THE EPIDEMIOLOGY OF MALARIA IN ZAMBIA

By

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AUTHENTICATION

THIS THESIS HAS BEEN SUBMITTED FOR EXAMINATION TO THE UNIVERSITY OF NATAL WITH OUR APPROVAL AS UNIVERSITY ACADEMIC SUPERVISORS

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DECLARATION

THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR A DEGREE IN ANY OTHER INSTITUTION OR UNIVERSITY

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JOHN MULENGA CHIMUMBWA

DEDICATION

This work is wholly dedicated to my dear wife and friend
Miriam A. CHIMUMBWA

PREFACE

Nearly half of the world's population lives in tropical and temperate climates where they may be at risk from one or more vector borne diseases. Approximately 2.1 billion people, living in more than 100 countries are at risk from malaria. While the malaria situation has improved in some places, the overall prevalence in Africa, Asia and the Americas continues to deteriorate. This has led nations, institutions, organisations and agencies including the World Health Organisation to call for development of new and innovative approaches to its surveillance and control.

In nature, maintenance of malaria transmission involves a complex interaction between the mosquito vector, the human host, the disease organism, and both the internal and external environments. An understanding of this complex relationship is the key to the prevention, control and eventual eradication of malaria. Malaria prevention and control programmes do not only have to be based on sound knowledge of how these factors interrelate, but also on an application of the political will of the concerned authorities.

This study attempts to identify some determinants of malaria and to characterise it in epidemiological zones in Zambia. The study aims at contributing to the body of knowledge that would support implementation of an evidence-based national malaria programme. This study has come at an opportune time when there is renewed focus on malaria prevention and control globally.

It is hoped that these aspects of the malaria programme in Zambia will not have to be rewritten in the foreseeable future, instead will be improved upon in order to progress to the delivery of quality assured malaria services as close to the family as possible based on the principles of community-health partnerships.

The study is presented in a series of chapters; each developed as a follow up to the previous one and forms a bridge to the next. In this way, it enables the reader to build a relatively complete picture of the malaria situation in the country. However, some repetitions could not be avoided with regard to descriptions of study sites.

In the chapters dealing with health systems and quantification of malaria risk, the country (Zambia) is taken as the study site. The remaining sections are based on specific sites, selected on the basis of their representing different aspects of the malaria situation in the country. Mapping of households and other referral points provided the basis upon which a Malaria Information System would in future be built. One of the

two study sites was special because most of the previously conducted malaria research in Zambia has been conducted at this site. While the other was not only new in terms of malaria research, it also represented locations in the high rainfall zone in Zambia.

The introductory chapter sets out the general principles of Geographical Information System (GIS), malariology, entomology, and health systems. The chapter reviews the current global burden of malaria including its implications for economic development of endemic sub-Saharan African countries, and discusses progress made in the light of drug and insecticide resistance and the changing global weather patterns. This section examines the position of the African continent in relation to the global malaria eradication era and the possible reasons why it was excluded from the global malaria eradication campaign of 1956-1969. It goes on to analyse new obstacles being faced in rejuvenating global interest in malaria programmes, starting with Primary Health Care through to the principles of Roll Back Malaria (RBM). It also emphasizes special Africa-specific initiatives related to malaria, such as the MARA/ARMA collaboration which (through the use of GIS) is providing a basis for evidence-based decision making.

The fist chapter deals with the historical aspects of malaria control in Zambia. It traces how malaria was successfully controlled over a period of 46 years. It starts with a rural set up where copper mineral deposits were discovered. From there it traces the history of malaria control spanning almost eight decades to the present day. It outlines the major milestones in both the malaria programme and in the political history of the country; from a British protectorate, through Federation to the present day nation, Zambia. The chapter demonstrates how malaria can be controlled in an intense transmission situation, using a combination of simple and relatively cost-effective interventions. It also demonstrates that political will is an essential element to disease control.

The second chapter examines the role of health systems in the delivery of quality, efficient and cost-effective services to the population. It examines the adequacy of health services in the light of time-limited Roll Back Malaria goals, according to the Abuja Declaration of 2000. This chapter analyses the capacity of the local health system to deliver on its health vision of taking quality assured health services (Malaria services) as close to the family as possible. Together, these goals are examined in terms of population accessing the facilities within 30 minutes' walking distance.

Chapter three focuses on identifying factors that facilitate or hinder households acquiring and using Insecticide Treated Nets (ITNs) in the

same locality. Specifically, distance of households to some reference points is examined. Also the effects of social, economic and educational status of heads of households are analysed. Together all parameters are analysed statistically to isolate the important reasons why some homes acquire ITNs while others do not. The study concludes with an analysis of the importance of ITNs in averting malaria among users. Some anecdotal evidence resented on the value of ITNs in reducing malaria incidence in the general population is presented.

GIS is employed in the fourth chapter to produce a malaria endemicity risk map for the country. It employs population *Plasmodium falciparum* infection rates. It proposes stratification and compares it with existing expert opinions and the climate-based Fuzzy Logic predictive model. The resultant malaria risk map is verified against existing maps and expert opinions. The chapter then discusses application for local decision making on policy and action.

Chapter number five is dedicated to identifying and studying the bionomics of malaria vectors at two sites. It reviews existing literature on this subject, from 1929 to date. It identifies possible malaria vectors, their behaviour and ecology at two sites representing two extreme situations of malaria endemicity in the country. The combination of *Anopheles* vector densities and their reliance on temperature and rainfall are analysed and the implications discussed. The chapter also looks at possible ways forward for the country in the light of the paucity of information in this respect. *P. falciparum* infection rates are estimated together with their entomological inoculation rates and possible implications for malaria transmission potential.

The final section (chapter six), highlights the major lessons and their implications for global goals and local health policies. It also outlines the way forward chapter by chapter.

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Chapter One: General Introduction

Introduction

The great explorer, medical doctor and missionary Dr David Livingstone suffered and died from *plasmodium falciparum* malaria in the interior of Africa. Harris (1973) gives an account of Livingstone's travels north of Bechuanaland where no white man had ever survived because of the fever. He was nursed at Chief Chitambo's village in central Zambia until he died in prayer on May 1, 1873 (Azania, 1997).

Problem of Malaria

Malaria remains by far the most important tropical disease in the world today (Mutinga *et al.*, 1992). So far, efforts to control it have consumed huge amounts of resources, but the disease continues unabated. It is even increasing in many places, including where it was previously controlled (Bradley, 1994; Shililu *et al.*, 1998; Snow *et al.*, 1998). Since the description of the malaria parasite life cycle by Sir Ronald Ross in 1897, considerable efforts have been made, first to eradicate it and later to control it (WHO, 1993).

Globally, malaria threatens about 40% of the world's population. It undermines the health and welfare of families, endangers the survival of children, debilitates the active population and strangles economic development. These, it does through excessive direct public health costs, low productivity and impaired human development (WHO, 1993; Sachs and Malaney, 2002). It is estimated that more than 170 million people world wide experience an attack of malaria annually, and between one and two million die from it (Bradley, 1994; Guiguemde *et al.*, 1994; Shililu *et al.*, 1998;). WHO has estimated that between 17% and 30% of health centre mortalities in sub-Saharan Africa are due to malaria (WHO, 1996). Those who suffer from a severe form of malaria have a 40% chance of dying, especially in rural areas. Other estimates claim that malaria-specific morbidity and mortality worldwide range between 300-500 million clinical cases and 1-3 million deaths. The blunt of this disease burden is borne by the poor and vulnerable, especially children under five years and pregnant women (Breman, 2001). Up to 90% of total global malaria mortality is confined to sub-Saharan Africa (WHO, 1996). In its global

assessments the World Bank ranked malaria as causing the greatest disease burden in Africa after HIV/AIDS (Hammer, 1993; World Bank, 1993; Sexton, 1994; Breman, 2001).

The malaria morbidity and mortality figures quoted above are estimates based on projections from observations in localised areas often based on small samples (McMichael *et al.*, 1996). In recent times, additional information is becoming available from non-traditional means of information identification. One such source is the Geographical Information System (GIS). Malaria distribution models are beginning to provide more accurate figures on malaria and its impact on communities (Choi *et al.*, 1995; Craig *et al.*, 1998; Mordiano *et al.*, 1998; Steketee *et al.*, 2001).

Using GIS, the distribution of infection risk from malaria has been shown to be approximately 360 million annually, and between 0.4 and 0.7 million people dying from malaria annually in Africa alone. These figures represent somewhat higher numbers than previous estimates by WHO (1996). The one million deaths that occur in Africa annually translate into one death every twelve seconds (WHO, 1996). In sub-Saharan Africa, 93% of the population lives at risk of malaria with only 7% living in malaria-free areas or areas at low risk of transmission with limited malaria epidemic potential (WHO, 1998).

Economic Impact of Malaria

The resources spent on malaria control activities through health care in many developing countries have resulted in reduced spending on other services and has to some extent increased dependence on foreign aid (Kaewsonthi and Harding, 1989; Kere and Kere, 1992; Piccard *et al.*, 1993). Considering the limited resources available for the health sector, including malaria control in these countries, communities are increasingly being called upon to bear the costs of preventive and curative services (Kere and Kere, 1992; Guiguemde *et al.*, 1994).

The problem of malaria in Africa goes beyond health and affects the economies of individual families, communities and nations. It represents a barrier to sustainable human development and reduces the quality of life of those affected. The devastating effects of malaria on tourism, agriculture and general human development have been documented many times (Sharp and le Sueur, 1996; Breman, 2001; Goodman *et al.*, 2001). Malaria is an obstacle to development in the third world, and a major cause of poverty (Binka *et al*, 1996; WHO, 1998; Sachs and Malaney, 2002).

Recently, malaria was a subject of a Heads of State meeting in Abuja, Nigeria (WHO, 2000). At the summit it was reported that malaria is responsible for direct and indirect costs to governments and communities, estimated at US$ 800 million annually. In addition, it claims 1540 million Disability Adjusted Life Years (DALYs) annually (World Bank, 1993). This represents more than 10% of all Southern Africa's regional resources combined (WHO, 1998). It costs sub-Saharan Africa some US$ 3.6 billion per year as a result of man-hours lost and provision of health services (Chinnock, 1997).

South African sugar mills provide an example of the direct impact of malaria on local economies. In 1932, the mills were losing on average, 77 out of 80 workers per day due to absenteeism as a result of malaria. Instead of 1500 tons of cane per day for processing, the mills were only receiving 5 tons of cane, representing a 300-fold drop (le Sueur *et al.*, 1993; Sharp and le Sueur, 1996). Likewise, the construction of the Panama Canal had to be abandoned twice due to effects of malaria on imported labour force. It was only possible to complete the work after malaria and yellow fever were brought under control. In 1938 cotton production and wax extraction in North-eastern Brazil recorded losses of between 70% and 80% as a result of a malaria epidemic. Also in Brazil, the electric power company, the Naval Academy and the Yellow fever service, all recorded high losses due to malaria during the same period. To a large extent, the development of the copper mining industry in Zambia was dictated by progress in malaria control (Watson, 1953).

Global Progress in Malaria Control

In Africa, early records show that malaria control started around the 1930s (Watson, 1953; le Sueur *et al.*, 1993). Curative services relied on atebrin and quinine, while vector control was based on paris green, natural pyrethrum and other plant extracts. Environmental control targeting vector species was practiced as species sanitation (Watson, 1953). The Second World War witnessed the discovery of *pp*-dichlorodiphenyltrichloroethane (DDT). Houses sprayed with DDT remained toxic to mosquitoes and other household pests for months. The first DDT trials were conducted in Cyprus, Italy, Mauritius, USA and Venezuela. In these experiments, malaria was eradicated within four years. Vector mosquitoes only returned to the island of Mauritius after spraying with DDT ceased and there was no malaria associated with these mosquitoes (Sharp, 1990).

With the successful introduction of DDT for malaria control, it was believed that the eradication of malaria was a tenable option. In 1956, the World Health Assembly (WHA) passed a resolution to eradicate malaria as the goal of a global programme (Hammer, 1993). In the subsequent years, the World Health Organisation (the implementing arm of the WHA), led the way in attempting to eradicate malaria for two decades at an enormous cost (Bradley, 1994).

As a result of the eradication effort, malaria was successfully eradicated from Europe, North America, most of the Soviet Union and on some islands. In other countries, significant gains were also made against malaria and it was reduced to low levels of no public health importance (Sharp, 1990; le Sueur *et al.*, 1993). In some other areas although malaria was reduced, how much was attributable to malaria control, economic development or the loss of mosquito breeding grounds to human settlements is unclear (Hammer, 1993). By the 1970s, malaria had been eradicated from 37 countries and territories, thus freeing some 500 million people from malaria risk.

For most of sub-Saharan Africa, however, there was no serious attempt to eradicate malaria. Better efforts were made in Asia where significant reductions were achieved, although following the withdrawal of the eradication attempt, these programmes collapsed dramatically and completely. This has resulted in the resurgence of malaria to near pre-eradication levels or worse in some countries (Hammer, 1993).

The African Perspective

A number of reasons have been advanced as to why the eradication programme failed on the African continent. Africa was not seriously included in the eradication programme. No one saw the possibility of eliminating malaria from the continent (Sharp, 1990). It was believed that African health systems were not developed enough to support an eradication effort. Others believed that African populations had enough tolerance to the disease, and therefore, it was not necessary to incur such high costs for its removal. The malaria endemicity in sub-Saharan Africa was considered too high and therefore, difficult to deal with (Bradley, 1994). Other factors cited for the failure of the eradication effort in sub-Saharan Africa included the realisation that environmental factors favoured the reproduction and subsequent survival of both the vector and the parasites. Some mathematical modeling experts at the time showed that the cost of malaria eradication in Africa would not be economically sustainable (MacDonald, 1957). Population size, spatial distribution and

movements were also taken into consideration and found too unstable for continued efforts on malaria control. The African populations also lacked skills base for sustaining the malaria eradication effort (Prothero, 1965). Currently, only a handful of countries in sub-Saharan Africa are dealing with malaria meaningfully. For the majority of countries, malaria is again on the increase. Government policies have shifted from dealing with malaria directly to integrated approaches (Kasonde and Martin, 1994).

Primary Health Care

Following the realisation that malaria eradication did not produce positive results everywhere, global emphasis shifted to malaria control, especially in malaria endemic situations. In 1969, WHO and its funding agencies (United States of America Agency for International Development and the United Nations Children's Fund) abandoned the idea of malaria eradication. At the same time the principle of community participation and empowerment enshrined in the Alma-Ata declaration (1975) on Primary Health Care (PHC) was introduced as the strategy through which key health problems affecting communities would be mitigated (Kasonde and Martin, 1994).

Primary Health Care was based on the principles of preventive, promotive and curative services, especially for rural populations (Kasonde and Martin, 1994). Countries were urged to do what they could locally and strive to maintain malaria control at locally sustainable levels (Sharp, 1990; Arrata, 1994). The cornerstone for malaria prevention was Mass Drug Administration (MDA), using chloroquine (Alonso *et al.*, 1993). The success of this intervention relied upon operational feasibility and sustainability of MDA (Menon *et al.*, 1990). It was obvious that such a high cost malaria control intervention was unsustainable and bound to fail just like the insecticide spraying programme before it, especially in Africa. There were problems associated with distribution, compliance, accountability, accessibility, development of resistance to chloroquine, availability of fake drugs, to mention but a few. Mass chloroquine distribution was abandoned before the second half of 1980 (Sharp, 1990).

Roll Back Malaria

The current global malaria control strategy is to move away from large centralised control programmes to community-based integrated ones (Choi *et al.*, 1995). It recognises that malaria distribution varies throughout the world. As such, there is no single formula for its control

applicable to all countries and all situations (WHO, 1993; Utzinger *et al.*, 2001). The strategy stresses the importance of sustainability, even if slow, compared to spectacular, but ephemeral success. It has set goals that are not only important, but also achievable. It recognises that malaria control is an essential part of health service development. It allows its goals and approaches to be modified in response not only to the expected progressive improvements of the epidemiological situation, but also to unexpected situations arising from social, economic, political or environmental trends. This is the basis for the social movement of Roll Back Malaria. Its target is to reduce malaria by 50% over 10 years and by a further 50% the subsequent 5 years (Nabarro and Taylor, 1998; Utzinger *et al.*, 2001).

Roll Back Malaria also draws upon the Harare declaration on malaria of 1992, in which African Heads of states and governments resolved to do everything possible to deal with malaria in their respective countries and urge the international community to support this effort as a part of Africa's development agenda (OAU, 1997; Nabarro, 1999).

Global Strategy

The four technical elements of the global strategy for malaria prevention and control are: 1) Early diagnosis and prompt treatment of malaria cases; 2) Planning and implementing selective and sustainable preventive measures including vector control; 3) Detecting early, preventing and containing malaria epidemics and 4) Strengthening local capacities in basic and applied research to build evidence as the basis for decision-making. These strategies serve as a guide from which countries can select different options to suit their needs (Nabarro and Taylor, 1998; WHO, 1998).

In implementing this strategy, it is recognised that for sub-Saharan Africa, where 90% of malaria mortality occurs, existing health services are still inadequate. Therefore, health services in these countries should be strengthened as a prerequisite (Brinkman and Brinkman, 1991; Carnevale and Nagera, 1993). It follows that for any intervention to be realistic it must pass the criteria of acceptability by the local population, should be easy to manage at community level, and be affordable to local governments and communities (Procaccim *et al.*, 1991; Nabarro and Taylor, 1998; Nchinda, 1998).

Drug Resistance

Despite numerous efforts in the past to launch effective malaria control programmes globally, various impediments have thwarted these efforts. At the present it is the emergence of resistant strains of *P. falciparum* to affordable and safe anti-malarial drugs. This development together with emergence of resistance to insecticides by some malaria vector mosquitoes presents the latest challenge threatening the success of prevention and control strategies (WHO, 1989; Bjorkman and Phillip-Howard, 1990; Afari *et al.*, 1992; Sexton, 1994; Choi *et al.*, 1995; Binka *et al.*, 1996; Mordiano *et al.*, 1998; Goodman *et al.*, 2001).

Chloroquine resistant *P. falciparum* (CRpf) has now spread to all but a few places. During the 1960s and 1970s, resistance became established in most Southeast Asian and South American countries, and during the 1980s in most of Africa (Bjorkman and Phillip-Howard, 1990). Clinical malaria episodes increase both in frequency and in severity as a result of unsuccessful treatment or chemoprophylaxis with ineffective drugs (Greenberg *et al.*, 1989; Breman, 2001; Goodman *et al.*, 2001). In addition, anemia due to low-grade parasitemias will become critical even if clinical effects are obtained by a non-radical cure. This in turn will increase the need for blood transfusions, which may have attendant HIV/AIDS transmission risks in Africa.

The WHO in the early 1990s estimated that relative costs of treating a malaria episode would increase as more countries shift their malaria treatment policies from chloroquine to more effective but expensive drugs. Apart from sulfadoxine-pyrimethamine, any other alternative to chloroquine will represent substantial increases in therapeutic costs (WHO, 1993).

Insecticide Treated Mosquito Nets

Many studies have demonstrated that sleeping under an Insecticide Treated Net (ITN) is associated with reduction in fever-related illnesses, which are transmitted by mosquitoes. Colonisation of Africa in the 20th century was partly made possible by the protective value of untreated mosquito nets to the colonisers. In many situations, it represented the difference between survival and death (Watson, 1953). With regard to malaria control, regular use of ITNs has been shown to confer positive outcomes on a number of malariometric indices. Decreased spleen rates, reduced parasitemias, reduced parasite loads in users, and less clinical attacks with heavy parasitemias have all resulted (McCormack and Snow, 1986; Gibson, 1988; Njunwa *et al.*, 1991; Alonso *et al.*, 1993; Dapeng *et al.*, 1994; Jaeson *et al.*, 1994; Binka *et al.*, 1996).

The effectiveness of an insecticide treated mosquito net in preventing febrile illness was demonstrated in controlled trials in the early 1980s (McCormack and Snow, 1986). Greenwood *et al.* (1995) explained that treating nets with insecticides is not new. The Russian army used pinol and cresol during the 1930s to treat or dip their nets. DDT was used successfully to protect troops against mosquitoes and other biting flies during the second world war, apparently by both warring sides; each side assuming that with DDT, it had an upper hand over the enemy. The discovery of pyrethroids revolutionalized the concept of net use because of their non- or low- mammalian toxicity (Graves *et al.*, 1987; Sexton *et al.*, 1990; Mellanby, 1992; Alonso *et al*, 1993; Dapeng *et al.*, 1994; Luxemburger *et al.*, 1994; Choi *et al.*, 1995; Greenwood *et al.*, 1995; Lengeler and Snow, 1996; Lines, 1996; Neville *et al.*, 1996; Carnevale and N'auessan, 1998;).

Greenwood *et al.* (1995), point out that nets do not offer 100% protection from malaria infection but only about 30%; implying that, there is still some exposure to malaria infections, which may be a better situation, as it offers an opportunity for inducing natural immunity. ITNs have also been shown to depress vector population densities (Magesa *et al.*, 1991; Mutinga *et al.*, 1992; Mutinga *et al.*, 1992; Stich *et al.*, 1994; Choi *et al.*, 1995;). Only Quinones *et al.* (1998) suggest that ITNs do not mass killing effect on vector populations.

Economic Impact of malaria

In places where malaria is endemic, most malaria deaths occur in children. The effect on productivity is profound and generally accepted that seven days of productivity are lost for each bout of malaria (WHO, 1993). There are many examples of direct links to economics such as industries incurring losses due to absenteeism, medical costs or lowered productivity outputs among workers due to malaria (Sharp and Le Sueur, 1996). The disease also undermines the effectiveness of investment in education. Repeated bouts of malaria do not only affect school attendance, but also the children's ability to learn.

The true costs of the disease exceed the direct costs of treatment seeking for two reasons. Firstly, there is morbidity before treatment is sought. Secondly, there are people who have decided that the costs of seeking treatment are too high, relative to letting the disease run its full course. For those in remote rural areas who may have to pay high transport costs to get treatment, or those affected at the peak of the agricultural season, these costs can be high, with long-term implications.

