems, and the interrelatedness of human populations with the natural environment within which they live, focussing on the impact of phenomena or activities within a system rather than purely on the spatial variations. Understanding these linkages will assist in improving the way that resources and space are used (Haggett *et al*, 1977; Haggett, 1979, 1990; Johnston *et al*, 1986, 1994). This aspect falls beyond the context of this study where the focus is on the reasons for the spatial variations and not on the impact of the human-environmental relations.

3. *Regional analysis - spatial patterns of regional variations*

Regional units are identified as a result of differences in their characteristics or variables, and the links between the different units are then investigated, necessitating some form of spatial analysis. In the context of this study, the spatial units are the numbered malaria sections into and through which the malaria parasite moves, resulting in spatial variations in the incidence of the disease over time. Spatial variations need to be considered when plans or policies are developed for areas with different disease profiles due to economic or demographic factors (Haggett, 1979, 1990; Johnston *et al*, 1986, 1994). As is in this study, geographical phenomena may be used as one of the causal factors in an epidemiological study, for example, the distribution of the malaria reservoir being related to the size and density of human settlements (Johnston *et al*, 1994).

In all three approaches, the scale of investigation is important as results presented from analysis undertaken at one scale may change if taken to another scale. The scale of a sample unit will effect the sample size, with smaller areas requiring relatively larger sample sizes than larger areas (Twigg, 1990). The time scale of the analysis is also important, as chance variations or data collected or observations done over an insufficient time period can effect the results and any decisions based on them (Haggett, 1979, 1990). The sample size for this project was determined by the number of malaria cases reported during the last six months of two years for which the relevant data was available at the start of this project. The two year period (1993 and 1994) was selected for this study to allow for any variations over time which may not have been reflected should only one year have been studied.

To investigate the issues described above, the earth's surface is traditionally divided into two manageable compartments for analysis:

- Regional geography which divides the earth's surface into identifiable regions in which spatial dimensions of its various components are emphasised, including environmental and population factors, structural groupings and political and social behaviour.
- Systematic geography which traces themes (systems) or topics, is not necessarily spatially limited but is narrow in focus. Only a few aspects of the characteristics are studied and is usually labelled with reference to the sub-field being investigated, such as medical geography (Johnston *et al*, 1986, 1994).

Maps provide the most succinct summary of geographical data as they recreate the spatial distribution of the features being investigated, hence the use of maps for this project (English in Elliot *et al*, 1996). Looking for causal relationships of spatial patterns by understanding the processes which affect them, necessitates describing the patterns as well as using theories and methods to guide the interpretations. Citing this research within the context of the spatial analysis approach of geography as described above provides a theoretical framework for interpreting its spatial patterns. This thesis falls within the sub-discipline of medical geography, which uses the principles outlined above, in conjunction with those of the medical sciences, to investigate the spatial relationships associated with health issues.

4.3 Medical Geography

Medical geography is traditionally a theoretical as well as empirical (applied) sub-discipline of geography which studies the spatial variations in human health or ill-health, and the delivery of health care (Eyles, 1997; Pyle, 1979; Johnstone *et al*, 1986). It is the application of geographical perspectives and methods to the study of health, disease and health care (Johnston *et al*, 1994). Medical geography became a recognised sub-discipline of geography during the 1950s, falling within the scope of 'human geography', with the goal of understanding disease dynamics, identifying their causes, minimizing their effects and reducing the resulting suffering (Mayer, 1982; Johnstone *et al*, 1986). It deals with the spatial patterns of disease, often displayed in map form, as an analytical tool to assist with explaining relationships (Learmonth, 1978). Mapping diseases provides the ability to reveal spatial patterns and disparities, contribute to identifying

high risk areas, plan health care, direct public health policy and generate hypotheses for research (Verhasselt, 1993). McGlashan (in Eyles and Wood, 1983) states that medical geography is to be used as a tool for applying geographical skills and methods to medical problems in order to provide evidence, and not proof, for medical hypotheses.

The term 'medical geography' dates back to France or Germany in the 18th Century, and the intent of the original French name (Geographie de la Santé - Geography of Health) was lost with its translation into the English 'medical geography' (Barrett in Pacione, 1986). In order to change the traditional emphasis from diseases to broader health issues, the Commission on Medical Geography was replaced by a Working Group on the Geography of Health in 1976 by the General Assembly of the International Geographical Union. Criticism of this change is based on the fact that the discipline does not in fact investigate or study 'health', rather it studies patterns and relationships associated with ill-health/disease and related medical issues, such as the placement of health facilities (Pacione, 1986). The term 'medical geography' is still currently in use and will be used for this study.

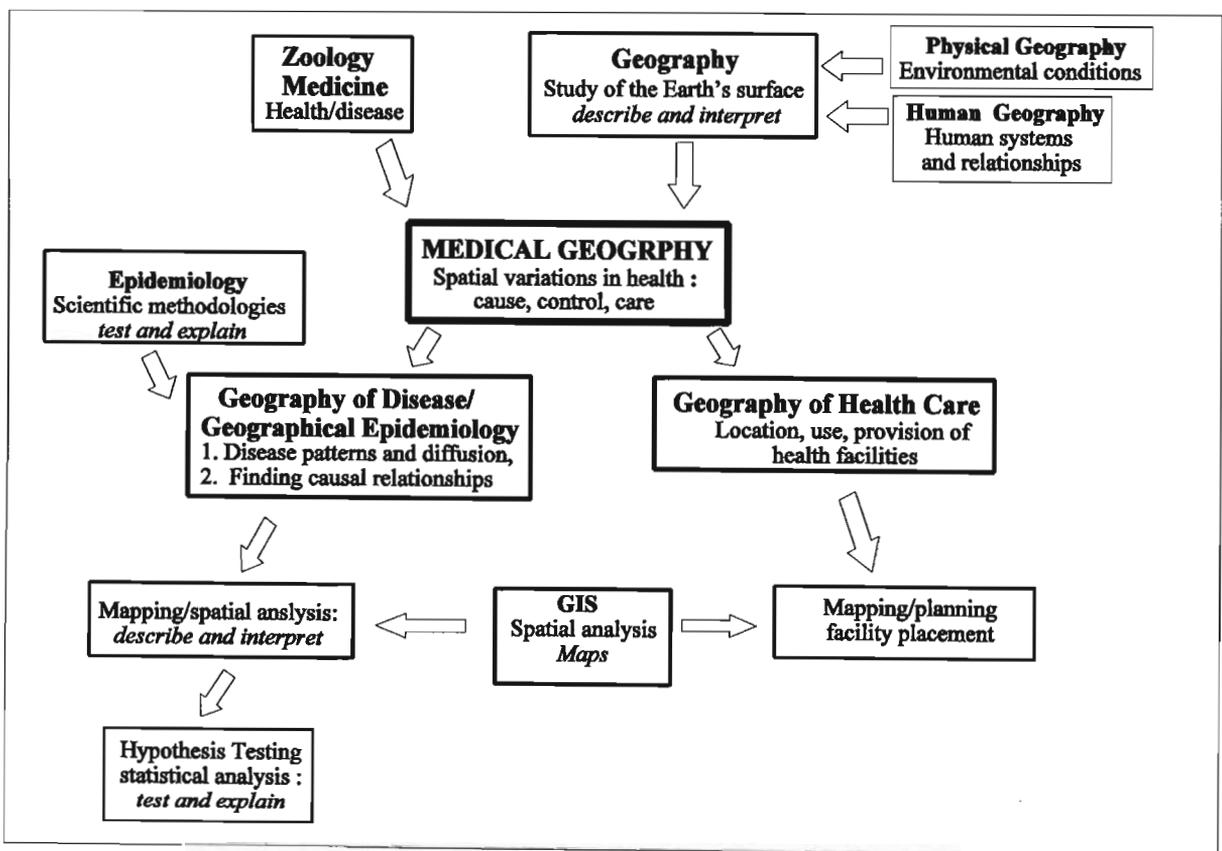
Medical geography is a combination of the two disciplines of geography and medical science (Figure 4.1):

1. Geography - which is broadly divided into:
 - a) Physical Geography - a focus on environmental conditions such as climate, soils, water and other aspects of the natural environment, together with the spatial concepts inherent in geography as described above (Woodcock, 1989; Johnston, 1986).
 - b) Human Geography - a focus on the characteristics and dynamics of human systems and their interaction with their environment, sometimes including a spatial component. By the 1980's, human geography had broadened to encompass the spatial dimensions of social, cultural and economic issues (Pyle, 1979; Verhasselt, 1993; Johnston, 1984). More recent concerns with public health and social theory and humanistic geography, and innovative thinking in the World Health Organisation's (WHO) health philosophy, have placed more emphasis on the social environment and the concept of 'health status' as opposed to 'medical condition' (Mayer, 1982).
2. Medical Science (Medicine and Zoology) - a focus on human diseases and health. The WHO has defined health as the "state of complete physical, mental and social well-being" and not simply the absence of disease (Pyle, 1979, 2). Diseases are defined as "patterned

responses or adaptations to harmful forces in the environment” (Pyle, 1979, 2). Medical science provides the understanding of disease dynamics, causes and effect.

Their integration into medical geography provides a basis from which to understand the spatial variations in human health/disease as a function of environmental conditions, in an effort to establish their cause so as to effect control and provide health care (McGlashan , 1972 in Eyles, 1997; Pyle, 1979; Johnstone *et al*, 1986).

Figure 4.1 Schematic Representation of Medical Geography



The desire for a state of health/well-being through disease prevention and health promotion has resulted in the monitoring of environmental conditions that can cause ill-health (Eyles, 1997). The relationship between health and the environment was recognised by the Hippocratic School of Healers in the fourth century BC, as is evident in the following quote from the school’s records (McGlashan, 1972, 4).

"He who wishes to study the art of healing must first and foremost observe the seasons and the influence each and every one of them exercise.... and further he shall take note of the warm and cold winds....so should he also consider the properties of the water..... The healer shall thoroughly take the situation into consideration and also the soil, whether it is without trees and lacks water, or is well wooded and abundant with water, whether the place lies in a suffocatingly hot valley or is high and cool."

Medical geography studies in the developed world are faced with different diseases and environments to those of the developing world, where environmental diseases are more prevalent (Learmonth, 1978; Eyles, 1997). Infectious diseases remain a more serious problem in developing countries where they are the cause of death and illness, many being carried by insect vectors which have been eradicated or controlled in the developed world (Learmonth, 1978).

Medical geography is traditionally divided into two themes (Figure 4.1):

1. The traditional focus of 'the geography of disease' or 'geographical epidemiology' which considers the spatial patterns of diseases, the principles and methodologies being influenced by zoology and epidemiology
2. 'The geography of health care' which deals mainly with the issues associated with the location and use of health facilities (Barrett in Pacione, 1986; Johnston *et al*, 1986; Dauskardt, 1992).

According to Barrett (in Pacione, 1986, 14) "both attempt to analyse distribution in order to understand processes that are revealed by patterns." Neither is confined to natural environmental conditions, as they also consider human activities which cause environmental conditions that can affect health, such as air pollution or smoking which can cause respiratory diseases (Johnston *et al*, 1986). This project falls within the traditional geography of disease or geographical epidemiological approach due to its aim being to investigate the proximity of the mosquito breeding sites to the malaria parasite-infected inhabitants. The geographical epidemiology focus will be reviewed followed by a brief review of the geography of health care to indicate their differences and the reason for this research falling within the former.

4.3.1 The Geography of Disease or Geographical Epidemiology

English (in Elliot *et al*, 1996, 3) defines the geography of disease, or geographical epidemiology, as the “description of spatial patterns of disease incidence and mortality”. He locates it within the descriptive focus of epidemiology with a desire to describe the occurrence of a disease with respect to demographic characteristics, (age, sex, race), place and time. The aim of studying geographical variations in disease rates is to formulate hypotheses about the cause of diseases by taking into account the spatial variations in their environmental factors. It is generally not possible to test a hypothesis about the cause of a disease from a descriptive assessment, this requiring the use of analytical tools (English in Elliot *et al*, 1996).

According to Spraycar (1995) epidemiology is a branch of medical science that deals with the incidence, determinants and distribution of diseases, health-related states or events in a population (not individuals), and the application of this study to control health problems. Determining factors may include climate, geology, vegetation, altitude, latitude, proximity to natural features such as mountains or rivers, level of economic development, culture, behavioural factors, population density and movement, race group, and urban or rural situation (Spraycar, 1995 ; Hayes, 1996). The contribution of ‘environmental epidemiology’ is its focus on the non-human aspects of the environment and provides the important link with medical geography. Environmental epidemiology is defined as:

"the study of the spatial or spatio-temporal distribution of disease in relation to possible environmental factors, and constitutes an important tool for better understanding the dynamics of parasitic infections and the development of suitable control and prevention strategies" (Diggle 1993 in Mbarke 1995, 115).

The focus here is largely on environmental parameters (climate, soil, geology, vegetation, natural features) which play a major role in vector-borne diseases as they generally determine the distribution and numbers of vectors (mosquitoes, ticks, fleas) available to transmit a disease, e.g. malaria (Glass *et al*, 1992).

The geographical epidemiology approach covers a range of themes, the main one being the relationship between contagious diseases and the natural environment, with a focus on the spatial

patterns and ecological relationships associated with their distribution (Mayer, 1982; Dauskardt, 1992). An early example of this was Dr John Snow's cholera map of Soho, when urbanisation, industrialisation and colonisation resulted the exposure of people to new environmental conditions that effected their health. The 17th and 18th Centuries in Europe saw the rise of the geographical epidemiological approach in medical geography, as the citizens of Europe and the New World succumbed to disease that were a result of their new circumstances (Dyck and Kearns, 1995). According to Eyles and Wood (1983), within the geography of disease, studies have tended to be divided between :

- 1) describing disease patterns and their diffusion (spread) and
- 2) finding causal relationships (associations) between variables and spatial patterns.

1. *Describing disease patterns and their diffusion* (spread): this considers issues such as the frequency of a disease, who suffers from it, how it spreads, where and when it occurs. The concept of 'diffusion' originated in 'cultural geography' and has expanded from its use in understanding the spread of cultural factors to the spread of diseases (Haggett, 1979). The Contagious Diffusion Model was proposed by Torsen Hägerstrand in 1953, and traces the diffusion of contagious or infectious diseases, which require direct contact for their perpetuation and are therefore largely a function of distance, which results in individuals closer to the source having a higher probability of being infected than those further away (Haggett, 1979).

Disease diffusion models are concerned with the spatial processes of the disease wave i.e. its shape, size, intensity, speed, direction of movement, all of which to some extent depend on the size, distribution and levels of immunity of the susceptible population, as well as any barriers to its movement (e.g. climatic conditions, intervention measures) (Haggett, 1979; Cliff and Haggett in Pacione, 1986). The disease wave spreads from a starting or 'seed point/foci' and progresses through four of stages which result in changes in its characteristics until there is no longer a susceptible population, a physical barrier stops its progress, or climatic conditions prevent its continued transmission. During this process, several foci may form from which the epidemic wave spreads as conditions become suitable, resulting in their waves intersecting at some point and obscuring the pattern of the individual waves (Haggett, 1979). The energy of the wave is highest at the source of the epidemic and tends to dissipate with increasing distance from it (Cliff and Haggett in Pacione, 1986). The disease foci may occur in a few breeding sites at the start of the season, spreading outwards as more sites becoming available with the onset of more

favourable climatic conditions. The diffusion of malaria through the study area was outlined in Chapter 3.8, with Figure 3.11 displaying its movement southward from the Mbagweni Corridor.

2. *Finding causal relationships* (associations) between variables and spatial patterns, such as the physical and mental factors that influence the distribution of a disease, which results in one person being affected and not another. Establishing associations requires determining which variables are likely to be significant for the study, these being based on logic or the results of previous research (Mayer in Pacione, 1986).

“Virtually every disease exhibits spatial variations. One of the major goals of medical geography is to describe and explain that variation” (Mayer in Pacione, 1986, 64). It follows that if the factors that affect the occurrence of the disease can be identified, understanding the nature and possibly the cause of the disease will be a likely result (Mayer in Pacione, 1986). This approach shifts the focus from the agent and host, to the environmental factors that influence their behaviour which result in the spatial patterns of a disease. One way of establishing these factors is by statistical association, however, an inherent problem in assuming such a linkage is establishing a causal relationship (Mayer in Pacione, 1986).

Mayer (in Pacione, 1986) stressed the need for studies to be done over extended time periods to ensure that chance occurrences do not form the basis of scientific results. There has also been an increasing emphasis on analysing disease patterns and their changing association over time as a result of non-environmental factors, such as population mobility. This has implications for the introduction of new strains or the reintroduction of existing parasite strains. This may result in alternative or supplementary methods of intervention being needed in certain areas which, it is hoped, this study will be able to identify (Terracini in Elliot *et al*, 1996).

R. Mansel Prothero was one of the first geographers to highlight the importance of migration on the spread and transmission of malaria (Prothero, 1962, 1968). He maintained that population mobility was one of the limiting factors in controlling the spread of diseases, and that control and eradication programmes needed to be devised that adequately take this into consideration (Prothero 1962, 1983). Prothero (1983) recognised a need for longitudinal studies to assess the changes that occur in the prevalence and distribution of malaria over different seasons, the aim

being to provide empirical evidence of relationships between factors which influence the distribution of diseases. He acknowledged the need for an integrated evaluation and an understanding of the complexity of relationships between humans, parasites, mosquitoes and the physical environment, and maintained that while a great deal is known about the parasite and mosquito, their interaction with humans needs further investigation (Prothero, 1962, 1977). He maintained that the spatial dimensions of health problems need to be investigated in order to understand and solve them (Prothero, 1968). His work on population migration focussed on describing the implications of mobility on disease distribution and patterns that effected the implementation of intervention strategies (Prothero, 1983).

Having a strong epidemiological influence, this approach has tended to focus on the categorising of diseases, looking for the 'sameness' of groups rather than 'differences' at an individual level, the emphasis being on the disease, with the body seen as an object or system acting as its host (Dyck and Kearns, 1995). The relationship between diseases and environmental parameters are investigated, with no consideration being given to people as physically unique individuals or to the broader circumstances within which they live (Young and Rowley, 1967 in Mayer, 1982; Dorn and Laws, 1994; Hayes, 1996). The term 'place' is restricted to a geographical location once it has been ascribed characteristics such as town or suburb (Kearns, 1993). Determining any causative spatial association is done by displaying the presence or absence of a condition, and by applying objective statistical tests to determine the likelihood of it being a chance occurrence (McGlashan, 1972; Johnston *et al*, 1986).

More recently, a new trend towards addressing issues of justice and equality has resulted in a fresh approach to health philosophies, with an emphasis on the social environment and 'health' as opposed to 'disease', resulting in a socio-ecological model rather than the traditional ecological one (Kearns, 1993). This has resulted in more emphasis being placed on the quality of life, with the individual becoming the unit of analysis, and health being defined as "that state that allows for effective functioning in society in the light of particular physical, demographic and social attributes (Eyles, 1997, 6). The definition of environment is broadened to include physical, social, political and cultural forces (Eyles, 1997). Diseases were no longer considered 'maladaptions', but occur when a number of factors coincide; environmental, cultural, economic, political and social (Mayer, 1982). The term 'place' has a human-centred focus, encompassing the values, history, culture, consciousness, practices, knowledge, perceptions and experiences

that are defined by a variety of identities (race, class, gender, culture) (Johnston *et al*, 1986; Kearns, 1993; Dyke and Kearns, 1995). This research however, falls within the more traditional approach of the geography of disease, with a strong link to the principles and methods of epidemiology which will now be outlined in greater detail in order to direct the methodology of this research.

Epidemiology brings to medical geography the scientific methods and analytical tools that take description and interpretations a step further to explanation and proof (Hayes, 1996). It is a recent scientific discipline, having previously been a sub-discipline of medicine and zoology, with many health related studies being done by medical doctors and statisticians who were interested in the occurrence patterns of a particular disease (Barrett, in Pacione, 1986; Rothman, 1986). Scientific experimentation forms the basis of epidemiological concepts with issues such as sample size, time frame, statistical significance, and source of information, the overall goal being the accuracy of measurement (Rothman, 1986). It brings to medical geography scientific methodologies which include experiments, measurement, observation, surveillance and hypothesis-testing, by investigating the time of occurrence, who is affected, how often and where the disease occurs (Glass *et al*, 1992; Diggle 1993 in Mbarke 1995; Spraycar, 1995).

Molineaux (1988) identified a three-phased approach for epidemiological investigations:

1. To describe and explain the distribution of a disease based on actual information which includes data editing, data reduction and effect estimation and is outlined further below.
2. To continually re-assess the distribution of diseases with new and appropriate methods, such as GIS, the use of which in this research will be outlined in Chapter 5 (Methodology) .
3. To contribute to planning and evaluating control measures, as is the aim of this study. The results of this research, and its potential for assisting in the planning and implementation of supplementary control measures (larviciding), will be outlined in Chapter 7 (Conclusion).

1. To describe and explain the distribution based on actual information

Rothman (1986) identified three broad stages in describing and explaining the distribution of a disease based on actual information in order to understand its causes. These will be integrated into the methodology and further described in Chapter 5 (Methodology) :

- a. Data Editing: the collection of data, reviewing it for accuracy, consistency and completeness, and transcribing the raw data into a computer or other preferred means.

- b. Data Reduction: the determination of what data goes into what table, and the summary or transformation of data into a concise form for analysis, usually into tables according to key factors or variables.
- c. Effect Estimation: the analysis stage includes 1.1) *descriptive studies* and 1.2) *hypothesis testing* (usually statistical) both of which are detailed below. The latter generally refers to the evaluation of a null hypothesis where results are presented in tabular or statistical format but seldom with a spatial component in the form of a map. Both are reliant on the quality of the data which are a function of disease diagnosis and reporting, as well as an element of chance variations (English in Elliot *et al*, 1996).

1.1 *Descriptive studies* usually use indicators to measure the frequency of a disease in a population (incidence per 1000 population) using large data sets to generate hypotheses, and to portray disease patterns according to person, place and time, including time-series analysis (National Research Council, 1991).

In an effort to describe the effects of the environment on the geographical variations in disease frequency, English (in Elliot *et al*, 1996) identified three types of descriptive studies :

- a. The description of the disease distribution in relation to its place of occurrence. In this study, the distribution of the malaria cases with respect to their distance from, or proximity to, the potential breeding sites where they are most likely to have hatched will be investigated.
- b. The description of the relationship between the degree of exposure (to an environmental agent) and the geographical variation in the disease. This research aims to establish whether the degree of exposure is a function of the proximity of the homesteads to the breeding sites, and to thereby establish the maximum likely distance of the female mosquito for a blood meal.
- c. The description and establishment of the changes in disease occurrence in migrants who move between high and low risk areas. This being particularly relevant to this study due to the movement of people between Mozambique and South Africa, and the important role that this plays in the continuing transmission of malaria in the province of KwaZulu-Natal.

The description of the disease distribution and resulting spatial patterns provides the basis on which further statistical analysis or hypothesis testing can be done, both being reliant on suitable data at the appropriate scale (English in Elliot *et al*, 1996).

1.2. *Hypothesis testing* in the form of statistical evaluations were introduced in the early 20th century in an effort to find scientific evidence to establish a probable association between two variables (Rothman, 1986). This method is seen as objective and definitive although Rothman (1986) cautions that using statistical analysis as the definitive answer to a hypothesis can be misleading, and that other forms of analysis also need to be considered. Statistical methods were developed to substantiate scientific investigation through a systematised knowledge of principles and methods derived from observation, experimentation and measurement (CNA Compact English Dictionary, 1981). “The broad area associated with the word ‘statistics’ involves the methods and procedures for collecting, classifying, summarizing and analysing data” (Kleinbaum *et al*, 1998, 14). Kleinbaum *et al* (1998, 14) advocate examining the data in graphs and tables before undertaking statistical analysis in order to represent the “essential features of the data in easily interpretable terms .” The statistical analysis for this study will be outlined in Chapter 5.

Hypothesis testing traditionally requires the proposing of a null hypothesis which, for this thesis, would be that the *Anopheles* mosquito is not localised to certain breeding sites during winter and that no relationship exists between them and the malaria cases. The probability of a statistically significant association will however be influenced by the sample size, hence the inclusion of two years for this study (Varkevisser *et al*, 1991). The National Research Council (1991) cautions excluding results which are not considered statistically significant in studies with small sample sizes where causal association do exist. Mayer (in Pacione,1986) also cautioned the use of significance testing in identifying possible correlations which may be minimal and others which it may not highlight. The researcher needs to know as much as possible about the epidemiology of the disease to select the correct variables and interpret the results from the statistical analysis (Mayer in Pacione, 1986).

To be able to reasonably conclude causal relationships between the variables and the spatial patterns, Kleinbaum *et al* (1998) and the Committee on Environmental Epidemiology (National Research Council, 1991) set out a list of several characteristics against which the results need to be evaluated:

1. Strength of association - strong associations over a number of studies limit the influence of bias.
2. Dose-response effect - the change in value of the dependent variable (e.g. malaria cases) with respect to changes in the suspected causal agent (mosquito).

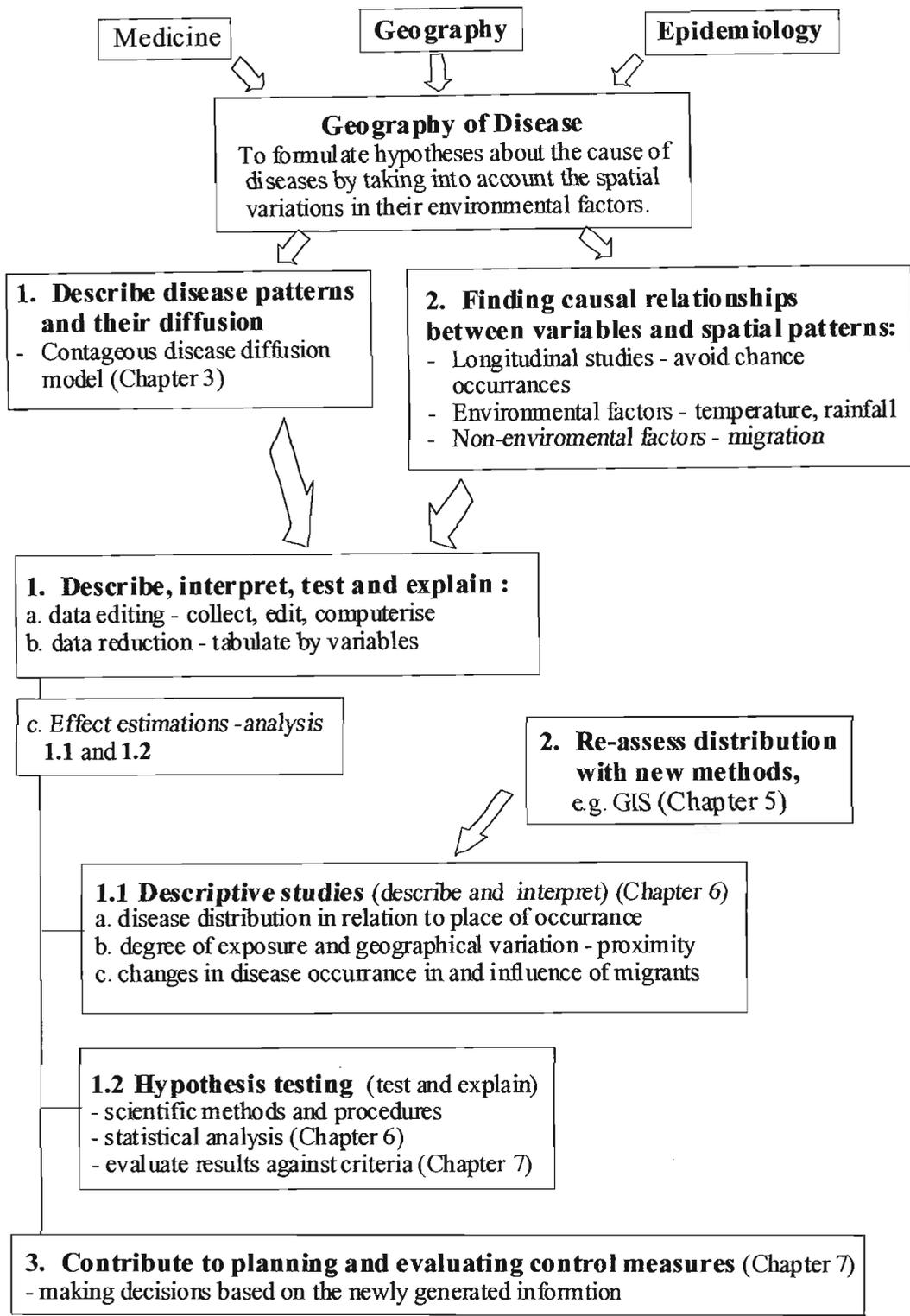
3. Lack of temporal ambiguity - the cause precedes the effect.
- c) Consistency of findings - similar studies find similar results.
- d) Biological and theoretical plausibility of the hypothesis - current theory supports the findings although there may be an insufficient body of knowledge.
- e) Coherence of the evidence - the findings are in line with the epidemiology of the disease.
- f) Specificity of the association - the cause (e.g. mosquito) is associated with only one disease (e.g. malaria) and nothing else transmits the disease.