The cost-effectiveness of an intervention is the ratio of costs of that intervention divided by the given outcome, usually lives saved, cases prevented, or life years saved (Hammer, 1993).

Mapping Malaria Risk in Africa

Among the first attempts at mapping malaria distribution on a continent-wide scale, was by the Malaria Committee of the Pan African Committee in 1935. This committee produced maps, which showed that malaria was uniformly distributed throughout the continent with the exception of parts of South Africa and some islands (Sharp 1990). These old maps relied upon limited and often crude geographical data and climate isolines (Craig *et al.*, 1999). Most of these "landscape" or climate zone malaria maps were produced during the eradication period.

Despite malaria being the single most important cause of morbidity and mortality on the African continent, its spatial distribution has been a subject of conjecture, educated guesses and expert opinion (Watson, 1953; Connor *et al.*, 1997). The MARA/ARMA (1998) collaboration has shown that there are enormous variations in malaria transmission on the African continent; ranging from areas of no transmission to places of intense transmission and a whole range in between. The intensity of transmission a population is subjected to, has a direct bearing on health outcomes (Watson, 1953; Omumbo *et al.*, 1998; Craig *et al.*, 1999).

Currently, low cost technologies are becoming available which are enabling a deeper understanding of important malariometric parameters, and how these interact within the environment. These tools, not only assist in the understanding of the nature and behaviour of the disease, but also predict the consequences, and where and when it will occur and with what severity. These are the computer-based Geographical Information Systems (GIS). They bring new dimensions to the analysis, prediction, dissemination, understanding and decision-making by using spatial relationships between disease, and time.

GIS allows the user to analyse and establish interrelationships between variables within their spatial and temporal contexts. The results can be used in prediction models. GIS has created an opportunity to define disease burdens according to their geographical relevance across continents, regions, countries and local areas. Their routine application at country level has not yet become a common feature of malaria programmes, especially in sub-Saharan Africa. This is despite the fact that some global environmental and meteorological datasets are available

free in the public domain (Omumbo *et al.*, 1998; Snow *et al.*, 1998; Craig *et al.*, 1999; Kleinschmidt *et al.*, 2000; Tanser, 2000).

Malaria in Zambia

Zambia is a country situated in the southern quarter of the African continent, between latitudes -8 ° and -18° south, and longitudes 22° and 34° east. Malaria is endemic in all nine provinces of the country, with an inclination towards the rainy season. The least affected are the urbanized provinces and the worst affected are the rural ones (Ministry of Health 1992). Early accounts of malaria in Zambia come from the writings of David Livingstone on his travels in central Africa, north of Bechuanaland in the 1870s. He noted that no white man could survive there because it was the unhealthiest place in Africa (Harris, 1973). Undocumented oral African history often refers to various plant remedies used to keep mosquitoes at bay while people slept or extracts which were used to treat fevers (Kandata personal communication, 1973). Malaria control in Zambia started in earnest in 1929, when the Ross Institute of England was hired to provide technical support to authorities of newly opened copper mines in Central Africa, north of the Zambezi, at a place called the Roan Antelope (Rodger, 1967). Within a year of setting up the programme, malaria incidence was halved in the European population. *Anopheles gambiae*, one of the two vectors identified was virtually eliminated. Other towns within the same province grew in a similar fashion and malaria control was taken into consideration at planning stages (Watson, 1953). This continued for approximately five decades. There have been a number of successes and failures in the malaria programme since this time.

Study Expected Outcomes

Evidence should form the basis for decision making in any public health programme intervention and malaria control is no exception. To plan and implement rational and cost-effective health programmes, there is need for an understanding of the magnitude and extent of the problem. Zambia like the rest of sub-Saharan Africa suffers from a serious paucity of relevant information and skills in the field of malaria. This broad-based enquiry into the epidemiology of malaria in Zambia is conducted to address this knowledge gap. The study examines various aspects of the malaria situation in Zambia, starting by tracing the historical path of the disease to enable the reader to understand the basis of the current

decisions and their implications for the future. The historical connotations are then put into context by examining the current global and local policy frameworks and health systems. The systems are then analysed in relation to hard evidence of malariometric indices, vector bionomics and other evidence on the ground, before moving on to modeling and producing the first ever malaria stratification map for the country. An attempt is made to identify and analyze both environmental and socio-economic determinants of insecticide treated mosquito net ownership at household level in poor rural environments. The analysis is concluded with a general discussion of lessons learnt and the way forward. Finally, possible research questions are raised, which may complement the presented body of knowledge. Each chapter is developed as stand-alone in line with scientific publication format, but sequentially arranged and cross referenced to make it as reader-friendly as possible.

Chapter Two: A Historical Perspective of Malaria Control in Zambia

Introduction

Malaria is a disease that has had a profound impact on the development of the world (Bradley, 1998). It is an ancient like plague, small pox, yellow fever and leprosy. Today it is competing with epidemic diseases like tuberculosis and HIV/AIDS. Judging by the way it is resurging in places where it was controlled before, malaria may still be around long after both tuberculosis and HIV/AIDS have been conquered (le Sueur *et al.*, 1993). A review and understanding of its historical perspective may facilitate the formulation of effective interventions against it.

The history of malaria control in Africa is introduced in the first chapter. In Zambia, even before the advent of the global malaria eradication campaign of the 1950s and 1960s, malaria had been successfully controlled in urban areas. It was reduced to low levels where it became a notifiable disease under the law of the country (Government of the Republic of Zambia, 1966). Over time, these gains have been lost as a result of failure to maintain vigilance and stringent control measures. This resurgence has also been attributed to poor economic environment prevailing in the country that has resulted in reduced expenditure in the social sectors including health, under whose domain malaria fall. The global momentum following the eradication era waned from 1970s to 1990s. This resulted in governments failing to adequately sustain the eradication programmes. Zambia was specifically involved in the political struggles for independence of almost all neighbouring countries. This exercise consumed huge amounts of local resources. The area of skilled local human resources in the area of malariology compounded the problem. The environmental factors also favour the proliferation of both the parasite and the vectors. The resurgence of malaria in these areas is partly the subject of this chapter (Ministry of Health, 1993).

Malaria is currently responsible for a high per capita burden of disease in Zambia. It accounts for the greatest number of Disability Adjusted Life Years (DALYs) lost annually due to disease. It causes losses amounting to 6.8 million DALYs. This is higher than acute upper tract respiratory infection, the second most important disease, responsible for 5.4 million DALYs lost. HIV/AIDS is the next, at 3.2 million DALYS

annually (Ministry of Health, 1993; World Bank, 1993; Ministry of Health, 1994).

The malaria incidence rate in Zambia has nearly tripled over the past quarter of the century. In 1976, the malaria incidence rate was 121.5 cases per 1000 population. This translated into a little more than one case of malaria for every 8 persons annually. By 2000, the incidence had risen to 348.4 per 1000 population, a rate exceeding one case for every 3 persons (Ministry of Health, 2000). WHO (1998) estimated a 90% under-reporting of malaria cases in sub-Saharan Africa. If this were true for Zambia, then the reported cases (above) represent only one tenth of the actual malaria caseload.

Malaria is endemic in all of the Zambia's nine provinces, with a national average incidence of 507.2/1000 in 1999. Ranging from the lowest in Northern province at 188.9/1000 and the highest in Northwestern at 507.2/1000. A comparison of the incidence within age groups shows that by far the highest burden occurs among under-five year old children. Nationally, the incidence rate in this age category is six times that in older age groups (Ministry of Health, 2000).

From 1976 to 2001, the proportion of malaria to the total outpatient caseload in health centres and hospitals increased more than two fold, from 10.2% to 21% for every 1000 health facility attendances. The proportion of total hospital admissions due to malaria, increased from 8.8% (1976) to 19.6% (2001). According to 1999 data, 35.1% of total hospital admissions were due to malaria (Ministry of Health, 2000).

Case fatality rate generally reflects the capability of the health system to manage complications and severe disease. This is affected by a combination of factors including the severity of the case when admitted, the effectiveness of drug treatment and adequacy of hospital care. From 1976 to 1989, the proportion of malaria cases admitted to health centres and hospitals, which resulted in death rose from 10.6 per 1000 to 27.4 per 1000. Children under five years of age accounted for 45.7% of all admissions and 48.6% of deaths in 1993 (Ministry of Health, 2000).

This chapter traces the history of malaria control in Zambia and links it to the present situation and future malaria control efforts. It is intended to demonstrate that historically, malaria was controlled in Zambia and cost-effectively so. In so doing, the study identifies key factors responsible for both the success and failure of the control programme.

This historical tracking of the development of malaria services in urban areas of the country is under-taken through a case study. The study focuses on one of the urban centres, as a window through which the

development of the malaria programme in the whole of Zambia is examined.

Early accounts of malaria control in Zambia come from the recorded travels of David Livingstone in central Africa. Livingstone was a missionary and explorer who traveled through central Africa during the second half of the 19th Century, searching for the source of the Nile river. In his memoirs, Livingstone records an area north of Bechuanaland where he saw the Victoria Falls. This area he described as the unhealthiest place in Africa and no white man can survive there because of fevers. Ironically, this was his last expedition as he eventually succumbed and died of malaria in 1873 in Northern Rhodesia, present day central Zambia (Harris, 1973).

There are numerous accounts from local people in Zambia of the many remedies used to treat convulsions and fevers, as well as for keeping mosquitoes away at night. There are even spiritual connotations to dealing with severe forms of malaria, especially when it develops into febrile convulsions in children (Kandata, personal communication. 1973).

Although copper had been discovered as early as 1902 near the Luanshya river by Collier (Rodger, 1967), the first mine in Northern Rhodesia only became operational in 1927. Following commencement of operations on the Roan Antelope Copper Mine (RACM, sometimes shortened as 'The Roan') in 1927, the immediate task for the mine authorities was to safeguard the health of skilled labour and their families to support the opening up and development of the mine. At the time, malaria and other tropical conditions were killing many expatriate workers as well as scaring away skilled potential artisans. It was known at the time in the towns of South Africa, where skilled labour could be recruited, that when one decided to go and work on the Roan, one took a one way ticket, for there was no returning alive (Watson, 1937). "The valley of death" as local inhabitants called the mine, was situated in the valley of the Luanshya River. The miners often suffered from fevers which in many cases resulted in death. Due to this, both Europeans and Africans were reluctant to work there. This resulted in numerous desertions from the mine and a high turnover in the African labour force. Apart from inconsistencies in artisanal skills of the African work force, this population movement had implications for malaria control (Watson, 1932; Watson, 1953).

Within a year of commencement of operations on The Roan, it was realized that the 'valley of death' was no misnomer. Between 1927 and 1929, there were 900 Europeans and 5,000 Africans working on the mine. The malaria incidence rate in Europeans was approximately 90 cases per

1000 per annum, with an all-cause mortality rate of 23.4/1000, of which 50% were malaria specific deaths. The management realized that disease in general and malaria, in particular, were a serious handicap to their operations.

To address the issue of ill health in the labour force, the mine consulted the Ross Tropical Institute in the United Kingdom, to solicit their assistance in dealing with the problem of malaria. In support, the Ross Institute sent a fact-finding expedition to the Northern Rhodesian copper mines. The team comprising Sir W. Simpson, Dr. AC Dalzell and Mr. CR Harrison reached The Roan in 1929. This was a group of experienced men, particularly Mr. Harrison, who had just successfully assisted in controlling malaria in Malaya's rubber plantations (Anon, 1932; Watson, 1937). Following preliminary investigations, Harrison was placed in charge of starting the malaria control operations later in the same year (1929). He remained in this position until Dalzel succeeded him in 1931.

Following commencement of malaria control operations, *Anopheles gambiae* s.l. and *An. funestus* s.l. were identified and implicated in the transmission of malaria (Harrison, 1930). The two vector species were found in large numbers around the mine settlement. *An. gambiae* s.l. was breeding in small water bodies especially those resulting from mining activities, brick making and to some extent from vegetable gardening by Africans.

Within a year of commencement of malaria control, using species sanitation and environmental modification (1930), *An. gambiae* s.l. was hardly found within the mines' residential perimeter. Overall mortality in the European population went down to 7.8 deaths/1000 and the incidence rate down to 19.5/1000 by 1931. This was despite an increase in the population of Europeans on the mine from 900 in 1929 to 4,500 in 1931. There were similar remarkable improvements in the health of Africans on the mines (Harrison, 1931). Later, Watson (1953) wrote that the success in 1929/30 of malaria control was a remarkable achievement and the first of its kind over *An. gambiae* s.l. in any part of the world.

An. funestus on the other hand, was breeding in the dambos on either side of the Luanshya river in shaded and overgrown areas, but not under dense vegetation, which excluded light. This breeding was dealt with by cutting contours perpendicular to the main river channel. These were then cleared and paved.

In 1931 a clinical laboratory was opened on the mine. Among other tests carried out was routine testing of all suspected malaria cases before being treated. The first technician in charge of the laboratory was Mr. English, recruited from the South African Institute of Medical Research in

1930. This marked the beginning of definitive malaria diagnosis and treatment (evidence-based decision making in clinical work on the RACM). The laboratory aspects also afforded health practitioners on the mine an opportunity to operate with more certainty. In time, the addition of this service also assisted in attracting well-qualified staff to the RACM (Watson, 1930; Watson, 1932).

Study Site Description

The RACM is situated in the Copperbelt Province on the border with the Democratic Republic of the Congo, being part of the southward extension of the Katanga copper deposits. It is situated to the southwest of Ndola, the capital of the Copperbelt province. Like the rest of the province, the urban portion is a district in itself, while the surrounding peri-urban and rural areas belong to another district, Mpongwe, formerly Ndola Rural District (Figure 2.1). It had 86,673 habitants, according to the 2000 census (Central Statistical Office, 2000). The district is in the high rainfall zone, with an average annual rainfall of 1000-1500 mm per annum. Rains start in October/November and end in March/April.

On the Roan, mosquito density was comparatively low at the end of the dry season (July-October). This changed dramatically with the onset of rains. Mosquito numbers increased rapidly and continued until early in the following year, when as a rule, heavy rains flooded streams and flushed out breeding places. This resulted in reduced mosquito breeding until the end of the wet weather in April. From this time until streams and swamps dried up in June/July, breeding continued with great intensity. *Anopheles* larvae were found in greater abundance from April to June than at any other time of the year. Numbers of larvae then diminished until the rainy season and hot weather started again.

Malaria cases peaked towards the end of the rainy season, with March and April being the worst months, although transmission occurred throughout the year. Transmission followed the start of the rains in November to a peak in December, and then broke down with the flushing effect of increasing rains. Transmission increased again to a second larger peak in March at the end of the rains (Figure 2.2).

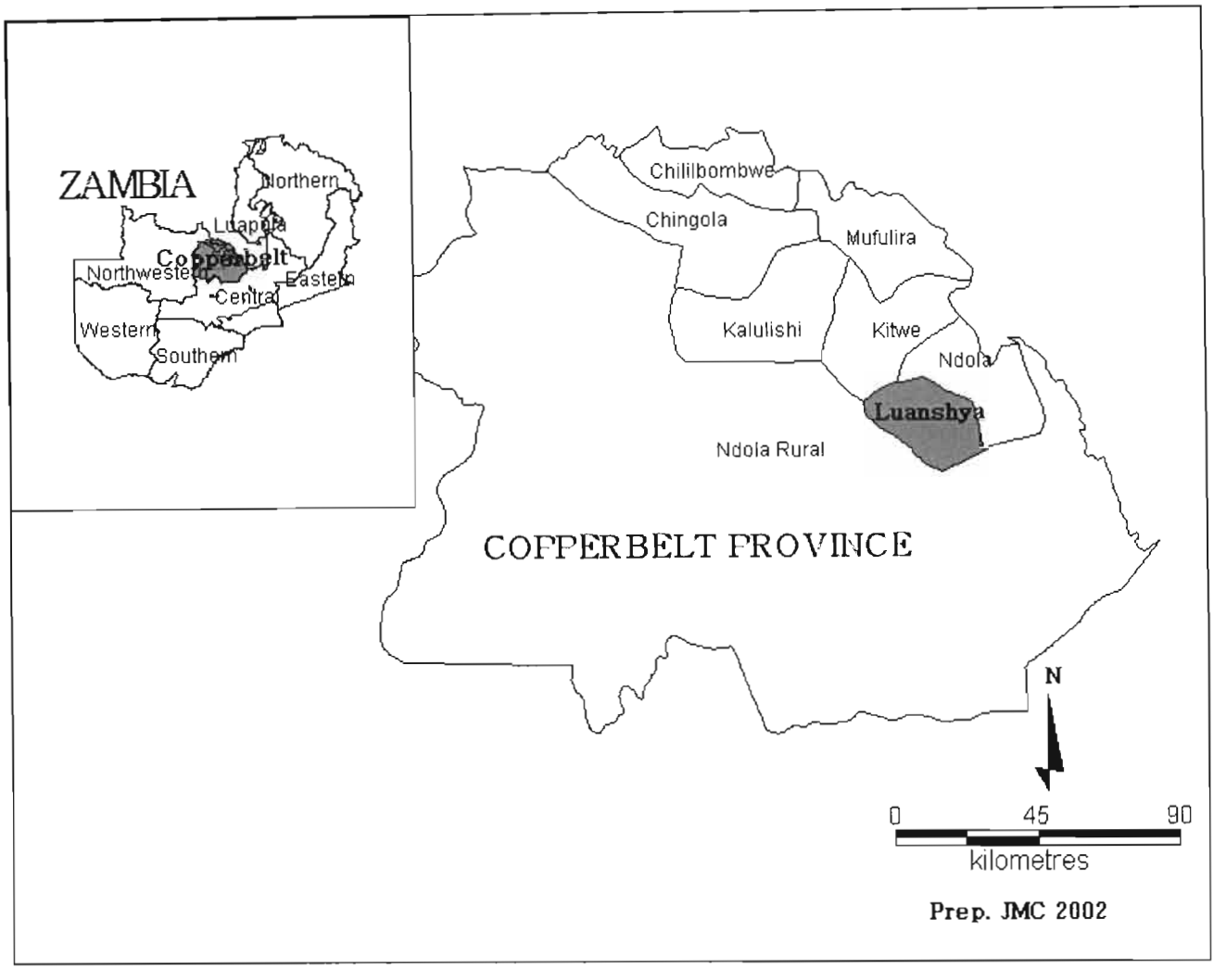


Figure 2.1. Map of Copperbelt province showing Luanshya where RACM is situated.

Trends in Malaria Epidemiology on the RACM

Prior to the formal malaria control programme on The Roan, European miners were already doing something about malaria on a personal level. They were sleeping under mosquito nets, taking quinine tablets for prophylaxis, and wore and slept in thick clothing at night. On their own, these measures were not effective at community scale, but when combined with swamp drainage, river clearing and the application of oil-based larvicides, impact was achieved at community scale (Dalzell, 1931; Watson, 1953; Utzinger *et al.*, 2001).

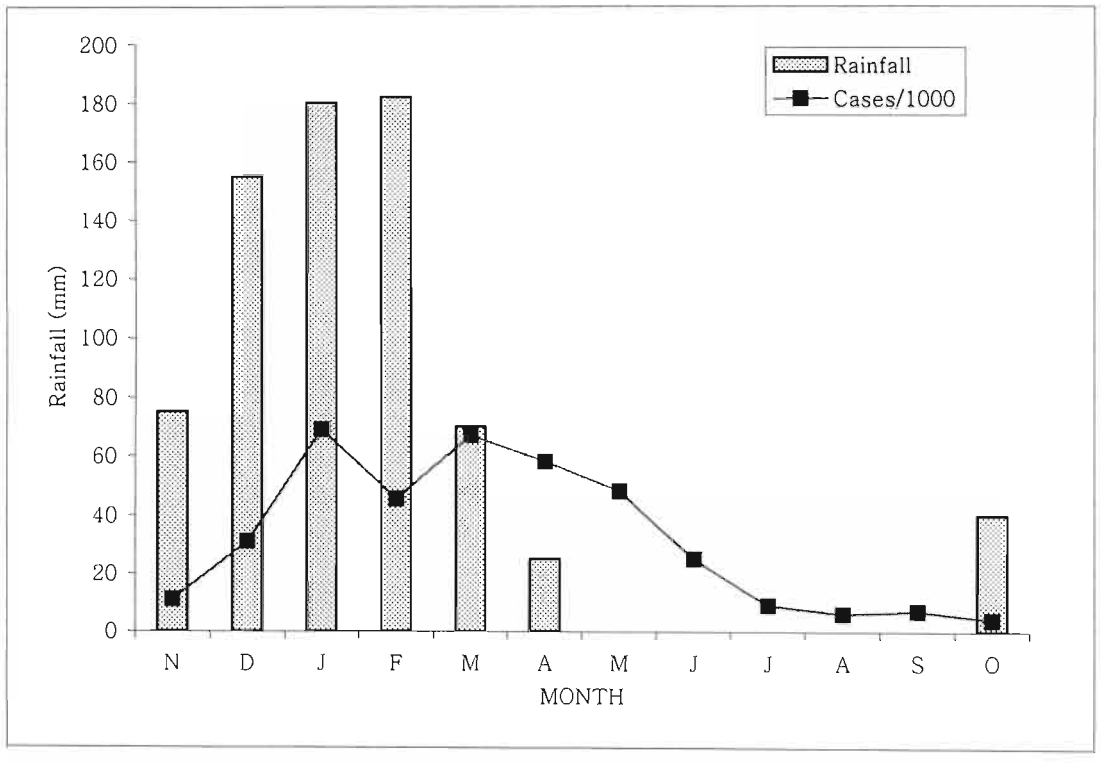


Figure 2.2. Rainfall pattern and annual malaria (Ministry of Health, 1993) incidence rate on the RACM 1942-1949 (after Watson, 1953).