While applying these criteria does not prove causation, the absence of experimental evidence may necessitate their use as a practical way of establishing the possibility of causality (Kleinbaum *et al*, 1998). The results of this research will be assessed against these criteria in Chapter 7.

Geography and epidemiology have in common their search for associations between variables, the importance of population mobility on the distribution and levels of intensity of a disease, the need to provide a descriptive analysis, the value of displaying data on maps, and the importance of accurate and reliable information at appropriate scales. Epidemiology contributes to the methods of medical geography the procedures with which to investigate, analyse and explain causal relationships between environmental factors and the distribution and severity of a disease. Its statistical emphasis provides an additional tool with which to analyse such relationships, the quality of which is determined by the type and quality of the data that is used. The use of scientific research methods to understand and explain disease distributions is essential if appropriate intervention strategies are to be planned, and it is to this that the geographical concepts are added in order to understand the spatial dynamics that fall within medical geography.

Understanding disease diffusion processes and causal relationships between environmental factors and the health status of a population has implications for the provision of services for epidemic and endemic situations. Describing and explaining the distribution and patterns of diseases and health related issues is important in order to appropriately locate health care facilities, this falling under the geography of health care. As this thesis is located within the geographical epidemiology branch of medical geography, the geography of health care will not be detailed.

Figure 4. 2 Schematic Outline of the Role of Epidemiology in the Geography of Disease.



4.4 Geographic Information Systems

Geographic Information Systems (GIS) are computer software packages that allow the input, storage, management, integration, retrieval, manipulation, modelling and analysis of spatial (locational) and the associated attribute (statistical) data, and presentation of the newly generated information as a map (Ventura, 1988; Aronoff, 1989; Guthe, 1993; Loslier, 1995). According to Maguire (1994), GISs are information management systems that focus on spatial objects and relationships that allow spatial analysis and modelling operations through the integration and organisation of spatial and attribute data sets.

GIS allows spatial data to be maintained and retrieved with a speed, consistency and precision that no other technology provides (Glass *et al*, 1993). Query capabilities allow attribute data as well as the associated spatial relationships to be displayed and modelled for interpretation and further analysis (MapInfo, 1994). Modelling tools are provided to assist in identifying clues to spatial patterns, either to support existing assumptions or for predictive purposes (Twigg, 1990). The principles and modelling capabilities of GIS, and its use in this research, will be outlined in greater detail in Chapter 5 (Methodology). GIS mapping and modelling capabilities are ideally suited to assist with spatial investigations, the modelling and analysis being on epidemiological principles in order to determine the methods and interpret the results (Loslier, 1995). The use of GIS in the geographical epidemiology branch of medical geography will now be outlined.

4.4.1 Geographic Information Systems and Geographical Epidemiology

The use of GIS in the field of health has grown considerably since its initial application during the early 1990's, with the first international workshop on the use of GIS in health in developing countries being held in 1994 (Hecht Jr, 1994). Hecht Jr (1994) advocated the use of GIS for health care planning to highlight a range of issues such as state health spending, shortages of health facilities and practitioners, areas of highest subsidies and home care for the poor.

The application of GIS as a tool to address health related issues is growing, as the benefits of understanding the spatial dynamics involved in the distribution of diseases, health care problems and the location of facilities are appreciated. Understanding the relationships of environmental

diseases, such as malaria, can be assisted by using this technology, as spatial patterns may reflect the factors associated with their transmission (Loslier, 1995). Mapping disease incidence allows questions to be asked about the reasons for a particular distribution and can indicate areas that require further research, particularly high risk or high incidence areas (Scholten, 1991).

GIS is being used in an increasing number of studies on plant, human and animal diseases. While the epidemiology of diseases may differ, GIS can assist in three ways:

1. Display the spatial relationships of a disease.
2. Assist in monitoring the disease and any changes that may occur amongst the contributing factors.
3. Provide modelling capabilities when given certain parameters for simulating reality and predicting scenarios (Lessard *et al*, undated).

For many branches of geography, "the prospect of improved description brought by information technology carries with it a greatly increased possibility of explanation and predication..." (Clark, 1984, 23). While medical geographers have for a long time understood the importance of the environment in health, it is only with the advent of GIS that a tool has become available that can use all the relevant variables, store, manipulate and model them in an attempt to search for explanations, to plan or pre-empt problems (McGlashan, 1972). Most epidemiological data are located in space and time, the display and analysis of which GIS is ideally suited to assist with (Nobre and Carvalho, 1995).

"Technologies such as GIS offer the epidemiologist and public-health administrators new and important methods from implementing solutions to disease-related problems and decision making. This technology incorporates data management, display, and manipulation methods that allow epidemiologists to view and analyse data more effectively. It permits the examination of spatial patterns of disease and helps in planning health-care interventions. The opportunities for using this technology in epidemiology and disease-related fields are immeasurable and are presently under used" (Tempalski, 1994, 38).

A growing number of health projects are using GIS to assist in their planning and continued monitoring, although there are still relatively few in Africa. Understanding the spatial patterns

of disease tends to be similar for all transmittable diseases, and include such questions as : where are people at risk or infected, where is the source of infection, how is the disease transmitted from its source to the people, and what are the associated spatial dynamics involved in transmission (Twigg, 1990). GIS is ideally suited to addressing these questions with constraints being experienced due not to limitations in technology, but to inadequate or incomplete data and information regarding the problem (Twigg, 1990). GIS can contribute to research and planning, the former being necessary to effectively implement the latter (Loslier, 1995). GIS provides the ability to encourage hypothesis generation in health research as a result of it being able to integrate large quantities of data, and to substantiate quantitative analyses in health care delivery and disease ecology (Verhasselt, 1993).

Manipulation and display assists with information flow, and allows decision makers to visualise and assess the current status, historical trends and future possibilities, as well as plan their strategies based on accurate and reliable information (Twigg, 1990; Guthe, 1993; Glass *et al*, 1993; Hecht Jr, 1994). GIS can also help to identify deficiencies in information, influence the future direction of research, and provide the potential to anticipate and model by simulating reality (Wilken, 1992). Timeous and reliable information require appropriate methodologies if they are to be effectively used for health research as well as disease prevention and control (Scholten and de Lepper, 1991). Reviewing methodologies of projects that have been undertaken to address similar problems will be outlined below to provide insight into ways of approaching health research using GIS.

4.4.2 Application of Geographic Information System in Geographical Epidemiology

The following literature review provides an overview of the research that has been undertaken using GIS to understand the spatial patterns of a number of diseases, most of which fall within the geography of disease. This is followed by an overview of malaria research projects which have included the use of GIS in an effort to effect greater control of the disease.

GIS, satellite images and Global Positioning System (GPS) were used to assist with controlling Rift Valley Fever which is spread by mosquito and had moved outside of sub-Saharan Africa by 1977. The identification of the winter breeding sites on the satellite images was followed by the application of larvicide which prevented the vector from developing to adulthood. Other

methods of treatment are also used and the two rivers associated with the area were dredged and straightened to improve their drainage (Decarlo, 1992).

Lyme disease, the most common vector-borne disease in the United States of America, is caused by a bacterium and transmitted by ticks which are carried on mice with their major food source being white-tailed deer. Most people are bitten by the tick in woodland areas but residential areas are now increasingly being seen as transmission sites. Having established the transmission path, GIS was applied to investigate the possibility of identifying environmental factors that could be associated with an increased risk of the disease and then to determine the possible location of risk areas (Glass *et al*, 1992). Using local population data in conjunction with identified environmental risk factors, it was estimated that less than 9% of Baltimore County's (Maryland) population lived in high-risk areas.

Tempalski (1994) used GIS and GPS to analyse the spatial distribution of Guinea Worm in the Republic of Benin, identify high incidence areas for priority intervention and the effectiveness of combatting it (Tempalski, 1994). Guinea Worm is transmitted by drinking water that is contaminated with the cyclops flea which carries the immature Guinea-worm larvae. Transmission usually occurs towards the end of the dry season when ground water and pond levels are low, and the pans and streams have dried up, resulting in alternative water sources being used (Tempalski, 1994). Villages with high incidence rates were identified and mapped, and the spatial patterns of the disease analysed. Urbanised villages with protected water points reported very few or no cases due to improved water supply and health services. There was a high correlation between infected villages and their location on transport routes due to population mobility as a result of trade, work, religious and family gatherings (Tempalski, 1994). The effects of providing water pumps in the most affected villages was monitored with the use of GIS and showed an encouraging reduction in the level of disease.

Niger has one of the highest infant mortality rates in Africa at 123 deaths per 1000 live births, and with 223 deaths per 1000 children between the age of one and four, one out of three children die before their fifth birthday. The government decided that the maximum distance to health services should be five kilometres and are using GIS as a planning tool to increase the number of people falling within this distance from 32% to 45% before the year 2000. This will mean establishing 181 new health centres and upgrading 122 of the existing 314 facilities (Long,

1995). Population figures from the 1988 census at village level are being used to place the facilities in the optimal position, avoiding overlapping zones of influence (Long, 1995).

Zwarenstein *et al* (1991) examined health care provision by using GIS to analyse the number of people per hospital bed in KwaZulu-Natal province of South Africa, in order to understand the implications of opening the formerly white-only and private hospitals to all races. Thiessen polygons were generated around existing as well as both the white-only and private hospitals in order to create hypothetical catchment areas. The results indicated a lack of hospitals in the peri-urban and rural areas, and the methodology showed potential for identifying the location of new facilities or upgrading existing clinics.

The major transmission routes of HIV infection have been mapped, highlighting how cities play a key role in the spread of the disease in central and eastern Africa. Simulation techniques were used to predict future patterns for health care planning purposes as understanding the spatial dynamics can influence the spread and therefore the control of the disease (Verhasselt, 1993).

There is increasing appreciation of the incorporation of a spatial dimension into the analysis of the distribution of diseases and the appropriate placing of health care facilities. An understanding of the patterns associated with the transmission of diseases is greatly enhanced with the display of the associated variables. While disease distribution and health care planning have tended to be separate branches of the traditional school of medical geography, an understanding of the distribution of diseases is essential for the appropriate planning of health facilities.

4.4.3 Application of Geographic Information Systems in Malaria Control

GIS allows for both the temporal and spatial examination of malaria incidence and transmission which is often influenced by season climatic variations (Nobre and Carvalho, 1995). The distribution of malaria is also influenced by the availability of a host, suitable breeding sites, and the proximity of the host to the breeding sites, the interrelations of which can be displayed and investigated with GIS. It is only recently that GIS has been used to assist with malaria research in order to improve the implementation of control measures and understanding the dynamics of the disease. The studies below briefly outline a range of methodologies and the use of GIS in malaria intervention initiatives.

The use of GIS in the Ivory Coast is helping to create a hierarchy of centres of illness as well as establish levels of malaria risk which will result in areas being identified for priority intervention and the initiation of an appropriate surveillance strategy. This is based on the knowledge that early intervention can assist in preventing a serious outbreak of malaria in an area where the disease is endemic (Hervouet, 1995).

Remote sensing and GIS technology have been used as tools to identify areas of disease risk in order to prevent the random spraying of all the pans and marshes with insecticides in Venezuela, as is the intention of this study (Corbley, 1996). Scientists analysed a variety of digital data so as to pinpoint likely mosquito breeding sites. Together with nearly 20 years of health and demographic statistics, potential breeding sites of various vectors, including malaria, were identified. A combination of vector-based maps and satellite images allowed land features to be identified that were associated with mosquito habitats. Assumptions were made about where water would be most likely to accumulate and the water bodies were ranked according to their possibility of being used as a breeding site by mosquitoes. A four kilometre buffer was set around each site and areas of human habitation within the zone were noted as potential risk areas, similar to this study, the distance correlating with that set out in Section 2.4.3. Historical records and on-site ground verification results were incorporated into the analysis and decision making processes (Corbley, 1996).

A study done by Ribeiro *et al* (1991) examined the seasonal clustering of malaria in an Ethiopian village in order to assist in determining an optimal control strategy. While their study considered the distribution of mosquitoes rather than disease incidence, it was an early attempt at mapping the spatial patterns of mosquitoes as indicators of possible disease distribution (Ribeiro *et al*, 1991). Mosquitos were caught in houses within the village as indicators of vector densities, and this showed that the vector was highly clumped, with the clusters being more evident at low mosquito densities and at the edge of the village. They found that the spatial clustering changed with the seasons, with the number of clusters increasing as identifiable breeding sites dried up during the dryer season. The rainy season brought with it heavy infestations of mosquitoes, similar to that experienced in the study area. They noted that selective control measures could target important breeding sites through the identification of the location of clusters (Ribeiro *et al*, 1991). However, they stated that they were unsure as to the extent to which GIS could be used to assist in planning disease control operations and that the costs involved in developing the

system and training personnel needed to be weighed against the advantages gained from the use of the technology as a tool in disease control (Ribeiro *et al*, 1991).

GIS was used to analyse the distribution of malaria in relation to water bodies in the dry zone of Sri Lanka during 1992/3, an area which experiences seasonal rainfall and epidemic malaria (Gunawardena *et al*, 1995). Each house in the area was numbered so as to be able to allocate incidence data to a house location, as is the case in northern KwaZulu-Natal and set out in Section 3.7.2. Both active and passive case detection methods were used to obtain data on the distribution of the disease. Passive case detection involved people reporting sick to the local health facility, and active detection necessitated house-to-house surveys in which blood smears were taken and tested (Gunawardena *et al*, 1995). A significant difference in incidence rates was noted between the two major different house structures in the area. The more traditional homes with incomplete walls and many openings through which the mosquitoes could enter had higher incidence rates than the modern houses. In addition, traditional houses situated close to water sources showed higher incidence of malaria than those further away. The incidence rate at the modern structures tended to be higher further from the water sources, suggesting other factors that have not been considered in the study as being important in the distribution of incidence rates for these house types (Gunawardena *et al*, 1995). This would suggest that changing the structure of the house could have implications for the risk levels of the inhabitants.

During the last 20 years, development projects in the valley of the Senegal River in Senegal have resulted in breeding sites for malaria and other vectors being provided with the construction of dams and irrigation schemes (Dusart *et al*, 1995). A project has been initiated where GIS will be used to assist in monitoring the changing conditions in the valley with the aim of providing advice for intervention once the database has been set up. Medical health officials are being trained with the intention of using the system to produce maps for management purposes. The project will also be used to identify areas with under-equipped facilities and overworked-health personnel, and to consider factors that are likely to influence the spatial distribution of the disease (Dusart *et al*, 1995).

This use of modern technology in developing countries has assisted in identifying possible causal relationships associated with malaria and resulted in efforts to reduce its distribution. The success of the projects need to be measured not only by the reduction in the number of malaria cases, but

also by the development of appropriate methodologies which can be applied to other situations. Some of the earliest GIS research for malaria was undertaken by the National Malaria Research Programme of the Medical Research Council in Durban and will briefly be reviewed.

4.4.4 Application of Geographic Information Systems in Northern KwaZulu-Natal

The existing ceiling of effectiveness in controlling malaria has prompted the continued investigation of alternative and supplementary malaria control measures in the high risk areas of the province of KwaZulu-Natal. The advent of GIS and its ability to display data with a spatial dimension resulted in it being seen as a tool worth investigating to assist with malaria control in the province (le Sueur *et al*, 1997).

An initiative was begun in the early 1990's by the National Malaria Research Programme and the Malaria Control Programme at Jozini with the aim of developing a Personal Computer (PC) based database which would be linked to digital maps and be used by the line manager in dealing with health issues. A Malaria Information System (MIS) was established at the NMRP in Durban using GIS and a data base management system (dBase) the structure of which is set out in Section 4.3 (le Sueur Project Proposal, no date). This was prompted by the poor provision of infrastructure and health services in the region as well as a lack of appropriate data on which decisions could be based. An extensive database with case epidemiology, method of detection, homestead population, type of house and other control related aspects was compiled for the portion of former KwaZulu which was under malaria control. It was proposed that the application of GIS would assist research, planning and managing malaria as well as health issues in general (le Sueur Project Proposal, no date). The integration of global positioning systems, geographic information systems and the existing databases of the region, had the potential to establish a cheap and effective PC based health and development tool. This resulted in an initial pilot project to determine the feasibility of using GPS to provide the coordinates of the homesteads being undertaken in 1992 in the Mamfene area of northern KwaZulu-Natal (Stuttaford, 1992,1994).

Its success resulted in the technology being applied to a number of other projects within the area, including an investigation into the impact that irrigation for rice cultivation in the Mamfene area was having on the *Anophele* mosquito populations and the implications for malaria

transmission (le Sueur *et al*, 1992). Sentinel homesteads in close proximity to the excess water outflow sites in the non-perennial Balamhlanga swamp and the irrigated rice paddies were identified. Their coordinate positions were obtained with a GPS receiver and displayed in the GIS with a map of the area in order to investigate the relationship between the homestead and the water bodies. Each homestead was fitted with a window-trap which was cleared every morning for one week of each month of the study, in order to monitor the number of mosquitoes leaving the homes through the windows as an indication of vector numbers (le Sueur *et al*, 1992).

It was found that the changes in the availability of breeding sites due to the presence of the water in the rice fields and the now perennial water in the Balamhlanga swamp from the overflow of excess water needed for the agricultural scheme, had led to changes in mosquito species composition and an increase in their numbers. The rice paddies and the pools that formed from the spillage of the excess water were sprayed with a larvicide which was suitable for use on potable water, had a low toxicity to fish and other aquatic organisms and had a residual efficacy of approximately two to four weeks (le Sueur *et al*, 1992).

The introduction of winter larviciding and subsequent sprays from 1989 to 1991 resulted in a marked drop in the number of mosquitoes in the window-traps over the three years and assisted in reducing the number of cases from 600-700 per year to less than 70 (le Sueur, 1991). An accompanying low rainfall during the time of application resulted in there being very few other possible breeding sites which could have contributed to the low number of mosquitoes (le Sueur *et al*, 1992).

Having established the viability of using GIS to assist with malaria control at the micro scale level, it was decided to assess the malaria situation at the regional level so as to identify high incidence and risk areas which would influence the allocation of resources at a macro level. The malaria case data was therefore displayed at Area and then Section level which resulted in the reallocation of resources within the region as well as the reassessment of the types of control measures that were being applied in low risk areas in relation to the cost of their implementation (le Sueur *et al*, 1997). It also served to highlight areas that needed a more detailed investigation and provided the tool which would allow including the spatial dimension which is so critical in the understanding of malaria transmission.

During the 1994/5 spray season, the remaining GPS coordinates of all other structures and homesteads for the two districts were collected. This resulted in a data base which houses the location of approximately 35 000 homesteads, the name of the owner and the number of people in each homestead amongst other fields of information. Numerous projects have been undertaken as a result of the establishment of this extensive database at the National Malaria Research Programme in Durban, all of which rely on having access to the coordinate positions of homesteads to assist with both planning projects and assessing malaria trends based on data from previous seasons. These projects include planning an insecticide-impregnated bednet trial (le Sueur *et al*, 1997); assessing the likely impact of a water feature based on new cases within a four kilometre radius (le Sueur *et al*, 1997); determining the population that live within set distances from clinics in order to determine their catchment populations and establish the optimal location of new clinics (le Sueur *et al*, 1995); and establishing the impact of distance on maternal and child health service specific utilisation for the placement of new facilities in this rural environment (Tsoka *et al*, research in progress).

The research undertaken by the NMRP in conjunction with the Malaria Control Programme has resulted in the reallocation of personnel and resources to high risk areas and an assessment of the implementation of any project which involves the use of water in terms of their potential health risks. While most of these malaria projects fall within the traditional geography of disease approach, all have attempted to improve the health of the local population by either providing better disease intervention strategies or enhanced health care through an improved understanding of spatial patterns and dynamics. The use of GIS continues to highlight new areas of research as a greater understanding of the local epidemiology of malaria becomes available and the breadth of applications to which the technology can be applied becomes more evident.

The usefulness of GIS for research purposes has been established and it is increasingly being used for research, however, its use as a management tool is still relatively limited. Providing sound research on which management decisions can be based is essential if effective policies are to be implemented. It is the intention of the NMRP to install the GIS software onto the computers of the Malaria Control Programme staff at the head office in Jozini in order to provide them with the capabilities to assist in making appropriate management decisions. This will require the transfer of existing data sets and the training of personal to allow them to analyse and query the data as the need arises.

4.5 Conclusion

Medical geography has been influenced by the disciplines of geography, medicine, zoology, epidemiology and more recently, paradigms from the social sciences. Despite its fairly late formalisation as a sub-discipline of geography, there has, for many centuries, been an understanding of the important association between disease and environmental factors. The addition to the spatial concepts and patterns of geography of the scientific methods that measure accuracy and test for significance from epidemiology, takes description and interpretation a step further to explanation, through testing for probable associations. Medical geography provides the tools with which to interpret, test and explain the processes and causal relationships that lead to disease patterns which can therefore assist in suggesting methods of control.

The focus of this study falls within the geography of disease or geographical epidemiology branch of medical geography, as it investigates the association between the likely winter breeding site of the female *Anopheles* mosquito and the homestead location of people infected with the malaria parasite. The use of GIS allowed the spatial patterns of to be modelled through repeatable operations in order to investigate causal relationships between the location of the potential breeding sites and the homesteads at which the malaria cases were reported. The principles identified in the Contagious Diffusion Model of disease foci or 'seed points' initiating the spread of the disease resulting in an increase in the number of cases in close proximity and a decrease with increase distance, will form the basis for identifying the potential breeding sites in this study. Molineaux's three-phased approach to epidemiological investigations will form the methodological base of this research in order to describe and explain the distribution of malaria based on actual information. Maps were used to display the distribution of malaria in relation to the breeding sites, this association being a function of the degree of exposure to the *Anopheles* mosquito. Being able to establish an association between the two required the results of the spatial analysis to be statistically tested. Concluding a causal relationship required the results to then be evaluated against a list of criteria.

An increasing number of projects are using GIS as a tool to assist in interpreting the spatial relationships in an effort to support health care decision makers in their efforts to plan, monitor changes and model scenarios. Many projects at the NMRRP now incorporate a GIS component, the benefits of which are acknowledged across malarious Africa for both research and

management purposes (MARA/ARMA, 1998).

Studies conducted in the field of health by social scientists and health professionals have broadened it into a more interdisciplinary field, with medical geographers playing a coordinating role. All these approaches point to the fact that "geographers are uniquely positioned to examine the processes of health and health care together over both time and space" (Dauskardt, 1992, 25).

CHAPTER 5

METHODOLOGY

5.1 Introduction

Establishing a causal relationship between the low season malaria cases (July to December) and the potential breeding sites of the *Anopheles arabiensis* mosquito in northern KwaZulu-Natal required displaying the location of both in a Geographic Information System (GIS) to investigate possible associations between them. It was anticipated that this would identify the breeding sites to be targeted for larvaciding as well as provide evidence of the likely maximum flight distance of the female mosquito given an adequate host population in close proximity.

This research falls under the geography of disease branch within the geographical epidemiology tradition of medical geography, where the focus is on describing, interpreting, testing and explaining the factors that lead to disease patterns. The methodology brings together the factors that affect malaria in the region within the theoretical framework which directs the investigation. This study combines the geographical description and interpretation of spatial patterns and relationships, and epidemiological testing and explaining through accuracy of measurement and the scientific methods of surveillance and hypothesis testing. Using the principles and methods of both disciplines, this project aimed to find probable associations between the distribution of the malaria cases and the location of the available water bodies that are used as breeding sites during the low season malaria months.

Locating the mosquito's winter breeding sites required using a technology that could display the position of the homesteads at which malaria cases were recorded as well as the water bodies most likely to have been used as breeding sites. This was provided by GIS which allow the display of information in tabular and graph form as well as on maps, where the associations could then be interpreted and analysed. The use of GIS required a number of procedures and methods to be followed to enable the relevant data to be collected, edited, stored, manipulated, modelled, displayed and analysed. The modelling and analysis was undertaken by mathematical procedures that ensured their repeatability, consistency and accuracy (Scholten and de Lepper, 1991; Glass *et al*, 1993).

Due to annual as well as seasonal variations in malaria distribution and incidence, data from 1993 and 1994 were used in the study to prevent a chance occurrence of one year affecting the results. These years were selected as the homestead coordinate locations and the malaria case information was available at the time that the study commenced in 1995. Although le Sueur (1991) identified the perennial pans as the most likely breeding sites during the dryer months from July to December, the dams and non-perennial pans have been included in this study. This was done as the large Qotho dam may well provide suitable conditions throughout the low season, and because it is not known when the non-perennial pans dry up and therefore to what extent they provide suitable conditions during the latter part of the year.

Research at the National Malaria Research Programme (NMRP) of the Medical Research Council (MRC) is undertaken by staff from a variety of scientific backgrounds, all of whom, to a greater or lesser extent, rely on the work and support of the Malaria Control Programme (MCP) in KwaZulu-Natal province for their data. As outlined in Chapter 3, the extensive infrastructure of the MCP and the health personnel in the region are responsible for the information that is distributed from the head-office in Jozini. The NMRP now includes a GIS laboratory with specialised GIS and database management staff who provided support and skills for this project. This project aims to contribute to the body of knowledge of the NMRP, to assist malaria control by providing results that will reduce the number of malaria cases in the province and propose a methodology that can be applied to similar spatially related research.

Undertaking this research required obtaining the necessary malaria data, homestead locations and topographic features, (roads, rivers, towns, pans) and using GIS to undertake spatial analysis followed, by statistical analysis, in order to describe, interpret, test and explain the resulting relationships.

The methodology will follow the first stage of Molineaux's (1988) three-phased approach as outlined in Section 4.3.1, in combination with categories traditionally used to undertake GIS projects (Scholten and de Lepper, 1991; Parr 1991 in Albert *et al*, 1995; Glass *et al*, 1993). The use of GIS fulfils Molineaux's second stage in which he advocates using new and appropriate methods to continually re-assess the distribution of diseases. The first stage entails describing, interpreting, testing and explaining the distribution of malaria bases on actual information, and is divided into the following sections:

5.2. Data Editing and Reduction

5.2.1 Data collection, editing and storage

5.2.2. Data management, retrieval and query

5.3 Effect Estimation

5.3.1 Data modelling, display and analysis.

The analysis will include an evaluation of the results against the criteria as set out by the Kleinbaum *et al* (1998) and the Committee on Environmental Epidemiology (National Research Council, 1991) to be able to reasonably conclude a causal relationship between the locations of the different types of water bodies and the malaria cases.

The results of this evaluation and the third phase of Molineaux's approach, namely, to contribute to the planning and evaluation of control measures, will be addressed in Chapter 7 (Conclusion) by making decisions based on the newly generated information.

5.2 Data Editing and Reduction

Data editing entails collecting the data, editing it to ensure its accuracy, consistency and completeness, and entering the data into a computer. Data reduction includes managing the data to allow the spatial and statistical analysis to be undertaken.

5.2.1 Data Collection, Editing and Storage

Data is information in the form of facts or figures, as qualitative statements or as quantitative data, and consists of spatial (co-ordinate or locational) and attribute (statistical) data. The characteristics of good information are accuracy, completeness, reliability, relevance, simplicity, timeliness, for it to be economical and have the ability to be verified (UNISA, 1992).

Four software packages were used for the project, the database management package dBase®, the vector-based GIS software packages AutoCad/ArcCad and MapInfo® versions 4.5 and 5.5, and the spreadsheet package Microsoft Excel® in which the statistical results were stored. Various members of the GIS team of the NMRP were called upon for assistance in executing this

project and are mentioned accordingly.