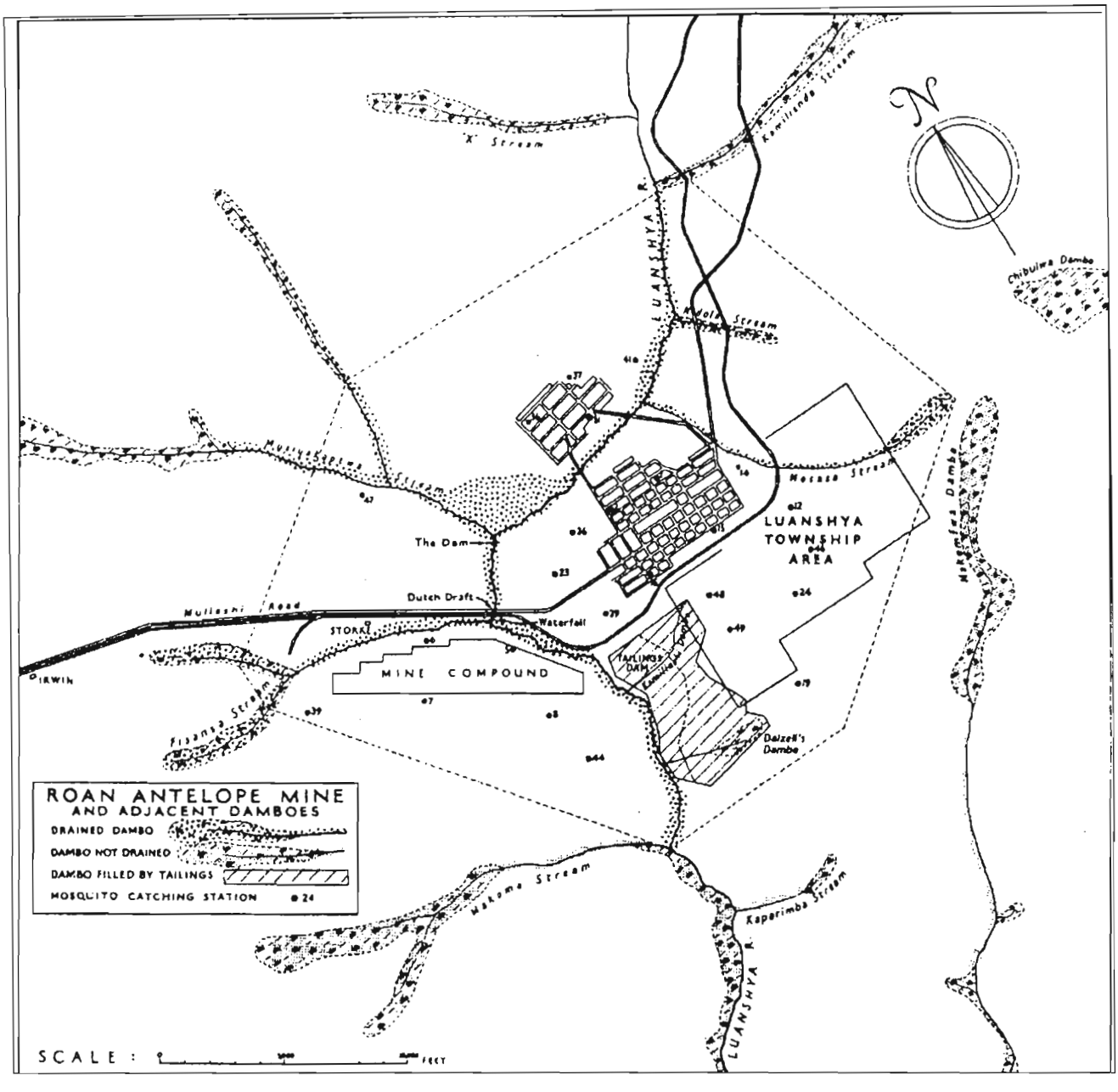


Figure 2.3. Layout of Luanshya showing Dambos in 1933 (after Watson, 1953).

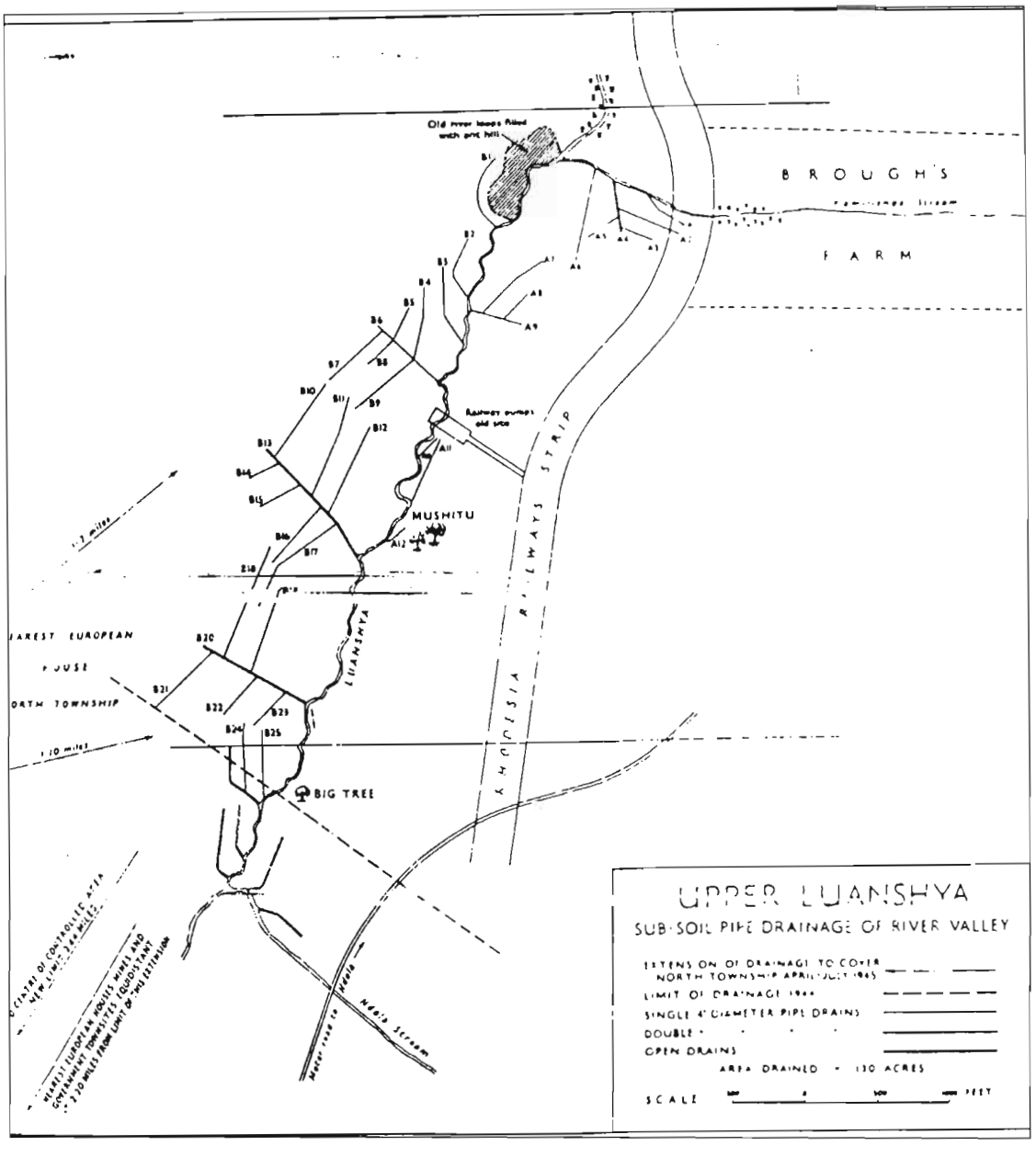


Figure 2.4. The RACM showing sub-soil drainage of the river Valley in 1933 (after Watson, 1953).

In 1931, the Times newspaper of London reported (February, 9 and 10) how the mining companies on the Copperbelt in Northern Rhodesia were making big efforts to get rid of tropical diseases such as malaria, permanently. The report also covered how money was being spent freely in ensuring that the lives of families working on the mines were safeguarded and made comfortable.

The following year (1932), the mine was advised to discontinue the application of larviciding oil to mosquito breeding sites. The advice came in the light of malaria transmission being so low on The Roan. It was considered wasteful since malaria had been virtually eliminated. Unfortunately, following this decision, malaria transmission increased in the following season from 9.0/1000 cases to 14.6/1000. Larviciding was immediately reinstated in the following malaria season (Harrison, 1932).

In the year 1933, the management of the malaria programme changed hands; Dalzell was replaced by Pyne as the malaria control officer for the RACM (Pyne, 1933). With the re-introduction of larviciding ensuring drainage and maintaining river flow through clearing vegetation (Figure 2.3 and 2.4), the malaria incidence rate in the European population once again reduced to 10.6/1000, compared to 14.6 in 1932, 19.5 in 1931 and 31.8 in 1929. The 10.6% translated into 120 individual malaria cases, of which 55% were infections occurring on the mine; the rest were imported from outside the controlled areas especially from hunting expeditions by European miners (Pyne, 1933).

The malaria efforts begun to pay dividends. The mining company was spending less on malaria prevention and case management. For example, at the start of mining operations, the mine authorities invested £4,800,000 in the business. Out of this the malaria programme from its inception in 1929 to 1935 had cost the mine a total of £33,000, averaging approximately £5,000 annually and representing only 0.7% of the total investment. In other words, less than 1% of the total investment was required to protect this capital investment when malaria is considered a social development problem in addition to being a public health one (Sachs and Malaney, 2002). An average of only one tenth of a percentage point (0.1%) per annum of the total capital investment into the mine was utilised for malaria control (Watson, 1932; Pyne, 1933). In 1938, De Meillon a renowned malariologist from the South African Institute of Medical Research visited the RAMC. He advised most of the mining operations on the Copperbelt, including the RACM, on a number of issues pertaining to malaria. He also conducted a number of entomological experiments. He carried out mark-release-recapture experiments, in which mosquitoes were re-captured 4 km away. This was an important observation, as it

proved to the mines that the 2.5 km malaria control buffer zone they had been maintaining between the controlled area and uncontrolled area, was too narrow.

De Meillon pointed out something else; that clearing of bushes around dwellings was not of any epidemiological importance to malaria prevention and control. It was not even useful for checking the flight of the mosquito while it was looking for a bloodmeal. He demonstrated this by collecting adult mosquitoes from houses whose surroundings had been cleared consistently. The mosquito collections carried out under the supervision of De Meillon showed a large number of different kinds of *Anopheles* species. At Nkana mine, he pointed out that there were up to 15 *Anopheles* species. He conducted dissections of *Anopheles* mosquitoes and reported sporozoite rates of 3% and 7% for *An. funestus* and *An. gambiae* s.l. respectively. He explained that for controlled areas, these rates were high, but not as high as in uncontrolled areas. De Meillon then advised both the mine and government on further improvements to the drainage systems by introducing hydrophilic trees such as blue gums (*Eucalyptus* spp) in water logged situations. The screening of dwellings was extended to covering domestic chimneys and public boarding facilities such as hotels (De Meillon, 1937).

Malaria-related mortality was reduced to practically zero deaths per annum in European miners. In 1938, Watson suggested the introduction of a natural plant extract to deal with household insect pests in African miners' houses (Watson, 1939). He was against the idea of Africans living in houses with concrete floors. He proposed the use of extracts from a plant called *Derris elliptica*, pointing out that since the floor of houses were not made of concrete, many pests lived there (Watson, 1939).

The malaria control officer (Pyne) carried out entomological dissections on the two vectors, *An. gambiae* s.l. and *An. funestus* and found *P. falciparum* sporozoite rates of 3% and 6%, respectively. These findings were similar to those of De Meillon at Nkana. In the same year, 1938, the RACM management passed a new decree for mine townships that were situated adjacent to rivers and other identified breeding sites. They were all required to ensure that the work force sleep under mosquito nets at night. Under this new scheme, residents could collect mosquito nets from the mine warehouses and pay for them in installments over time. Supervisors of mining teams were obliged to ensure their sections did not produce breeding sites for mosquitoes.

Watson again visited the RAMC in 1939 and developed further on points raised by De Meillon the year before. In the same year the British Prime Minister, Chamberlain shifted the 'commemoration of the Mosquito

Day' from August 20 to May 13, which was Ross' birthday in memory of his novel discovery of the life cycle of the parasite inside a mosquito (De Meillon, 1937).

The following few years were war years and the status quo was maintained until 1944 (Federation of Rhodesia and Nyasaland, 1940-1945; RACM, 1943), when the 13th Ordinance for the extermination of mosquitoes came into force. Violators were liable for prosecution. In 1945, as a test case of this ordinance, the malaria control officer issued a legally binding warning to named mine employees who were found with open water habitats on their premises. They were required to immediately comply and deal with the problem or face prosecution and subsequent fines. According to the 13th Ordinance, offenders were liable to pay for the hire of, what the Malaria Control Officer deemed sufficient competent skills to deal with the problem.

The annual malaria incidence rate rose during the war years. As would be expected during the war, there were many disruptions to the control programme. The increase was also attributed to the presence of large numbers of Polish refugees and British troops from many parts of the world. In 1944 the government for the first time imported DDT (Bulawayo Chronicle, 1945). Following the end of the war in 1945, malaria cases once again declined sharply, especially following the departure of both the troops and refugees.

In 1946, the 13th Ordinance was converted into Roan Antelope Copper Mine Township bylaw number 65 (d). It demanded that all residents exercise extreme caution with regard to keeping water reservoirs on their premises (Pyne, 1948).

In 1947 the key events on the malaria calendar were the discovery of chloroquine and the approval by the RACM of the use of DDT on mosquito screens in houses occupied by European miners. African miners were not to benefit from DDT as they were supposed to be left with "a certain amount" of malaria to help them retain their tolerance of the disease (Fisher, 1967). The malaria incidence rate fell further in 1947, to only 2.2/1000 and mortality due to malaria was once again practically nil at 0.1/1000. This situation led the Chief Medical Officer (Fisher) to note that, "following the introduction of DDT in 1946, the chance of catching malaria on the RACM was a once in a lifetime event". In the same year (1947), the Government Director of Medical Services (chief technical advisor to government on health matters) Robinson issued a statement in the Northern Rhodesia Legislative Council to the effect that DDT was not solely responsible for the dramatic reduction of malaria cases in urban areas and should therefore not take all the credit. Instead heavy rains

were responsible for the reduction. He went on to state that in fact there were better chemicals for malaria control than DDT. The Director of Medical Services in the same address stated that he saw no reason why government should take steps to protect the population against malaria (Northern Rhodesian Government, 1948). This statement dampened the spirits of all those who had worked hard at reducing malaria and were proud to be the examples of success for the British Empire. A few years following this statement, the government of Northern Rhodesia discontinued their annual subsidy to the RACM to control malaria in both the government and mine areas of Luanshya town. Also of significance in 1947 was the introduction of paludrine at RACM for use in chemoprophylaxis by European miners (Pyne, 1948).

There was a further drop in the malaria incidence in 1948 from 2.2/1000 to only 1.1/1000 (Figure 2.5). The Bulawayo Chronicle newspaper, carried an article about the success of malaria control on the Northern Rhodesia mines, quoting the RACM Board Chairman, Chester Beatty who noted that it was doubtful whether the disease (malaria) had been combated more intensely anywhere else in the world than at the RACM (Bulawayo Chronicle, 1948). In the same article, the author pointed out the lack of seriousness by the government in contrast to the shining example set by The Roan (an apparent reference to the Director of Medical Service's address to the Legislative Council the previous year).

In 1949, Martin reviewed the consequences of introducing insecticides in public health and agriculture, and discussed the possible appearance of resistance to DDT, as had been observed in houseflies elsewhere (Martin, 1949). He proposed an insecticide rotation as a possible way to prevent resistance from developing. The mines immediately introduced gammatox for residual application onto house screens in rotation with DDT.

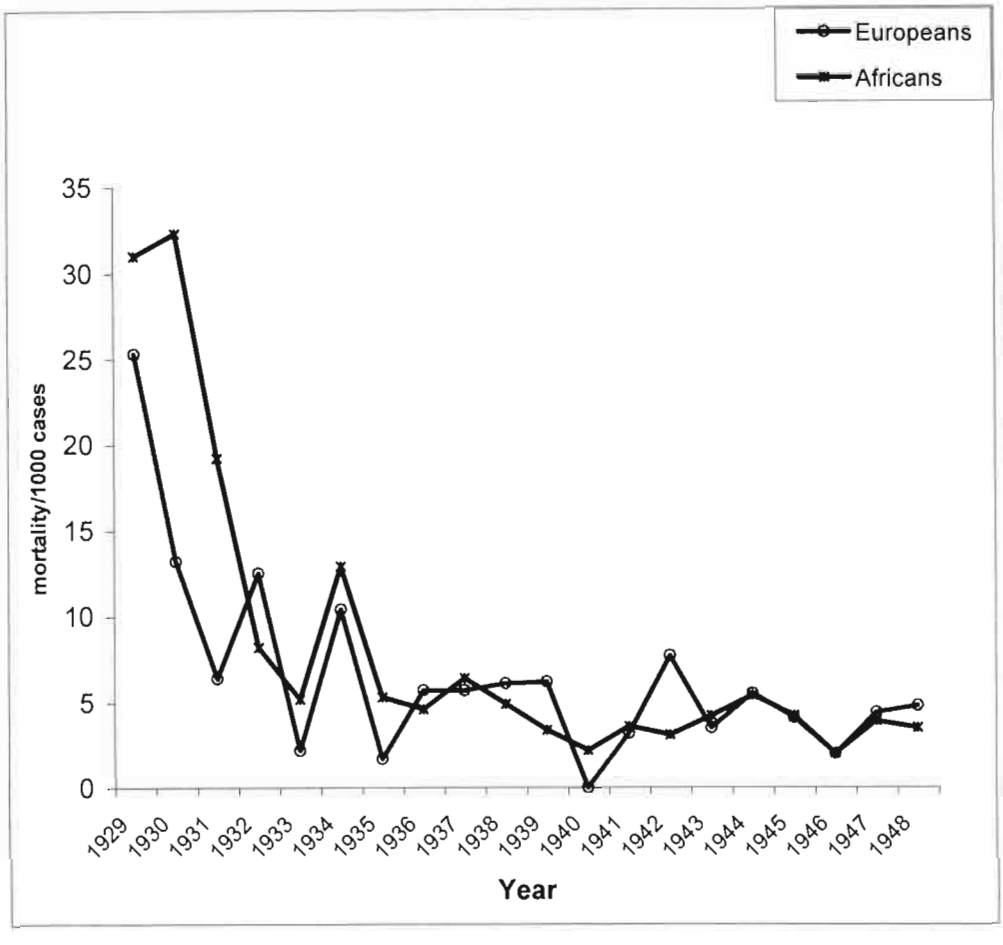


Figure 2.5. Annual malaria mortality rate on the Roan (after Watson, 1953).

The annual malaria mortality rate was maintained at a low level of approximately 2-3 deaths per 1000 population (Figure 2.5). The Northern Rhodesia Government adopted the Roan Antelope Copper Mine Township byelaw number 65 (d) as law. It became Chapter 537 of the laws of Northern Rhodesia, known as the Extermination of Mosquitoes Act, of 1944 and was reviewed in 1945, 1949, 1963 and 1966. During this period, only two Government statutory notices were issued under it, both in 1964 (Government of the Republic of Zambia, 1966).

Following the formation of the Federation of Rhodesia and Nyasaland in 1958, the federal ministry of health requested Northern Rhodesia to abandon anti-larval measures and concentrate instead on anti-adult indoor residual spraying, perhaps based on the work of De Meillon in South Africa in 1936. South Africa itself only abandoned anti-larval measures in 1956 (Sharp *et al.*, 1988). The federal government also withdrew prophylaxis from Africans, as they were considered immune to malaria. The federal government also proposed that Northern Rhodesia

should synchronise and co-ordinate all indoor residual spraying programmes undertaken by the mines, the local councils and the Federal Ministry of Health with the other members of the Federation (Federation of Rhodesia and Nyasaland, 1944).

In 1962, Rodger wrote how the success story of malaria control at the RACM had attracted the attention of experts from southern Africa, and how they came to study the control methods and later went to apply them widely in their own countries. For some unclear reasons, the Federal Ministry of Local Government, Housing and Social Welfare repealed the Extermination of Mosquitoes Ordinance in 1962. It also withdrew the 50% grant it was providing to the mines to carry out malaria control work on its behalf in government compounds situated in mining towns. It replaced it with another ordinance which recognized indoor application of residual insecticides as the only means of malaria control. The government then proposed to reinstate the 50% subsidy to the mines for malaria control provided they (the mines) adopted the new law and abandoned larviciding and drainage management. RACM considered this as undermining their efforts and lodged an official complaint with the government. Pointing out that without regular attention to breeding places, mosquitoes would increase and eventually develop resistance to insecticides. They further noted that the country as a whole did not have sufficiently developed health services, and therefore, could not carry out spraying programmes properly (Rodger, 1967).

Regrettably, the successes in malaria control achieved by the mines were not replicated to the rest of the country, especially the rural areas. Only case management was introduced throughout the country. The main reason being, the government did not adopt a steady policy on malaria control. The changes in national administrations from Northern Rhodesia, to the Federation of two Rhodesias and Nyasaland, to independent Zambia, did not help matters. Malaria trends continued to rise and this was further compounded by the unreliable government health information system, which was using reports from only seven hospitals to represent the whole country. Due to population segregation policies, malaria morbidity and mortality in each race was reported separately. It is not clear from available records what denominators were employed to determine malaria rates in the population. In some cases actual numbers were reported, in which case the population size needs to be known to compute both incidence and case fatality rates. However, Figure 2.6 is a graphic representation of actual mortality reported in health facilities outside The Roan, based on Watson's (1953) work (Federation of Rhodesia and

Nyasaland, (1940-1945); Northern Rhodesian Government, 1948; Government of the Republic of Zambia, 1967).

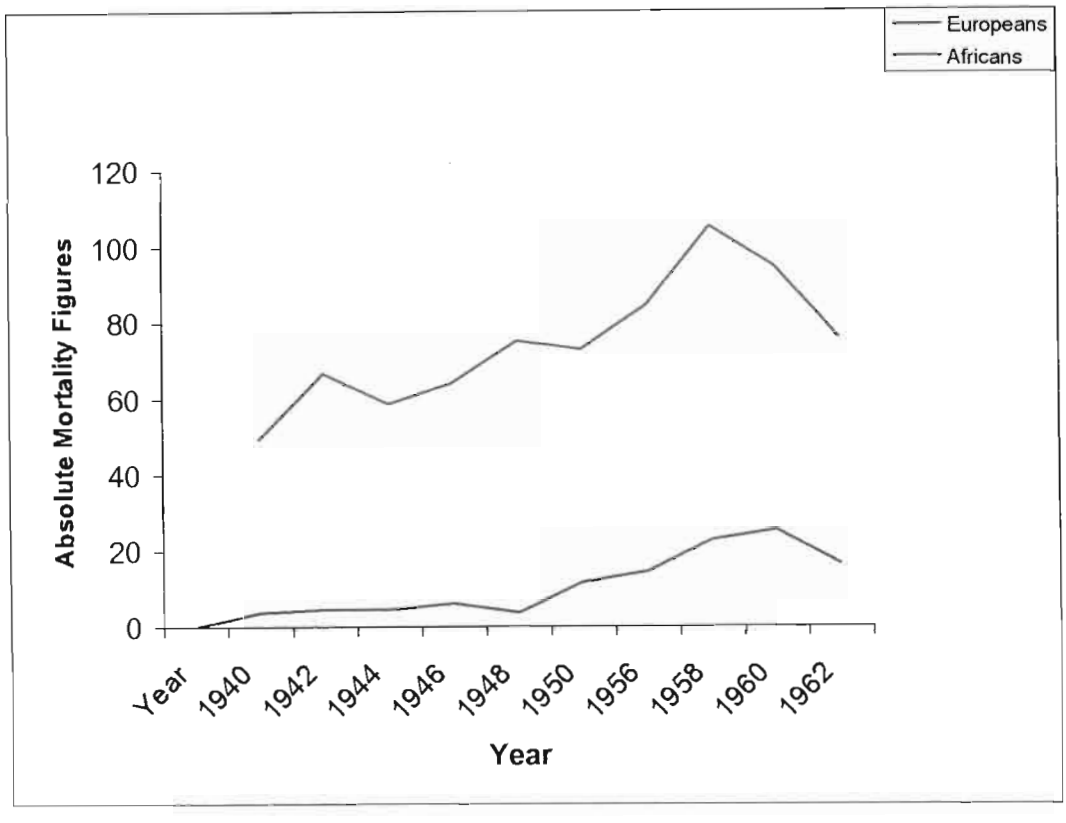


Figure 2.6. Malaria (actual) annual mortality outside The Roan based on Watson's (1953) data.

The break up of the Federation of Rhodesia and Nyasaland occurred in 1963 and in the following year, Northern Rhodesia became a state (Zambia) independent from British rule. The RACM remained in private hands and the malaria programme continued to function well for the next four years. The year 1968 was a milestone in that RACM was nationalized together with all other copper mines. They fell under direct government control through an umbrella body, the Zambia Consolidated Copper Mines (ZCCM). The RACM could only be distinguished as the Luanshya division of ZCCM (Government of the Republic of Zambia, 1969).

Relevant to the RACM, in 1968, the malaria programme replaced DDT with BHC or Dieldrin. The RACM also abandoned residual spraying and reverted back to species sanitation through environmental manipulation and once again relied only on anti-larval measures as had been the case at the start of mining operations in 1929. In 1969, the same

year, the government constituted the Malaria Research Laboratory (MRL) as the central government organ to coordinate and provide technical support to malaria control operations on the ground (Government of the Republic of Zambia, 1968). For a decade post-independence, malaria was practically eliminated from the townships on the Copperbelt, including the RACM. In addition, other towns outside Copperbelt province had instituted their own malaria programmes through residual spraying with DDT, and their achievements were just as impressive. Only one case of malaria was notified in 1975 at RACM, and this particular case was infected outside the mine area. However, the following year (1976) recorded 13 malaria cases. Although this rise was attributed to imported cases, it was probable that they were in fact locally transmitted (Zambia Consolidated Copper Mines, 1967).

Parallel to the above, the district administrative boundaries of Luanshya were also changing over time, consequently affecting population denominators for computing malaria case indices. Prior to 1964 malaria cases were recorded separately for Europeans and Africans. Eventually Asians and other races were also included and following political independence in 1964, the denominator changed again, and malaria was recorded for all races (Government of the Republic of Zambia, 1966, 1967). Nevertheless, the copper mines maintained their reporting system separate from government. With such unstable denominators it was not possible to compare malaria cases over a long period across all racial groups.

In the case of Africans, early records are unreliable because of the high turnover of this population. The mine maintained an open labour policy for this race group. They could leave employment and get re-employed as they wished. They traveled freely between their rural homes and the mines, which were often in different malaria endemicity strata, with considerably higher transmission rates outside the mine. These population movements made it difficult to follow up malaria cases and even to accurately notify. Despite this, the Africans who worked on the mines, particularly at RACM, were well catered for in terms of malaria prevention and control (Watson, 1953).

Residual insecticide spraying was reinstated in the late 1970s, but was not as successful as it had been before. For example in 1982, the Luanshya division could only manage 58% during the first and 72% coverage second annual spraying cycles, respectively. However, the original drainage system of the early 1930s, which by this time was protected with concrete, continued to function well and was still being regularly maintained. After a period of about 30 years, a confirmed

malaria death was once again recorded in Luanshya in 1984. In the same year, two rounds of residual spraying were performed at the start and end of the rainy season. Coverage was raised to 73% and 83%, for first and second round spraying cycles, respectively (Government of the Republic of Zambia, 1972).

Another milestone during 1984 was the approval of sub-contracting of drainage clearance to private contractors by mine authorities. Between 1986 and 1989 the residual spraying programme included both government and mine townships, as had been the case prior to 1962. It was conducted twice a year with coverage reaching 93%. The last residual spraying round was carried out in the first quarter of 1994, and at the time Luanshya division of ZCCM was once again due for privatisation.

Discussion

The foregoing account outlines how one of the copper mines in Zambia managed successfully to decrease and maintain low levels of malaria incidence, which resulted in substantial reductions in disease burden in a high malaria transmission situation, albeit on a relatively small scale.

When mining operations started in Northern Rhodesia, it was soon realized that diseases like malaria, dysentery and pneumonia were serious threats to their operations. However, it was malaria, with its complication of black water fever cerebral disease and high mortality, which was the main scourge. It was responsible for more than 50% of the mortality among the European work force. Although there are no accurate records, it would seem Africans working on the mine were also to a large extent affected by malaria. This may explain why on seeing their friends going down with malaria, many deserted employment, believing there was a curse on The Roan.

However, following the introduction of malaria control measures in 1929, not only did the number of deaths due to malaria drop dramatically, but also those from other causes, such as dysentery, diarrhoea, anemia, kidney disease, abscesses and convulsions in children. All-cause mortality reduction was observed within the first season (1929/1930) of introducing malaria control measures in RACM. This is one of the few examples globally where malaria was virtually eliminated in a hyperendemic situation. It was reduced using a combination of residual spraying and environmental control. During the malaria eradication era in the 1950 and 1960s, it was not considered feasible to control malaria in

places with high transmission intensities (Hammer, 1993; Sharp, 1990; Sharp and le Sueur, 1996; Bradley, 1994; Sachs and Malaney 2002).

On the copper mines of Northern Rhodesia, experts from the Ross Institute found and identified two of Africa's most efficient vectors of malaria and immediately instituted control measures against them. They found *An. gambiae* s.l. Giles and *An. funestus* s.l. Giles. *Anopheles gambiae* s.l. Giles, because of its ubiquitous breeding sites, proved a formidable problem especially in an area with 1000-1500 mm rainfall annually spread over six months. The situation was compounded by the fact that this was a mining operation in which large quantities of clean underground water were pumped to the surface as part of the core business. The second species *An. funestus*, bred in more permanent water bodies, such as the margins of streams and swamps from which the mine drew its water supply, i.e. the Luanshya stream (Figure 2.3 and 2.4). It was relatively easy to eliminate this species.

The common practice was to start malaria control operations without evidence as to the specific species confronting the programme. There are some examples in Africa where indoor residual spraying programmes targeted exophilic species, with disastrous consequences (Watson, 1953; Coetzee *et al.*, 2000). Such operations undermine the credibility of good malaria interventions in the eyes of policy makers, resulting in the relegation of malaria control to the lowest priority.

Sir Malcolm Watson wrote in 1932 that malaria was a great disabling and lethal disease in the tropics. Its control was the only solid foundation upon which other preventive measures could be built. As early as these times it was realized that successful malaria control needed special skills, without which a medical officer was bound to fail. Yet over the years, the special skills in malaria control that had been cultivated from the time of Ross in the 1900s to the end of the eradication campaign in 1969 have been lost in most countries and regions (Sharp, 1990). Staff with inadequate skills ended up in charge of running malaria programmes. It should be noted that malariology is an exact science and therefore requires specific skills and experience.

A number of global public health initiatives have had lasting impact on malaria control globally. Examples include: malaria eradication; Primary Health Care; Integrated Health Services; decentralisation of health services; The African Initiative on Malaria; Harare and Abuja Declarations and more recently the social movement to Roll Back Malaria (Organisation of African Unity, 1997; Hill *et al.*, 2000; WHO, 2000).

Firstly, Primary Health Care faced difficulties in realizing its targets in sub-Saharan Africa because the health sector and other community

structures were not sufficiently strong to support the principles. Malaria was tackled through identification of the disease, provision of first line drugs and possibly referral of patients to the next level. In addition, there was chloroquine mass drug administration programme through primary schools. This contributed to increased drug pressure, which resulted in chloroquine losing its efficacy through development of drug resistance. The community under the supervision of the community health worker was to drain swamps and carry out application of larvicides and adulticiding, just as Harrison did on the RAMC from 1929. The only difference is that Harrison was a university graduate with several years of experience in Malaya and elsewhere on environmental and water management.

Secondly, Roll Back Malaria seems to be repeating the PHC principle where the role a qualified frontline technician in malaria control is trivialised. For RBM to succeed it would take a vertical military-type operation led by experienced malariologists to achieve the type of results envisaged by the social movement to roll back malaria.

Thirdly, the latest addition to official global declarations the Abuja Declaration (WHO, 2000) on malaria, probably failed before it had even begun. It is simply a statement borrowed from the 1978 Alma Ata Declaration dealing with malaria in a social movement, with unrealistic targets of health for all by 2000 (WHO, 1978). This time however, it proposes to halve transmission in 10 years. Three years have passed since the count down began. By the year 2003, there is no country in sub-Saharan Africa on the path to the realisation of Abuja targets. It took Harrison and his team a single transmission season to reduce malaria at The Roan mine by more than 50%. These global pronouncements on malaria appear too simplistic and provide evidence of global inertia in ridding Africa of malaria.

Even at country level the importance of controlling malaria is not always recognised as a priority by national authorities. To begin with, it is known by malariologists that if malaria is controlled, other diseases may also be controlled. This was in fact the case at The Roan in 1929 as stated earlier. Secondly, a situation where malaria is controlled represents a rubric within which economic development can take place. The authorities of the Roan proved this and it is illustrated by the decisions taken by the Northern Rhodesia government over the RACM malaria programme. In 1947, the government Director of Medical Services solely declared that DDT was not very important in the reduction of cases of malaria. It is not clear from the records what could have led to this statement. However, this statement had major implications for the

maintenance of a perfectly functional and successful malaria programme. Later in 1958, possibly based on advice from the same office, the government reversed on this position. The RACM was ordered to abandon anti-larval measures that had worked well in reducing malaria, and to replace them with DDT residual spraying alone, not-withstanding the fact that the two measures compliment each other.

The government made statements to the effect that it was not their responsibility to carry out malaria control for the population. The federal government requested RACM to stop supporting the government side of the town. This decision was reversed again by the (Zambian) Government which requested mines to re-introduce residual spraying across the whole town in 1974.

In the 19th century malaria was still prevalent in Europe just like in Africa and it took massive efforts to deal with the problem. Reasons have been given above why it was not possible to eradicate malaria out of sub-Saharan Africa. The result was a decision to control malaria through case management through Primary Health Care (WHO, 1978), has been shown to have reduced neither incidence nor mortality due to malaria.

In some circles blame for the failure of malaria eradication is placed on the behaviour of the affected communities as the reason why malaria could not be eradicated in Africa. Prothero (1965) stated that it was not possible to set up any successful malaria programmes in Africa because population movements were going to bedevil it. However, Africa, pilot eradication projects conducted in Cameroon, Liberia and Uganda, all proved that malaria could be controlled, just as in other parts of the world. Recently, evidence has been provided that malaria keeps Africa poor and not vice versa (Breman, 2001; Breman *et al.*, 2001; Gallup and Sachs, 2001).

One might ask whether malaria elimination or economic development should come first. It is common knowledge that malaria is a preventable and treatable disease and in the light of what is currently known, "malaria in the population is no longer excusable", wrote Harrison (1936). It was demonstrated as early as 1929 (Watson, 1953) that once malaria has been controlled, the impact of other common childhood diseases is also reduced. The same was proven again in the 1990s using ITNs (Lengeler, 1998). Where large-scale ITN trials have been carried out, a reduction in malaria mortality coupled with an all-cause mortality reduction (albeit difficult to quantify), has been demonstrated (Alonso *et al.*, 1991; Binka *et al.*, 1996; Nevill *et al.*, 1996).

The philosophical framework within which malaria was dealt with on The Roan was the principle of protecting the mining investment. There

was in the real sense, no racial divide in the application of interventions. On the contrary, rational decisions were made on the basis of the best available knowledge and tools at the time. It was true that adult Africans were more tolerant of the disease and preserving their tolerance to malaria was a positive factor. It assisted many of them to retire back in their villages, without which they could have been victims of the "rebound effect" (Lengeler, 1998).

The mine authorities could not have known at that time that malaria was a heterogeneous disease and within the African labour population, there were different levels of immunity as well. The fact that African miners came from further afield as South Africa and Kenya with a whole range in between, meant some of them got unfortunate treatment on the mine when they were "allowed to keep some malaria" (Craig *et al.*, 1999). The question of distribution of malaria is dealt with in Chapter Four of this study. It should be noted that, while the European population spent most of its time on the mine, this was not the case with African miners. The African miner moved back and forth between the mines and their rural homes. Had their immunity been completely eliminated through limited exposure to malaria challenge, it could have increased mortality in miners returning to their traditional homes.

The Africans on The Roan benefited as much as their European counterparts from these malaria control measures, although at different levels. The main reason for the separation of reporting formats was because the African worker population was highly mobile and thus made tracking malaria cases difficult.

Watson (1939) noted (talking about an African child born on the mine) that health in the future for the child would depend on the "stamina vitae woven in childhood". What the mines had done over half a century of malaria control was to give sound health to African children, to lay a solid foundation of health, which they could not have acquired in their villages. If later they were exposed to unhealthy situations, they should show greater resilience. It was the greatest gift to Africans on the mines. For their European counterparts, the conditions created on the mine made it possible for miners to live without worrying about bringing their families to live with them on The Roan. The mines were then able to recruit and retain highly skilled workers from the world market and avoided frequent changes in management.

Rodger (1967), wrote that those who lived in the attractive little town of Luanshya, which had all the amenities one could expect in a modern community, found it hard to remember or visualize the amount of planning, effort and expense which had gone into creating it. The older inhabitants

had seen the steady improvements in housing standards, gradual increase in tarred roads, planting of more shrubs, trees and lawns, and laying out of bigger and better facilities, but few had been aware of the unseen but continuous struggle to control disease and to safeguard more effectively the community's health.

Chapter Three: Health Systems Development in Zambia

Introduction

Access to health services is one of the fundamental and basic human rights. Where the community cannot afford this right, the state should make at least the basic form of it accessible to the poorest of the poor. Public health cannot therefore be privatized and be left to market forces, especially in developing countries. It is an acknowledged fact that improved health status of a population is directly related to its children's ability to learn and later in life to become economically productive citizens. It also adds to efforts aimed at breaking up the vicious cycle of poverty and this is a priority for sub-Saharan Africa. There is a direct relationship between malaria and poverty, each being responsible for the other.

Before an individual decides to use a health service, they first have to perceive the need for it. Then the appropriate service has to be available within a reasonable distance and time, and the consumer has to deem the service acceptable. The consumer has to have confidence in the service and finally the person should possess the means to obtain the service in terms of cost and the type of illness. Whether or not a person seeks care at a particular facility is also determined by factors like the type of facility, the number and type of providers, the volume and distribution of services in the area, and the way they are organised.

Within the framework of a basic needs approach to human development, the criterion for universally acceptable standard of health care is access to basic health care. This basic service is defined by the United Nations Children's Fund (UNICEF) as "the proportion of the population with access to services using locally available means of transportation, within an hour" (Grant, 1988). WHO defines adequate access to health services to be within half an hour traveling time between the household and the nearest health facility (Kasonde and Martin, 1994). It also recommends an average of 10,000 people to be served by a single health facility (Chetty, 1995). The government of Zambia in its health policy has set a standard of 12km as the furthest a household should cover to access a health service in a rural area and 5km for an urban area.

This access to basic services approach was at one point seen as the key to achieving acceptable levels of health care throughout the world.

Access was especially poor in low resource countries (WHO, 1978; Chapman & Gouws, 1991; Kasonde and Martin, 1994; Tanser, 2000).

Following the abandonment of the malaria eradication campaign and the withdrawal of WHO support from it in 1969 (Sharp 1990), the global strategy shifted to mortality prevention and mitigation through clinical services. To this effect, PHC was introduced under the Alma-Ata Declaration in 1978 (Kasonde and Martin, 1994). Following this Declaration, community-based provision of health services became popular. However, evaluations of PHC have shown it not to have been effective in realizing its main objective of lessening childhood mortality in comparison to disease specific interventions or vertical programmes prior to it (WHO, 1978; Hill *et al.*, 2000).

After fifteen years of PHC, it was realized that malaria was killing more people than before. The Amsterdam Conference of 1992 was organized to map out a new way forward for malaria control. This conference adopted a global malaria control strategy based on a number of technical elements: early diagnosis and treatment; selective malaria prevention, including vector control; prevention of epidemics and strengthening local capacities for evidence building (WHO, 1993). For malaria-endemic countries, the goal was to prevent mortality and minimise morbidity and economic loses due to malaria. In malaria-free places, the goal was to maintain the status quo. Malaria control was to be an integral part of national health system development and part of the national development agenda. Partnership was also recognised as an essential element for the success of these strategies.

The conference noted that there were enough tools globally with which to realize these strategies. Special emphasis was to be placed on remote rural areas (Ghebreyesus *et al.*, 1999), where poverty is greatest, population densities are low, and the quality and coverage of services is poor (WHO, 1993; Trigg and Wernsdorfer, 1999).

The next milestone in the history of malaria control following PHC was the signing of the Harare Declaration by African heads of state and governments in 1997. They declared malaria a developmental issue. Malaria deserved to be paid serious attention, if African economic recovery and poverty alleviation were to be achieved (OAU, 1997). Following the Harare Declaration, the global response through the World Health Organization was to establish the African Initiative on Malaria, which eventually resulted in attempts at baseline data collection from some sites in some countries.

Recognising that the African political leadership was taking malaria seriously, the global forum supported this by forming the social movement

of Roll Back Malaria (RBM) in 1997 (WHO, 1998). It adopted the strategic framework of the 1992 Amsterdam Conference (WHO, 1993). It also borrowed community-based action, partnership and social economic development from the Harare Declaration (OAU, 1997) and intra- and inter-sectoral collaboration from PHC. These elements form the pillars of the societal movement to Roll Back Malaria out of Africa (WHO, 1998).

RBM offered itself as a pathfinder in the development of general health services in malaria endemic countries. RBM has been defined as a social movement made up of partners like governments, developmental organizations, private institutions, media and research institutions. It encourages affected countries to work through social mobilization, inter-sectoral action and human development initiatives. The host government plays the leadership role of coordinating the actions of partners. Commercial partners are seen as extensions of the national strategy and not as competitors. RBM aims at cutting the current global malaria burden in half by the year 2010 (WHO, 1998; Breman, 2001; Breman *et al.*, 2001). Further reductions are aimed at 50% installments at five-year intervals (Nabarro, 1999). The principle is to utilize scientifically proven interventions, locally effective and acceptable to the affected community (Snow *et al.*, 1998; Sachs and Malaney, 2002).

It is assumed that households would know what to do with fever cases at home and reach health service support within 30 minutes from the time of on-set of malaria danger signs. Pregnant women and other vulnerable populations will be protected from severe malaria through effective intermittent presumptive therapy and chemoprophylaxis (Goodman *et al.*, 2001; Steketee *et al.*, 2001). Households, especially children and pregnant women, will be shielded from vectors through Indoor Residual Spraying (including, but not limited to DDT) and insecticide treated materials or environmental protection. Malaria epidemic-prone localities will introduce simple field-based early warning and response systems to either prevent or combat epidemics (WHO, 1993; Nabarro, 1999; Sachs and Malaney, 2002).

In support of the RBM movement, African Heads of State and governments met in Abuja, Nigeria, in April 2000. They appended their signatures to the Abuja Declaration on RBM. They committed themselves and their countries to the core principles and frameworks of Roll Back Malaria. Essential elements of the declaration bind the signatories to recognise that malaria places disease and economic burden on hundreds of millions of Africa's poor people. It constitutes one of the major barriers to socio-economic development and is a major catalyst of Africa's poverty

(WHO, 1998; WHO, 2000; Gallup and Sachs 2001; Sachs and Malaney 2002;).

The Zambian Government is committed to providing its population with equitable access to quality-assured health services close to the family and to the ideals of RBM. Through this principle, timely access to health services is *sine qua non* of implementation. By creating an enabling environment, the government hopes empower an individual or family to take adequate action in relation to poor health.