Accurate and relevant data form the basis of any GIS project and understanding the limitations of the available information is important when interpreting the analysis (Twigg, 1990). The data limitations, such as missing homestead coordinates, were identified at the start of the project as detailed in Chapter 3. It was anticipated that the missing data would be random errors that would not effect the overall results of the project.

a. Spatial Data

Spatial data is that which can be displayed on a map such as roads, rivers, clinics, health districts. It is traditionally available as hard-copy paper maps but the advent of GIS has enabled the data to be converted to a digital format. The spatial data for this project consisted of homestead location, water bodies (pans, dams and non-perennial pans), roads, rivers, forests, reserves, towns, and administrative boundaries (malaria areas and sections, international borders).

Vector-based GIS's such as MapInfo®, store spatial data in the form of points and connected line segments resulting in three types of spatial features (Clarke, 1997). These are :

- points - homestead locations (x and y coordinate)
- lines - roads, rivers (start and finish coordinates, joined by lines, with direction and distance);
- areas/polygons - malaria areas and sections (points, joined by lines, enclosing a space with area and perimeter length).

The data can be entered into the computer in several ways such as by satellite imagery, scanning, importing, digitizing or field surveys using Global Positioning Systems (GPS), the latter two being used for this project (Twigg, 1990; Guthe, 1993; Glass *et al*, 1993).

Scale

During the National Malaria Research Programme's (NMRP) initial stages of using GIS in the early 1990's, maps of the Ingwavuma and Ubombo districts in northern KwaZulu-Natal were digitized at a scale of 1:250 000 and in parts, at 1:50 000. The former was used to display the regional malaria situation at area and section level, highlighting the high risk areas of Ndumu and

Makanis Drift in the north. These high risk areas were then digitized at a scale of 1:50 000 in order to investigate in greater detail the spatial relationships involved in the distribution of the disease. Due to the study area experiencing little change since the maps were printed by the Surveyor General in 1980, it was decided that they would provide an adequate representation of the geographical features for use in this study. It was however anticipated that the smaller perennial and non-perennial pans that could be used as breeding sites were unlikely to be visible at this scale which resulted in the acquisition of a set of orthophotographs (orthophotos) at a scale of 1:10 000 from the KwaZulu Department of Surveying in Ulundi from which these features were digitized.

The water-bodies were originally digitized from the 1:50 000 maps and later from the orthophotos, and were classified into three different categories (perennial pans, non-perennial pans and dams). The field surveys for the compilation for the orthophotos occurred during the period 1979 to 1993 and the distribution of the water bodies was assumed to represent the current situation. The season in which the orthophotos were taken was not recorded which resulted in the water bodies being classified according to the amount of water they contained, these being compared to the classification of the 1:50 000 water bodies for verification. The names of the water bodies were obtained from the 1:10 000 orthophotos and 1:50 000 maps.

Maps at a scale of 1:250 000 display data at a coarser level of detail than those at 1:50 000. The level of detail is further enhanced at a scale of 1:10 000 and the use of a variety of scales in combination resulted in varying levels of resolution being displayed on the maps. This resulted in lines being offset from each other when they should have fallen on top of each other. For example, the malaria areas and sections were captured at a scale of 1:250 000 while the rivers and water bodies were captured at 1:50 000 and 1:10 000. The malaria boundaries are offset from the rivers, the latter being considered the more correct location. The integration of GPS points, with their potential level of error at up to 100 metres, resulted in some points falling outside of the malaria area and section boundaries into which they should have fallen according to their household address.

Homestead GPS Points

The need to investigate the micro-level detail of malaria that could not be addressed with the data

displayed at malaria area and section level resulted in the collection the latitude and longitude location of the approximately 35 000 homesteads. This data was needed to link the case incidence to a location as well as to collect data such as area name, section number, homestead number, and homestead population as outlined in Chapter 3. The coordinates were collected during 1993 by the MCP field staff using GPS receivers and recorded on data collection forms designed by the database manager of the NMRP. The data sheets containing the coordinates were taken to the Jozini head office on completion and forwarded to the NMRP in Durban where the data was entered into the database (dBase®). This file formed the basis of the Malaria Information System (MIS) to which all other files with data at household level were linked.

The GPS points were captured using Trimble Ensign GPS receivers (non-differential) which were subject to a random Selective Availability error that was controlled by the Department of Defence in the USA. This error distorted the actual location of a coordinate position up to 100m (50m on average) from its true position. All the GPS points were therefore up to 50m away from their actual location, but with the distance and direction of the error being unknown, the points could not be adjusted to account for this distortion. While this random error changed every second and prevented the capturing of an exact location, this level of error was considered adequate for use by both the NMRP and the MCP due to the dispersed rural distribution of the homesteads, with most being more than 100m away from their nearest neighbour. The latitude and longitude coordinates were entered into dBase® in degrees, minutes and seconds, and converted to decimal degrees for use in MapInfo®. These were displayed with the malaria area and section boundaries so as to identify those that were incorrectly located due to a data entry error.

Spatial Data Capture and Accuracy

Two types of spatial features were captured for use in the GIS, those providing reference features so as to situate the project within its geographical context (roads, towns, the national boundary with Mozambique, the perennial rivers and game reserves), and the water bodies that were potential mosquito breeding sites (dams, perennial pans and non-perennial pans). Although borrow-pits, from which road construction materials were extracted at the side of the road, were identified by le Sueur (1991) as potential breeding sites, they were not visible on the orthophotos or the maps and were therefore not included in this study.

Important considerations which effect the accuracy of digitized data, and therefore the quality of the work, are the map projection and the Root Mean Square (RMS) error. Map projections are mathematical formula devised in order to display the curved surface of the earth on a flat two-dimensional surface, and results in distortions in area, shape, direction and/or distance. The data was captured from maps obtained from the Surveyor Generals office which were in the Gauss Conform Projection, with a Central Meridian of 33° east using Clarke Spheroid 1880. The data was converted to the Geographic Coordinate System to ensure that the spatial features were in their correct location relative to each other when displayed simultaneously. The RMS error is the amount of distortion in the map in relation to where the coordinate points should be as determined by the chosen projection or coordinate system (Autodesk, 1992).

The spatial data was digitized at the NMRP in Durban during 1994 using a Computer Aided Drawing (CAD) AutoCAD, a vector CAD package, on a Summagraphics MicroGrid II A0 digitizer, a 486 Auva computer with 16 megabites of RAM (Random Access Memory) and 1.2 gigabites hard drive, and was later transferred to a Mecer® Pentium III. GIS capabilities were provided by an add-on package called ArcCad®. MapInfo® had very limited digitizing capabilities before 1996 and was therefore not used for digitizing. Every effort was made to digitize the geographic features as accurately as possible so as to reproduce the spatial relationships. Forms were designed on which relevant information or metadata was recorded about the maps e.g scale, date, projection, source, geo-reference points.

Editing procedures were carried out in the AutoCad/ArcCad® combination package to ensure the highest possible quality of the spatial data. This included ensuring that all the roads and other line features (rivers, international boundary) intersected where necessary and that the polygons (pans, dams, game reserves) were closed and correctly identified in terms of water body type. No labelling was done at this stage as the data was transferred to MapInfo® in DXF (Digital eXchange Format) which did not allow for the transfer of associated data. Names were attached to the geographic features once they had been imported into MapInfo®. Each category of spatial data (roads, marshes) was stored in a separate layer so as to allow it to be viewed and manipulated in any combination (Twigg, 1990; Eastman, 1995; Loslier, 1995).

b. Attribute Data

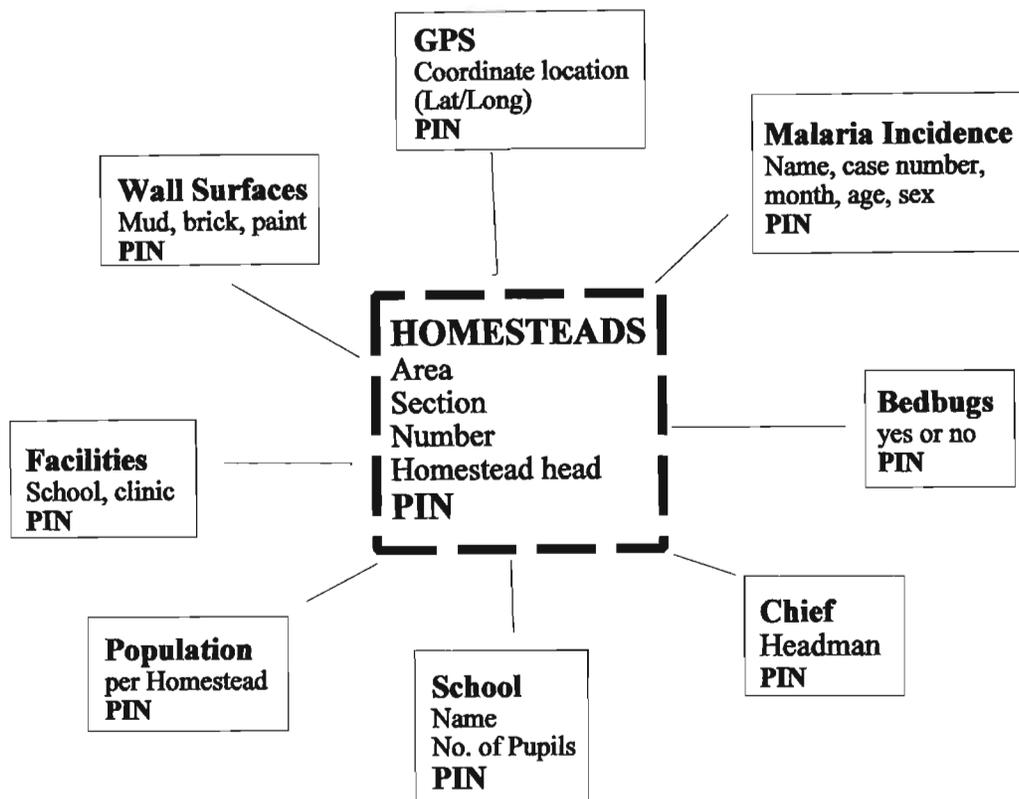
The attribute data consisted of the active (surveillance agents detecting parasite carriers) and passive (sick patients reporting to clinics) malaria cases for 1993 and 1994, homestead address and population as well as rainfall and temperature. The homestead address in terms of the area name, section number and homestead number were also recorded in order to link the coordinate locations with reported malaria cases. The number of residents in each homestead was recorded when the GPS coordinates of the homesteads were taken as no other source of data was available at this level (Chapter 3). An average population increase of 2.2% per year was recorded in the area based on comparisons between the numbers recorded during 1992 and 1994/5, this figure forming the basis on which the 1993 population figures were calculated. The population per homestead for both the data collected in 1992 and 1994/5 showed an average of 7 people per homestead which was the figure used for the study. The malaria data was stored in a relational as opposed to a flat structure database. A flat structure database is one in which all the data is entered and stored in a single table or file. This becomes particularly slow and cumbersome when queries are run on large data sets (UNISA, 1992).

The relational database of the MIS consists of many files, separated by their content, all of which contain a common field in which is recorded a unique common identifier, such as a name or a PIN (Figure 5.1). The PIN is initially allocated to the homestead file (area, section, homestead number) and is repeated in all files in which data associated with that homestead is recorded. This was particularly important for the large MIS database which contains a record of over 35 000 homesteads and their associated information (population, type of structure).

This format allowed the different files to be linked and data extracted according to the PIN. The same PIN was attached to the spatial map feature to ensure that it could be linked with the correct attribute data. This format allows tables with new attribute data to be added as new data becomes available as long as the PIN is included (Ventura, 1988; Twigg, 1990; UNISA, 1992; Glass *et al.*, 1993). The advantages of a relational database are its speed of retrieval, manipulation and output; improved data integrity; ease of modification, updating and access to information; and standardisation and protection of data (UNISA, 1992). All the queries for extracting the relevant data for this project were undertaken by the database manager of the Malaria Programme of the MRC due to her familiarity with the software and data.

The malaria case records provided the attribute data for this research, with the associated data including the week of reporting, method of detection (active or passive), persons name, area, section and house number.

Figure 5.1 Schematic Diagram of the Structure of the Malaria Information System Relational Database



Active and Passive Malaria Cases

Malaria is a notifiable disease in South Africa, and both the active and passive cases are positively identified by microscope in the Department of Health’s laboratory in Jozini and quality controlled in the Department of Health’s laboratory in Edendale Hospital in Pietermaritzburg (Pers. Comm. Mr Mthembu, 1997). The cases are then written into a case register with patient details as indicated above and in Chapter 3, this being the source of the malaria case data for this project. The active and passive malaria cases were analysed separately in the study in order to take into account the spatial variations that may present as a result of the reasons for their different methods of detection, namely, the affect of immunity. Combining the active and

passive may have resulted in the blurring of any spatial relationships that were a result of these differences. Areas of higher numbers of actively detected cases reflect raised immunity, and their exclusion from the study could result in potential breeding sites that should be sprayed with a larvicide not being identified.

For the purposes of this study, the calendar year was divided into two incidence seasons (high and low), the high season months being from January to June and the remaining months, July to December, being classified as the low season. This was done not so much as to reflect the case locations, but to investigate the breeding sites at which the female mosquitoes would have been laid from where they would have dispersed to find a host. As indicated in Chapter 2, the time between the eggs being laid and cases being reported from the resulting female adults, increases from approximately 40 days in summer to 64 days in winter, then the female mosquito also lives longer and therefore has a longer time during which to transmit the disease. The July cases therefore reflect the breeding sites available during late May and June, which is when the minimum temperature begins to drop well below the desired 20° C (Appendix 2). Similarly, the December cases represent the breeding sites that were available at the start of the malaria season in October and November, shortly before the minimum temperature rises above the 20° C level.

Very little rain falls in the area between May and September, during which time the female mosquitoes are restricted to laying their eggs in the more permanent water bodies. Spring rains provide new breeding sites in October and November, but it was anticipated that the winter sites would continue to be used while the new ones were being discovered. The cases during the low season therefore represent the breeding sites that would be available from May/June to October/November. It is anticipated that mapping the cases that were reported from July to December would assist in identifying the 'seed point' breeding sites to which the mosquitoes are restricted during the dryer months of the year.

Rainfall and Temperature

Monthly rainfall as well as minimum and maximum monthly temperatures were obtained for each month of 1993 and 1994 from the South African Weather Bureau by electronic mail (e-mail) (Appendix 2). Due to rainfall being the only climatic data collected at the Ndumu weather station in the study area, temperature data was obtained from the Makatini weather station further

south along the flood plain approximately 50 kilometres away. This data was considered suitable for use due to the flatness of the area and the climatic conditions being very similar across the coastal plain. This data was obtained in order to substantiate the inclusion of July (June breeding sites) in the low season category, as the average minimum temperature dropped from approximately 15°C in May to 9°C in June, while the number of cases drop to winter levels in July, indicating the start of the low season. The rainfall and temperature data were entered and stored in files in the Microsoft® spreadsheet software package Excel. The data was stored in files which contained discrete categories of information such as rainfall and maximum and minimum temperatures per month for both 1993 and 1994.

This first step of data collection, editing and storage encompassed both the data editing and data reduction stages as identified by Rothman (1996) in Chapter 4 (Methodolog) as being necessary when undertaking research. The data sets then required careful management to ensure timeous retrieval and query on which to base the modelling and analysis.

5.2.2 Data Management, Retrieval and Query

a. Data Management

Data management included setting up a directory structure for both the spatial and attribute data, and establishing standardised naming conventions and metadata standards. The non-spatial quantitative data was stored in the form of words and numbers, and the spatial quantitative data was stored as numbers, in the form of coordinates and MapInfo® files, which allowed mathematical calculations to be performed on the figures (Hamlyn, 1988). The data for the project was managed to ensure its appropriate storage and ease of retrieval. Copies of all files for this research were backed up onto the MRC's server.

Metadata (information about the data) records were kept on the source and location of the original data sets, possible distortions or problems, the scale of the original map, projection of capture, who captured or entered the information, the original format of imported data as well as other relevant information regarding the acquisition and incorporation of the data into the GIS. This was considered necessary in order to be able to trace data resources and to check the data should problems arise.

b. Data Retrieval and Query

Accessing both the spatial and attribute data in a timely and usable manner was made possible by a well structured database which allowed the customised data queries from within different data sets to be obtained. The directory structure of the spatial data was such that the different geographic features were easily found and retrieved. Querying information is the ability to extract data based on certain criteria, be it spatial, such as distance from a location, or attribute, such as homesteads with more than six people.

The database manager extracted data from the MIS to create new files by selecting the relevant malaria areas and sections (Makanis and Ndumu areas, sections 1 to 10). Two files were created for both 1993 and 1994 which contained malaria case related data, one for the actively and the other for the passively detected cases. The new files contained the following fields for each reported case of malaria: area, section, homestead number, homestead population, active or passive case detection, month of case reporting, and latitude and longitude coordinates. Records for which location data was missing (area, section and coordinate location) were excluded from the study due to an inability to display them. The total number of active and passive cases collected per month as well as those that were usable for use due to missing information are presented in Table 6.1 and detailed in Appendix 3 and Appendix 4.

Table 5.1 Total and Usable Number of Active and Passive Malaria Cases

Cases	Total Number	Number Usable	% Usable
1993 Active	1415	1190	84%
1993 Passive	1088	749	58%
1994 Active	1283	1049	81%
1994 Passive	1170	749	64%

The files containing the active and passive data for both years were imported from dBase® into MapInfo® where points were created from the latitude and longitude coordinates and stored as MapInfo® format files. This resulted in the creation of two sets of data, one for the analysis and one for the display. Having collected, edited, stored, managed, retrieved and queried the data, they were then modelled, displayed and analysed.

5.3 Effect Estimation

This consists of analysis through both descriptive studies and hypothesis testing. The descriptive studies consists of indicators to measure the frequency of a disease in a population (incidence per 1000 population) in relation to the place and time of occurrence, in this instance using maps, tables and graphs. Hypothesis testing entails undertaking statistical analysis in order to substantiate the descriptive findings.

5.3.1 Data Modelling, Display and Analysis

Modelling entails performing mathematical procedures to query the locational and/or attribute data, and results in the display of a new set of information (Glass *et al*, 1993; Clarke *et al*, 1996). The mathematical modelling procedures provided by GIS ensure the repeatability of operations, with the same modelling tools being applied to the monthly data sets for 1993 and 1994. The results of the spatial modelling for this research were displayed on maps, tables and graphs, and the information obtained from the statistical analysis was displayed in tables (Twigg, 1990; Glass *et al*, 1993; Brêtas, 1995).

Of the modelling procedures provided in MapInfo, the following were used to investigate the spatial concepts of this project :

- overlaying - placing one layer of data over another layer of data to display the spatial relationships or patterns that exist between the two, and extract data for further analysis. The malaria cases were overlaid with the potential breeding sites to establish any spatial patterns that would indicate a causal association between the two as a result of their proximity.
- buffering - a mathematical procedure to delineate a zone of influence (or buffer) around an object (water body) at a specified distance. This was done in order to investigate the relationships between the water body and the location of the malaria cases around it with respect to distance/proximity (Twigg, 1990; AGI GIS Dictionary, date unknown).

One of the functions, known as 'ring buffering', was used for this project and provides the ability to create a number of buffers or zones of influence at set intervals around one or more objects. Objects could be individually buffered so that the zones of adjacent objects overlapped or, as

with this project, several objects were collectively buffered to create continuous zones of influence around adjacent objects where the buffers intersected. This was done where the water bodies of the same type were close together and it was not possible to determine which one had been used as a breeding site. The latter form of buffering was used for this project as it was anticipated that once the type of suitable breeding site used during the low season had been identified, it would be possible to visibly identify those specifically used as 'seed points' due to the number of cases in close proximity.

Continuous zones of influence (buffers) set at intervals of one kilometre, up to a distance of four kilometres, were created by the GIS around each of the different types of water bodies, the shape of the zones being determined by that of the water body. These intervals were set in order to establish at what distance within the 4 kilometre limit, as indicated in the literature in Chapter 2, most *Anopheles* mosquitoes are likely to fly, given a host supply in close proximity. The zones were labelled with respect to their outer kilometre (km) limit, with zone 1 being the area between the edge of the water body and the 1 km limit, zone 2 between the 1 km and the 2 km limit, etc, and the area between the 4 km limit and the edge of the malaria areas (Makanis and Ndumu) being labelled zone 5.

The data was then displayed, with the different layers being used to create composite maps in order to identify the location of the most likely 'seed point' breeding sites. The maps included reference features such as the roads, rivers, game reserves, malaria areas and sections, and for analysis purposes, the malaria cases and the zones of influence. The data was also displayed in graphs and tables to display aspects of the data that were not clearly evident on the map.

Clarke *et al* (1996, 88) identify spatial analysis as the "ability to manipulate spatial data into different forms and extract additional meaning as a result", and encompasses the methods and procedures developed in geography, statistics and epidemiology. Spatial relationships based on proximity and relative location form the core of spatial analysis, as is the case with this project (Clarke *et al*, 1996).

The water bodies were investigated in the following order :

1. Perennial pans - passive cases, 1993 and 1994
2. Perennial pans - active cases, 1993 and 1994
3. Non-perennial pans - passive cases, 1993 and 1994

4. Non-perennial pans - active cases, 1993 and 1994
5. Dams - passive cases, 1993 and 1994
6. Dams - active cases, 1993 and 1994

The modelling, display and analysis was undertaken within the framework of description, interpretation, hypothesis testing and explanation as outlined in Chapter 4, and each of the above categories was divided into the following three divisions which are outlined below:

- a. Spatial modelling: maps, graphs, tables and interpretation
- b. Statistical modelling: tables and hypothesis testing
- c. Conclusion

a. Spatial Modelling: Maps, Graphs, Tables and Interpretation

Identifying the low season breeding sites that act as 'seed points' (perennial pans, non-perennial pans and dams) and malaria cases through a descriptive analysis of their proximity necessitated overlaying the July to December malaria cases (passive and active) in their respective malaria sections, with the three different water bodies and the zones of influence (buffers), and interpreting the resulting spatial patterns. This was done for each of the six different combinations of breeding sites and malaria cases in the order as described above.

Establishing the most likely winter breeding site from the maps was however not possible due to the number of cases in each zone not being reflected as a proportion of the number of people at risk. In order to determine the number of cases as a proportion of the population at risk, the number of active and passive cases within each zone for the three types of water body was calculated by the GIS, as was the total number of homes per zone. The results were entered into tables created in Microsoft® Excel and the population for each zone calculated by multiplying the number of homestead by seven, this being the average number of people per homestead as described in Chapter 3. This allowed the number of cases per zone to be adjusted as a proportion of 1000 people so as to be able to compare the number of cases within each zone as a function of distance from the water bodies. This information was presented in line graphs for 1993 and 1994 to indicate the incidence of the disease per 1000 people at risk within each zone with respect to distance from the water body.

Tables were also created to present this data and to reflect the number of cases per zone as a percentage of the total number of cases surrounding each type of water body. The tables contained the case incidence and percentage for 1993 and 1994, the combined incidence total of the two years, the average incidence and average percentage per year. It was anticipated that the graphs and tables would also assist in identifying the winter breeding sites that acted as 'seed points' as well as the maximum likely flight distance of the female mosquitoes for a blood meal given an adequate host population in close proximity.

Where there was a strong association between the potential breeding site and the location of the malaria cases, the graphs and tables indicated a higher number of cases in the zone closest to the breeding site, with the number of cases decreasing with increasing distance. As described in Hägerstrand's diffusion model in Chapter 4, a rise in the number of cases with increasing distance from the water body would indicate the presence of suitable breeding sites other than the one being investigated. However, as this descriptive interpretation of the maps, graphs and tables did not constitute adequate scientific evidence on which causal associations could be explained, further statistical analysis was undertaken.

b. Statistical Modelling: Tables and Hypothesis Testing

In order to test the interpretation of the results presented in the maps and graphs as described above, a statistical analysis was undertaken to determine a causal relationship between the number and proximity of cases surrounding the different potential breeding sites. The results were presented in tables with an associated explanation in order to refute or substantiate the hypothesis as set out in Chapter 1. The hypothesis stated that the malaria vector (*Anopheles arabiensis*) is localised to certain breeding sites during winter that can be detected by mapping them in relation to the low season malaria cases. Establishing a statistically significant relationships between the potential breeding sites and the malaria cases will substantiate the findings made during the spatial modelling, and provide evidence of the maximum likely distance that female mosquitoes will fly for a blood meal given an adequate host population in close proximity.

To establish a statistically significant relationship between the malaria cases and the different zones of the potential breeding sites, a computerised statistical analysis was undertaken by the

MRC statistician, using Stata® Statistical Software: Release 6.0. This consisted of a number of variables being integrated into a computerised generalised linear regression model which assumed a Poisson Distribution for the count of malaria cases. This was undertaken for the months of July to December for both years. A Poisson distribution determines “how one or more independent variables are related to the rate of occurrence of some outcome” (Kleinbaum *et al*, 1998, Pg 12). Generalised Linear Regression Analysis is a type of multi-variate technique which is the statistical assessment of relationships among a set of two or more variables, one dependent and one independent, which fits a straight line to the trend in a scatter of points (Johnston *et al*, 1986; Kleinbaum *et al*, 1998). The variables were divided between those that were dependent and those that were independent. The dependent variable (malaria cases) were dependant on the independent variables (malaria season, type of water body, method of detection, distance from breeding site) all of which play a role in malaria transmission as outlined in Chapter 2 (Kleinbaum *et al*, 1998).

The variables presented below were statistically compared to establish the feasibility of combining each month of 1993 and 1994 for analysis as opposed to analysing them separately. This was considered statistically viable and the variables were combined for the analysis and the results presented in tables. The five variables used in the model were :

1. Month of disease occurrence. To assess the number of cases with respect to their distance from the water bodies as a function of the month.
2. Numbers of malaria cases per zone. These were corrected for the population at risk and multiplied by 1000 to allow for comparisons between the different zones.
3. Method of detection (active or passive). To determine any difference in incidence with respect to the different methods of detection as a reflection of the level of immunity which is a function of infected mosquito bites.
4. Type of water body (perennial pan, non-perennial pan or dam). To establish which of the water body types act as winter ‘seed points’ from which the summer distribution spreads.
5. Zone number (from zone 1 to zone 5). To determine the effect of distance from the water bodies on the number of malaria cases.

The results of the statistical analysis included :

- The Incident Rate Ratio (IRR). The IRR is the total number of new cases within a set area that occur during a specified time (month, season, year), divided by the population at risk. This

study requires one zone to be reflected as a ratio of another zone for comparative purposes, resulting in this being a Ratio. In this study, zone 1 (next to the water body) was the zone against which all the outer zones were compared. Zone 1 therefore had a value of one and the zones beyond had larger (e.g. 1.3) or smaller (e.g. 0.6) values than one depending on whether there were higher or lower case numbers. A decrease in the IRR with increasing distance from one type of water body indicated a higher probability of that type of water body acting as a suitable low season breeding site. Conversely, a decreasing IRR with increasing distance from the water body indicated that there were other types of water bodies that were more suitable for breeding purposes.

- The Probability or P-value. The P-value reflects the probability of a result occurring by chance, usually expressed as a proportion of 100, with the traditionally accepted probability of 5% or less being considered statistically significant, and is usually represented at $P < 0.05$. As indicated by Varkevisser *et al* (1991), the probability of an association will be influenced by sample size, with small sample sizes having the possibility of indicating higher P-values than project with large sample sizes. However, the National Research Council (1991) cautions exclusion of higher P-value results in studies with small sample sizes where causal associations are known to exist.
- The 95% confidence intervals. The confidence intervals consist of lower and upper ranges within which the true value is likely to be encompassed. A 95% confidence interval means that there is a 95% likelihood of the values falling between the lower and upper limits (Varkevisser *et al*, 1991). This interval is however affected by the sample size, with small sample sizes tending to be indicated by wide intervals (Mayer in Pacione, 1986).

The statistical analysis entailed assessing the relationship of the variables with respect to the effect of distance (proximity) to the potential breeding sites. As cautioned by Varkevisser *et al* (1991) in Chapter 4, the probability of association will be influenced by the sample size which for some months of this study were very low. All three aspects of the statistical analysis were therefore considered when the results were analysed.

5.4 Conclusion

The type of analysis was determined by the epidemiology of malaria, in that *Anopheles*

arabiensis female mosquitos are reported not to fly more than 4 km for a blood meal given an adequate host supply in close proximity, and that only a limited number of suitable breeding sites are available during the dryer months of the year as described in Chapter 2. Interpreting and explaining the results of the analysis required an understanding of the theoretical principles that underpin both the epidemiological and spatial components.