Following political independence in 1964, the country's long-term prospects for economic development appeared promising. Zambia assumed responsibility for the health portfolio which hitherto had been operated by the colonial government and missionaries. The aim was to embark on a programme of making health services universally accessible to the population, especially in rural areas. This worked well until the late 1970s. Hospitals increased by 81% and smaller health facilities (urban clinics and rural health centres) increased by 64% during the same period. Twenty years after independence, 75% of the population was living within a 12km radius of health facilities. The entire urban population and 50% of the rural population were living within a 12 km radius of a health facility (Ministry of Health, 1984). About this time, the nation started experiencing serious economic constraints, as a result of poor performance of the economy. This led to a crisis that over a 20-year period resulted in the general dilapidation and collapse of infrastructure, a scarcity of essential drugs, a shortage of qualified personnel and general dissatisfaction by the consumers in the health services (Ministry of Health, 1990).

With a change in government in 1991, a new vision for provision of health services was formulated: "To provide Zambians with equity of access to cost-effective quality-assured health services as close to the family as possible" (Ministry of Health, 1990). The health sector reform programme for Zambia was designed on the principle of sustainability and purposeful change to improve efficiency, equity and effectiveness of the sector.

Malaria remains one of the most significant health problems in the country, accounting for 20-30% of hospital admissions, with a case fatality rate of 75/1000 malaria admissions. It accounts for 33% of all outpatient attendances. Nearly 50% of all malaria admissions and deaths occur in children under the age of five years. Parasite resistance to chloroquine has reached unprecedented levels exceeding 75% in some areas.

While government policy is clear on acceptable levels of equity of access to services, it does not disclose how much has been realized. The

present study is a pioneering study seeking to assess spatially the adequacy of health service accessing in relation to population distribution in Zambia. The study analyses available data in relation to existing national policy and to specific global declarations. The study also provides critical commentary and suggestions for future planning and priority setting. The study specifically aims to collate data on the spatial distribution of public health facilities in Zambia, analyse this information in a GIS environment and make recommendations to address the resultant imbalances.

Methodology

To quantify access to health services by the population, public health facilities in Zambia were geo-positioned and mapped. Facilities proposed but not completed by 1998 together with those classified as health posts or dispensaries were not included in the analysis (Ministry of Health, 2000). The population is divided into sub-district structures called constituencies. Constituencies are not official administrative units, but rather political ones. The population to health facility ratio is employed as a measure of adequacy and quality of service. The ratio is estimated for each constituency by dividing its population by the number of health facilities within its boundaries. For the purpose of this study, it was assumed that people attend the nearest health facility and both health facilities and population are evenly distributed, although in both cases this may not be the case depending on whether the place is urban or rural; the attitude of the staff, availability of certain services, denominational preferences etc. It is possible for people to attend a facility in another constituency, district or province, as a matter of proximity or preference. By the same token this will tend to equalize consumption of services (Zwarenstein *et al.*, 1991; Chetty, 1995).

The Ministry of Health facility placement register was the main source of data, although it had not been updated since 1989. Apart from the government, other major providers of health services in the country including The Churches Health Association of Zambia (CHAZ), the Zambia Flying Doctor Service and the Mining Conglomerate. Approximately 80% of facilities were geo-positioned using GeoName and GeoNet components of the Africa Data Sampler® (World Resource Institute, 1995). Of the remaining 20%, a further 12.5% were physically positioned using hand-held Global Position System® units (Trimble Geo Explorer II). The remainder (7.5%) were positioned using paper maps from the Health Information Unit of the Ministry of Health. Several discrepancies were

noted with regard to new health posts and facilities. Some institutions listed as under-construction would have been completed and in some places the catchment population would have changed considerably. All facility lists were verified by District Health staff for completeness and approximate position of facilities, as well as new constructions and services. The verification process faced some problems, as health staff were often not sure about the exact number and location of some health facilities in their catchment areas in relation to the district centre. Population data were obtained from the 2000 national census based on constituency basis (Central Statistics Office, 2000).

This study represents the first time that health facility information in Zambia has been digitised. Data were entered into an Access database (Microsoft Access® 2000) and later exported to MapInfo® 6.5 for analysis in Database IV format. Inconsistencies in coordinates and names were verified and corrected. Facilities situated less than 5 km apart were treated as the same facility.

The parliamentary constituency was the lowest level at which the health facility data layer was created and the base map was obtained from the Electoral Commission of Zambia at 1:1,500,000, scale (Government Printer, 1991). This was digitized at the Geographical Information System (GIS) Centre (Malaria Research Programme) of the South African Medical Research Council, Durban and exported to MapInfo® in 2001.

Health centre catchment population was determined by assuming uniform distribution of the population in a constituency. Where multiple health facilities were found in a single constituency, they shared the consumer population equally. The best fit of the population to facilities was estimated using computer-generated Thiessen polygons. These polygons represented hypothetical "catchment areas" which are the best artificial estimate of consumer location in relation to other nearby health facilities (Illing, 1994). Theissen polygons or regions were created using the vertical mapper function of MapInfo® from points created by geo-location of health facilities in the country, using the Delaunay Triangulation method (Eastman, 1999). The method is based on building natural neighbourhoods around data points, resulting in a network of regions called Thiessen polygons, a collection of which forms a Voronoi diagram. The computation draws an area around a point where any location within the area will always be nearer to its enclosed point than the enclosed point of any other region. A dividing line is drawn equidistant between two points (health facilities). This line equally bisects catchment populations between the two concerned facilities. The health

facility included in the polygon is the closest one using the line-of-sight distance (Zwarenstein *et al.*, 1991; le Sueur *et al.*, 1997).

Using the 2000 national census data at constituency level, populations assigned to constituencies were apportioned equally to each Thiessen polygon; the common denominator being that each area exerted a natural influence over adjacent sites. Using natural neighbourhood analysis, the area of each Thiessen polygon was computed in square metres and using the assigned "catchment" population, the population density was computed. The resulting population was analysed using surface interpolation statistics to generate a new continuous population density surface.

To determine the area of the country within specific distances of health facilities, the total surface area of the country was used as the denominator. Ring buffers were thrown around each health facility at 5, 10 and 30 km distances. The first two distance measurements were selected on the basis of national policy for urban and rural populations respectively, while 30km was arrived at by considering a half-day's walk to the nearest facility at the speed of 5km/hour. This provided a proxy indicator of the proportion of the vulnerable population living within 30 minutes' travel time of a health facility (le Sueur *et al.*, 1997; Ministry of Health, 2000).

Since the study was examining access of households to the nearest (and therefore first) health service assistance, health facilities were treated uniformly as PHC facilities, because all levels of health care in Zambia, from tertiary to health post, provide outpatient services for common illnesses including malaria. Although PHC goes beyond fixed health facilities, for the purpose of this analysis only static facilities are included. This is based on the assumption that the existing community-based provider system (Community Health Worker) has in all respects collapsed as a result of lack of incentives for this cadre (Kasonde and Martin, 1994; Chetty, 1995; Ghebreyesus *et al.*, 1999).

Results

A map of the constituencies of Zambia was used as the base map within which both health facilities and population distribution were plotted. There were 144 constituencies that were originally designated using criteria such as population density, distance from district centres, presence of a traditional ruler, schools and other infrastructure. Figure 3.1 shows the constituency map of Zambia overlaid on district boundaries, the next highest administrative structure. On average, there were three

constituencies per district (range 1-7). Seven hundred and eighty health facilities were digitized and mapped with constituency boundaries as shown in Figure 3.1 and 3.2.

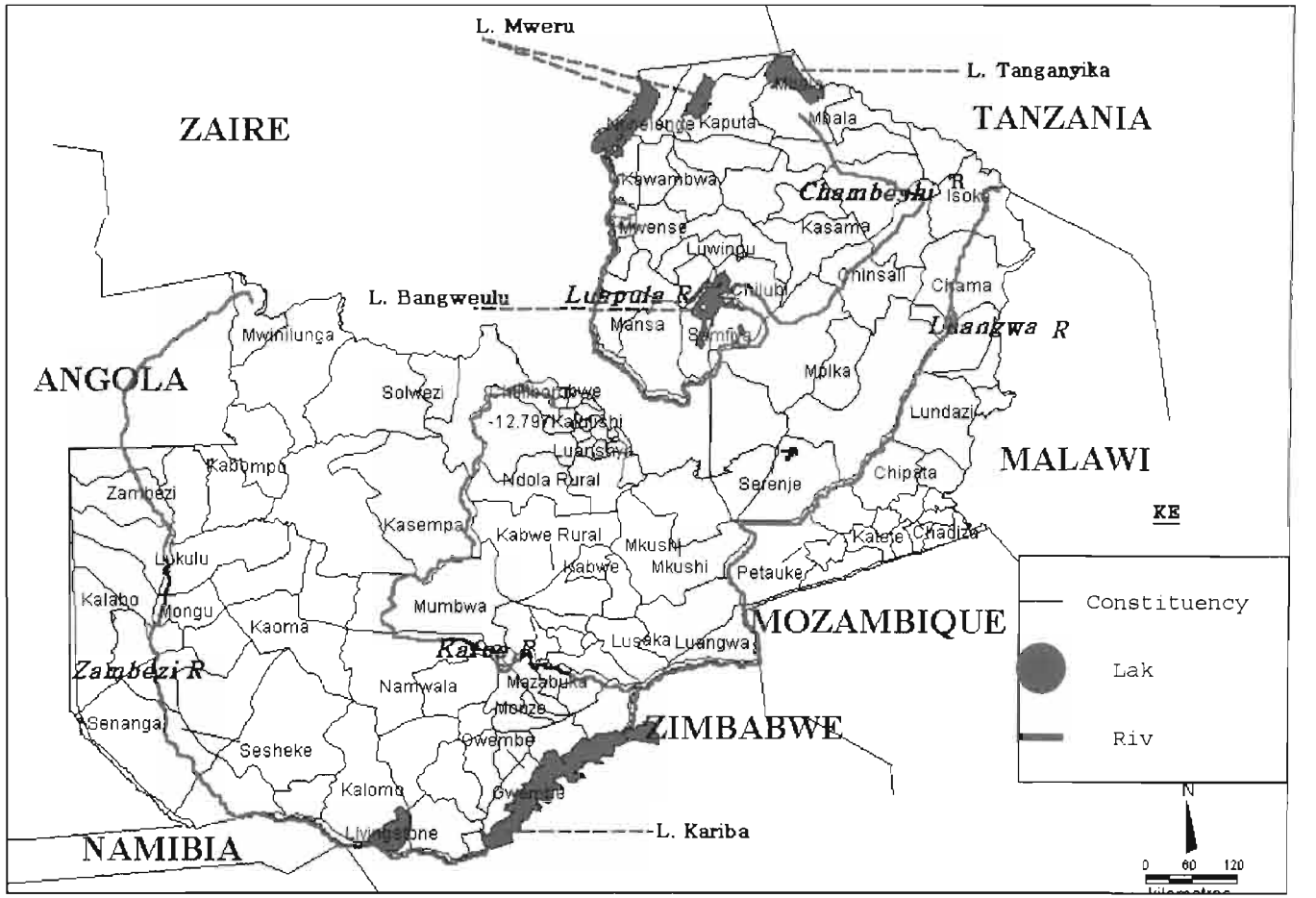


Figure 3.1. Map of Zambia showing constituency boundaries.

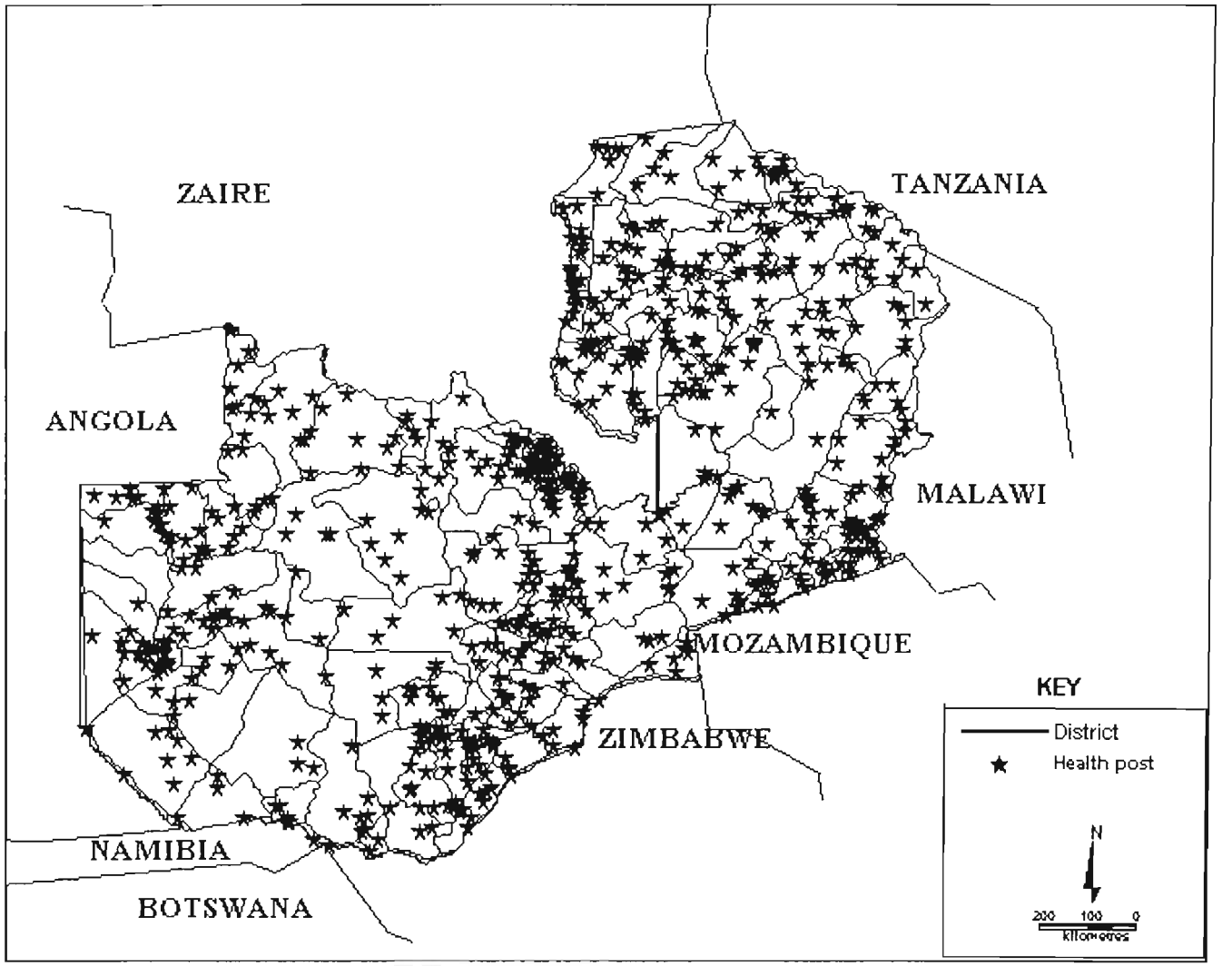


Figure 3.2. Map of Zambia showing health facilities in constituencies.

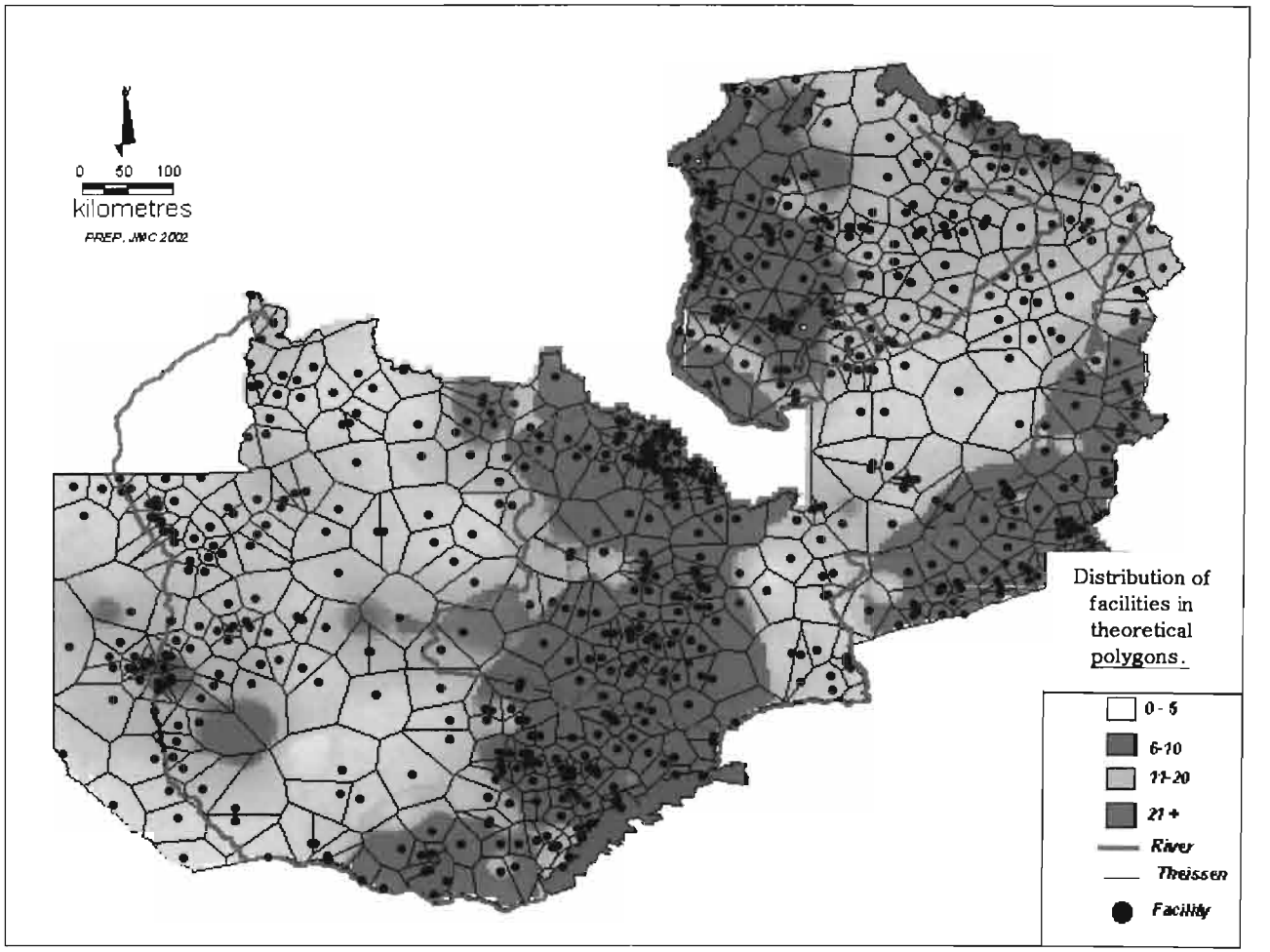


Figure 3.3. Provincial representation of user population to facility ratios (legend represents population in 1000s).

Lighter color = low population density; Red = high density

The Voronoi diagram for Zambia shown in Figure 3.3 was constructed from health facility coordinates as input data. It was based on Delaney Triangulation employing the concept of natural neighbourhoods analysis of a data point (Illing, 1994). Theissen polygons were computed around each set of coordinates as an attribute point. Calculation of Thiessen polygons from a dataset depends on the premise that no two data points should share exactly the same geo-coordinates.

Constituency-based population data were transcribed from the 2000 national census (Central Statistics Office, 2000) and the population densities computed for each Thiessen polygon by dividing its area into the number of people assigned to it. The average number of people per constituency was 15,014, representing 0.15% of the national total in the range 0.02% (n=1,895) to 1.1% (n=121,407). The population densities of constituencies were determined by dividing their areas into their assigned populations and the result obtained in square kilometres. The average national population density for Zambia is 13.67 people/km^2, with a range of 7/km^2 (Northwestern province) to 20.4/km^2 (Lusaka province).

The population density following analysis yielded a continuous distribution surface shown in Figure 3.4. The population-to-facility ratio mirrored the population density patterns. Provinces with higher population densities also tended to have a higher consumer-to-facility ratio (Figures 3.3 and 3.4).

An overlay of the theoretical catchment areas and the population densities presented in Figure 3.3 shows the theoretical population density supported by particular health facilities included in each Theissen polygon. It also demonstrates population densities spreading away from particular foci from the time of facility planning and construction to current use. The emerging pattern shows population concentrations along water bodies, especially the Luangwa valley in the eastern and the Luapula valleys in the northwestern edge of the northern half of the country. The main trunk roads and urban centres also seem to attract higher population concentrations. Population concentration along the line of rail was also demonstrated. This could be seen by drawing an axis from the Copperbelt province to the Southern province (Figure 3.3). The health facilities catering for the lowest population densities were encountered in the Northern province, particularly the central and southern districts. The central districts of Central province and the western half of the country comprising the northwestern, western parts of Central province, northern and western extremities of Southern province and the whole of Western province, with the exception of the provincial

capital Mongu also showed scattered population and thinly spread health facilities (Figures 3.3 & 3.4).

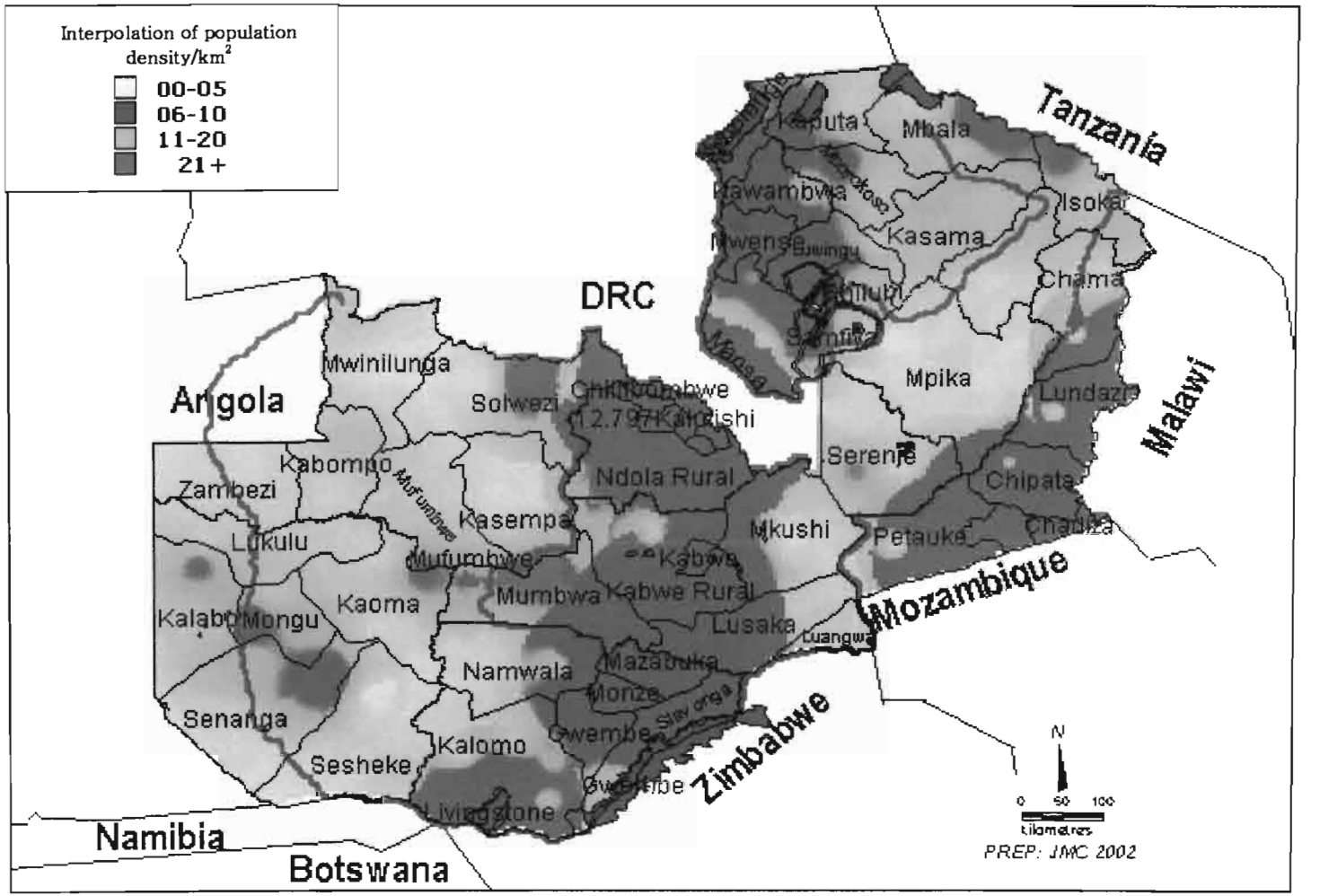


Figure 3.4. Interpolated population density map of Zambia.

Buffers were thrown around each health facility, at theoretical distance thresholds of 5, 10 and 30km (Figure 3.5). The 5km radius buffer included approximately 49,007km^2 of the total landmass (6.5%) of the country. Using a 10km radius, the included area increased to 16.3%. Increasing this radius to 30km around health facilities, the percentage of the country surface area included rose to 66.7% (two thirds). Within the number of health facilities currently in operation, it would take buffers at 44.5km radius to include 99% of the country's surface area.

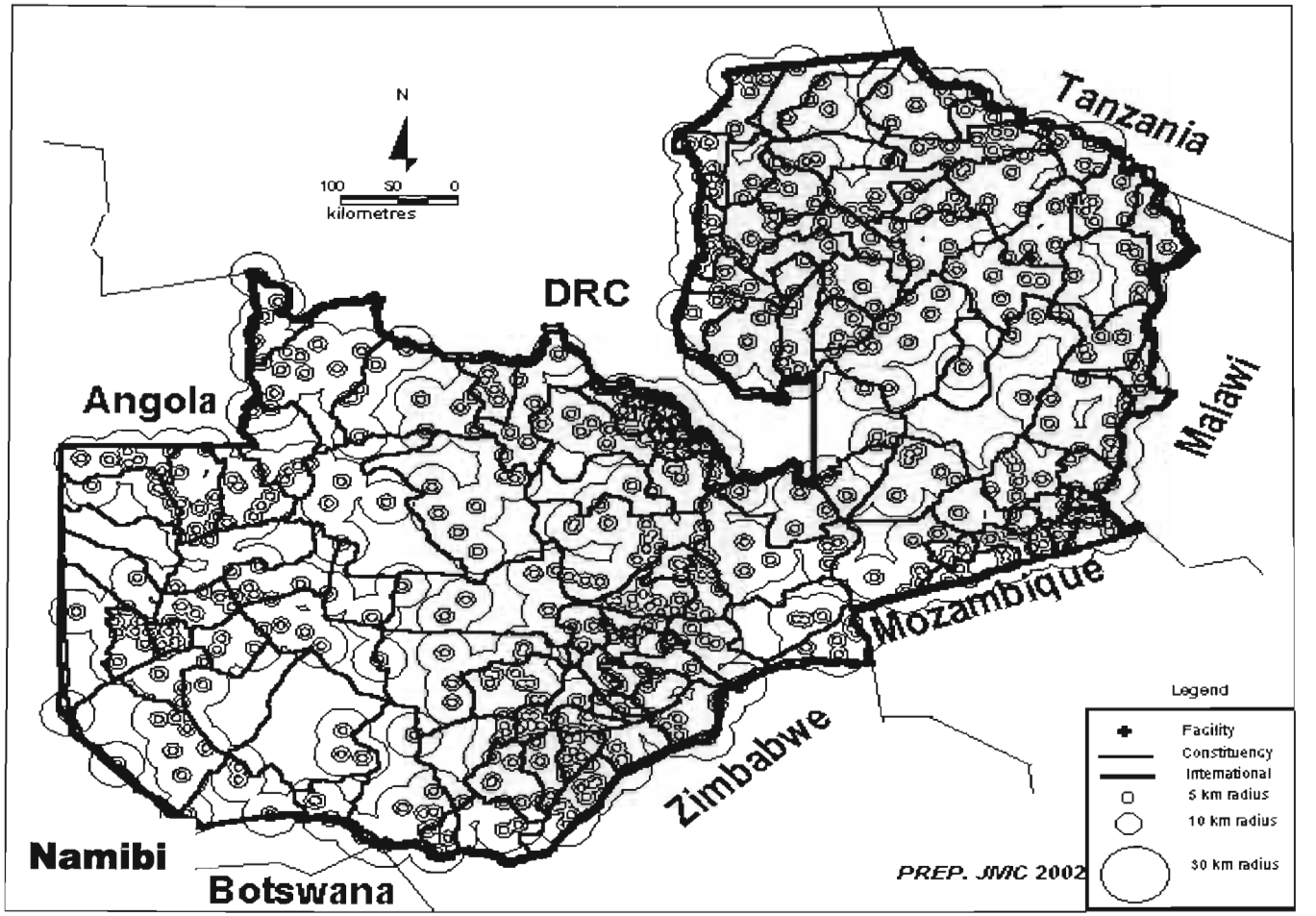


Figure 3.5. Health facility catchment areas in constituencies (5, 10 &30 km buffers).

Figure 3.6 presents changes in malaria incidence per 1000 population over a 20-year period, from 1976 to 1999 based on the number of cases diagnosed each year. It should be noted that these figures are facility-based and therefore may under-estimate the actual incidence at the community level. This is particularly true for rural areas where an unknown number of cases were not reported (Murray and Lopez, 1997; Breman, 2001; Breman *et al.*, 2001). The data also excludes situations where malaria was not the primary diagnosis but where it might have been a compounding factor (Snow *et al.*, 1998).

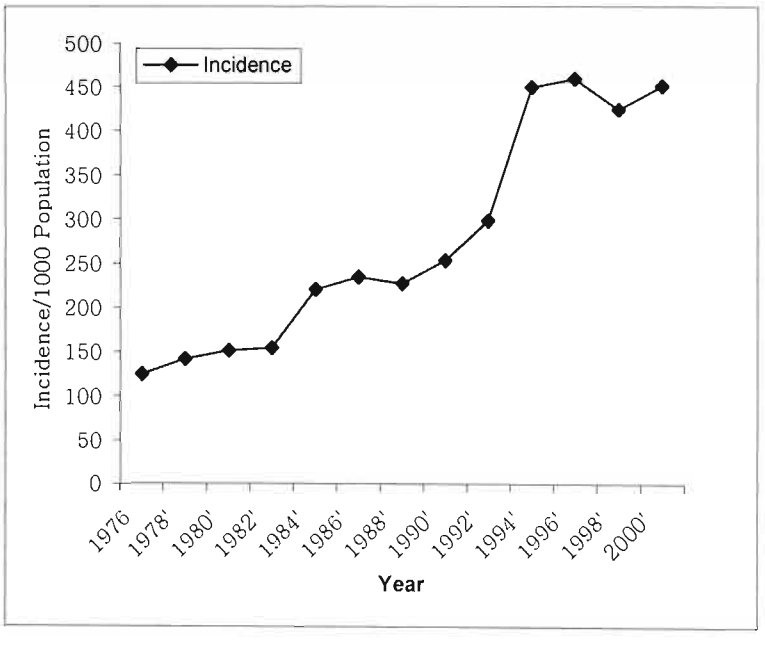


Figure 3.6. Malaria incidence rates in Zambia, 1976-1999 (per 1000 population).

Incidence rates have nearly tripled over the past 23 years, from 1976-1999. In 1976 the incidence rate was 121.5 cases per 1000 population, a little more than one case of malaria for every eight persons. WHO (1996) estimated a 90% under-reporting of malaria in Africa. If this is true for Zambia, then, the number of reported cases (above) represents only 10% of the actual cases occurring in the country.

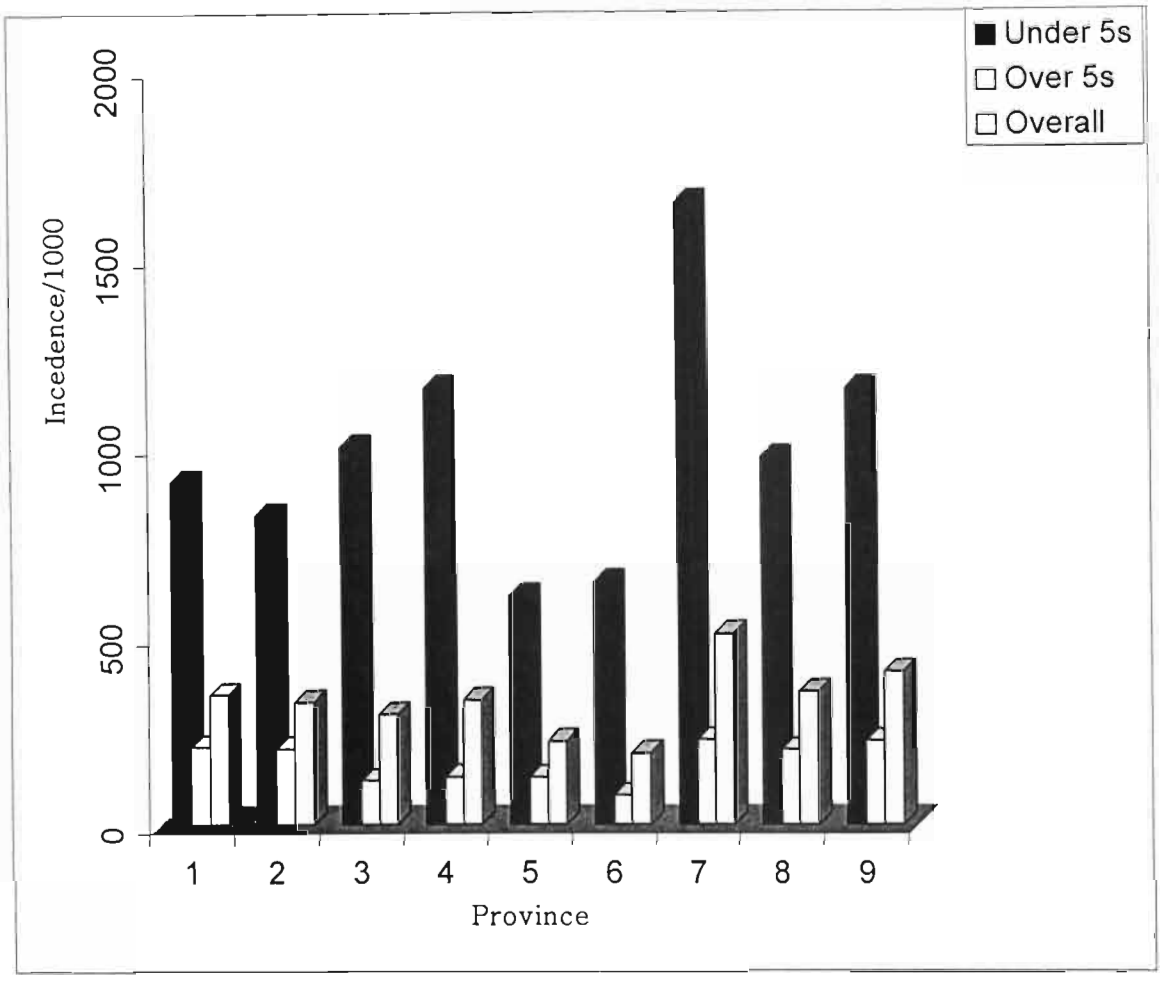


Figure 3.7. Malaria Incidence Rates per 1000 population by Province & Age, 1999. (1=Central; 2=Copperbelt; 3=Eastern; 4=Luapula; 5=Lusaka; 6=Northern; 7=Northwestern; 8=Southern; 9=Western Province)

Figure 3.7 compares malaria incidence rates by province and by age group for 1999. The overall incidence was found to be high in all provinces, with the lowest rate at 188.9 cases per 1000 persons in Northern province and the highest at 507.2 cases per 1000 persons in Northwestern province. When incidence was analysed by age group the highest incidence rates in all provinces were found among children less than five years of age. Rates for these young children nationally were nearly six times those of the older age group.

The Case Fatality Rate (CFR) represents the proportion of cases admitted to health facilities which result in death. This rate generally reflects a combination of factors, including the severity of the infection at admission, resistance of the parasite to anti-malarial drugs and the adequacy of health care. Figure 3.8 shows an increase in deaths over the past 12 years among persons admitted to health facilities for malaria. In

1976, 10.6 deaths were reported for every 1000 malaria cases admitted to health centres and hospitals. This is more than equal to one death for every 100 persons admitted for malaria. Twelve years later, in 1994, the rate had risen five-fold to 51.3 deaths per 1000 malaria cases admitted to hospital. This is equal to one death for every 20 persons admitted for malaria. By the year 2000, the CFR had risen to just under 70 deaths/1000 admissions.

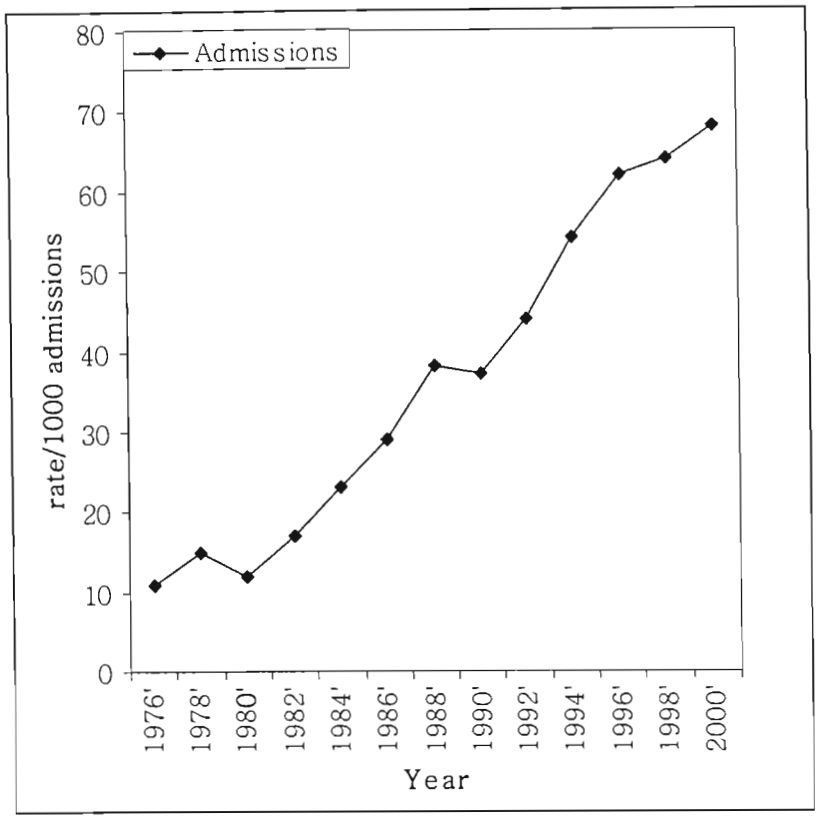


Figure 3.8. Malaria case fatality rates for Zambia, 1976-1994 (per 1000 admissions).

Discussion

Generally, the country has achieved a relatively well-developed health infrastructure over the past three decades. Fixed health facilities having grown from 352 units at independence in 1964 representing 14,000:1 to 928 in 1990 with a user ratio of 10,000:1. This represents a 164% increase, or 22.3 new health facilities being constructed annually. It also demonstrates that there has been a reduction in the number of users per health facility. The health system is run with a district focus, with the bulk of resources being allocated to community-based activities. Currently, there are 72 administrative districts in the country. This

represents 9 more than the number in 1996. Considering that digital boundaries are not yet available for the 9 new districts, the pre 1996 number of 63 has been employed. The next level in the administrative hierarchy is the province, of which there are 9. There are a total of 150 constituencies but only 144 could be identified from the paper map (Figures 3.1), the remaining 6 are geographically too small for visibility at the map scale used.

Following political independence in 1964, the country's long-term prospects for economic development appeared promising. The new government became responsible for provision of health services for the population. It immediately embarked on a programme of providing universal access to services especially in rural areas. Until the late 1970s, the government expanded and improved health facilities and during this accelerated phase it appears that population density was a key determinant in sitting health facilities. The population was clustered around urban centres, including provincial and district capitals. From the maps (Figures 3.1-3.4), there was also a concentration of the population along railway lines from Copperbelt to Southern provinces. Two river valleys, the Luapula in Luapula province and the Luangwa in Eastern province also have higher concentrations of health facilities to cater for high population densities along these valleys.

From the above, with the exception of four provinces (Northern, Northwestern, Western and parts of Central provinces), it may seem that in urban Zambia, the distribution of health facilities is adequate, conforming to both the national policy and international targets. As stated in the introduction, Zambia is one of the most urbanised countries in sub-Saharan Africa with 55% of the population living in urban areas, implying that as long as urban areas are well catered for, half the country's population is well served. However, higher access rates are offset by population growth in these areas. These areas show much higher population density-to-facility ratios than recommended. For example, Copperbelt and Lusaka provinces demonstrated consumer ratios as high as 43,000-62,000 people per health facility, compared to the recommended 10,000 according to WHO (1978).

The Ministry of Health (1984) evaluation of Primary Health Care services in the country showed that virtually 100% of the urban population lived within 5 km of a health facility. The government has a deliberate policy to supply urban areas and other higher population concentrations with development-related amenities including health facilities (Kasonde and Martin, 1994).

Rural areas especially Northern, Northwestern, Western provinces and the northern districts of Central and Southern provinces showed large tracts of land with isolated health facilities scattered within them (Figures 3.3-3.5). Ironically, these are the areas with low user-to-facility ratios similar to the WHO (1978) recommendation of 10,000 people to a health facility. They averaged 10,002 per health facility compared to that of 12,581 in highly populous areas (Figure 3.4). Kasonde and Martin (1994) noted a 50% to 90% access difference between rural and urban populations, with a national average of 75%. Chetty (1995) found similar ratios in South Africa. In terms of equity of access to services, it would appear these areas are under-served and this could explain why malaria-related morbidity and mortality are higher (Figures 3.7-3.8).

Although reasonably close to the recommended ratio of user: facility, the population of Zambia as a whole had no real access to services, according to the recommended normal walking distance of 30 minutes between households and health facilities (WHO, 1978; Grant, 1988). This target translates into a majority living less than 2.5km away from facilities, at the average human walking speed of 5km/hour. Even this would be considered too far for a sick person, or someone carrying a sick person on their back.

The Voronoi diagram in Figure 3.3 shows for the first time in Zambia where health facilities are inadequate, over-supplied or adequate. Over the past three to four decades, the population has increased numerically and expanded spatially. For example, the population is flowing eastwards along the Luapula valley in Luapula province and westwards in Eastern province. In each of these cases, a higher concentration of health facilities still coincides with the area of higher population density as originally planned. Higher population densities would in the meantime have expanded into some places, which were designed for lower population densities. This is especially so with increasing population pressure and as a result of more people being retrenched from regular employment in urban areas.

The value of Thiessen polygons is that they present a simple impression of the areas that should benefit from health services. The same mosaic can be applied to provision of other services to the community, such as schools, water points and other developmental amenities. In the present study the Thiessen polygon diagram should be interpreted in relation to two assumptions: that the population was uniformly distributed within each polygon and that the population attends the nearest health facility. Since it also does not take into account other features, particularly geography, existing roads, etc, validation should

form an integral part of the data cleaning process before producing actual catchment areas. Ideally, an accurate estimation of the population, which utilizes a particular facility, may be obtained from an actual census of the catchment population in relation to its geographical position or health facility surveys. True population utilisation is only possible at micro-level with regular population surveys (Zwarenstein *et al.*, 1991).

When compared to the continental model generated by MARA/ARMA (1998), the population density surface generated in this study was similar in depicting of where population concentrations are located in the country (Figure 3.3-3.5).

Ring buffers in sparsely populated areas (Figure 3.5) reveal areas not well supplied with health infrastructure. The population density surface map was based on the assumption that population was uniformly distributed in both the constituency and in a Thiessen polygon. In reality however, it is possible the population was concentrated near health facilities, within 5km-10km. In such a case, although the area covered by the 5 and 10 km ring buffers represented only 6.5% and 16% of the total areas respectively, they covered the vast majority of the catchment population. The converse of this would be that the population is clustered away from the health facilities. In the later scenario, service provision would be inadequate due to greater distances involved.