Obtaining meaningful results required using appropriate data sets at the correct scale which consisted of the homestead coordinate locations being obtained from Global Positioning System receivers, as well as the rivers, boundaries and other relevant features being digitized from topographic maps and orthophotos ranging in scale from 1:250 000 to 1:10 000. The data was stored, edited and managed in dBase® and MapInfo®, and accessed as required. GIS provided the platform to display the maps for the initial display and interpretation and from which data was extracted for the statistical analysis, thereby providing a more rigorous scientific analysis of the data. Using the same mathematical models to undertake analysis on different data sets ensured consistent results and will allow the model to be used on other data sets where the same type of analysis is required

The results of this analysis were measured against the list of criteria as set out by Kleinbaum *et al* (1998) and the Committee on Environmental Epidemiology (National Research Council, 1991) in order to be able to reasonably conclude a causal relationship between the locations of the different types of water bodies and the malaria cases. As detailed in Chapter 4, applying these criteria does not necessarily prove causation, however, in the absence of additional experimental evidence, their use is a practical way to establish the possibility of a causal relationship (Kleinbaum *et al*, 1998).

The resulting decisions based on the newly generated information will be made available to the Malaria Control Programme managers of KwaZulu-Natal province as well as the scientific community. Decisions regarding the viability of using le Sueur's (1991) recommendation that larvicides be applied at the end of July to reduce the mosquito population that reach adulthood, can then be addressed by both the local research and control communities. While the main objective would be to provide results on which management decisions could be based, it could also reveal new patterns, such as the relationship between the active and passive cases, which could direct future research.

CHAPTER 6

ANALYSIS OF THE RELATIONSHIP BETWEEN THE PROXIMITY OF THE MALARIA CASES TO THE POTENTIAL BREEDING SITES

6.1 Introduction

This chapter presents the spatial and statistical modelling and analysis that was undertaken by combining the first two stages of Molineaux's (1988) three-phased approach to epidemiological investigations, namely, to describe and explain the distribution of a disease using new and appropriate methods. Finding a causal relationship between the spatial patterns that presented as a result of the proximity of the location of the malaria cases to the likely breeding sites was done by identifying those water bodies around which the incidence of malaria decreased with increasing distance. Identifying the sites that act as 'seed points' will, through the application of larvicides, assist in limiting the distribution of malaria and lower the disease incidence levels in the region. Establishing the likely maximum flight distances of mosquitoes to blood meals will identify those people most at risk as well as those areas requiring additional prevention and control activities.

Identifying the breeding sites that act as 'seed points' during the winter months was done by displaying the water bodies in relation to those of the low season (July to December) active and passive malaria cases of 1993 and 1994, and undertaking spatial and statistical modelling. These months were selected to reflect the breeding sites from which the mosquitoes would have hatched between 40 and 64 days prior to the case being reported (Chapter 2). The actively and passively detected cases were analysed separately in order to identify any difference in their spatial patterns. The analysis is presented in the following categories:

- perennial pans with passive cases : 1993 and 1994
- perennial pans with active cases : 1993 and 1994
- non-perennial pans with passive cases : 1993 and 1994
- non-perennial pans with active cases : 1993 and 1994
- dams with passive cases : 1993 and 1994
- dams with active cases : 1993 and 1994

The spatial modelling entailed creating maps which displayed the homestead locations at which the malaria cases occurred, the potential breeding sites and their respective distance zones. The number of cases in each zone was corrected for the population at risk, and presented in graphs to display the monthly case incidence per zone, and in tables to present the case incidence and percentage for each of the 5 zones. For each category, an interpretative description of the results is followed by statistical modelling with the results being presented in tables. This entailed using a generalised linear regression model to compare the number of cases in each of the zones beyond zone 1 with those in zone 1. Based on the results from the spatial and statistical modelling, the breeding sites of the female *Anopheles* mosquitoes during the low season months were identified as well as the maximum likely flight distance.

To establish the possibility of undertaking the statistical modelling by combining the 1993 and 1994 cases, a statistical comparison of the 1993 cases with respect to those in 1994, based on method of detection (active and passive) was undertaken, the results being presented in Table 6.1. An IRR of less than 1 indicates that there were fewer cases in 1994 than in 1993, and one higher than 1 indicates that there were more cases in 1994 than in 1993. The number of passive malaria cases for each of the three breeding sites was therefore higher in 1994 than the number in 1993, while the opposite is true for the active cases. In all instances, the p-value (chance probability value) was less than 0.05 indicating that the results are statistically significant and that the data can be used in combination. The 95% Confidence Interval indicate that the lower and upper values are fairly close together despite the relatively small sample size. The malaria cases for 1993 and 1994 were therefore combined for the statistical analysis based on method of detection.

Table 6.1 Statistical comparison between the 1993 and 1994 active and passive malaria cases with respect to the three different types of breeding sites.

Breeding Sites and Malaria Cases	Incidence Rate Ratio	P> z	95% Confidence Interval	
			Lower	Upper
Perennial Pans and Passive Malaria Cases	1.17	0.003	1.06	1.30
Perennial Pans and Active Malaria Cases	0.88	0.0	0.81	0.98
Non-Perennial Pans and Passive Malaria Cases	1.17	0.0	1.06	1.30
Non-Perennial Pans and Active Malaria Cases	0.88	0.0	0.81	0.96
Dams and Passive Malaria Cases	1.24	0.0	1.11	1.37
Dams and Active Malaria Cases	0.86	0.0	0.79	0.94

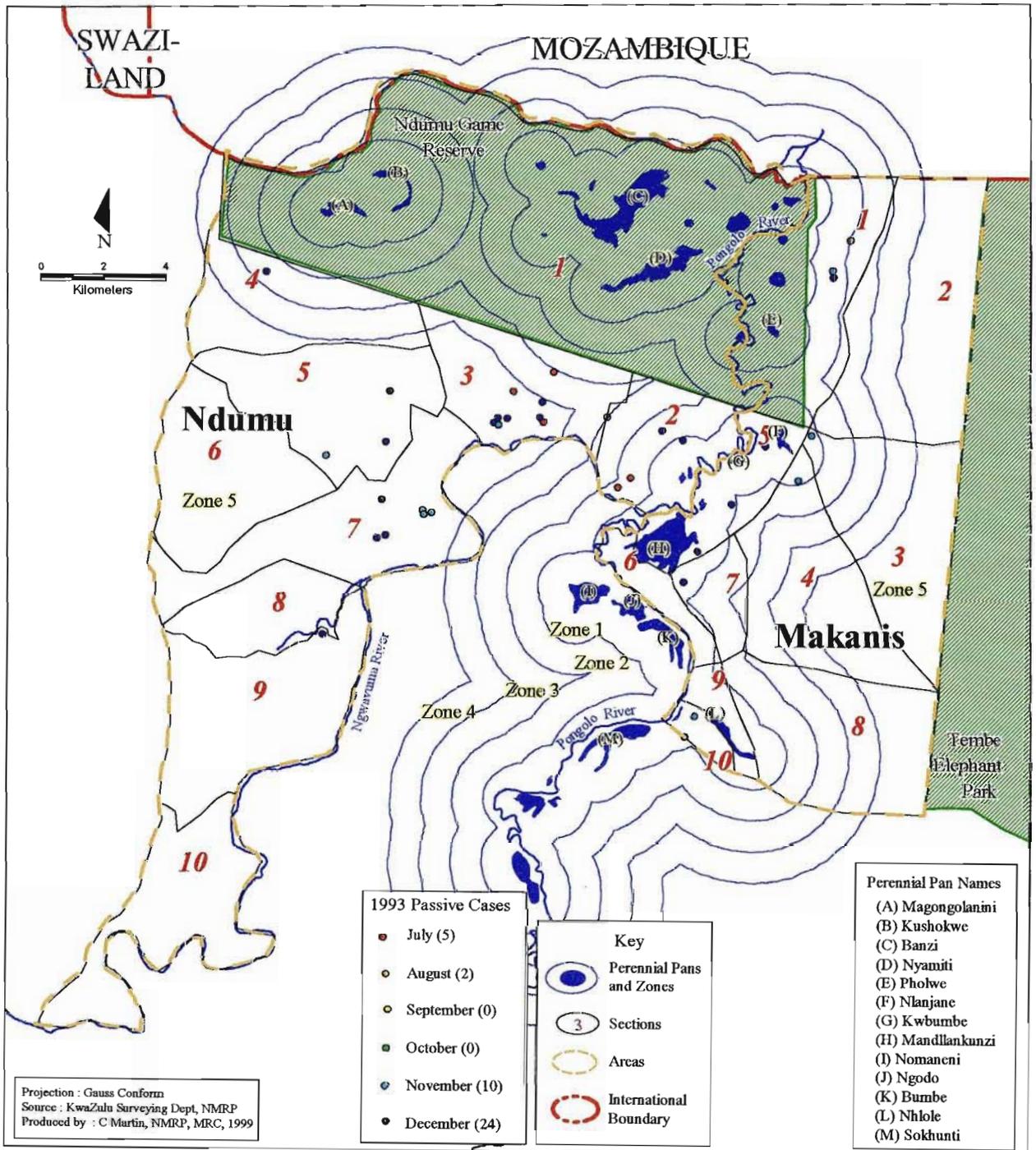
6.2 Perennial Pans and Passive Cases : 1993 and 1994

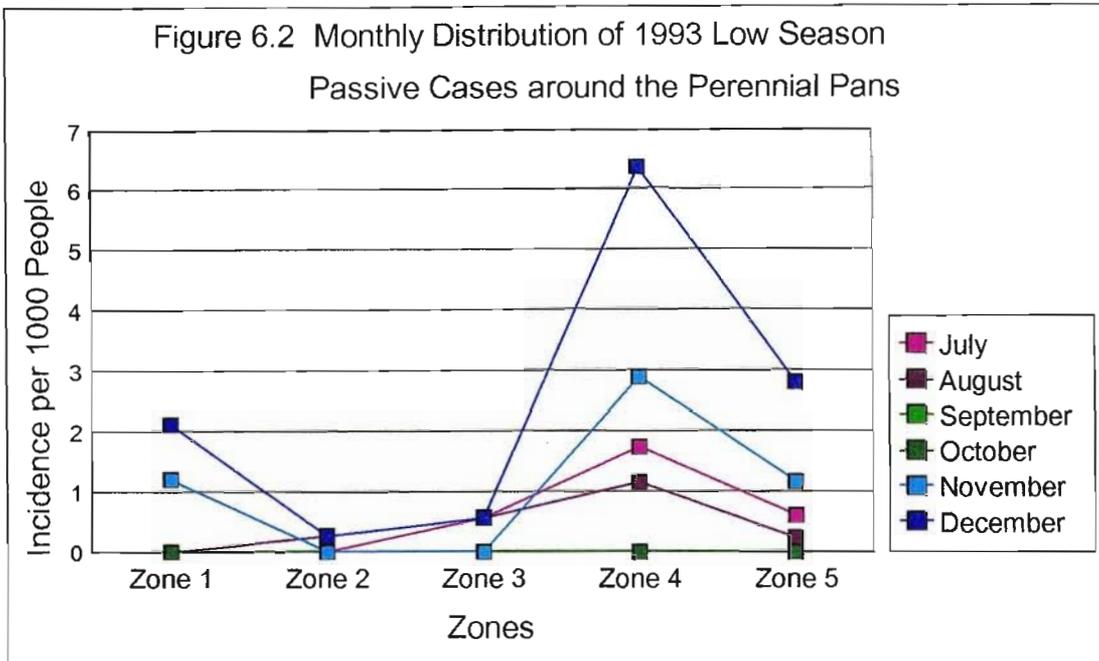
The perennial pans are those water bodies that contain water throughout the year but which may contract in size during winter and expand again with the onset of the spring rains. They vary in size and are characterised by a lack of vegetation, little shade, calm water and are generally fairly shallow. The passive malaria cases are those that are recorded when patients are positively diagnosed as having malaria at health facilities.

6.2.1 Spatial Analysis of Perennial Pans and the 1993 Low Season Passive Cases

The distance zones around the perennial pans, and the distribution of the homesteads at which the passive low season malaria cases occurred during 1993, are presented in Figure 6.1. Figure 6.2 indicates the distribution of passive cases in the five zones surrounding the perennial pans during July to December of 1993 with the incidence reflecting the cases per 1000 people at risk. The only months in which the number of cases decreases from zone 1 to 2 are November and December, which is at the start of the malaria season. During the July and August, the number of cases gradually rises with increasing distance from the perennial pans peaking in zone 4, indicating that alternative breeding sites were used for the passive cases. Figure 6.2 indicates no association between the perennial pans and the locations of the passive cases, with an increase in malaria cases beyond zone 3 suggesting the presence of alternative breeding sites during the low season months. There is also no evidence to indicate the maximum likely flight distance of the mosquito given a host supply in close proximity.

Figure 6.1 Zonal Distribution of low Season 1993 Passive Cases around the Perennial Pans





While many (78.6%) of the 41 cases fall within 4 km of the perennial pans (Table 6.2), only 14.7% occurred in the first zone, and 54% occurred in zone 4, indicating that it is unlikely that the perennial pans were used as breeding sites for these cases. Several cases do fall near the Nhlanjane (F), Kwabumbe (G) and Mandlankunzi pans (H) however, due to the low case number, it is difficult to establish whether there is any association between them and the pans. Most cases in zone 5 occurred during December in Ndumu sections 3, 5 and 7, indicating the presence of additional sites to the west.

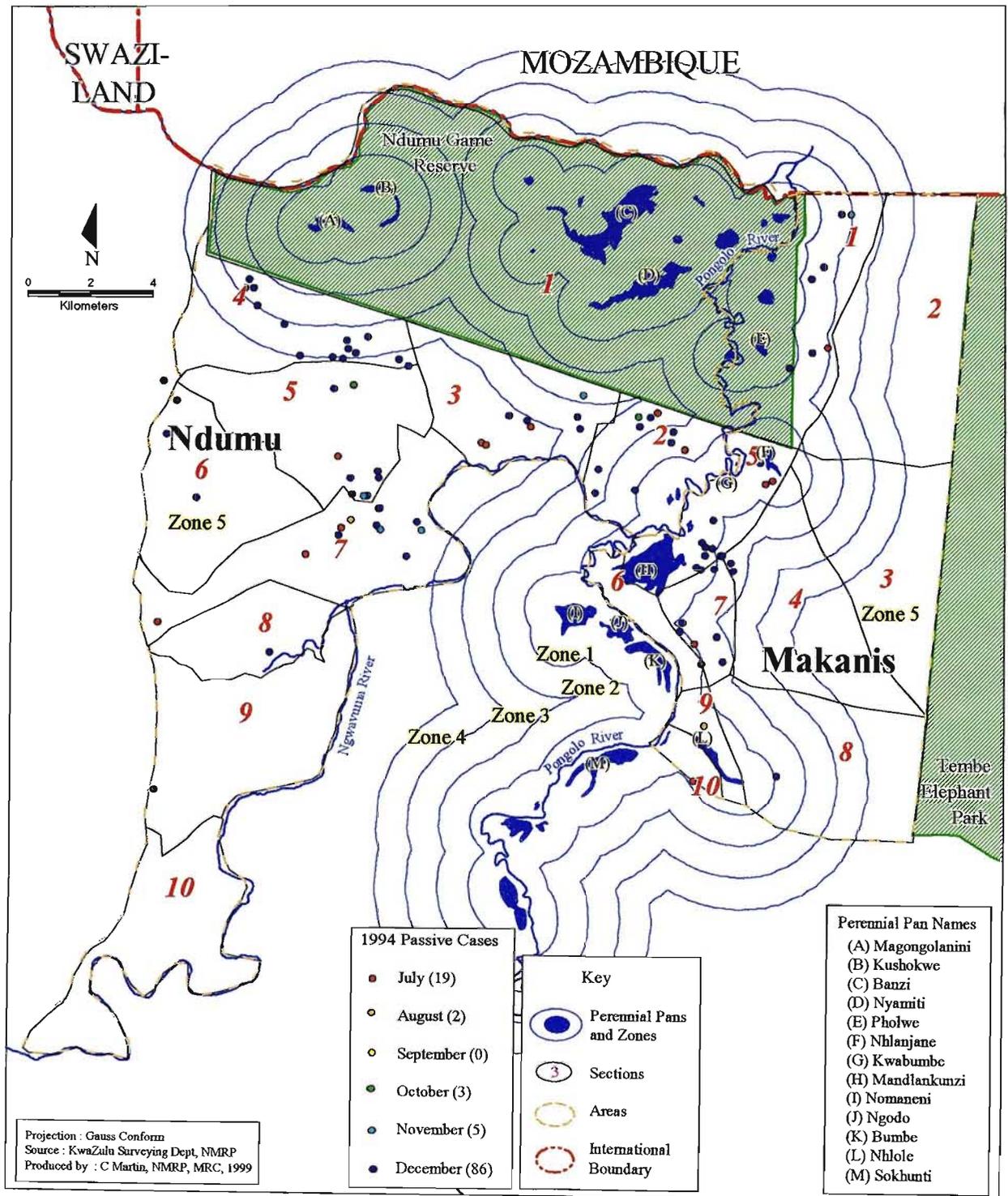
Table 6.2 Low Season 1993 Passive Malaria Cases per Zone around the Perennial Pans

Zones	Incidence per 1000 population	Percentage
Zone 1	3.3	14.7
Zone 2	0.5	2.3
Zone 3	1.7	7.6
Zone 4	12.1	54.0
SubTotal	17.6	78.6%
Zone 5	4.8	21.4
Total	22.4	100%

6.2.2 Spatial Analysis of the 1994 Low Season Passive Cases

Of the 115 passive cases that occurred during the 1994 low season, 86 were reported in December and 19 in July, their distribution being presented in Figure 6.3. Many of the cases do fall within 4 km of the pans and there is some clustering in the inner zones along the Pongolo River, particularly in December.

Figure 6.3 Zonal Distribution of 1994 Low Season Passive Cases around the Perennial Pans



However, there are also cases in zone 5 and in the outer zones in Ndumu 2, 3 and 4 which indicate the presence of alternative breeding sites. Due to the low number of cases from August to November, it is difficult to establish a causal relationship between the location of the perennial pans and the passive malaria cases for 1994. Their distribution with respect to the distance zones per month is presented in Figure 6.4, and with less than 2 cases per 1000 for all months except December, it is unlikely that the perennial pans were used as breeding sites.

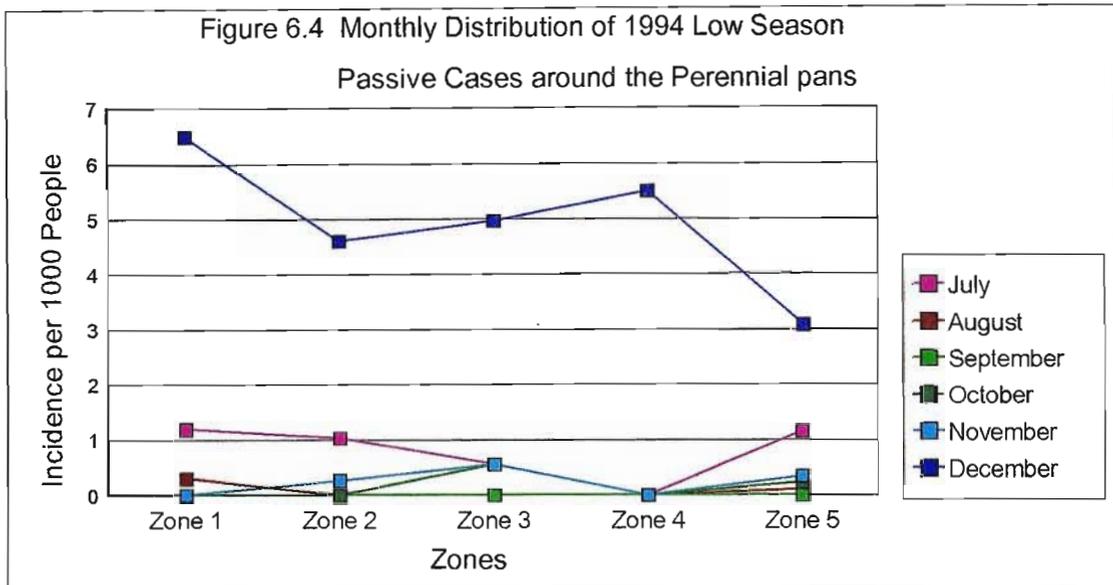


Table 6.3 presents the case average incidence per zone for the low season months of 1994 around the perennial pans. The percentage of cases is higher in zone 1 than in zone 2 and over three quarters of the cases occur within 4 km of the perennial pans, however, this may be due to the high number of December cases which account for more than two thirds or 81% of the cases. There is no consistent decrease in case incidence or percentage from zone 1 for 1994, and it is therefore unlikely that the perennial pans were used as the main breeding sites during the low season months which resulted in the reporting of the passively detected cases.

Table 6.3 Low Season 1994 Passive Malaria Cases per Zone around the Perennial Pans

Zones	Incidence per 1000 population	Percentage
Zone 1	8.0	25.9
Zone 2	5.9	19.2
Zone 3	6.6	21.3
Zone 4	5.5	17.7
SubTotal	26.0	84.3
Zone 5	4.9	15.9
Total	30.8	100

6.2.5 Statistical Analysis of the Perennial Pans and Passive Malaria Cases

The results of the Generalised Linear Regression Model that was used to statistically model the relationship between the perennial pans and the passive malaria combined cases for 1993 and 1994 are presented in Table 6.4. All the zones beyond zone 1 contain fewer cases than occurred in the first one (1) according to the Incidence Rate Ratio (IRR), with very little variation between the incidence in zones 2 to 5 showing no consistent increase or decrease with respect to proximity. The p-value is higher than the desired 0.05 in all the zones except zone 5, indicating no statistically significant relationship, which could be due to the small number of passive cases during most of the months except December. The confidence intervals show a large range between the lower and upper levels which could be a function of the small number of samples or a wide range of values that fall within that zone.

Table 6.4 Perennial Pans and the Passive Malaria Cases: Generalised Linear Regression Model Results for the Combined Low Season Months of 1993 and 1994.

Zonal Comparisons	Incidence Rate Ratio	P> z	95% Confidence Interval	
			Lower	Upper
Zone 1 against Zone 2	0.66	0.07	0.39	1.04
Zone 1 against Zone 3	0.69	0.23	0.37	1.27
Zone 1 against Zone 4	0.66	0.19	0.35	1.23
Zone 1 against Zone 5	0.64	0.03	0.43	0.96

6.2.4 Conclusion - Perennial Pans and Passive Cases

The results from both the spatial and statistical analysis indicate that the perennial pans, with respect to the passively reported malaria cases, were not the primary breeding sites used during the low seasons of 1993 and 1994. The low number of cases as a result of the data limitation as described in chapter 3 may have been a contributing factor. The increase in case numbers in zone 1 for December 1994 indicates that the perennial pans may be used at the start of the malaria season. The statistical analysis confirms the findings of the spatial analysis and indicate that the perennial pans are unlikely to have been used as the main breeding sites for the mosquitoes which caused the infections that were passively reported during July to December of 1993 and 1994. There is also little evidence suggesting the maximum likely flight distance of the female mosquito given a host supply in close proximity.

6.3 Perennial Pans and Active Cases : 1993 and 1994

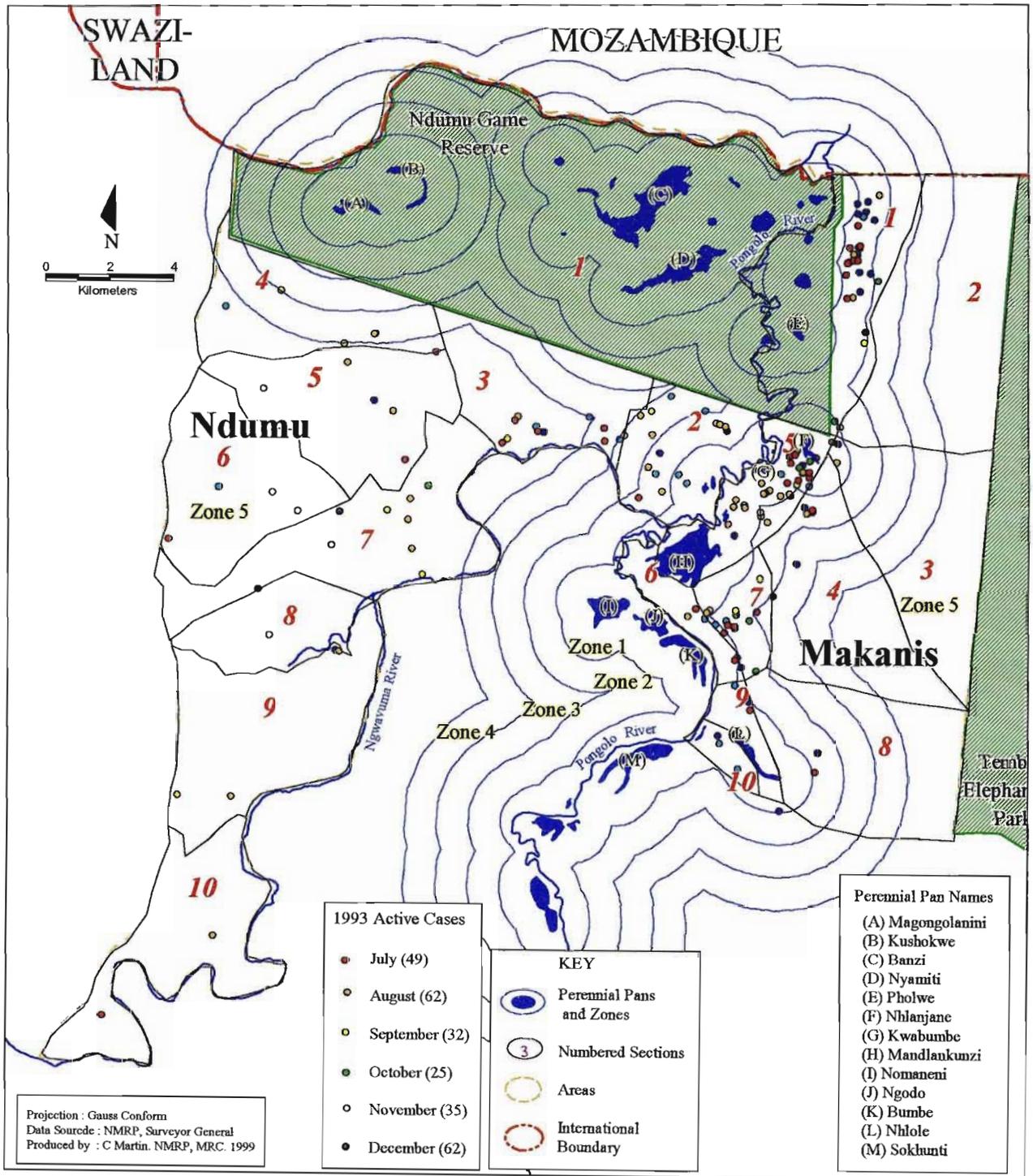
The active cases are those that are detected by the surveillance agents who randomly take blood slides from inhabitants to detect the presence of malaria parasites. These asymptomatic parasite carriers do not report ill to health facilities and therefore provide a reservoir of parasites with which the female mosquito infects other inhabitants.