Figures 3.7 & 3.8 present a malaria situation analysis in the country over the last 20 years. Overall, indicators show unprecedented rises in all common malaria indicators demonstrating that some or all aspects of the malaria programme are not functioning as well as they should.

Population growth should be one of the key inputs to planning provision of health infrastructure to the population. The GIS analysis demonstrates that changing population demography may be exerting pressure on the health system by requiring it to cater for population numbers higher than designed. This maybe presenting another barrier to population access to health services. Chetty (1995) argues that although WHO recommends a user-facility ratio of 1/10,000, this is just a guide and health facilities can cater for more than this number especially in places where distances are short, such as urban areas. If Chetty's analysis were true, then the ratios of up to 62,000 people per facility in the urbanized provinces of Zambia are still acceptable. This is supported by Zwarenstein *et al.*, in 1991, who cautioned that health facilities are a vast accumulated capital resource and should therefore be utilised with maximum efficiency. Access is sometimes hindered by staff related factors like when it is open and how long, the attitude and sometimes

gender of staff, how often they travel out of station, usually to attend to personal matters.

The present study examines spatial access to health facilities. It is possible that at higher user-facility ratios, a saturation or breaking point may be reached where, despite the ease with which contact is made with health facility, the actual utilization of the service is hindered by a high user-provider ratio. In such a case, both quality and access may be compromised by lack of, or limited interaction between, provider and consumer. Other confounders such as erratic or limited supply of drugs, equipment, unqualified personnel, and physical and systemic barriers may also lower effective access to health services (Fiedler, 1981; Kasonde and Martin, 1994).

The late Jim Grant (1978) noted that every household reserves an inalienable right to information and awareness about the availability of health services dealing with child and maternal survival and development. This can only be possible where the household has access to services within reasonable time and cost. Application of this ideal in a country like Zambia, with high levels of illiteracy and poverty, requires either provision of more health facilities within 10km from homes or by community-based provision of services. This ought to be a national priority.

Nchinda (1998), discussing the role of PHC in malaria control, explained that the malaria programme should be integrated within the general health services and that this process should be country-specific. RBM on the other hand emphasizes providing general health services close to the family and available within two hours of onset of malaria symptoms. This study has shown that in Zambia, access to health services by the vulnerable within this time is not always possible. The population, especially the rural poor, usually live more than two hours (>10 km) away, and access is mostly on foot. The Abuja Declaration (2000) goals can only be realized by providing more facilities in under-served areas, as identified by the Thiessen polygon map (Figure 3.3). The inherent problem with this approach is that countries struggling under the greatest burden of malaria also lack resources to provide adequate health facilities for their populations. For Zambia, the principle of access within two walking hours, especially in sparsely populated areas, is already defeated by the government acceptance of the 5-30 km radius. This means that under the present policy framework, the Zambian government cannot realise the Abuja goals, this government policy is the first hurdle to the realisation of these ideals (Fiedler, 1981). Under this constraint, in order for the country to even begin to entertain the idea of realizing the Abuja Declaration goals of RBM, it would have to re-visit the

concept of a community-based health provider. It would have to re-activate and motivate the Community Health Worker (CHW) or develop another cadre at community level to support key childhood survival interventions at lower population-provider ratios.

This study has demonstrated that health systems in Zambia are not uniformly distributed. There exist large differentials between rural and urban areas. Urban areas have more physical access than rural areas, but there is no evidence to suggest that one sector is better served than the other. The application of GIS has demonstrated how spatial analysis of a situation can lead to a simple and realistic solution as well as rational deployment of scarce resources. The provision of health facilities in this study has only been examined the spatial dimension only. Densely populated areas possess greater potential for consumers to reach the facilities but entry into the system may not necessarily be guaranteed and may be constrained by congestion in health facilities. In places with lower population densities, distance and a poor transport network already compromise access to the health service and limit user-information reaching the consumer at the household and village levels.

Chapter Four: Spatial Determinants of Community Access to Insecticide Treated Nets (ITNs)

Introduction

Malaria constitutes one of the major obstacles to development and child survival in Africa (Nabarro, 1999). There are 60 million children living at risk of malaria in sub-Saharan Africa (World Bank, 1993; World Bank, 1994; Nevill *et al.*, 1996; Schellenberg *et al.*, 1998; World Bank, 2000). Despite it being recognised as one of the biggest public health problem not much progress has been made in reducing its impact on the population (Mutinga *et al.*, 1992; WHO, 1996). In most African countries the approach to malaria control consists treatment of clinical cases under Primary Health Care (Kasonde and Martin, 1994). It has become clear over time that this strategy has little impact on malaria morbidity and mortality (MacCormack and Snow, 1986; Choi *et al.*, 1995; Binka *et al.*, 1996).

History of self-protection using mosquito nets

Following the failure of the malaria eradication strategy in 1969, the search for effective and low-cost interventions led to renewed attention to self-protection with mosquito nets. Untreated mosquito nets are useful in reducing man-vector contact, but they are not able to lower the incidence of episodes of clinical malaria (Alonso *et al.*, 1993; Sexton *et al.*, 1990; Sexton, 1994).

The application of insecticides onto nets makes them effective in lowering the incidence of clinical episodes of malaria, all-cause mortality and a number of other malariometric indices. The practise of applying insecticides to mosquito nets was first used on a large scale during the Second World War. DDT and some organophosphates were used to impregnate mosquito nets and soldiers' uniforms (Mellanby, 1992). In late 1970s and early 1980s, there was renewed interest in the use of insecticide treated mosquito nets for personal protection. An Insecticide Treated Mosquito Net (ITN) is not only an effective means of malaria prevention and control, but also a sustainable one and applicable at community level (Brinkman and Brinkman, 1995; Lines, 1996).

The use of ITNs as a global strategy for malaria prevention was officially recognised by the ministerial conference on malaria in Amsterdam in 1992 (WHO, 1993; Lengeler, 1998, Mordiano *et al.,* 1998). Following this meeting, the World Health Organization (WHO) commissioned large-scale trials at a number of sites. In Africa, four trials were commissioned and results of these have now been published. The Gambia study (Alonso *et al.*, 1993) demonstrated a 25% reduction in all-cause childhood mortality. The Kenya study (Nevill *et al.,* 1996) lowered childhood mortality by 29%. In Ghana, Binka *et al.* (1996), reported 18% efficacy and the Burkina Faso study 14% (Habluetzel *et al.*, 1997).

Despite the demonstrated efficacy of a net to which an insecticide has been added in protecting the user, it has been proven now that even under research conditions, re-treatment of nets is very low. At best some projects have recorded re-treatments of about 20% (Lengeler, 1988; Snow *et al.*, 1999; Sexton *et al.*, 1990). The consequences of untreated nets are referred to already. It was hoped that this problem would be addressed with the availability of pre-and permanently treated nets. However, this technology has to be approved through the WHO registration system which might take at least 5-10 years of independent research before the technology can be cleared for public health use. By the time this work was going for binding only one Long Lasting ITN had WHO approval and 2-3 other products have almost completed the rigorous process of obtaining WHO approval and registration.

WHO through its Technical Support Network for Insecticide Treated Netting materials has come up with a framework for linking the public sector and the commercial sector for improving access to the ITN technology. The framework is based on the principles and lessons learnt over the past few years. These include that a balance has to be found between sustainability and equity. The public sector aims to provide equity as it has a duty to provide access to ITNs as equitably as possible. The private sector provides sustainability. It brings public health benefits at no cost to public sector budgets. On the other hand, the private sector is blind to issues of equity, and in practice, commercial markets address the needs of those who are able and willing to pay. The Abuja goals can only be achieved through the combined strengths of both private and public sectors (WHO/RBM, 2002). The two components of an ITN, the net and the insecticide, are different from each other, and the appropriate balance between public and private sector roles may therefore be different for nets and for insecticide (Figure 4.1).

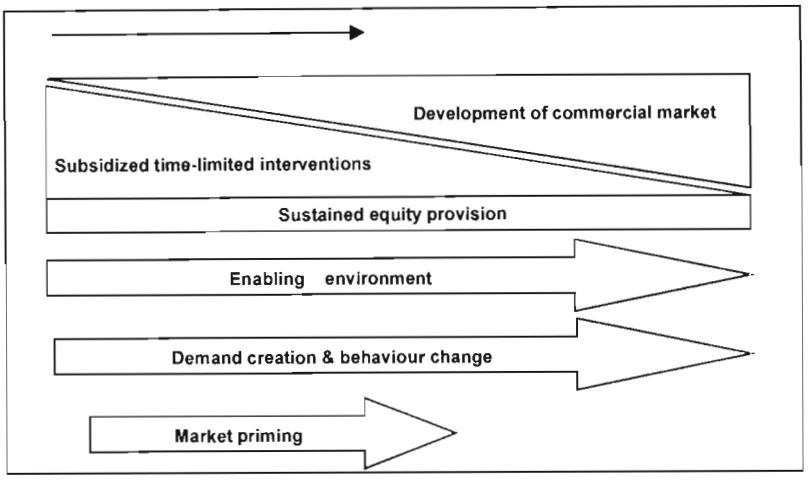


Figure 4.1. Global Framework for Scaling up ITNs in Africa (after RBM, 2002).

Under experimental conditions ITNs have been shown to reduce sporozoite infection rates. Rowland *et al.* (1997) reported that in terms of results, a single year of an ITN campaign is equal to two years of residual spraying. Luxemburger *et al.* (1994), point out that it is 2.4 times cheaper to protect a single person per year with ITNs than with DDT spraying, while Kere and Kere (1992) reported a per capita annual protection ratio of 1:2.2 for ITNs and DDT respectively. Costs per person protected with DDT spraying were US$ 1.86 compared with US$ 0.72 for ITNs, over a three-year period. On the Solomon Islands, Brinkman and Brinkman (1995) determined the cost of protecting an individual to be US$ 1.97 and US$ 4.37 for ITNs and DDT respectively. Curtis (1997) noted that for the price of a limited amount of insecticide applied to a family's net, approximately the same number of mosquitoes were killed when 10 times the quantity of insecticides was used to spray the inside surfaces of walls and roof of their house at the recommended concentration.

Problems associated with Insecticide Treated Nets

There are a number of disadvantages associated with the use of ITNs for malaria prevention and control. At higher doses, e.g. 25mg/m^2 as used in Africa, insecticides on nets irritate and repel *Anopheles* mosquitoes. This results in lower knockdowns and mortalities compared to the less irritating, lower dose used in China (10-15 mg/m^2). The higher concentrations have also been reported to irritate users who then wash the nets before they are due for re-impregnation (Hii *et al.*, 1995).

In The Gambia, 50% of nets had been washed at least once by the time project was ready for the first re-impregnation (Alonso *et al.*, 1993). The effectiveness of ITNs and other insecticide-treated materials such as curtains and wall clothes decrease with time due to chemical degradation, dust, smoke, weather, and washing. After each wash, 50% of the insecticide is lost (Mutinga *et al.*, 1992).

The expected effectiveness of ITNs has so far not been demonstrated under field conditions. In one study in Tanzania, introduction of ITNs increased sporozoite infection rates in the mosquito population. At low coverage, ITNs show no impact on malariometric and entomological indices and in fact it is still not clear what coverage thresholds indicate where effectiveness starts and ends (Quinones *et al.*, 1998; Van Bortel *et al.*, 1996). In Africa, people are not accustomed to sleeping under nets. Exceptions are The Gambia and Tanzania (Mutinga *et al.*, 1992).

Just as the logistical organization for residual insecticide spraying is complex, so is that needed to organize a net re-impregnation exercise (Njunwa *et al.,* 1991). For most African countries nets or netting material have to be imported but despite being cheaper at source, they eventually attract import duty and other taxes which inevitably increase their prices. Authorities in these countries tend to look at nets as luxury goods and therefore, taxable. At the household level the purchase of a net has to be weighed against other competing priorities in the family budget. For example, in The Gambia, purchase of an ITN consumed 93% of a household's disposable income (Alonso *et al.*, 1993; Brinkman and Brinkman, 1995).

Despite numerous controlled ITN trials, re-treatment rates remain low (Sexton *et al.*, 1990). It was hoped this would be resolved by availability of affordable permanently treated mosquito nets but as of now the permanently treated net still has a long way to go before it becomes available at affordable prices for poor communities.

Access, Delivery and sustainability of Insecticide Treated Nets

There are many issues and factors responsible for community access to health interventions and services. As noted in Chapter 3, an indication of a population having adequate access to health and other social services is the proportion of that community which can reach the appropriate service within 30 minutes using local means of transportation. A case in point is access to an ITN when the household requires one. Even after making contact with the health service, other barriers within

the organization of the service still affect its use (Grant, 1988). There are also differentials between the rich and the poor, between urban and rural areas, between males and females, children and adults.

Access is an inter-play of individual, family, physical and community factors, which are in turn subject to the operational policies of the government (Fiedler, 1981; Deichmann, 1997). Before an individual can utilize a service, they must acknowledge the need for it. For this to happen, the right kind of service has to be available within acceptable distance, time, and cost. A case in point is access to an ITN when the household requires one.

Access to services is influenced by social and cultural factors such as annual income, transport, religion, occupational status, and relationship with health staff, knowledge, information, cost and distance. Efficiency in the spatial distribution of social services in relation to potential consumers is of importance because it minimizes the average travel distance and tends to equalize utilization (Zwarenstein *et al.*, 1991).

Distance as a component of access, is the main focus of this study, since it governs entry into the health service by an individual or household (Rahaman *et al.*, 1982; Stock, 1985; Kloos, 1990; Müller, 1988). Euclidian distance is considered a major factor in the consumption of services at the local level (Tanser, 2000; Airey, 1992). This study examines the impact of distance on access to malaria interventions in general and ITNs in particular.

Aim of Study

In Zambia, provision of health services is governed by the national health policy (Ministry of Health, 2000). Within the national policy, quality of the service, distance to the service, and affordability of the service are key. Distance from households to various features was examined as a possible physical and time barrier limiting community access to ITNs. On the socio-economic front, the study looked at the impact of some household characteristics between families that owned ITNs, and those that did not, including: household socio-economic status (based on property ownership) and educational level of head of household (Laximi and Cleland, 2000).

The goal of this study was to identify and analyse factors that influence uptake of ITNs by households. It was aimed at determining the extent to which distance from households to a number of social amenities affect the community's ability to acquire and use ITNs is affected. The

study was undertaken in a rural community with high intensity malaria transmission.

The study focused specifically on examining the mean distance of household from health facilities, roads, waterbodies, schools, places of worship, community health worker, traditional leader and traditional healer. The study examined how these distances explain ITN ownership in the target community. It also analyses some intrinsic household characteristics and how these varied between ITN user and non-user households. An analysis was made of the effectiveness of ITNs in averting malaria illness by comparing the frequency of clinical malaria episodes between ITN users and non-users.

Methodology

The ITN project on which the study was based commenced in one district in 1995. It was first reviewed in 1996 and then in 1997. It was recommended for scaling up and it has subsequently been extended to cover five provinces out of nine in the country. The programme was implemented according to the principles of partnership under the Community Health Initiative Fund (CHIF) concept. Proceeds from ITN sales were banked in accounts managed by community representatives. Technical supervision of the project is provided by health service staff. ITNs were sold, treated and re-treated at household level by community health workers, who were selected by the target community and trained by district and health centre staff. In addition to ITN sales, CHWs promoted health awareness.

Study site

Mwense district is situated in Luapula Province of Zambia and is divided into three constituencies: Mwense, Chipili and Mambilima (Figure 4.1). Within Mwense constituency there is a group of villages under chief Lukwesa with a population of approximately 40,000 people (Central Statistical Office, 2000). There are a number of government facilities typical of an area of this size. Health facilities are well equipped by sub-Saharan standards, with running water, telephone and electricity. Both Mwense district hospital and the Lukwesa rural health centre are government facilities and are managed by Clinical Officers, Nurses and Environmental Health Technicians. A health facility outside of the Lukwesa group of villages was used as the control.

The Lukwesa group of villages occupies an area of 2,894 km^2 on the banks of the Luapula River (Figure. 4.1). The area is situated within the high rainfall zone at grid reference 10.226667S and 28.790000E, at an altitude of 900m above mean sea level. The site lies on the north-western part of the northern half of the country. The Luapula River forms the international boundary between Zambia and the Democratic Republic of Congo (DRC).

Ecologically, the region is mainly savannah patchy forest inter-spaced with open grasslands. Miombo woodlands are characterized by trees such as *Jubernardia, Isoberlinia and Brachystegia* species. Grass species include *Sagitaria, Ludecia* and *Phragmites* along the riverbanks.

Rainfall averages 1500mm per annum, mainly falling between November and April. Mean annual temperatures range from 18°C in cooler months to 28°C in October, with high relative humidity between 50% and 100%.

The main ethnic groups are the Lunda-Luba speaking people. The main economic occupation of the population is fishing along the Luapula river and farming on the plateau. Trading constitutes a significant component of community activities, especially with the DRC. There are no records of malaria control activities other than curative services and more recently, drug resistance trials. Expert opinion on malaria transmission places Mwense district between hyper- and holo-endemicity. Only the central part of the community is urbanized. It has a market, shops, telephone, electricity and other social amenities.

The lowest level for which digital boundaries exist officially in Zambia is the district. Constituencies and village boundaries only exist in paper map form. The boundaries used for this study were obtained from a paper map from the government printer's department in the Ministry of Lands at a scale of 1:1,500,000. The map was digitized by the Geographical Information System (GIS) Unit of the South African Medical Research Council, Durban. Households were geo-positioned using hand-held Global Positioning System (GPS) (Trimble Geo-Explorer II) differential units. Five or more readings were taken at the centre of the cluster of buildings comprising a household and noted as the co-ordinates of that household. The same process was followed to geo-position other features such as schools, churches, roads, and health centres. Co-ordinates for rivers and roads were recorded by three sets of five readings each along their length at appropriate points, including points of intersection with other geographical features. Some places already had existing co-ordinates and these were used to verify the GPS readings taken for that point. Hand-drawn maps from the district health

management team showing relative positions of places and features were employed for verification.

All data including GPS co-ordinates were entered and stored in a Microsoft Access® database and exported to MapInfo® for analysis and map production. Data were double entered at the Biostatistics Unit of the South African Medical Research Council. District and constituency censuses were obtained from the Central Statistical Office (Central Statistical Office, 2000).

Definition of household

For the purpose of this study, household refers to filially related individuals with traceable kinship who take food prepared from a common kitchen. Being married and owning a house did not necessarily meet the criteria for a household, as there were many cases where young couples were clearly part of an older person's household. Further, a cluster of housing units or structures making up a household did not necessarily contain all members of that household. It was common for members of one household to lodge within another, but for all purposes of domestic management report back to their household. Thus for this study, the household was taken to mean "a number of inter-related family members getting their food from the same kitchen, on a daily basis, and falling under the leadership of one matriarch or patriarch". In some instances, two households appeared as one by virtue of this definition. This was particularly common between sibling and friendly households. Separate homes bring their food to eat together, but the use of separate kitchens could clearly separate these. Although meals would be taken together, they were prepared in separate kitchens.

A representative sample of household members whose age ranged from 16-66 years was selected for the survey. A three-stage stratified cluster-sampling procedure was used (Chapman and Gouws, 1991) to select 250 households, from which the head or their adult representative became the respondent. Criteria for inclusion included being domiciled in Lukwesa village continuously for the last 24 months or more and freely consenting to participate in the survey. Random selection was used to select the 250 households. A sampling interval was determined by assigning random numbers to all households listed under the Lukwesa ITN project. Numbers were then placed into a hat from which 250 were randomly drawn. The unit of measure was the household.

Cross tabulations were used to examine relationships between social demographic variables and knowledge, attitude and behavioural

variables. The questionnaire was pre-tested in the adjacent Chipili constituency. Prior to the survey, it was translated into Bemba, the local language spoken in the area. The survey was undertaken between August and December 2000, and conducted by a team of six enumerators and two supervisors. Both supervisors and enumerators underwent a two-day training session to familarise them with both interviewing skills and survey tools. They were also given general information about malaria and insecticide-treated mosquito nets. All completed questionnaires were checked by a qualified social scientist for completeness. Incomplete ones were separated and re-administered the following day.

Data Collection

In addition to the author, two senior technicians of the National Malaria Control Centre (NMCC) made the field measurements and observations in this study. The technicians received training specific to each component of data collection and similarly trained district-based field co-ordinators assisted them. They made all GPS readings, collected maps and all other information pertaining to the study. They visited the field site for seven days every month from April 2000 to April 2001. The author spent a total of five days per month in the field. Either a member of the district team or health centre staff accompanied all visits to the community. The author was responsible for checking all data brought in from the field. Queries on data were immediately addressed in consultation with the two technicians or noted for verification in the field during the next visit.

To estimate the effect of distance of households from various key village points on the uptake of ITNs, a generalized linear multivariate logistic regression model was employed. A logistic regression approach was relevant because outcome variables were dichotomous. Either a household owns an ITN or does not (Laxmi & Cleland, 2000; Aitkin & Longford, 1986). The first step in the analysis involved examining relationships between unadjusted links or associations between the variables. In the subsequent model, only variables showing significant unadjusted associations at the 5% level of confidence were retained. They were first subjected to the student two-sample *T-test* with equal variance. Assumptions were made that the data came from normal populations and that there was no spatial correlation between the observations. Fischer's exact test was used to determine Relative Risk (RR) of contracting malaria between ITN user and non-user populations.

Results

The total population in the Lukwesa group of villages was approximately 40,000 inhabitants, with 48.4% males. There were 10,685 households, giving a mean of six people per household (Central Statistical Office, 2000). Figure 4.2 shows the location of Lukwesa catchment area in relation to the country. Figure 4.3 shows the spatial distribution of households with and without insecticide treated mosquito nets.