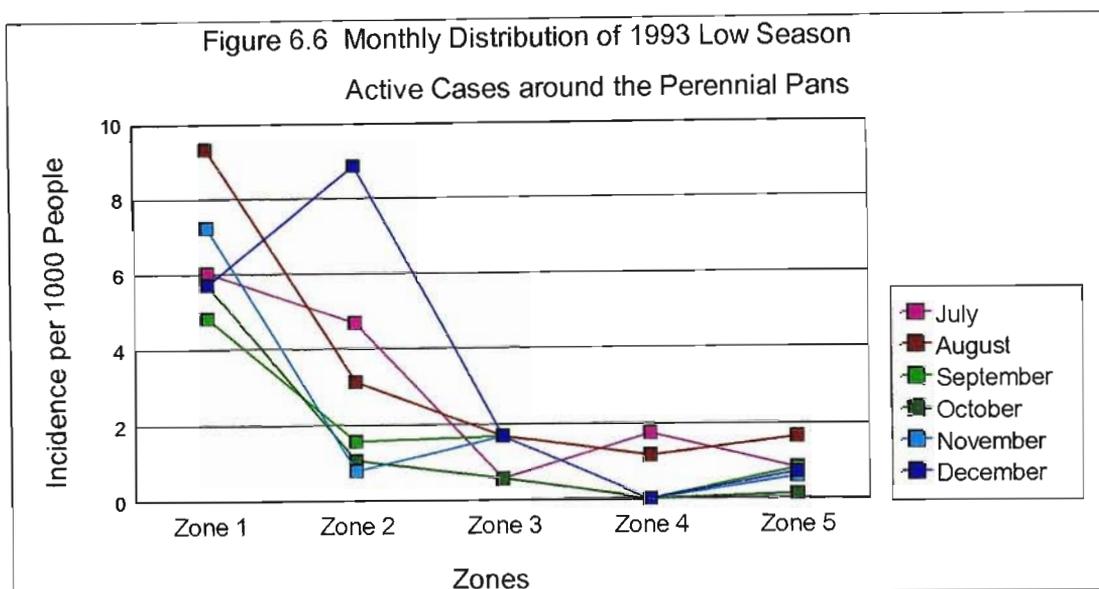
6.3.1 Spatial Analysis of Perennial Pans and the 1993 Low Season Active Cases

The distribution of active cases during July to December as presented on Figure 6.5 clearly shows a clustering around the inner zones surrounding the perennial pans along the Pongolo River, and in the Mbagweni Corridor in Makanis section 1. The highest concentration of cases are in Makanis in close proximity to Nhlanjane (F), Kwabumbe (G) and Mandlankunzi (H) pans, as well as near the Mozambique boarder in section 1. A number of cases are scattered throughout Ndumu for all six months indicating the presence of additional sites. The majority of cases fall within the first four zones surrounding the perennial pans, suggesting that they are important breeding sites during the dryer winter months. Their concentration in fairly close proximity to the breeding sites would also provide evidence to suggest that mosquitoes do not fly more than four kilometres for a blood meal when a host supply is in close proximity.

Figure 6.6 indicates the number of active cases in the zones around the perennial pans for the low season months of 1993. For all months except December, the number of cases is highest in zone 1 after which it drops by at least 50% from an incidence of above 4 cases per 1000 people to less than 2. It rises very slightly for all cases except July, indicating the presence of other breeding sites beyond a distance of 4 kilometres. The number of December cases rises from zone 1 to zone 2 and drops sharply to zones 3 and 4. This consistent patterns indicates a strong association between the location of the perennial pans and the malaria cases, and also suggests that mosquitoes tend to fly no more than 2 km given a host supply in close proximity.

Figure 6.5 Zonal Distribution of the 1993 Low Season Active Cases around the Perennial Pans





The incidence and percentage per zone drop from zone 1 to zone 4, with a slight increase thereafter (Table 6.5). While 93.7% do not fly more than 4km, 79.3% fly no more than 2km, and 89,8% fly no more than 3km, indicating a strong association between the perennial pans and the location of the active cases.

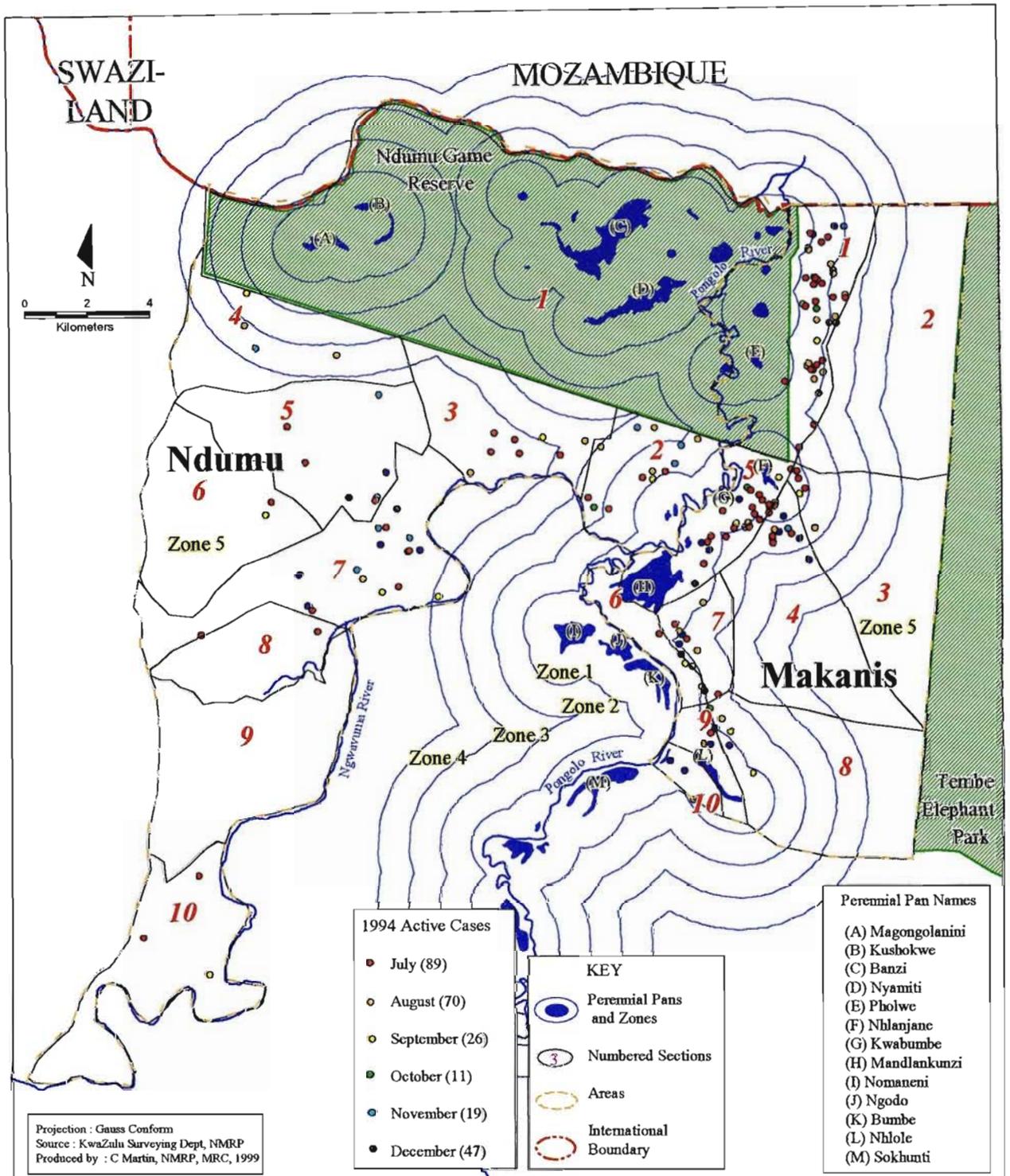
Table 6.5. Low Season 1993 Active Malaria Cases per zone around the Perennial Pans

Zones	Incidence per 1000 population	Percentage
Zone 1	38.8	52.3
Zone 2	20.0	27.0
Zone 3	7.8	10.5
Zone 4	2.9	3.9
SubTotal	69.5	93.7%
Zone 5	4.7	6.3
Total	74.2	100%

6.3.2 Spatial Analysis of Perennial Pans and the 1994 Low Season Active Cases

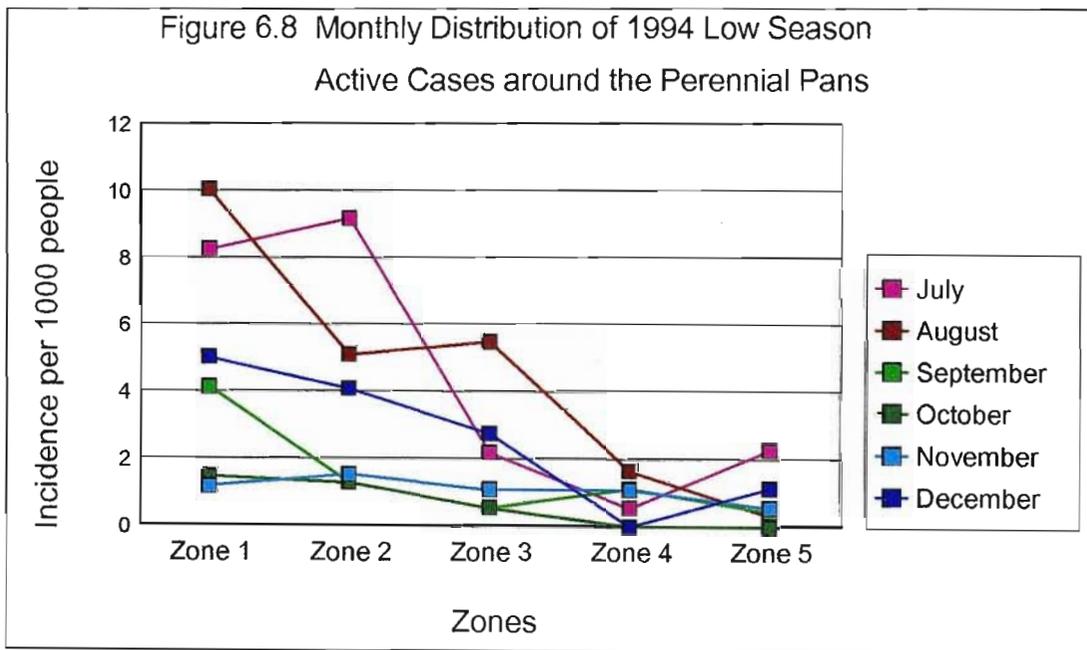
The number of active cases reported during the low season months of 1994 drop from 89 in July to 11 in October and rise to 47 in December, totalling 262 cases. The distribution of the cases is presented in Figure 6.7, with most being concentrated along the eastern side of the Pongolo River in Makanis sections 1 and 5, to a less extent in sections 6, 7 and in the northern corner of 4. All of the cases in Makanis fall within 4 km of the perennial pans with most falling in the zones 1 and 2. A number of cases are scattered throughout zone 5 in Ndumu, indicating the presence of additional breeding sites during the winter months.

Figure 6.7 Zonal Distribution of the 1994 Low Season Active Cases and the Perennial Pan



The concentration of cases along the banks of the Pongolo River, where most of the perennial pans are situated, suggests that they are important breeding sites during the dryer winter months. The location of most cases in Makanis within the inner two zones suggests that mosquitoes do not fly more than 2 km for a blood meal when an adequate host supply is in close proximity.

Figure 6.8 indicates the distribution of the active cases for the low season months of 1994 around the perennial pans. The July and November cases increase from zone 1 to 2, but the remaining months experience a gradual decrease in cases from zone 1 to zone 4. The incidence of cases in zone 1 drops gradually from July and August as the number of cases decreases as indicated in Figure 6.7, and increases in December.



The malaria incidence per zone is presented in Table 6.6, and indicates a continuous decrease in cases with increasing distance from the perennial pans. The percentages of cases in the zones for 1994 clearly indicate a decrease in the number of cases with increasing distance from the perennial pans. While 93.5% of cases occurred within the first 4 zones, 70.3% occurred within the first 2 km, indicating a strong likelihood that the perennial pans were used as breeding sites which resulted in the reporting of actively detected cases.

Table 6.6. Low Season 1994 Active Malaria Cases per Zone around the Perennial Pans

Zones	Incidence per 1000 population	Percentage
Zone 1	30.1	40.5
Zone 2	22.4	30.0
Zone 3	12.6	17.0
Zone 4	4.4	6.0
SubTotal	69.5	93.5
Zone 5	4.8	6.5
Total	74.3	100

6.3.3 Statistical Analysis of the Perennial Pans and the Active Malaria Cases

The results of the Generalised Linear Regression Model used to statistically analyse the relationship between the active cases in relation to the perennial pans for the 1993 and 1994 cases combined are presented in Table 6.7. The Incidence Rate Ratio falls consistently from 1 in the zone 1 to 0.11 in zone 4, and rises slightly in zone 5. Zone 3 is one third of zone 1 and one half of zone 2, and zone 4 dropping still further to level off in zone 5. These findings have little probability of being a chance occurrence as indicated by the very low p-values of 0.0 for all zones. The lower and upper confidence intervals are fairly small, indicating that most cases fall within a very limited range.

Table 6.7. Perennial Pans and the Active Malaria Cases: Generalised Linear Regression Model Results for the Combined Low Season Months of 1993 and 1994.

Zonal Comparisons	Incidence Rate Ratio	P> z	95% Confidence Interval	
			Lower	Upper
Zone 1 against Zone 2	0.62	0.0	0.51	0.75
Zone 1 against Zone 3	0.30	0.0	0.21	0.42
Zone 1 against Zone 4	0.11	0.0	0.06	0.19
Zone 1 against Zone 5	0.14	0.0	0.11	0.18

6.3.4 Conclusion - Perennial Pans and Active Cases

The results of the spatial and statistical modelling of the active cases during July to December of 1993 and 1994 indicate that the perennial pans were important breeding sites during the dryer winter months. The results of the spatial analysis show that almost half of the cases were reported in zone 1 with the number dropping consistently thereafter, with over 90% occurring within the first four zones. This provides evidence to suggest that the female mosquito is unlikely to fly more

than 4 km for a blood meal given a host supply in close proximity. The results of the statistical analysis support these results, and indicate that the perennial pans are likely to act as 'seed points' to which the mosquitoes are restricted during the dryer winter months, and from which they spread with the onset of suitable environmental conditions at the start of the following malaria season.

6.4 Non-perennial Pans and Passive Cases : 1993 and 1994

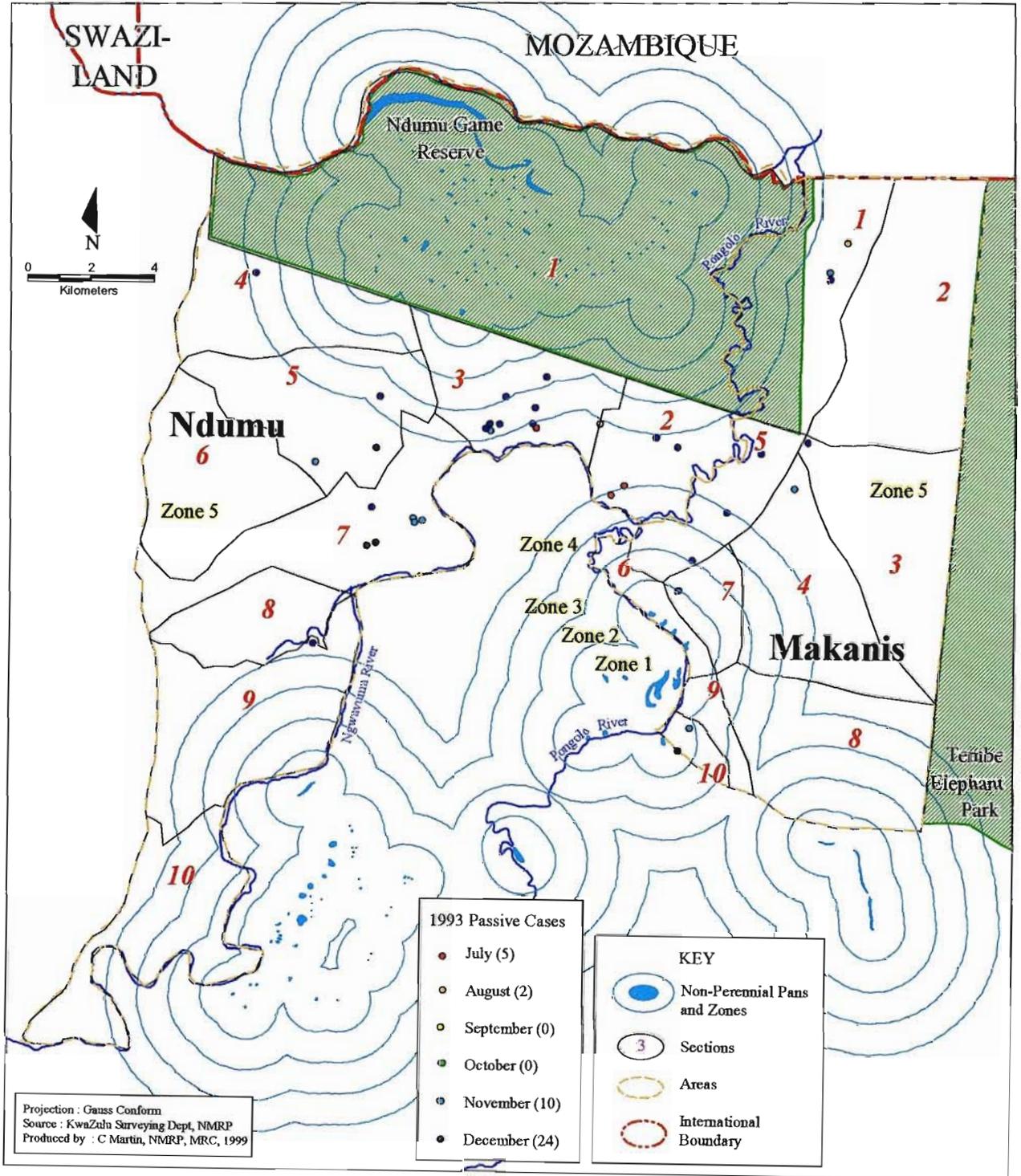
The non-perennial pans are those water bodies that occur naturally but do not contain water throughout the year. They vary in size, are generally calm, shallow, vegetation free and exposed to sunlight. They occur along the banks of the Pongolo and Ingwavuma Rivers as well as in the Ndumu Game Reserve.

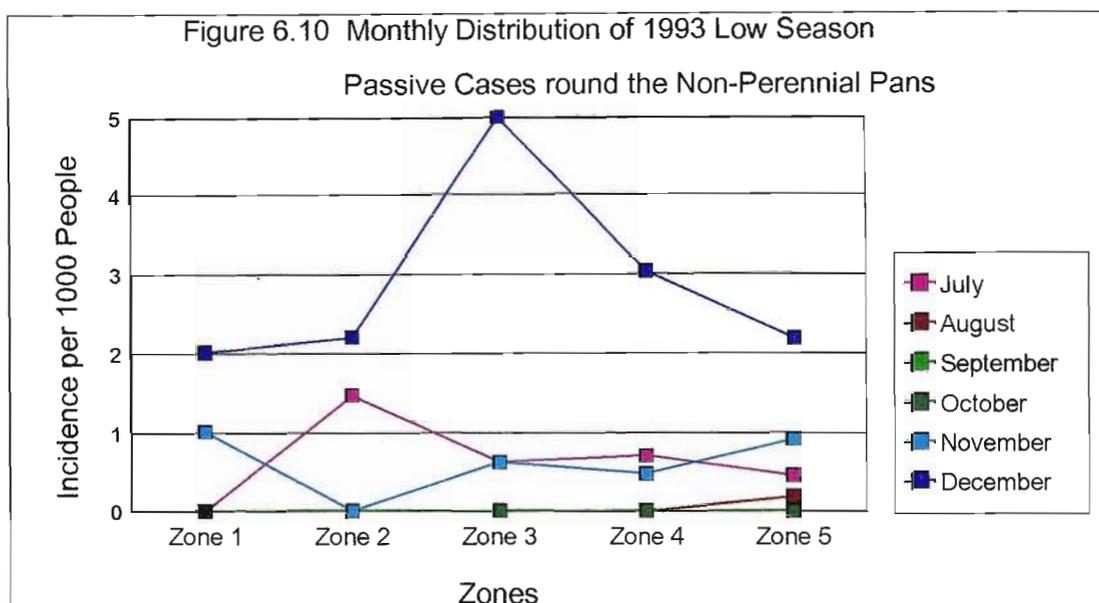
6.4.1. Spatial Analysis of the Non-Perennial Pans and the 1993 Low Season Passive Cases

The location of the passive malaria cases within the zones surrounding the non-perennial pans during July to December of 1993 and 1994 are presented on Figure 6.9. While some of the cases do fall within the first four zones in Makanis sections 5, 7 and 10, and Ndumu sections 2, 3, 4 and 5, however they tend to be located in the outer zones rather than in close proximity to the non-perennial pans. A number of cases fall in zone 5 such as in the northern sections of Makanis and in Ndumu sections 5 and 7. This indicates that there is little association between the locations of the breeding sites and the homesteads at which the malaria cases were reported.

Figure 6.10 shows that the incidence of malaria cases in zone 1 for the low season months of 1993 around the non-perennial pans is very low, with no more than 2 cases per 1000 people for any of the months. There is no consistent drop in the number of cases with increasing distance from the water bodies, and the rise in case numbers in zone 3 during December indicates the presence of additional breeding sites during October/November with the onset of the spring rains. The distribution of cases in the zones indicates that it is unlikely that the non-perennial pans were used as breeding sites during the low season months of 1993. There is also no indication of any maximum likely flight distance of the mosquitoes.

Figure 6.9 Zonal Distribution of 1993 Low Season Passive Cases around the Non-Perennial Pans





The incidence per zone is presented in Table 6.8, as is the percentage for each. The incidence and percentage increase from zone1 to zone 3, and the decrease thereafter, indicates that the non-perennial pans are unlikely to have been the major breeding sites during the winter of 1993. The figures are unable to substantiate other research findings on the maximum likely flight distance.

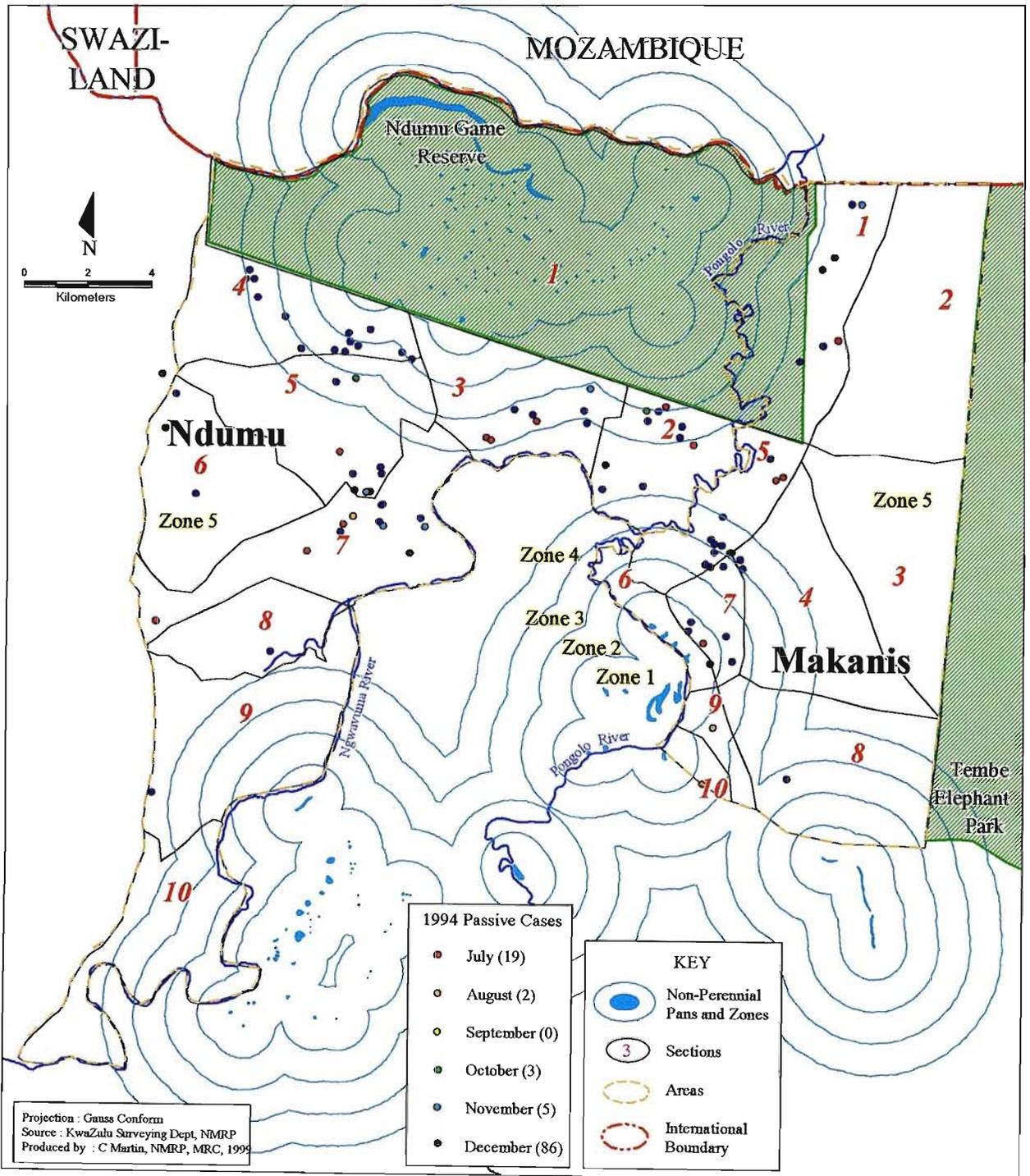
Table 6.8. Low Season 1993 Passive Malaria Cases per Zone around the Non-Perennial Pans

Zones	Incidence per 1000 population	Percentage
Zone 1	3.0	14.4
Zone 2	3.7	17.8
Zone 3	6.2	29.8
Zone 4	4.2	20.2
SubTotal	17.1	82.2%
Zone 5	3.7	17.8
Total	20.8	100%

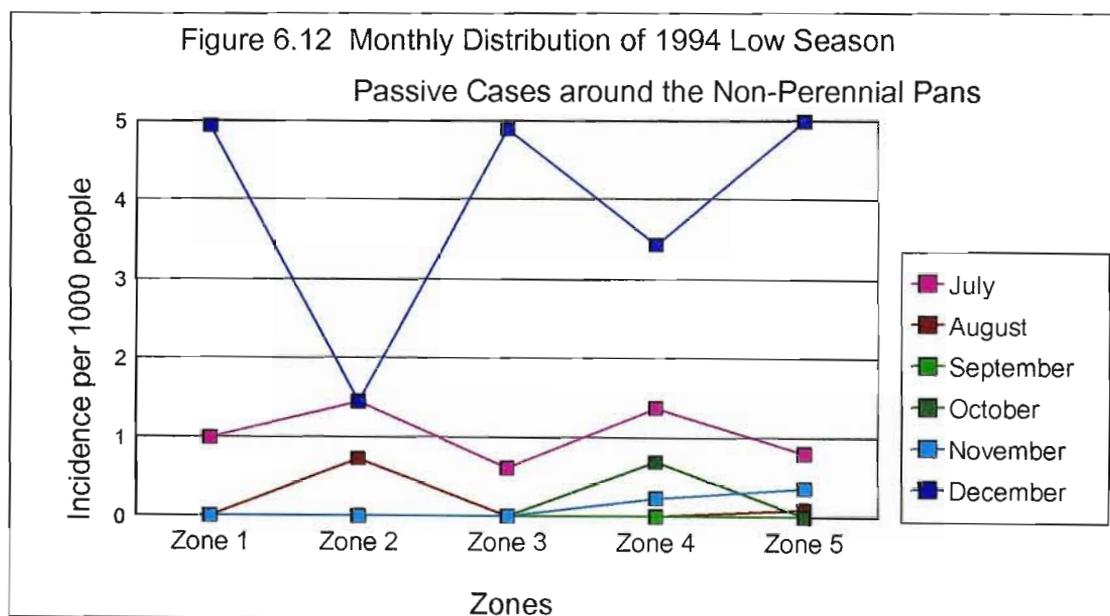
6.4.2 Spatial Analysis of the Non-Perennial Pans and the 1994 Low Season Passive Cases

The distribution of the 1994 passive cases around the non-perennial pans is presented in Figure 6.11, and although there are more cases than during 1993, the majority occur during December (89). Many of the cases are located within the first 4 zones, however they tend to occur beyond 2 km, thereby indicating that the non-perennial pans are unlikely to have been used as breeding sites during the winter months. Figure 6.12 presents the zonal distribution of the passive case for the low season months of 1994 with respect to the non-perennial pans.

Figure 6.11 Zonal Distribution of 1994 Low Season Passive Cases around the Non-Perennial Pans



For most of the months, the incidence in zone 1 is very low at 1 case per 1000 people or less, after which it rises and falls in a manner that indicates that these water bodies are unlikely to have been the 'seed points' from which the disease spreads with the onset of suitable conditions. The rise in December cases in close proximity to the breeding sites indicates that they may well be used for breeding once conditions become suitable in spring. However, the inconsistent pattern of these cases does not indicate that they are the main breeding site during this time. The zonal distribution also give no indication of the likely flight distance.



The distribution of passively reported cases within each zone is presented in Table 6.9, with a little variation between them. This table needs to be seen in conjunction with Figure 6.12 above which indicates that the cases in zones 1, 3, 4 and 5 occurred predominantly in December. This indicates that the non-perennial pans are unlikely to have been a major breeding site for the mosquitoes during winter but may well have been important at the start of summer. It also give no indication of the maximum likely flight distance.

Table 6.9. Low Season 1994 Passive Malaria Cases per Zone around the Non-Perennial Pans

Zones	Incidence per 1000 population	Percentage
Zone 1	5.9	21.9
Zone 2	3.6	13.4
Zone 3	5.5	20.4
Zone 4	5.7	21.2
SubTotal	20.7	76.9
Zone 5	6.2	23.1
Total	26.9	100

6.4.3 Statistical Analysis the Non-Perennial Pans and the Passive Cases

Table 6.10 presents the results of the Generalised Linear Regression Model used to statistically analyse the relationship between the non-perennial pans and the active cases that were reported during the low season months of 1993 and 1994 combined. The number of cases, as shown by the Incidence Rate Ratio, drops from 1 in zone 1 to 0.40 in zone 2 thereafter rising to almost the same as zone 1. This may indicate that the proximity of the homes to the non-perennial pans in zone 1 may result in the inhabitants being at greater risk of being infected with the malaria parasite, however, the increase in cases from zone 3 onwards indicates that other sites are also used for breeding during this time. The p-values of between 0.11 and 0.93 show that there is a high probability that these are chance occurrences and are not statistically significant results which may be due to the low number of case during some of the months. The wide confidence intervals also indicate the wide monthly variations and the lack of consistency of spatial patterns which could be a result of the small case number.

Table 6. 10. Non-Perennial Pans and the Passive Malaria Cases: Generalised Linear Regression Model Results for Combined Low Season Months of 1993 and 1994.

Zonal Comparisons	Incidence Rate Ratio	P> z	95% Confidence Interval	
			Lower	Upper
Zone 1 against Zone 2	0.40	0.11	0.14	1.21
Zone 1 against Zone 3	0.96	0.93	0.42	2.23
Zone 1 against Zone 4	0.90	0.78	0.43	1.88
Zone 1 against Zone5	0.93	0.84	0.47	1.85

6.4.4 Conclusion - Non-perennial Pans and Passive Cases

The spatial analysis of the low season passive cases for 1993 and 1994, with respect to the non-perennial pans, indicates that the case incidence increases outward from zone 3, and that these water bodies are therefore unlikely to act as winter breeding sites. The results are supported by the statistical analysis, and also provide little evidence to suggest that the maximum likely flight distance of the female mosquito given a host supply in close proximity. The non-perennial pans are therefore not considered ‘seed point’ breeding sites to which the application of larvicides should be applied.

6.5 Non-perennial Pans and Active Cases : 1993 and 1994

6.5.1 Spatial Analysis of the Non-Perennial Pans and the 1993 Low Season Active Cases

The location of the active malaria cases with respect to the zones surrounding the non-perennial pans during July to December of 1993 and 1994 are presented on Figure 6.13. While some of the cases in the southern sections of Makanis and the northern sections of Ndumu do fall within the first four zones, the many cases in Makanis sections 1 and 5, fall in zone 5. The cases in the Makanis sections 6, 7, 9 and 10 fall within the first two zones, indicating that these non-perennial pans may have acted as breeding sites during some of the winter months. However, there is little indication that the non-perennial pans were the main winter breeding sites during the winter months of 1993.

Figure 6.14 presents the monthly active cases during 1993 per zone as they occurred in relation to the non-perennial pans. The cases for July, August and November show the highest number of cases in zone 1, with the July and November cases dropping gradually to zone 4, and August dropping in zone 2 to rise thereafter. This indicates that the non-perennial pans may well have provided suitable breeding conditions at the end (June) and the start (December/ January) of the malaria season. The cases in the remainder of the months show not clear pattern with respect to the non-perennial pans.

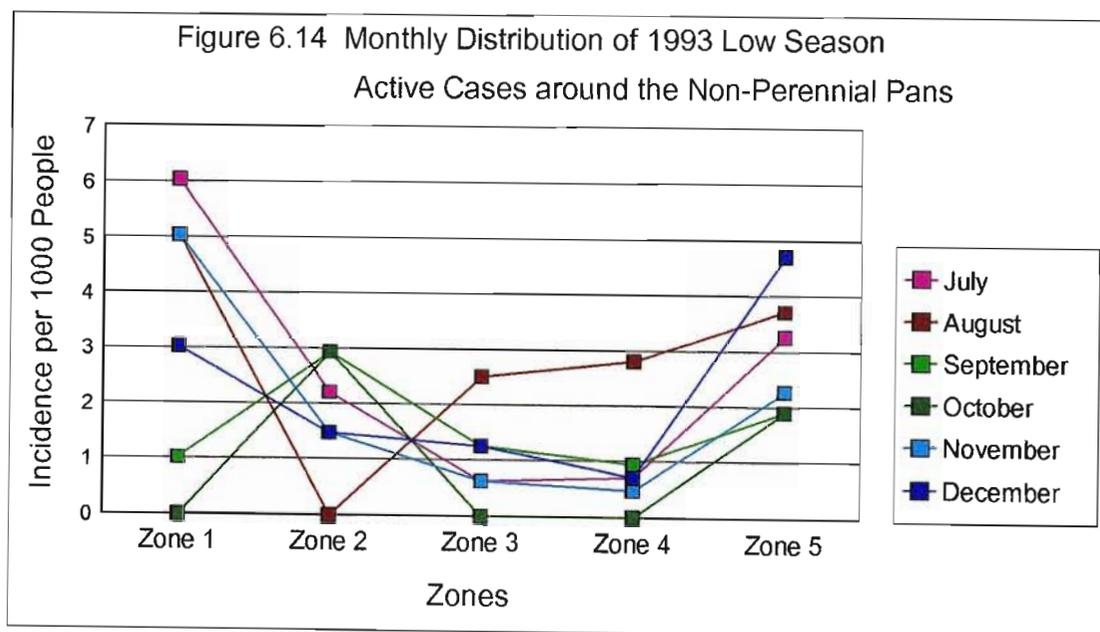
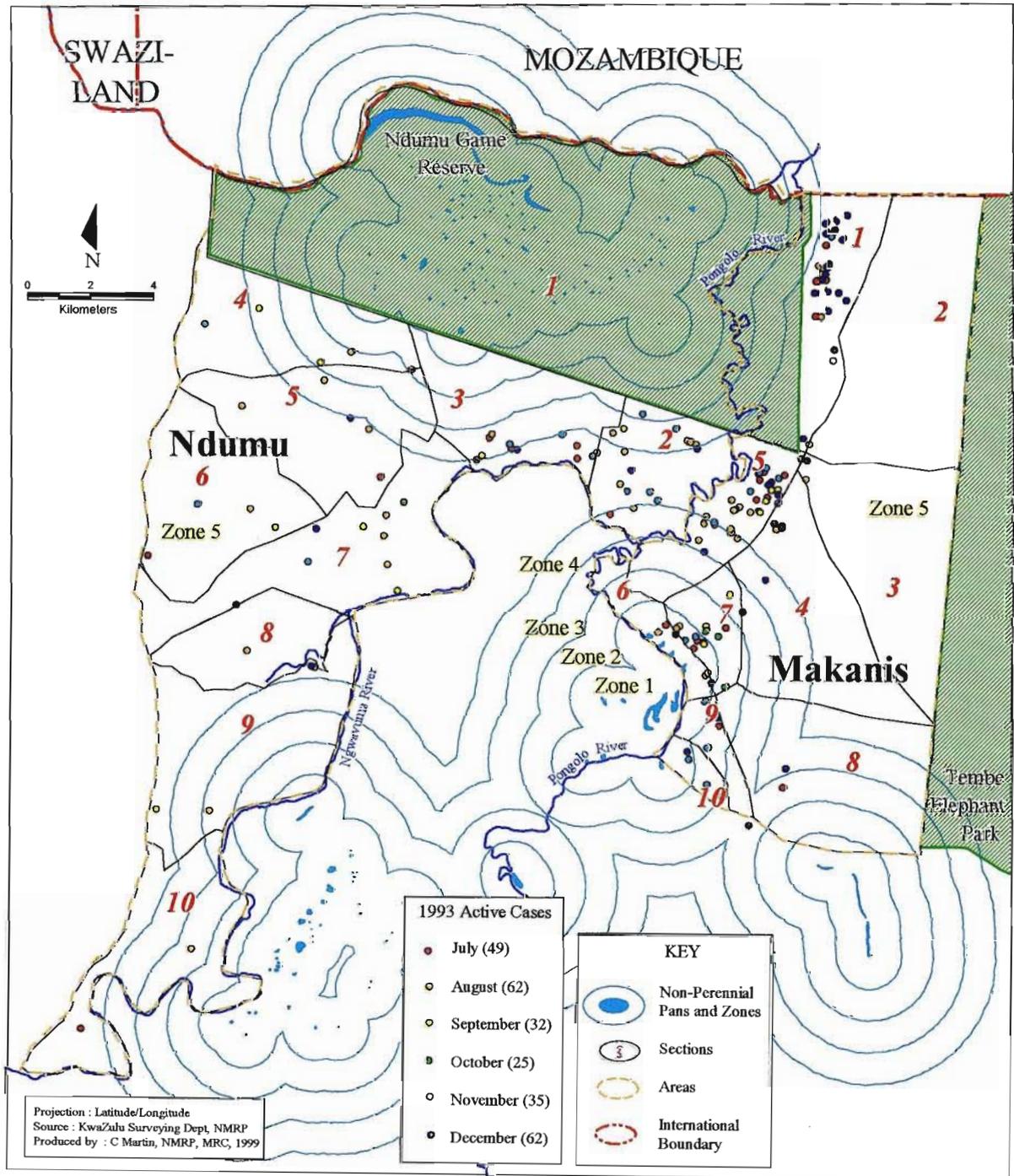


Figure 6.13 Zonal Distribution of 1993 Low Season Active Cases around the Non-Perennial Pans



The distribution of July and November cases within the zones supports the research which indicates that the maximum likely distance is 4 km. This rise in cases in zone 5 indicates the likelihood of there being alternative breeding sites beyond 4 km from the perennial pans. While the non-perennial pans may have provided suitable breeding conditions at the start and end of winter, it is unlikely that they were the 'seed point' breeding which could be targeted for larval control.

The malaria incidence per zone is presented in Table 6.11, and although the figures indicate a gradual decrease from zone 1 outwards, they need to be seen in combination with Figure 6.14. Which indicates no clear spatial pattern. The table provides evidence to suggest that the female mosquitoes flies no more than 4km for a blood meal and 70.7% of cases occur within 4km. However, as almost 30% of cases occur in zone 5, it is likely that alternative breeding sites are available beyond 4km from the non-perennial pans.

Table 6.11. Low Season 1993 Active Malaria Cases per Zone around the Non-Perennial Pans

Zones	Incidence per 1000 population	Percentage
Zone 1	20.1	33.1
Zone 2	11.0	18.2
Zone 3	6.2	10.2
Zone 4	5.6	9.2
SubTotal	42.9	70.7%
Zone 5	17.8	29.3
Total	60.7	100%

6.5.2 Spatial Analysis of Non-Perennial Pans and the 1994 Low Season Active Cases

The distribution of active cases, with respect to the non-perennial pans, that were reported during July to December of 1994, are presented in Figure 6.15. The pattern is similar to that of 1993 but there appear to be more cases in Makanis sections 1 and 5 which fall in zone 5. There are a number of cases in zones 1 and 2 in Makanis sections 6, to 10, and zones 3 and 4 in northern Ndumu. It appears that many of the cases do not fall within 4 km of the non-perennial pans and that they therefore were not used as the main breeding sites during the winter months of 1994.

Figure 6.15 Zonal Distribution of 1994 Low Season Active Cases around the Non-Perennial Pans

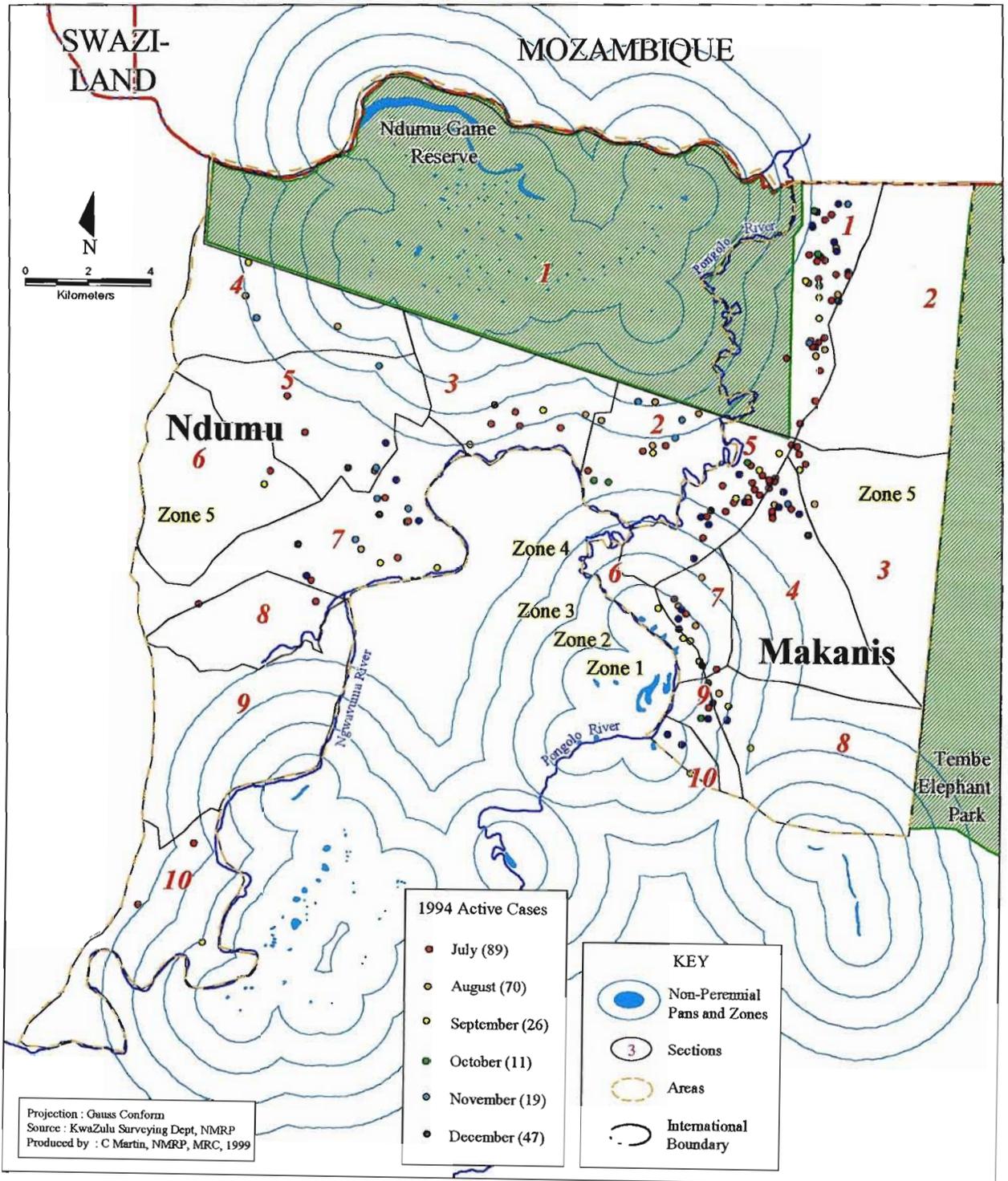


Figure 6.16 presents the active case with respect to the zones during the low season months of 1994, and shows no clear pattern with respect to the monthly distribution of the cases. The July case incidence is higher in zone 1 (3) than in zones 2 and 3, after which it rises to more than twice that of zone 1 (6.5), indicating the presence of additional breeding sites in zone 5. There are more cases in zone 2 than in zone 1 during August, September and October, after which the incidence drop and then rise again, indicating that the non-perennial pans were not the main breeding sites used. December experienced the highest incidence (6) in zone 1, dropping to below 1 in zone 4, and rising slightly thereafter, indicating that the non-perennial pans were used at the start of the malaria season but not during winter. The distribution of the December cases also provides evidence that the female mosquito does not fly more than 4 km for a blood meal.

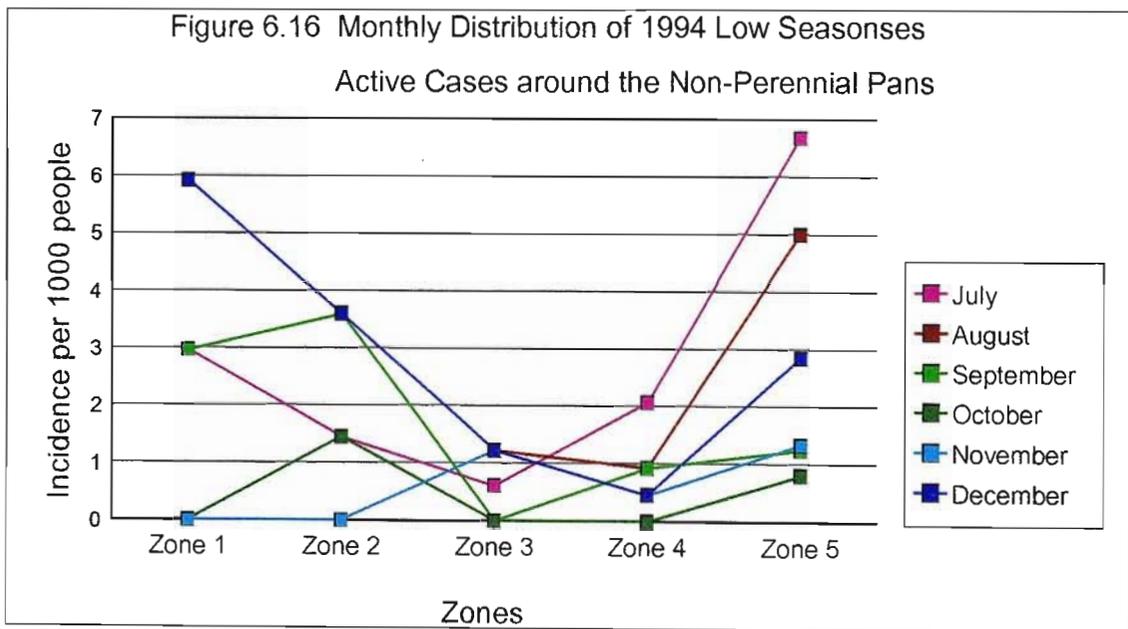


Table 6.12 indicates the distribution of active malaria cases per zone, however, these figures need to be seen in conjunction with Figure 6.16 due to variations in the monthly distribution of cases. The higher percentage of cases in zone 1 is due to 50% of the cases occurring in December. On average, only two thirds of the cases fall within the first four zones indicating the presence of additional breeding sites in zone 5. The July, September and December cases result in 50% of cases occurring within 2 km of the non-perennial pans, but the lack of consistency of in the distribution of the cases throughout the winter months, as well as the fact that over 30% of cases occurred in zone 5, suggest that there are other water bodies in the area which provide suitable breeding conditions.

Table 6.12. Low Season 1994 Active Malaria Cases per Zone around the Non-Perennial Pans

Zones	Incidence per 1000 population	Percentage
Zone 1	14.8	26.7
Zone 2	13.6	24.5
Zone 3	4.3	7.8
Zone 4	4.8	8.7
SubTotal	37.5	67.7
Zone 5	17.9	32.3
Total	55.4	100

6.5.3 Statistical Analysis of the Non-Perennial Pans and the Active Cases

Table 6.13 presents the results of the Generalised Linear Regression Analysis providing the statistical analysis of the relationship between the 1994 active cases and the non-perennial pans. The Incidence Rate Ratio indicates that there were fewer cases in zone 2 than in zone 1 followed by a further decrease in zones 3 and 4 and a rise in zone 5 to above that of zone 1. This suggests the presence of alternative breeding sites in zone 5. Zone 2 as a proportion of zone 1 has a high p-value indicating that here is a probability of these results having occurred by chance. The accompanying large confidence level range indicates the presence of few cases or that there are a wide range of case numbers occurring over the months of this season. The p-value for zones 3 and 4 is significant while the relationship between zones 1 and 5 have a high probability of the case distribution occurring by chance. The confidence interval ranges for zones 3 and 4 reflect the narrow range within which the cases fall, and the wider ranges for zones 2 and 5 indicate the greater variation in case numbers within the different months.

Table 6.13. Non-Perennial Pans and the Active Malaria Cases: Generalised Linear Regression Results for Combined Low Season Months of 1993 and 1994.

Zonal Comparisons	Incidence Rate Ratio	P> z	95% Confidence Interval	
			Lower	Upper
Zone 1 against Zone 2	0.71	0.15	0.44	1.13
Zone 1 against Zone 3	0.30	0.0	0.17	0.54
Zone 1 against Zone 4	0.30	0.0	0.19	0.46
Zone 1 against Zone 5	1.02	0.9	0.72	1.44

6.5.4 Conclusion - Non-Perennial Pans and Active Cases

The spatial analysis provides little evidence to suggest that the non-perennial pans were important breeding sites around which active cases were reported during the winters of 1993 and 1994, although the distribution of 1993 cases suggests that they were used during the warmer, wetter months at the end of winter. This is substantiated by the statistical analysis which indicates the likelihood of the presence of additional breeding sites beyond the 4 km zone. Applying larvicides to the non-perennial pans during the dryer months would therefore probably have little effect in reducing the number of larvae that develop into adults which then spread to other breeding sites. The presence of 30% of cases in zone 5 indicates that these sites were not the 'seed points' from which the mosquitoes spread under more suitable environmental conditions. The July, November and December cases of 1993, and the December cases of 1994 provide evidence that the female mosquito tends not to fly more than 4 km for a blood meal when an adequate host supply is in close proximity.

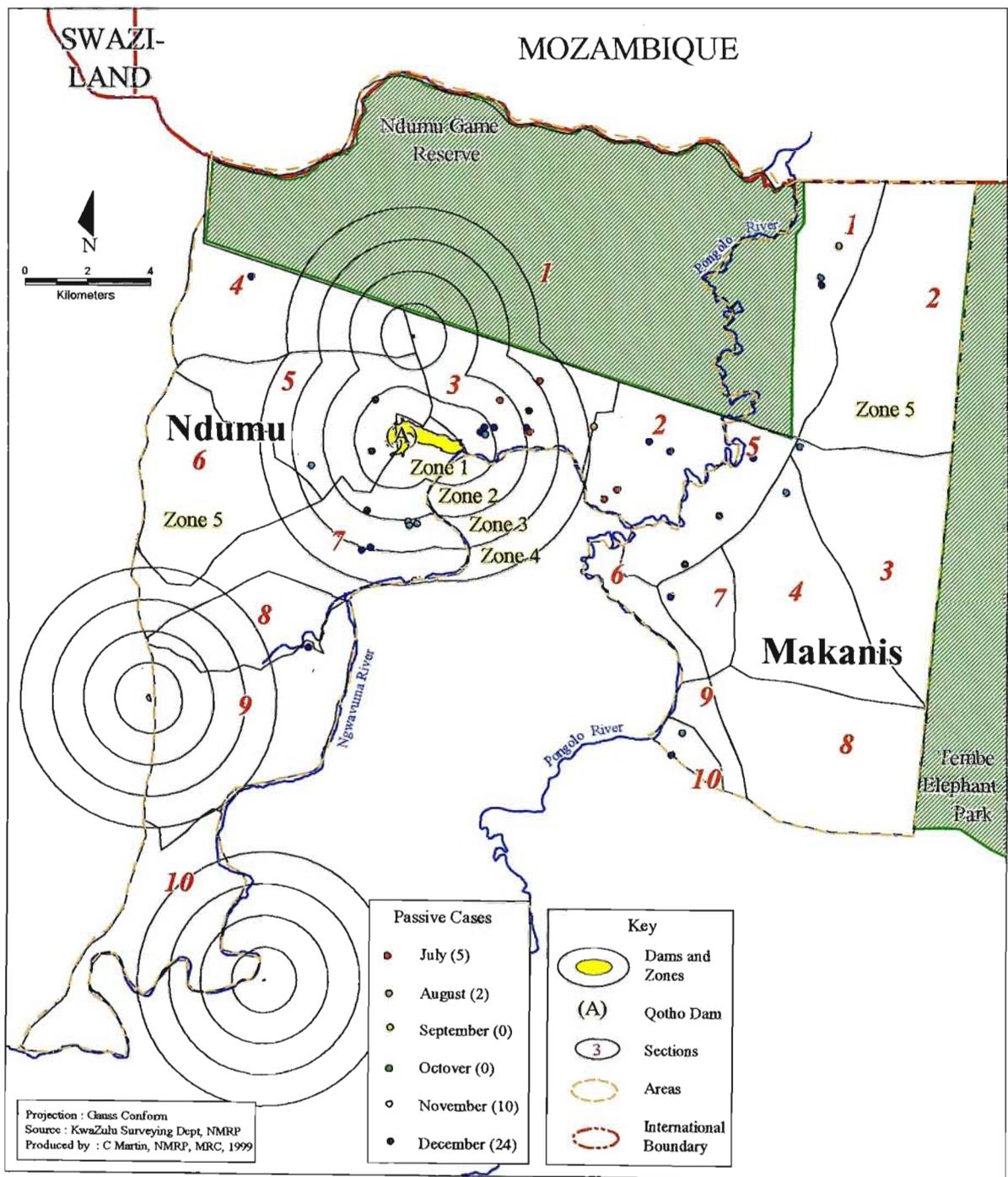
6.6 Dams and Passive Cases : 1993 and 1994

The dams in this area fall in Ndumu and consist of the large Qotho Dam in the north-west corner of section 7, a smaller ones in section 3, one outside the western boarder of section 9 and another outside the eastern boarder of section 10. Despite falling outside the study area, they have been included due to their zones of influence overlapping the Ndumu area. The Qotho Dam in section 7 was originally a non-perennial pan and was dammed at the eastern end where it flows into the Ingwavuma River.

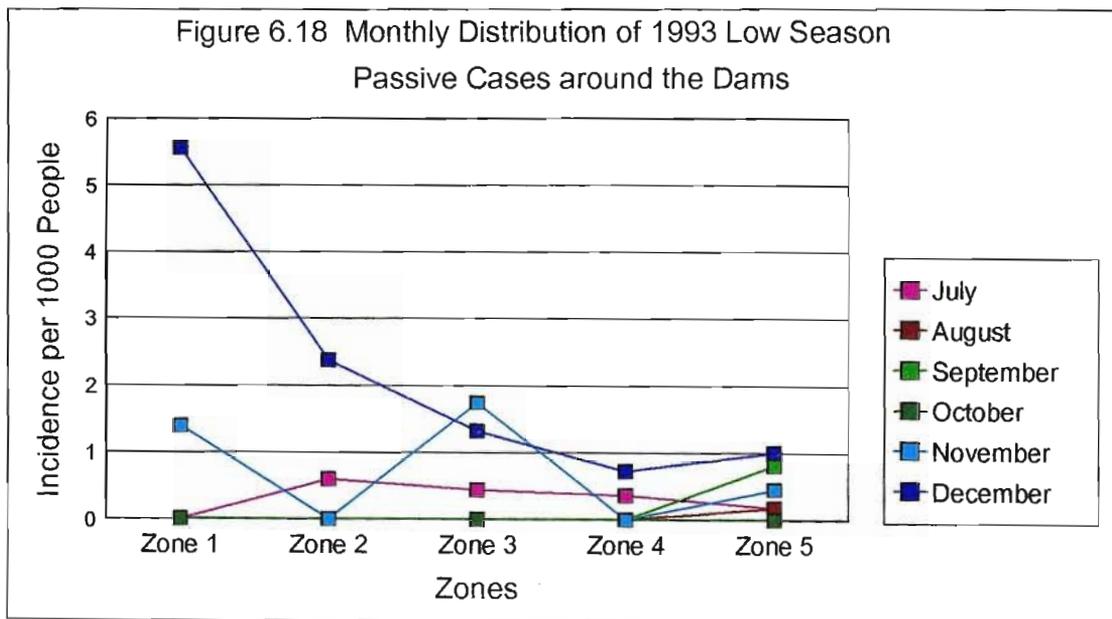
6.6.1 Spatial Analysis of the Dams and the 1993 Low Season Passive Cases

The distribution of the 1993 passive cases from July to December in relation to the zones surrounding the dams is presented in Figure 6.17. A number of passive cases are situated within the 4 km zones of the Qotho Dam during 1993 but there is little evidence of any clustering in close proximity to it. The remaining three small dams have no cases falling within the four zones surrounding them. The majority of cases in zone 5 fall on either side of the Pongolo River which is some distance form the dams.

Figure 6.17 Zonal Distribution of 1993 Low Season Passive Cases around the Dams



The distribution of passive cases for 1993 with respect to their proximity to the dams is presented on Figure 6.18. All months except December present a case incidence of less than 2 cases per 1000 people in zone 1 as well as the remaining 4 zones, indicating no association between the dams and the location of the passive cases. December experiences the highest number of cases in zone 1, decreasing consistently to zone 4 and rising slightly thereafter. This distribution indicates that the dams are not important breeding sites but that with the onset of suitable environmental conditions in spring, the Qotho Dam provided suitable breeding conditions.



The combined incidence of cases for the 5 zones around the dams is presented in Table 6.14, which must be seen in conjunction with Figure 6.18 as the majority of cases in zone 1 occurred in December. This resulted in 40% of the cases being allocated to zone 1, with a decrease thereafter to zone 4. Although 84.8% of cases occurred within the first 4 zones, the dominance of the December cases prevents the conclusion that the dams provided suitable breeding sites. Due to the influence of the December cases, it is not possible to establish a maximum flight range.

Table 6.14. Low Season 1993 Passive Malaria Cases per Zone around the Dams

Zones	Incidence per 1000 population	Percentage
Zone 1	6.9	40.4
Zone 2	3.0	17.5
Zone 3	3.5	20.5
Zone 4	1.1	6.4
SubTotal	14.5	84.8%
Zone 5	2.6	15.2
Total	17.1	100%

6.6.2 Spatial Analysis of the Dams and the 1994 Low Season Passive Cases

The distribution of passive cases around the dams for the low season months of 1994 is presented in Figure 6.19, and shows that the cases fall within the 4 km zones of the Qotho Dam and two of the smaller ones. There is little evidence of any clustering of the cases in the inner zones surrounding the dams, with many cases fall in zone 5, particularly close to the Pongolo River.

The monthly distribution of low season passive cases with respect to the zones around the dams is presented in Figure 6.20. The cases from August to November show a rise and then fall of cases beyond zone 1 indicating that the dam is not the primary breeding site in the area and that additional sites were available. The July and December cases reflect the breeding patterns at the start and end of winter. It indicates a high case incidence in December in zone 1 (<7) after which it falls to less than 2 in zone 4 and then rises in zone 5. The July cases decrease from almost 7 in zone 1 to fluctuate around 2 case per 1000 people from zone 2 onwards. Both months clearly indicate that the dams become important breeding sites during the months of more favourable environmental conditions. The December cases in particular provide evidence that the female mosquito flies no more than 4 km for a blood meal when a host supply is in close proximity.

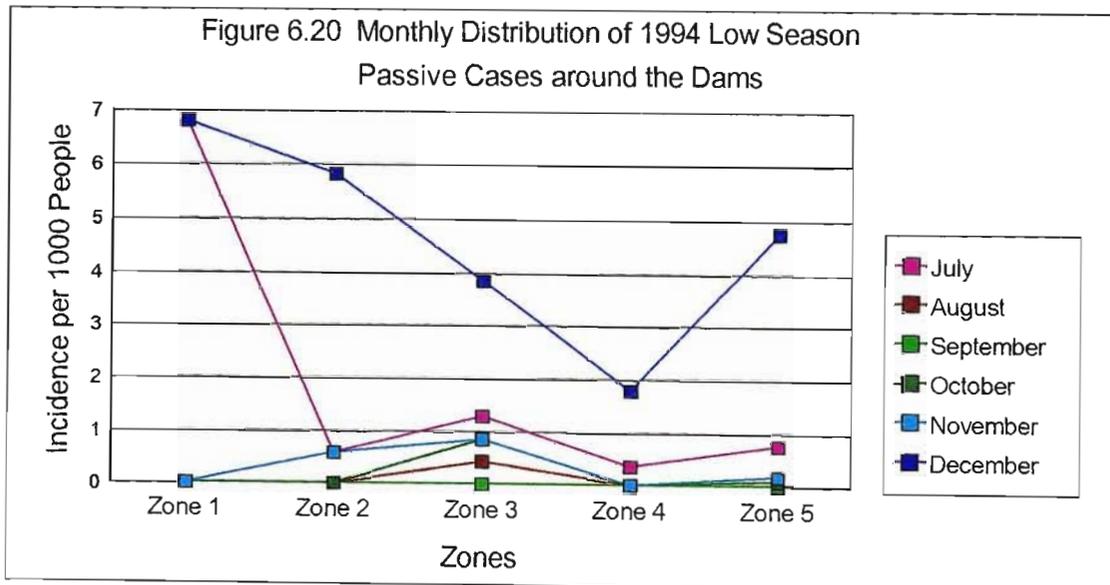


Figure 6.19 Zonal Distribution of 1994 Low Season Passive Cases around the Dams

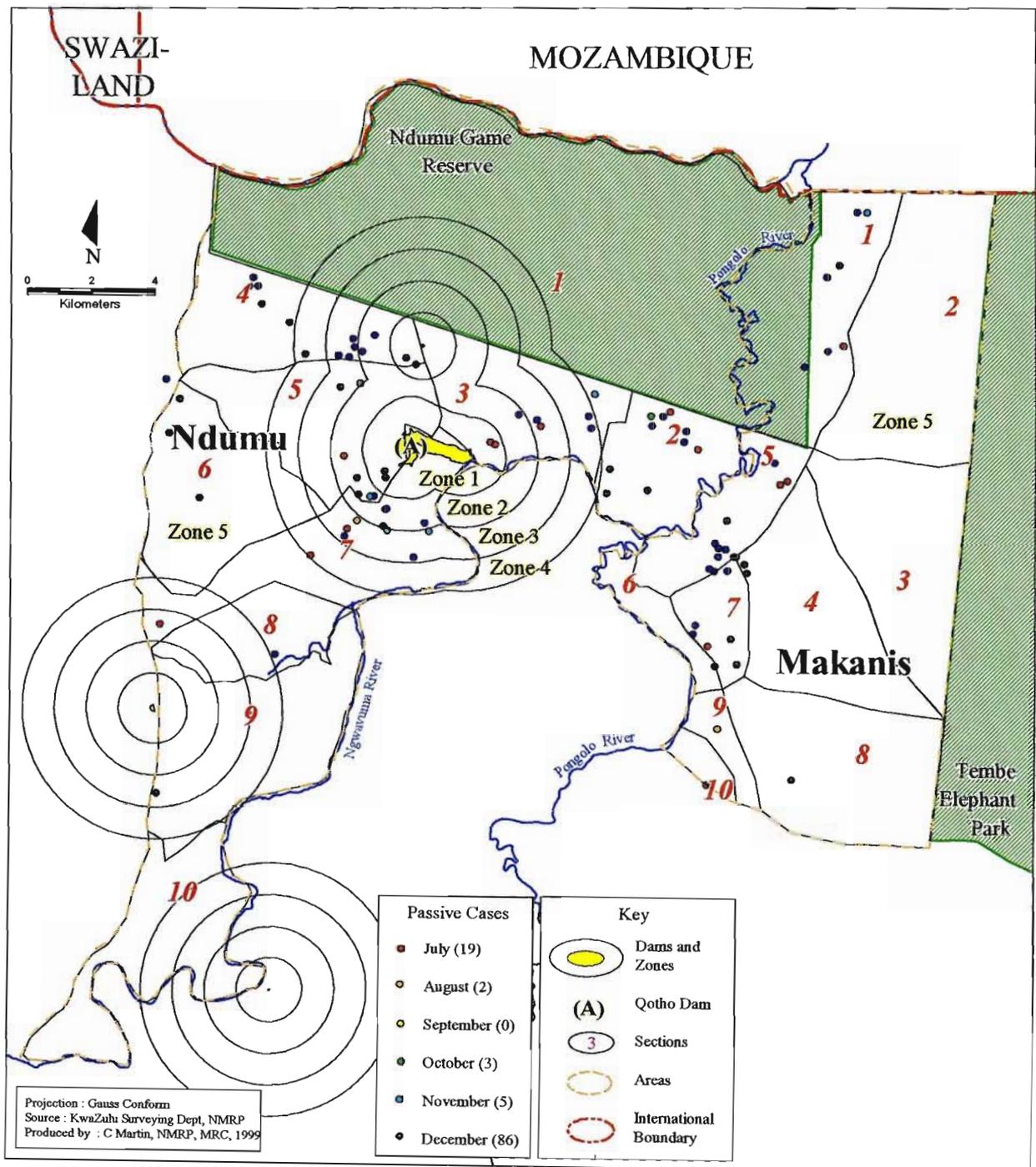


Table 6.15 indicates the incidence and percentage per zone for the low season months of 1994, and needs to be seen in conjunction with Figure 6.20 in which the high number of July and December cases in zone 1 are presented. The incidence and percentage of cases in the first 4 zones are dominated by the December cases which provides evidence to suggest that the mosquito does fly no more than 4 km in search of a blood meal. However, it is unlikely that the dams were used as the 'seed point' breeding sites which resulted in the reporting of passive cases.

Table 6.15. Low Season 1994 Passive Malaria Cases per Zone around the Dams

Zones	Incidence per 1000 population	Percentage
Zone 1	13.6	38.0
Zone 2	7.0	19.7
Zone 3	7.2	20.1
Zone 4	2.1	5.9
SubTotal	29.9	83.7
Zone 5	5.8	16.3
Total	35.7	100

6.6.3 Statistical Analysis of the Dams and the Passive Cases

Table 6.16 presents the results of the statistical analysis that was undertaken using the Generalised Linear Regression Model to investigate the relationship between the distribution of the low season passive cases and the dams. The IRR shows a drop in case incidence of over 50% from zone 1 to zone 2, rises slightly to 0.52 in zone 3, and decreases to 0.16 in zone 4, rising slightly to 0.37 in zone 5. A p-value for all the relationships indicates little probability of these values occurring by chance as they are all on or below the statistically significant level of 0.005. The confidence interval margins are wide for the zones in which there is a large range between the different monthly cases numbers (zones 2 and 3) and narrows as the variation between the p-value improves, indicating low case numbers and a wide range of values particularly in zones 2 and 3.

Table 6.16. Dams and the Passive Malaria Cases : Generalised Linear Regression Model Results for the Combined Low Season Months of 1993 and 1994.

Zonal Comparisons	Incidence Rate Ratio	P> z	95% Confidence Interval	
			Lower	Upper
Zone 1 against Zone 2	0.48	0.04	0.24	0.97
Zone 1 against Zone 3	0.52	0.05	0.28	0.99
Zone 1 against Zone 4	0.16	0.0	0.07	0.36
Zone 1 against Zone 5	0.37	0.0	0.21	0.63

6.6.4 Conclusion - Dams and Passive Cases

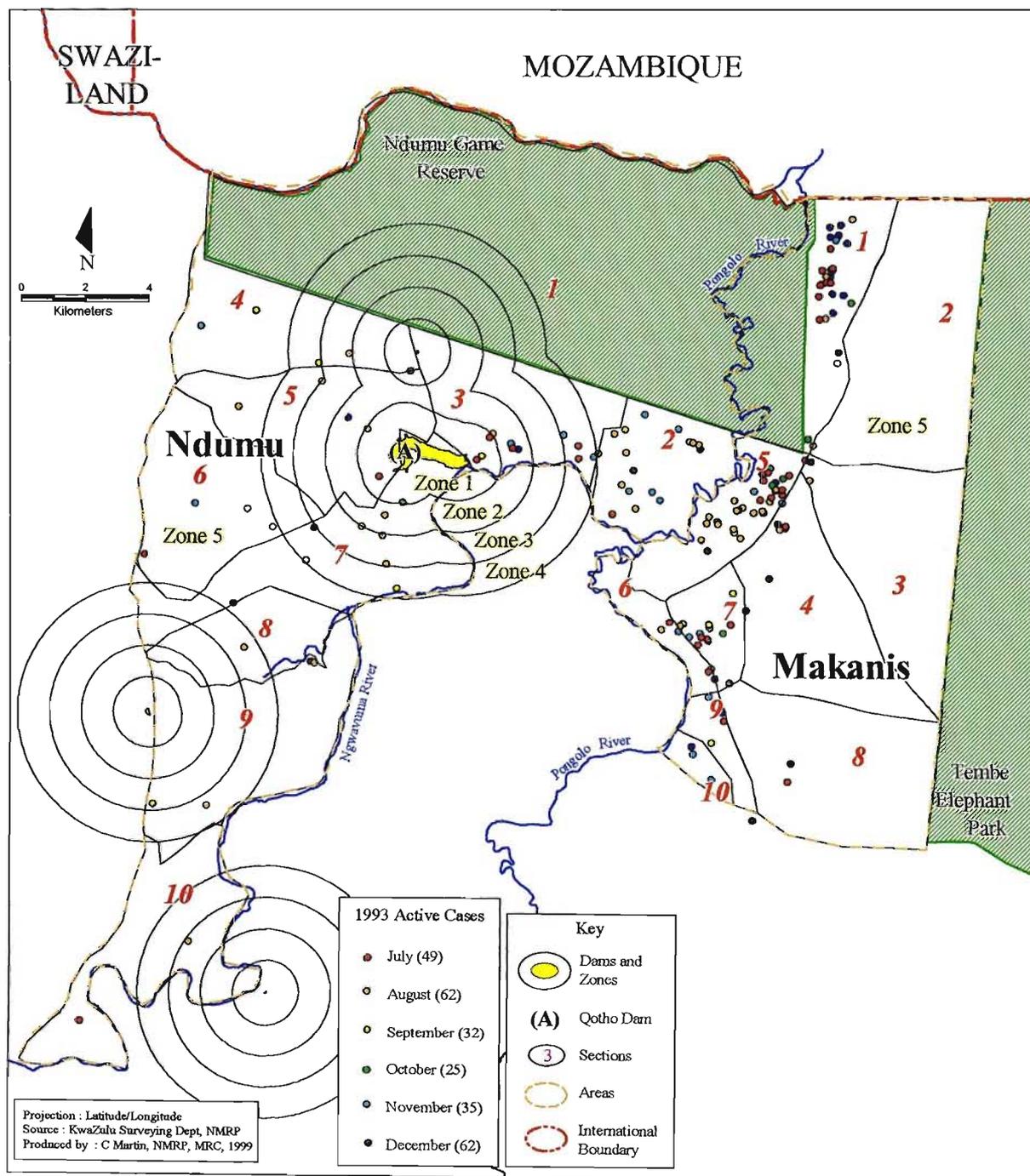
The spatial analysis indicated that many of the July and December passive cases are located within 4 km of the dams, indicating the likelihood of the dams being the breeding sites at the start and end of the winter months. The distribution of the December cases for both 1993 and 1994 supports the research that indicates the maximum likely flying distance to be 4 km. The statistical analysis shows a statistically significant relationship between the proximity of the cases to the breeding site but this again reflects the high number of cases for July and December in particular. The dams are therefore not considered the winter 'seed point' breeding sites to which larvicides should be applied.

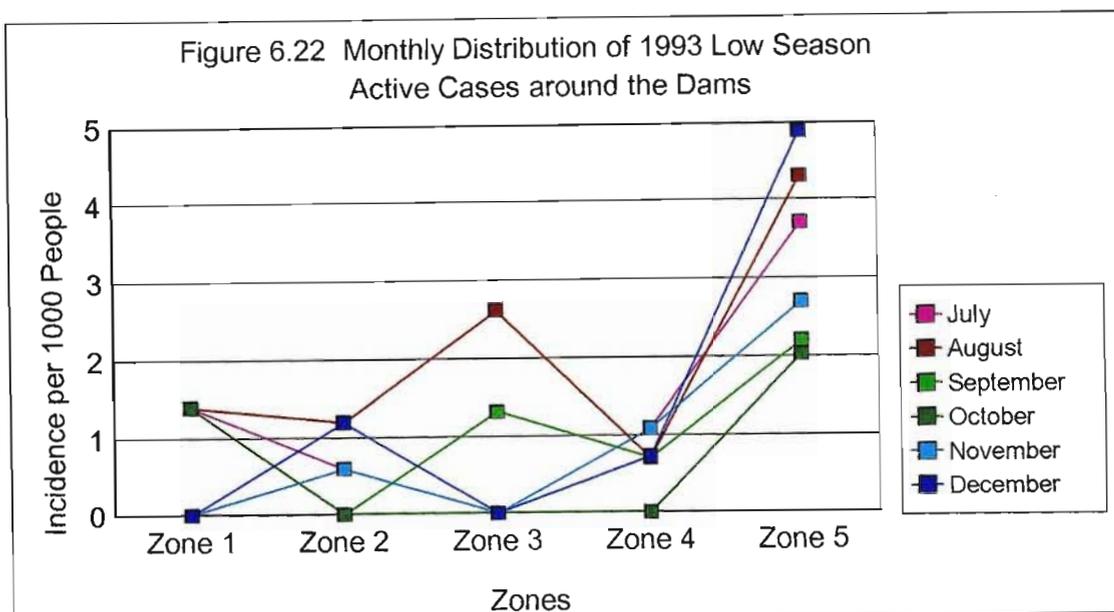
6.7 Dams and Active Cases : 1993 and 1994

6.7.1 Spatial Analysis of the Dams and the 1993 Low Season Active Cases

The distribution of the 1993 active cases from July to December with respect to the dams is presented in Figure 6.21. All four dams have cases within the first four zones, however, the map indicates that most of the cases fall in zone 5, particularly in Makanis. This suggests that the dams were not the major breeding sites for the winter of 1993. The monthly distribution of the 1993 active cases with respect to the zones surrounding the dams is presented on Figure 6.22. The case incidence in the first 4 zones is largely less than 2 cases per 1000 people, after which it doubles sharply to in zone 5, indicating the presence of alternative breeding sites beyond a distance of 4 km from the dams.

Figure 6.21 Zonal Distribution of the 1993 Low Season Active Cases around the Dams





The incidence and percentage of cases per zone is presented in Table 6.17. As the cases in each of the first 4 zones all fall below 20% and those in zone 5 account for more than 50%, it is evident that the dams were not used as breeding sites during the winter months.

Table 6.17. Low Season 1993 Active Malaria Cases per Zone around the Dams

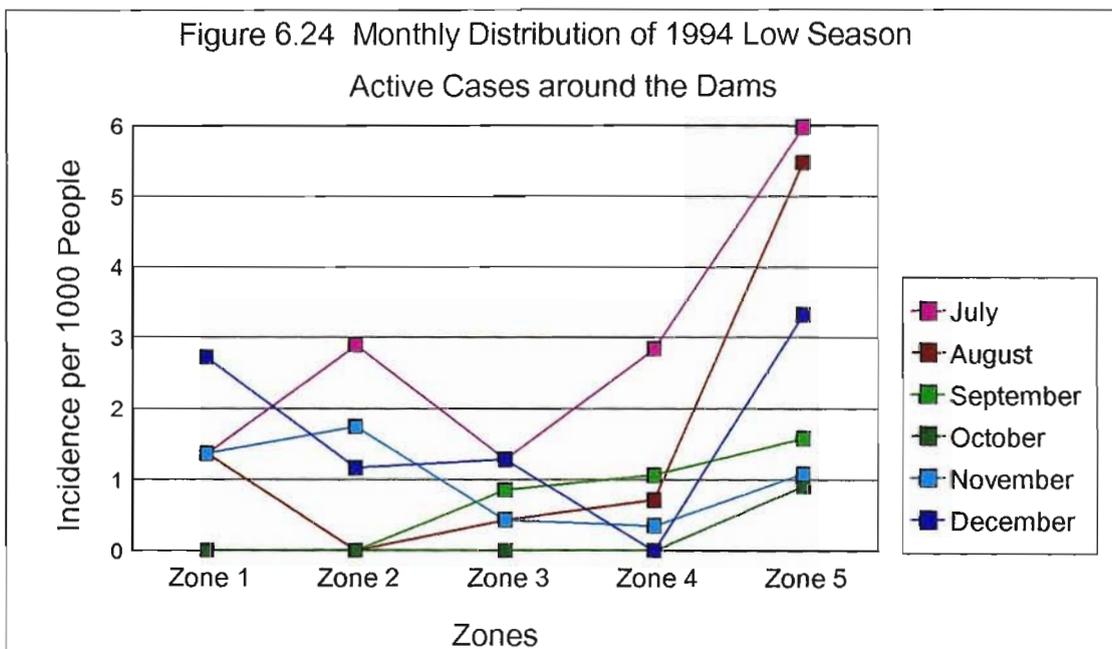
Zones	Incidence per 1000 population	Percentage
Zone 1	5.5	14.8
Zone 2	3.6	9.7
Zone 3	3.9	10.6
Zone 4	4.3	11.6
SubTotal	17.3	46.7
Zone 5	19.8	53.3
Total	37.1	100

6.7.2 Spatial Analysis of the Dams and the 1994 Low Season Active Cases

The distribution of the 1994 active cases around the dams is presented in Figure 6.23, and shows that the majority of cases are located along the banks of the Pongolo River away from the first four zones surrounding the dams. All the dams have cases within the four zones but the majority are concentrated around the Qotho Dam. The monthly zonal distribution of the cases is presented on Figure 6.24, and indicates no clear spatial patterns. The cases are concentrated below 3 cases per 1000 people in zones 1 to 4, after which they rise in zone 5 indicating the presence of additional breeding sites. All the months, except November, present with the most cases in zone 5, indicating that the dams are unlikely to be the main breeding sites.

The November and December cases, both of which have fewer cases in zones 3 and 4 than in zone

1, provide some evidence to support the assertion that the maximum likely flight distance is no more than 4 km. Their distribution also suggests that the dams were used for breeding to a limited extent during the winter months but were not the main 'seed point' breeding sites.

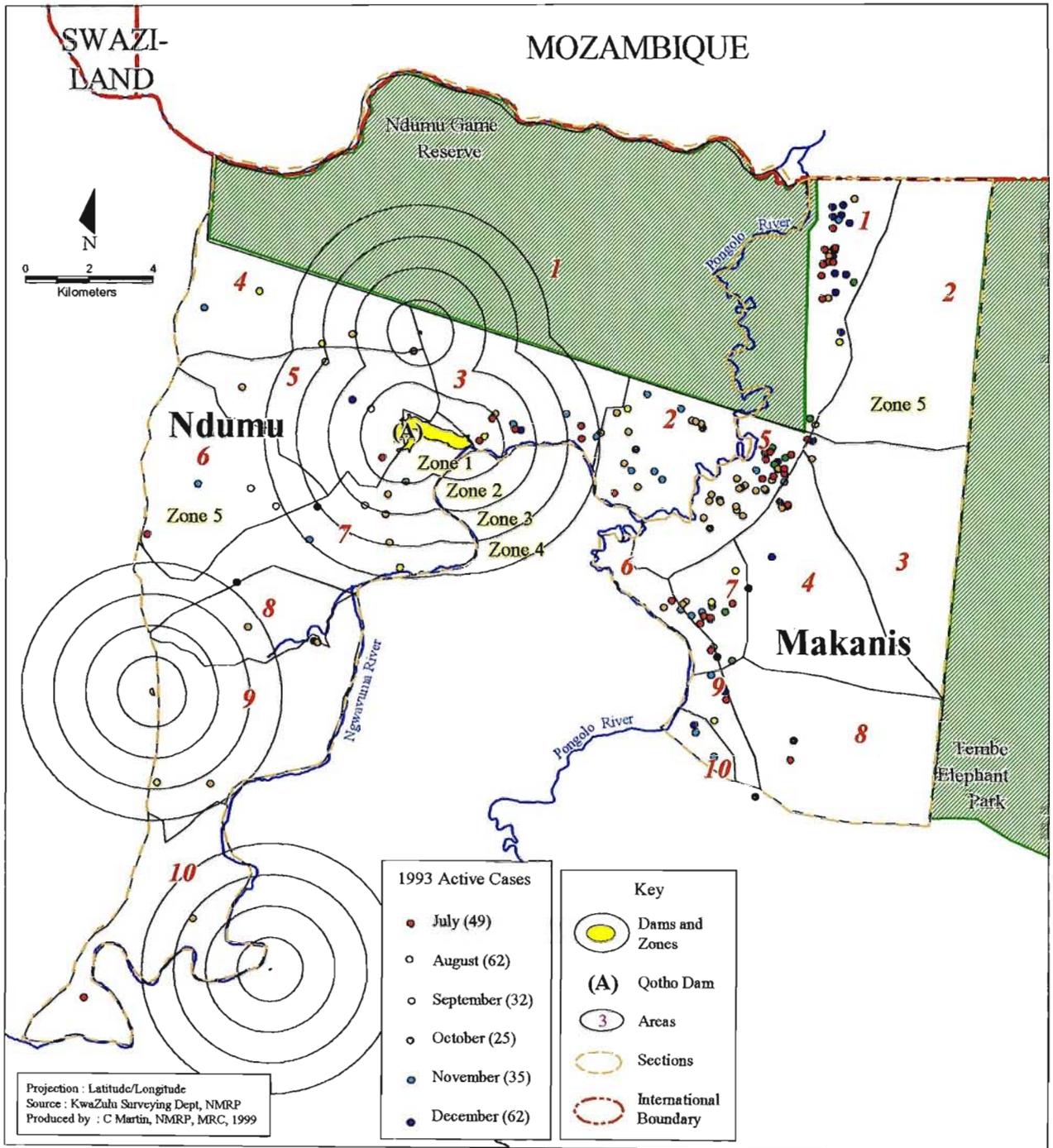


The incidence and percentage of cases per zone is presented in Table 6.18, with only 54% of cases occurring in the inner 4 zones during 1994. The presence of almost 50% of the cases in zone 5 indicates that there were alternative breeding sites that were used during the winter months.

Table 6.18. Low Season 1994 Active Malaria Cases per Zone around the Dams

Zones	Incidence per 1000 population	Percentage
Zone 1	6.8	16.9
Zone 2	5.8	14.3
Zone 3	4.3	10.8
Zone 4	5.0	12.4
SubTotal	21.9	54.4
Zone 5	18.3	45.6
Total	40.2	100

Figure 6.23 Zonal Distribution of 1994 Low Season Active Cases around the Dams



6.7.3 Statistical Analysis of the Dams and the Active Cases

The results of the statistical analysis using the Generalised Linear Regression Model to investigate the relationship between the active cases of 1994 and the dams are presented in Table 6.19. The Incidence Rate Ratio in zones 2 to 4 are lower than in zone 1, three times higher in zone 3. The p-value is higher than the statistically significant 0.005 for all the zones except zone 5 and the confidence intervals are wide for all the zones, particularly zone 5 due to the range in case numbers during the different months.

Table 6.19. Dams and the Active Malaria Cases : Generalised Linear Regression Model Results for Combined Low Season Months of 1993 and 1994.

Zonal Comparisons	Incidence Rate Ratio	P> z	95% Confidence Interval	
			Lower	Upper
Zone 1 against Zone 2	0.76	0.51	0.03	1.72
Zone 1 against Zone 3	0.66	0.31	0.30	1.46
Zone 1 against Zone 4	0.75	0.46	0.35	1.61
Zone 1 against Zone 5	3.09	0.0	1.60	5.97

6.7.4 Conclusion - Active Cases and Dams

The maps of the active cases with respect to the dams show that most of the cases fall beyond 4 km for both years. This is substantiated by the graphs which show a marked rise in the number of cases in zone 5, as well as in the table where the percentage of cases per zone indicates that 50% of the cases fall beyond 4 km. The statistical analysis supports these findings, and confirms that the dams were not used as the 'seed point' breeding sites which resulted in the location of the active malaria cases during 1993 and 1994. They also provide little evidence of the maximum likely flight distance of the female mosquito give a host supply in close proximity.

6.8 Conclusion

The spatial analysis, through the use of maps, graphs and table, resulted in an interpretation of the spatial relationships between the proximity of the potential breeding sites to the malaria cases. This was followed by a statistical analysis of the variables that affected the distribution of the

malaria cases with respect to the potential breeding sites, in order to explain any causal associations between them. To be able to reasonably conclude that the explanations of the causal associations were correct, they will be evaluated against a list of several characteristics as set out by Kleinbaum *et al* (1998) and the Committee on Environmental Epidemiology (National Research Council, 1991). The results are presented in Chapter 7 (Conclusion) in order to meet the third of Molineaux's three-phased approach which is to contribute to planning and/or evaluating malaria control measures. The identification of the winter breeding sites that act as 'seed points' from which the onset of transmission spreads in the area during the following season, will allow these sites to be targeted for winter larval control measures. Reducing malaria in this high incidence area will contribute to limiting the distribution and lowering the levels of malaria intensity in the region. Furthermore, the establishment of the likely maximum flight distances of mosquitoes to blood meals will identify those people most at risk requiring additional prevention and control activities.

CHAPTER 7

CONCLUSION

7.1 Introduction

A major problem in sub-Saharan Africa is the lack of realistic and sustainable tools to combat malaria. Treating the disease and using expensive toxic compounds are not the long-term, sustainable answer although they will remain important in high risk areas. Tools for prevention should ideally be nontoxic, cheap, effective and applicable (Nevill, 1990). Total eradication of malaria is the perfect condition, but where this is not possible, every effort needs to be made to control it (le Sueur *et al*, 1993b). The differing malaria situations around the world prevent a single control formula being applicable to all affected countries, rather, each one needs to identify its own practicable approach to its specific problems, and to design and implement appropriate intervention strategies (WHO, 1993b). Ngxongo (1993) maintains that the implementation of control strategies should be based on an understanding of the epidemiological characteristics of the disease which are generally area specific. International health officials now stress the importance of using a variety of methods in an integrated approach to controlling the vector which includes Primary Health Care (PHC) centres and environmental management (Sharp, 1990; Johnson, 1993).

The presence of malaria is determined by a combination of environmental conditions, land-use patterns, cultural habits, parasite resistance to drugs, mosquito resistance to insecticides as well as the amount of funding and manpower assigned to combat the disease (Nevill, 1990; Brêtas, 1995). Implementing any control measures will require careful consideration of the local conditions and restraints, and will have implications for the vector and parasite populations, the local community and malaria control programme (NTIS, 1993).

The continued reintroduction of the parasite into South Africa from its neighbours highlights the need for regional cooperation. Current control efforts are expensive to maintain but without them, higher incidences of the disease and more fatalities would be inevitable (Ngxongo, 1993). Competing demands on the national and provincial health budgets could cause decision makers to re-direct funding to what are perceived as more pressing needs. A reduction in these control

measures could seriously undermine the gains that have been made in limiting the extent of the disease, and could result in its resurgence with similar consequences to those experienced earlier in the century (le Sueur *et al*, 1993a). This highlights the need to investigate alternative and supplementary control strategies that will reduce malaria transmission to ever lower levels in order to justify the continued input of resources. It also highlights the importance of sound empirical research which provides the basis for control planning and management.

The traditional geography of disease approach of medical geography combines investigating the epidemiological principles and methods of a disease with the spatial patterns of geography in order to understand their causal associations. This integration formed the basis of this research, resulting in the spatial and statistical modelling and analysis of the data to describe, interpret, test and explain the spatial relationships between the potential winter breeding sites and the location of the malaria cases. The use of GIS in the field of medical geography, particularly this traditional approach, provides the ability to displaying and investigating the spatial relationships associated with the cause and effects of environmental diseases such as malaria (Eastman *et al*, 1993).

"GIS capabilities must be closely tied to basic operations or research, monitoring, analysis, interpretation and reporting. They should direct and modify the way we organize and evaluate information. In addition, the approach should promote a stronger linkage between science and policy" (Wilken, 1992, 55/56).

GIS was used to test the hypothesis that the malaria vector, *An. arabiensis*, is localised to certain breeding sites during winter in the study areas of Ndumu and Mkanis in northern KwaZulu-Natal, which could be identified by mapping them in relation to the low season (July to December) malaria cases. This was done by undertaking a spatial analysis of the proximity of the potential breeding sites to the malaria cases and was followed by a statistical analysis in order to substantiate these findings. It was anticipated that this methodology would also provide evidence of the maximum likely distance that female mosquitoes will fly for a blood meal given an adequate host population in close proximity.

The results of the spatial and statistical modelling and analysis of the perennial pans, non-perennial pans and dams with respect to the proximity of the active malaria cases, clearly indicated that the perennial pans acted as the 'seed points' during the dry winter months of 1993

and 1994. These results support the findings of Ribeiro *et al* (1991) who found seasonal variations in mosquito densities, with spatial clustering increasing as the number of breeding sites decreased with the onset of the dry season. They noted that selective control measures could be used to target these breeding sites through the identification of the location of the clusters. Gunawardena *et al*, 1995 also used both both active and passive methods of case detection, and found that people living close to the water sources experienced greater incidence of malaria than those living further away.

The results of this research indicate a 4 km limit as the maximum likely flight distance that the female mosquito will fly for a blood meal with an adequate host supply was provided by the results, however, those living within 2 km are particularly at risk as indicated by both the spatial and statistical analysis. These results supports the findings of De Meillon (1937), Learmonth (1978), and Corbley (1996) who used GIS and satellite images to identify mosquito likely breeding sites based on malaria case records and environmental data. It also support Rafatjah's findings (1988) of highest concentration of cases being within 2 km of the breeding sites.

This project therefore incorporated all three of Molineaux's (1988) steps in his approach to epidemiological research : 1) to describe and explain the distribution of a disease based on actual information 2) using new and appropriate methods, such as GIS, 3) to contribute to the planning and evaluating control measures. While the results cannot be held as proof that the perennial pans act as the 'seed points' from which the mosquitoes spread to other sites as they become available, Kleinbaum *et al* (1998) and the Committee on Environmental Epidemiology (National Research Council, 1991) they will be evaluated against several characteristics in order to conclude a causal relationship between the location of the malaria cases and their proximity to the low season breeding sites. These consist of:

1. Strength of association: recent and historical studies in the province and elsewhere (Chapters 3 and 4), support the association between the proximity of the breeding sites and the malaria cases
2. Dose-response effect: changes in the suspected causal agent, the *An. arabiensis* mosquito, affect changes in the number and distribution of malaria cases.
3. Lack of temporal ambiguity: the cause of the disease, namely the presence of malaria parasites and vectors, precedes the effect which is the resulting morbidity and mortality caused by the disease.

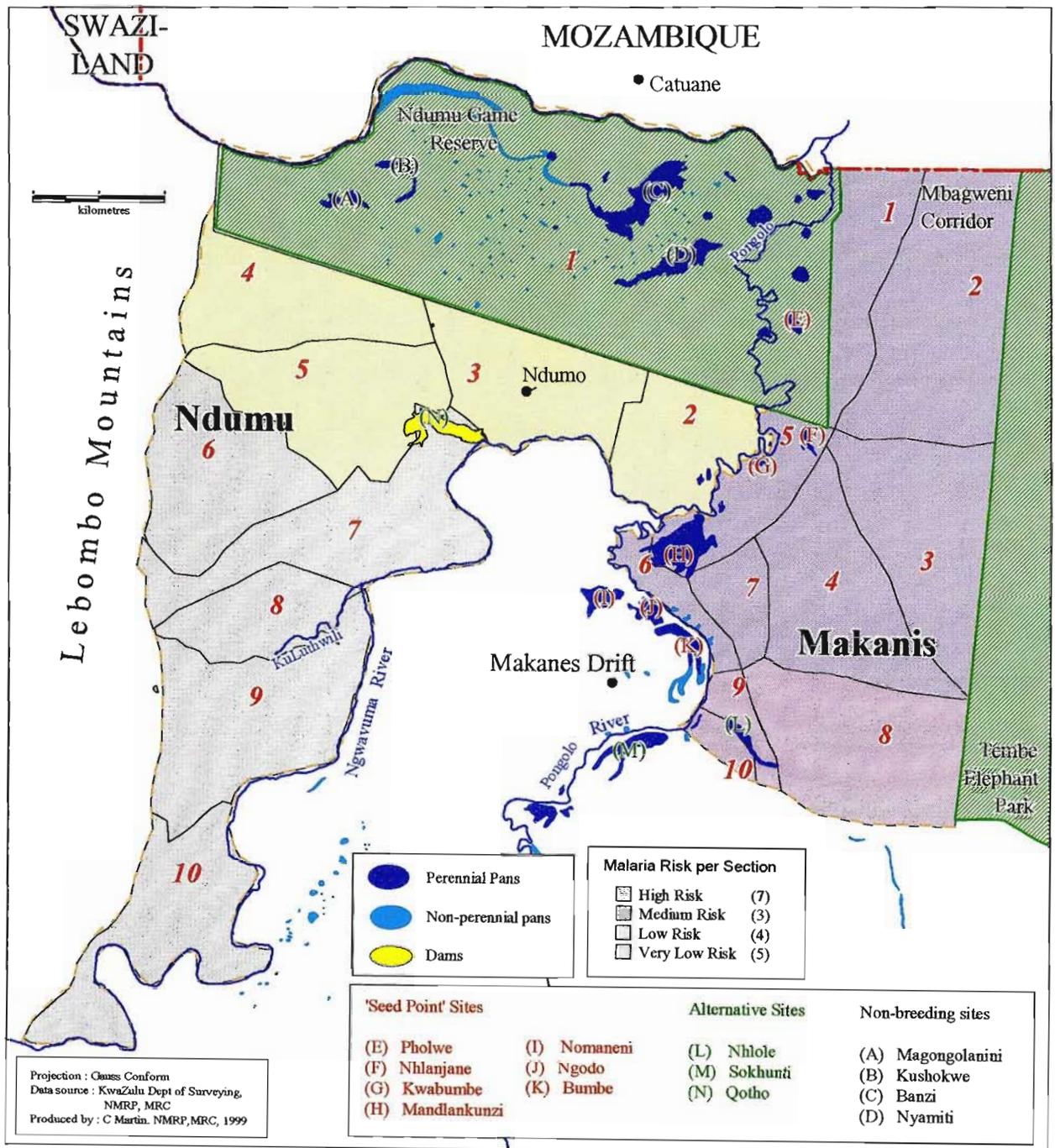
4. Consistency of findings: similar findings were presented in Chapter 2 with respect to the maximum likely flight distance, and in Chapters 3 and 4 with respect to causal relationships between the location of the breeding sites and their proximity to the cases.
5. Biological and theoretical plausibility of the hypothesis: current theory as presented in Chapter 2 supports the findings although there may be an insufficient body of knowledge.
6. Coherence of the evidence: the results of this research are in line with the epidemiology of the disease as outlined in Chapter 2.
7. Specificity of the association: the cause of malaria has been scientifically proven to be the malaria parasite which is only transmitted by the mosquitoes, particularly the *An. arabiensis* mosquito in the study area.

Based on the evaluation of the results against these seven criteria, it can reasonably be concluded that the proximity of the malaria cases to the breeding sites is a function of distance which supports the findings of the spatial and statistical analyses. The identified breeding sites can therefore be assumed to be the breeding sites to which the cases are localised during the winter months and from where they spread at the start of the malaria season. This last step of Molineaux's three-phased approach, namely, to contribute to planning and evaluating control methods, will now be reviewed by making decisions based on the newly generated information.

7.2 Contribute to Planning and Evaluating Control Measures

The perennial pans that are considered 'seed point' breeding sites to which larvicides could be applied are indicated on Figure 7.1, where the malaria sections are divided into areas of high, medium, low and very low risk. These are perennial pans in Ndumu section 1, and Makanis section 5 and to the south-east of section 6. The perennial pans consist of (E) Pholwe, (F) Nhlanjane, (G) Kwabumbe, (H) Mandlankunzi, (I) Nomanini, (J) Ngodo and (K) Bumbe. The pans inside the Ndumu Game Reserve will need to be sprayed with the consent and cooperation of the custodians of the reserve as the presence of animal, bird and fish species will limit the type of larvicide that can be applied. Efforts may also need to be made to ensure that there are no other water bodies in the Mbagweni Corridor or close to the border in Mozambique which could be used as breeding sites. The application of larvicides will need to be accompanied by the careful monitoring of the disease in the area to determine the effectiveness of the intervention.

Figure 7.1 'Seed Point' Breeding Sites and Risk Levels in the Malaria Sections of Makanis and Ndumu



The seasonal changes in the duration of the different stages of the mosquito, particularly its aquatic stage, make larviciding a viable supplement to the current control methods. The most suitable type of larvicide would be determined by local epidemiological and environmental conditions. As identified by le Sueur (1991), the most appropriate time to apply the larvicides would be from the end of July into August and September while the bulk of the mosquito population is in the larval stage. Reducing the number of larvae during this time would reduce the number of mosquitoes in circulation at the start of the malaria season and thereby delay its onset. The reduced number of adult females would be unable to transmit malaria to the current peak malaria levels during April and May, and the mosquito population as well as the malaria cases, would drop to below current June levels with onset of the winter condition (le Sueur, 1991). A reduction in the number of mosquitoes in circulation at the onset of winter may also reduce the number of eggs that are laid and therefore the number of larvae that survive into adulthood the following malaria season.

Further research to investigate the reasons for the temporal and spatial variations between the active and passive cases within the study area could assist in understanding the local epidemiology of the disease and therefore in its prevention and control. The methodology may also assist in identifying marginal or low risk disease areas that could become high risk areas with the onset of global warming and changing environmental conditions. The methodology could also be applied to investigating of other vector-borne environmental diseases

The results of this research will be made available to the Malaria Control Programme of KwaZulu-Natal and the scientists of the Malaria Research Programme (MRP) of the Medical Research Council who will assess the implications of this research and the potential for implementing the recommendations. It is anticipated that the results of this research will contribute to the body of scientific knowledge of the MRP and the broader scientific community by assisting with control efforts to reduce malaria case numbers locally.

This project highlights the need for regional cooperation to combat the effects of the disease and to use cost effective technology to integrate research and control. Research efforts need to assist in developing multi-disciplinary approaches to health problem that are cost effective and use appropriate technology (ANC Health Department, 1994).

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GLOSSARY

- Active case detection - malaria cases that are actively sought by surveillance agents going into the field and collecting blood slides for testing
- Asymptomatic - not showing any symptoms of disease.
- Blood-meal - the taking of blood from a victim by the mosquito
- Buffer - a delineated area within a set distance of an object
- Cartography - the art and science of compiling and drawing maps and charts
- Chemotherapy - the treatment of diseases with the use of chemical agents
- Developing countries - social change implied by a transformation of the relations of production, usually identified by a number of indicators.
- Developing countries - those that are seen to be moving from a state of Underdevelopment to one of achieving the goals associated with being Developed.
- DDT - dichlorodiphenyl trichloroethane, a chemical used as an insecticide
- Digitize - the tracing of features with a copper based mouse/puck on a magnetised tablet which allows the digital equivalent of the features to be transferred and stored in a computer programme. Digitizing involves the digital tracing of features which have been securely placed on a magnetised board which is attached to the computer and a power source. Tracing the required map features with a puck/mouse that contains copper wire and is attached to the computer, allows the traced features to be stored digitally by a GIS software package and displayed in map form on the screen (MapInfo, 1995).
- Endemic - a disease that is continuously prevalent in a particular locality
- Endophilic - indoor feeding mosquitoes
- Entomology - the branch of science that studies insects
- Epidemic - diseases that are not continuously present but which spread rapidly through a population
- Epidemiology - the study of epidemic diseases, the dynamics of their transmission, their impact and their control
- First World - countries with advanced capitalist economies
- Fungicides - a substance that destroys fungi
- Geographic Coordinate System - flat representation of the earth's surface using latitude and longitude coordinates referenced to the equator and Greenwich meridian. All coordinates above the equator are designated plus (+), and all below are designated minus (-). Coordinates east of Greenwich are plus (+) and to the west are minus (-). The coordinates of South Africa are therefore -° south and +° east.
- Geographic Information Systems - computer based systems/software package that allow the input, storage, manipulation, analysis and output of spatial and attribute data in a newly generated map
- Geo-referencing - referencing the map in terms of its coordinate location (latitude and longitude) on the earth's surface. This entails allocating at least 4 widely dispersed points on the map, usually the corner points, with their correct coordinates, these being entered into the computer once the location of each point had been identified with the mouse on the digitizer. The software automatically calculated the location of each entered point with respect to where it should be according to the selected projection.
- Global Positioning Systems - a collection of satellites which circle the earth and transmit signals to computerised receivers which allows the latter's coordinate location to be identified
- Gravid female mosquitoes - pregnant female mosquito

Herbicides - chemicals used to destroy plants, usually weeds

Horizontal Control Programme - a control, programme that includes community participation in solving malaria related problems

Host - an animal or plant that supports a parasite

Immunity - the ability of an organism to resist disease by producing its own antibodies or as a result of inoculation

Impregnated bednets - bednets that are immersed in a chemical substance which impregnate into the fibres of the fabric

Infectious disease - one that can be transmitted from one person to another

Insecticide - a chemical substance used to destroy insect pests

Larva - the immature form of many animals /insects that develops into a different adult form by metamorphosis

Larviciding - a chemical substance used to destroy larva

Malariologist - a scientist who studies malaria

Migration - the movement from one place to settle in another

Morbidity - ill health, disease

Mortality - death, loss of life

Parasite - a living organism which lives in or on another from which it is sustained by

Passive case detection - malaria cases that are detected through people who report to health facilities with the signs and symptoms of the disease

Pesticides - a chemical substance used for killing pests, usually insects

Pupa - an insect during the nonfeeding immobile stage of its life between the larvae and adult stage when many internal changes occur.

Projection and coordinate system - mathematical formula devised in order to display the curved surface of the earth on a flat two-dimensional surface and results in distortions in area, shape, direction and distance.

Prophylaxis - the prevention of disease or the control of its possible spread

Chemoprophylaxis - the prevention or control of disease through chemical substances

RMS error - The Root Mean Square (RMS) error is the amount of distortion in the map in relation to where the coordinate points should be as determined by the chosen coordinate system. This figure, multiplied by the scale of the map, gives an indication of the amount of distortion of the map. Inaccuracies in the digitized maps will result in errors in all data that is displayed in terms of distances and relative positions. This can be a problem when maps have to be joined or when data from other sources needs to be overlaid with them.

Residual Spray - a spray that remains effective for an extended period after its application

Resistance - the capacity to withstand something

Scale - the ratio between the size of something real and a representation of it. Maps are made in a proportional relationship to the area they represent on the ground.

Symptomatic - showing symptoms of a disease

Synthetic Pyrethroid - inorganic compounds

Thematic maps - maps that are designed to display a particular theme

Third World - countries that do not have advanced capitalist economies and generally considered to be those that are underdeveloped.

Underdeveloped countries - those countries that do not benefit from the transformation of the relations of production and experience the resulting lack of social conditions.

Vertical Control Programme - a control programme with little community participation and a top down approach to solving malaria related problems.

APPENDIX 1 : Larval Control Methods

Larvicides are available in liquid and dry formulations, the use of which will be determined by the nature of the breeding site and the ecology of the particular mosquito. Retreatment in most instances needs to be done every seven to ten days, depending on the local conditions. The cost of purchasing, applying and reapplying each type of larvicide will also be important in considering its application. There are six broad categories of larvicides, each with a unique effect and therefore applicable under differing circumstances. Unless otherwise stated, the reference source is Gratz and Pal, 1988.

1. Larvicidal Oils : Oils (kerosene, diesel oil, gasoline, crude oil) are effective against most mosquito species and their toxicity to humans is low. Contact with the volatile oils causes death to the mosquito larvae after exposure for a few seconds up to a minute. Certain stages of larval and pupae development are affected which has implication for the time intervals of re-application in order to kill all the larvae.

2. Arsenicals : This category of larvicides is particularly suitable for Anopheles larvae which feed from the surface and on which it acts as a stomach poison. They are mixed with appropriate dilutions of either talc, calcium carbonate, marble dust or vermiculite, are non-toxic to other non-target life forms, and floats well on the surface so have no effect on the pupae which do not surface-feed. Paris Green is an example of this group and consists of 90% copper acetoarsenite.

3. Chlorinated Hydrocarbons : Resistance to DDT and Dieldrin, its accumulation in the biotic chain, low biodegradability and relatively low effectiveness in polluted waters are disadvantages and has resulted in this category of larvicide seldom being used as a larvicide.

4. Organophosphorus Insecticides : These chemicals act by blocking the transmission of nerve impulses. Some are quickly degraded by bacteria and therefore have limited action necessitating regular applications. Some are unsuitable for use in potable water sources or where fish or other wild life use the water. Others have effectively been used against Anopheles larvae with no effect on water quality or use.

5. Pyrethrum and Synthetic Pyrethroids : No resistance to Pyrethrum, the oldest known effective insecticide, has been reported. Synthetic pyrethroids are highly effective against mosquito larvae and are very safe to use. They are not used extensively for anopheline control due to their high cost and relative instability under conditions of intense sunshine.

6. Development Inhibitors : New products are being developed such as those that imitate the natural growth hormones which prevent the mosquitoes surviving into adulthood (Nielson, 1979). Their use against anopheline mosquitoes is presently limited but effective against both larvae and emerging adults. The period of effectiveness depends on the quality of the water and can vary from a few days in polluted water to weeks in clear water although anopheles mosquitoes tend not to breed in polluted water.

While the above categories of larvicides are the predominant focus of larval control, it is interesting to note that biological and environmental control methods have also been tested. The role of biological agents in combatting the disease is still meagre. Control agents include bacilli/bacteria, mermithids, crustacea, fish and snails (WHO, 1987). Eradication by inundating the natural population with sterilized insects that have been exposed to gamma-radiation or chemosterilants has occurred in only a few places (Davidson, 1969; Miles, 1985). Due to the vast numbers that are required, this has proved unviable for controlling malaria vector populations.

Larvivorous fish are used only to a limited extent as a means of larvae control due to problems relating to rearing and distribution the predators. The most promising bacterial agents produce endotoxins which act as stomach poisons to the insect larvae, but they need to be periodically reintroduced into the ecological system (Miles, 1985). Fungal pathogens must be used with caution as the pathogens could mutate and detrimentally effect beneficial insects or even vertebrates (Busvine, 1975).

Freshwater species with low tolerance of salinity levels may be effectively controlled by a salinisation programme, the cost of which makes it an attractive alternative to larvicides and insecticide. The possibility of increased salination as a result of this method is not considered a threat as the onset of heavy rains at the end of winter would substantially dilute the salt content, however this method would require further investigation (Muir, 1988; le Sueur, 1991)

With each larval species having a defined geographical distribution which occurs with a combination of biological, chemical and physical characteristics, environmental measures should only be applied with the fullest understanding of their epidemiology, population density and habits (WHO, 1982).

Table 1 : 1993 Monthly Climate Figures for Ndumu and Makanisdrift (Source : SA Weather Bureau, 1996. NMRP, 1996).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall mm	15.8	119	25.5	39	0	0	5	24.5	10.5	75.2	25	93.5
Temp max°C	33.9	31.4	30.2	29.9	27.3	26	25.9	26.2	29.2	27.2	29	32.1
Temp min °C	21.4	21.5	19.7	17.7	15.1	9.3	11.4	11.8	15.6	18.2	18	20.1
Active cases	29	68	268	250	351	147	52	77	37	30	35	71
Passive cases	45	90	187	272	304	133	7	3	3	0	15	29

Table 2 : 1994 Monthly Climate Figures for Ndumu and Makanisdrift (Source : SA Weather Bureau, 1996. NMRP, 1996)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall mm	98.6	43.2	129	11	12	0	4	11	3.6	91.7	87	38.5
Temp max°C	32.4	32.8	31.7	29.9	No data	26.3	24.9	26.2	28.6	26.1	30	31.3
Temp min °C	20.4	20.3	19.4	17.9	No data	9.2	7.8	10.7	15.1	14.6	18	19
Active cases	51	59	165	240	345	139	97	72	28	13	20	54
Passive cases	46	124	235	349	54	153	51	3	4	8	21	124

APPENDIX 3 : The Population of Ndumu and Makanis Malaria Sections.

Section Number	Makanis Population		Ndumu Population	
	1993	1994 estimates	1993	1994 estimates
1	322	328	Ndumu Game Reserve	
2	455	464	2709	2763
3	277	283	2477	2527
4	565	576	699	713
5	1327	1354	1841	1878
6	211	215	1208	1232
7	1112	1134	2566	2617
8	655	668	688	702
9	359	366	1031	1052
10	233	238	965	984

APPENDIX 4 : Active Cases Detection Methods.

"Active" cases are detected in four ways:

- 1) House-to-House Surveys : each surveillance agent routinely covers the same region every six weeks, collecting blood smears for analysis from his respective area.
- 2) Epidemiological Surveys : a field team takes blood smears within a set radius (usually approximately two kilometres) of the home of an infected person.
- 3) Special Surveys : a localised outbreak of malaria is followed by a mass blood examination involving both or either of the above methods in order to detect and treat parasite carriers. The goal is to reduce the potential of further transmission, and covers a much larger area with blood slides are taken from all residents.
- 4) Mass Blood Surveys : blood smears are taken from all the residents of an area that experienced a high incidence rate during the previous transmission season in order to reduce the reservoir of parasites before the start of the new transmission season (Ngxongo, 1993). The slides are examined at the Jozini office of the Department of National Health laboratory with quality control being done at Edendale hospital in Pietermaritzburg (Sharp et al, 1988).

Table 1 : 1993 Active Cases for Ndumu and Makanis (NMRP, 1996)

Month :	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Slides taken	2070	1660	2205	2225	1930	1770	1855	1610	1550	2515	1545	2665	23 557
Positive results	29	68	268	250	351	147	52	77	37	30	35	71	1 415
% Positive	1.4	4.1	12.2	11.2	18.2	8.3	2.8	4.8	2.4	1.2	2.3	2.7	
Missing home No.	0	0	4	10	19	8	0	0	1	3	0	0	45
Missing spatial data	4	10	45	35	31	22	3	15	4	2	0	9	180
Usable cases	25	58	219	205	301	117	49	62	32	25	35	62	1 190

Table 2 : 1993 Passive Case for Ndumu and Makanis (NMRP, 1996)

Month :	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Positive results	45	90	187	272	304	133	7	3	3	0	15	29	1 088
Missing home No.	1	20	28	62	129	80	2	1	2	0	2	1	328
Missing spatial data	7	17	22	29	28	11	0	0	1	0	3	4	122
Usable cases	37	53	137	181	147	42	5	2	0	0	10	24	638

Table 1 : 1994 Active Cases for Ndumu and Makanis (NMIRP, 1996)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Slides taken	1690	1790	1800	2010	2160	1600	2540	2180	2830	2340	2165	2535	25 640
Positive results	51	59	165	240	345	139	97	72	28	13	20	54	1 283
% Positive	3	3.3	9.2	12	16	8.7	3.8	3.3	1	0.6	0.9	2.1	
Missing home No.	0	2	5	14	37	1	1	0	1	0	0	1	62
Missing spatial data	6	7	23	35	60	22	7	2	1	2	1	6	172
Usable cases	45	50	137	191	248	116	89	70	26	11	19	47	1 049

Table 2 : 1994 Passive Cases for Ndumu and Makanis (NMIRP, 1996)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Positive	44	124	235	349	54	153	51	3	4	8	21	124	1 170
Missing home No.	12	21	23	57	20	57	29	1	4	5	14	29	272
Missing spatial data	0	21	36	52	4	22	3	0	0	0	2	9	149
Usable cases	32	82	176	240	30	74	19	2	0	3	5	86	749

APPENDIX 7: Homestead and Population Numbers in the Zones around the Breeding Sites

Table 1. 1993

Zones	Dams		Perennial pans		Non-perennial pans	
	Homesteads	Population	Homesteads	Population	Homesteads	Population
Zone 1	103	721	475	3325	142	994
Zone 2	241	1687	549	3843	195	1365
Zone 3	328	2296	255	1785	229	1603
Zone 4	395	2765	248	1736	612	4284
Zone 5	1687	11809	1227	8589	1576	11032
Total	2754	19278	2754	19278	2754	19278

Table 2. 1994

Zones	Dams		Perennial pans		Non-perennial pans	
	Homesteads	Population	Homesteads	Population	Homesteads	Population
Zone 1	105	735	484	3388	145	1015
Zone 2	246	1722	560	3920	199	1393
Zone 3	335	2345	260	1820	234	1638
Zone 4	403	2821	253	1771	624	4368
Zone 5	1721	12047	1253	8771	1608	11256
Total	2810	19670	2810	19670	2810	19670