National baseline data shows less than 10% mosquito net usage in the country (Ministry of Health, 2000). Other traditional methods of protection against nuisance mosquitoes in Lukwesa included, burning plant derivatives, cow dung, hanging specific plants around windows and doorways, and keeping fires going in sleeping rooms at night. It was also common to find Kenaf sacks sewn together to form bednets providing a physical protective barrier against mosquito and other flying insects, as well as for privacy.

Between 1995 and 1999, 60,000 ITNs had been distributed to the target community. This theoretically provided 100% coverage at the rate of 2-3 people per net. There was no other source of nets or insecticide during the study period apart from a handful of relatively over-priced untreated nets in local shops. Results of the 1996 external evaluation showed that pregnant women and children were given priority to sleep under treated mosquito nets. Willingness to pay was determined through a pre-intervention knowledge, attitude and practices survey. The respondents were willing to purchase ITNs because they could pay either in many installments, or could barter an ITN with whatever economic goods were acceptable to the seller.

Figure 4.4 shows the incidence of malaria in the community where the ITN project had started in 1995. By the end of one year of ITN use, the incidence of malaria had shown a downward trend among ITN users (Figure 4.5).

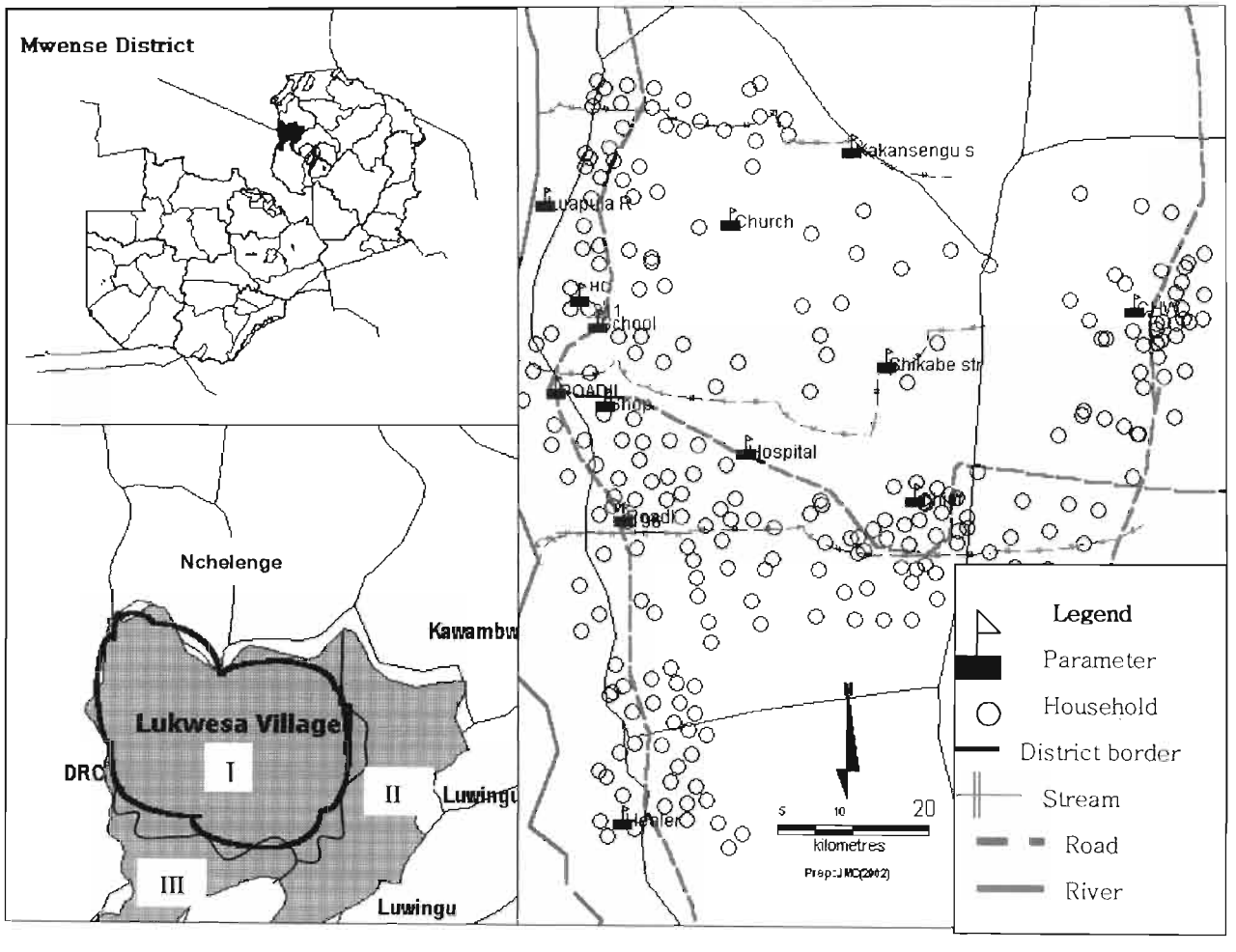


Figure 4.2. Map showing Mwense district and Lukwesa community.

(Constituencies: I=Mambilima, II=Chipili and III=Mwense)

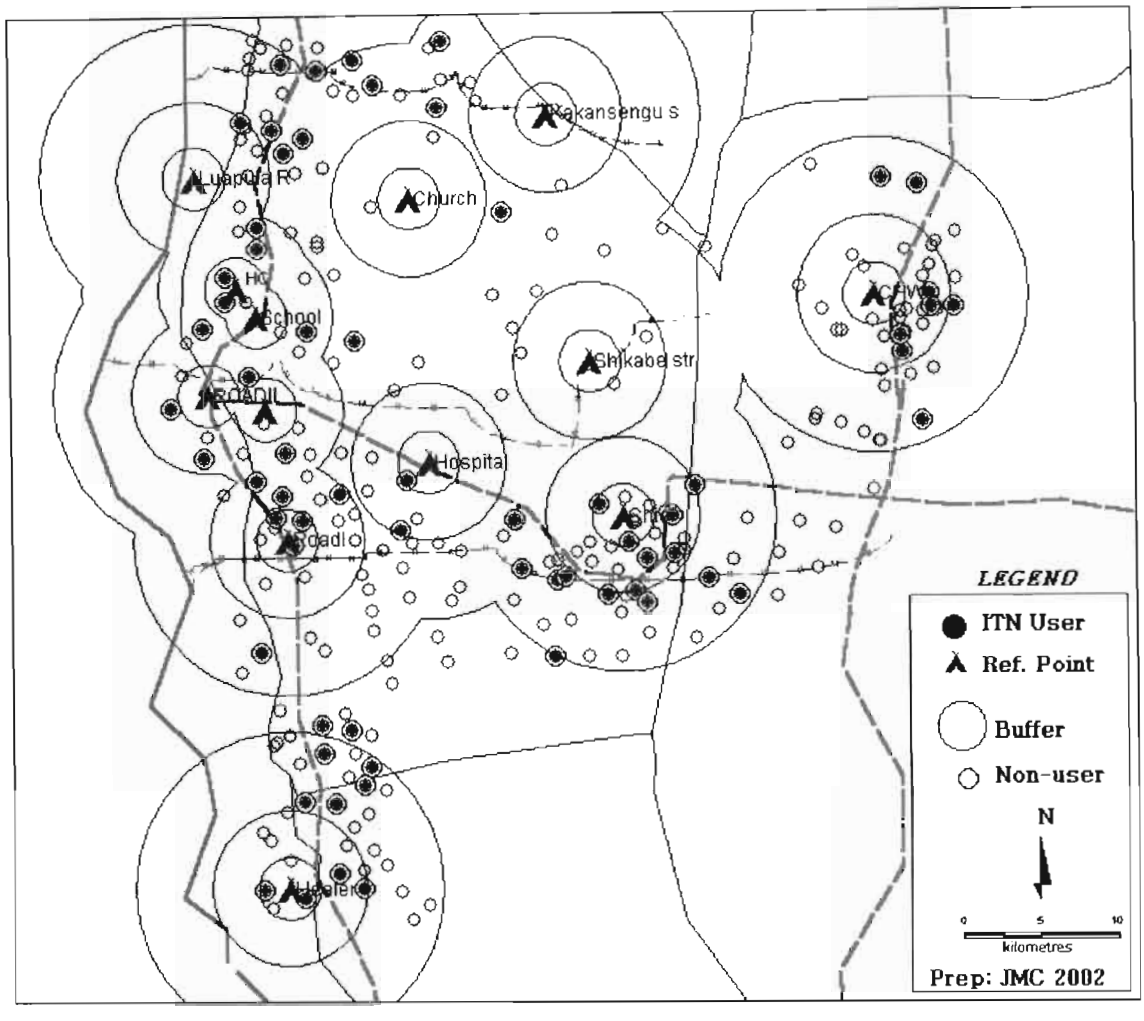


Figure 4.3. Distribution of ITN users and non-users in Lukwesa with buffers around reference points. (Distances represented by buffers: small circles = 2km, medium-sized circles = 5km and large circles = 10km)

Figure 4.3 illustrates the spatial distribution of ITN users and non-users in Lukwesa village and shows an even spread of both. When buffers were thrown around each reference point at 2, 5 and 10 km, there was no significant correlation between mean buffer categories and ITN ownership (~~the~~ student *t*-test ~~result was~~ (t = 0.171, dof = 64, P> 0.689). The same was ~~also~~ observed for non-net owners. There was also no statistical relationship between buffer categories and non-ITN ownership (t = 0.546, dof = 181, P> 0.553). The GIS display of results shows that the population tended to concentrate along rivers and roads. The church and the hospital represented two features least attractive in relation to population settlement. The community health worker, traditional leader, health centre, school, and traditional healer had more households close by.

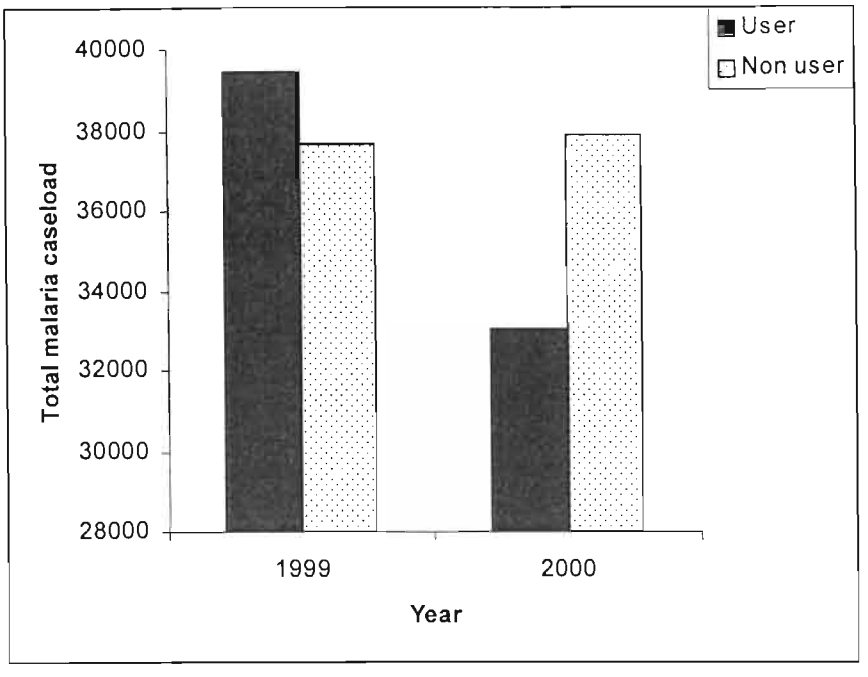
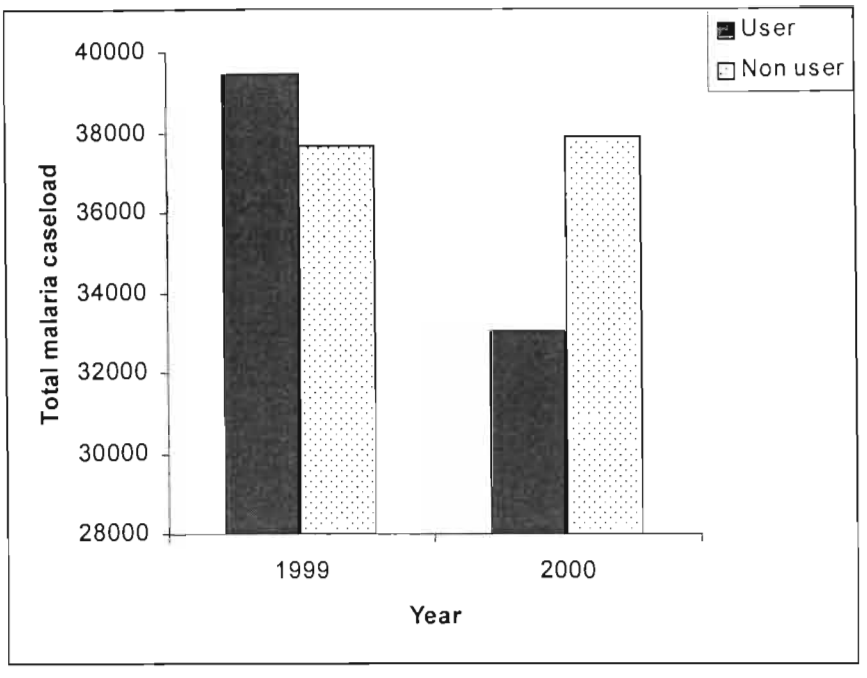


Figure 4.5. Total malaria cases in Mwense district one year after ITN introduction in 1999.

From the socio-economic survey among adults who headed households, 1.1% had no formal education; 66.5% spent at least four years in school to acquire lower primary school education; 30.0% had seven or more years' schooling to acquire an upper primary education and 2.4% had completed 10 or more years of schooling. There was a statistically significant association between the number of years spent in school by the head of the household and owning at least one ITN in that household (X^2 = 24.029, dof = 2, P<0.001).

Household possessions were used as a proxy indicator of household wealth or socio-economic status. Ownership of a bicycle, radio, bed and mattress, firearm, sewing machine, fishing boat (or large canoe), and more than two fishing nets were the considered assets. Of the 250 households sampled, 80.8% owned at least one asset. Among those who were recorded as having assets, 38.4% had one asset, 29.6% possessed two, 9.2% had three and the remaining 3.6% owned four or more assets (Figure 4.6). A statistically significant association was found between ITN ownership and the wealth of the household (X^2 = 24.57, dof = 4, P<0.001).



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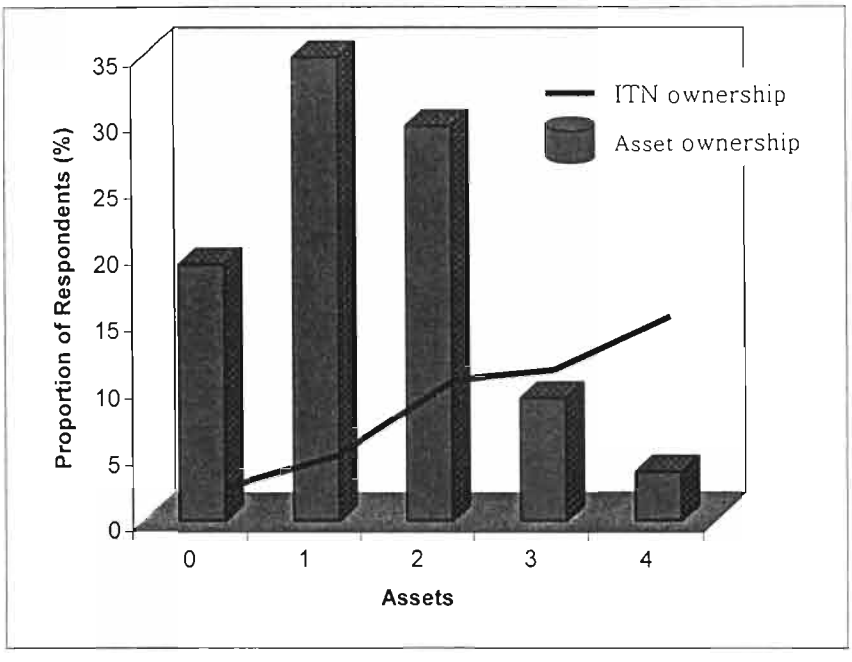

Figure 4.6. Socio-economic status of Lukwesa households and ITN ownership.
(0=no asset, 1= one asset, 2= two assets, 3= three assets, 4= four assets)

In response to an open question asking why some households had not yet bought ITNs, responses were received as shown in Figure 4.7. The most common response was that ITNs were not affordable.

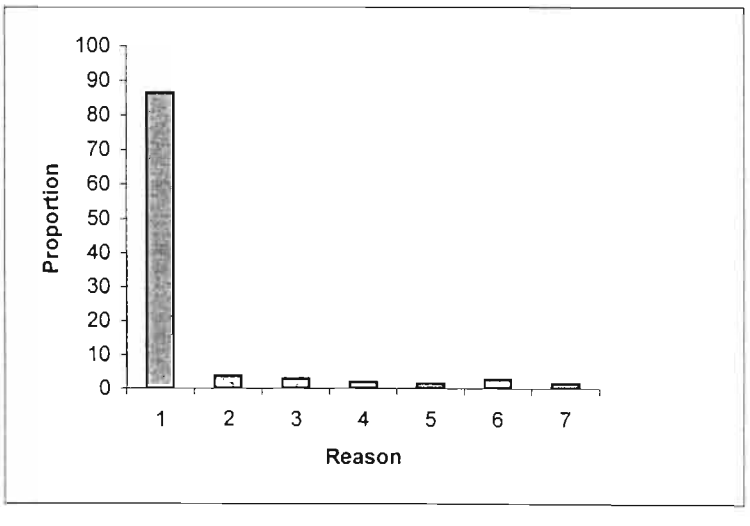

Figure 4.7. Reasons why households do not own ITNs.
(1=cannot afford; 2=not priority; 3 =mosquitoes not problem;
4 =other means of protection; 5 =ITN not available;
6 =others; 7 = do not know)

With regard to multiple ITN ownership by households, 40% owned only one ITN, 10% had two, and 0.5% had three and only 0.01% owned more than

three ITNs. Most nets were bought from the ITN programme through the community health worker, 77% (n=49). Seventeen percent (n=11) were procured from the local shop, while 6% were obtained from other sources. Male and female parents had reportedly used 50% of the ITNs in the community the night prior to the interview, children <5 years had used 25% and the remaining 25% was shared between parents and children.

Comparisons using facility records were made between ITN users and non-users on reasons for visiting the health centre. Cases were only considered malaria cases when malaria was recorded as the primary reason for visiting the facility. Cases on the health centre register were traced to households through ITN catchment registers and village and home addresses given by consumers during registration at the health centre. The graph (Figure 4.8) shows malaria presentations had progressed one year following introduction of ITNs. A Kruskal Wallis statistical comparison of non-normalised ranks for the three groups (users, non-users and a control community outside the ITN coverage area) showed a statistically different distribution of ranked means (X^2=19.7, dof=2, P<0.001). ITN users had an average of 8.2 malaria cases per month reported to the health facility, non-users 20.1 episodes of malaria and those from the control site had a mean of 27.1 infections reported to health facilities per month (Figure 4.8). In addition, the disease incidence pattern among non-ITN users followed typical seasonal pattern of low malaria cases seen in health facilities during the cool dry season (May-September) compared to the rainy warm season (October-April). In the control community, the seasonal trend was not detected probably because it is situated near a swampy area, where mosquitoes breed throughout the year.

The distribution of households which visited the health centre with malaria as the primary complaint was mapped and the results are presented in (Figure 4.9). This map shows a random distribution within both user and non-user households in the village.

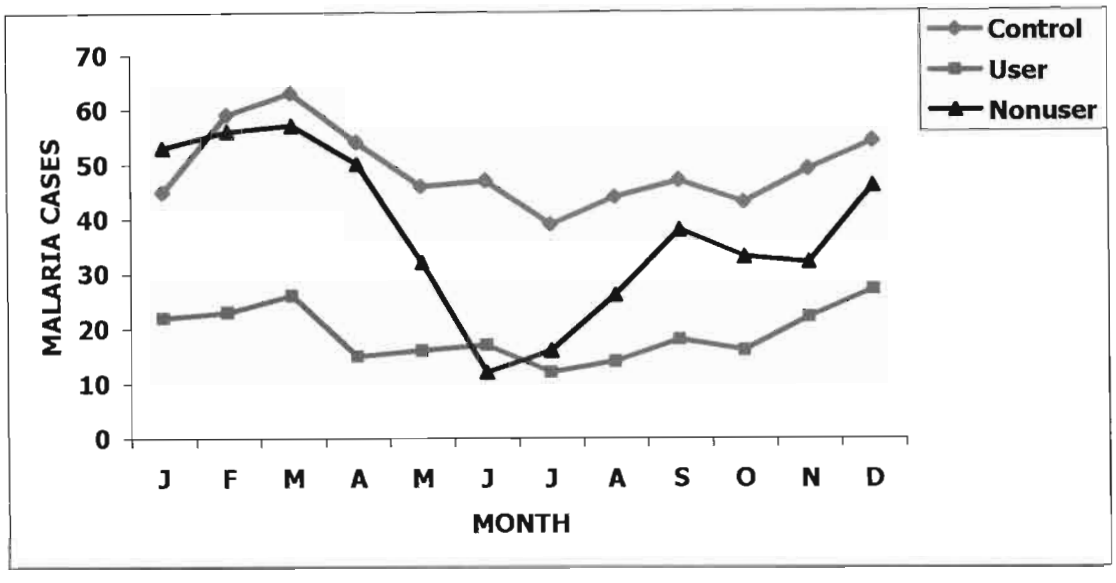

Figure 4.8. Health Centre out-patient attendance with malaria as the primary complaint in 2001.

Results of a Students *T-test* comparison of average distances from 10 reference points in the village between ITN user and non-user households are shown in Table 4.1. Only the distances between the two groups of households and the roads were significantly different ($P<0.05$) although only marginally so ($t= 2.05$, dof= 1, $P<0.05$). However, although not significant, non-user households tended to be situated slightly further away from each parameter compared to their counterparts with ITNs in their households.

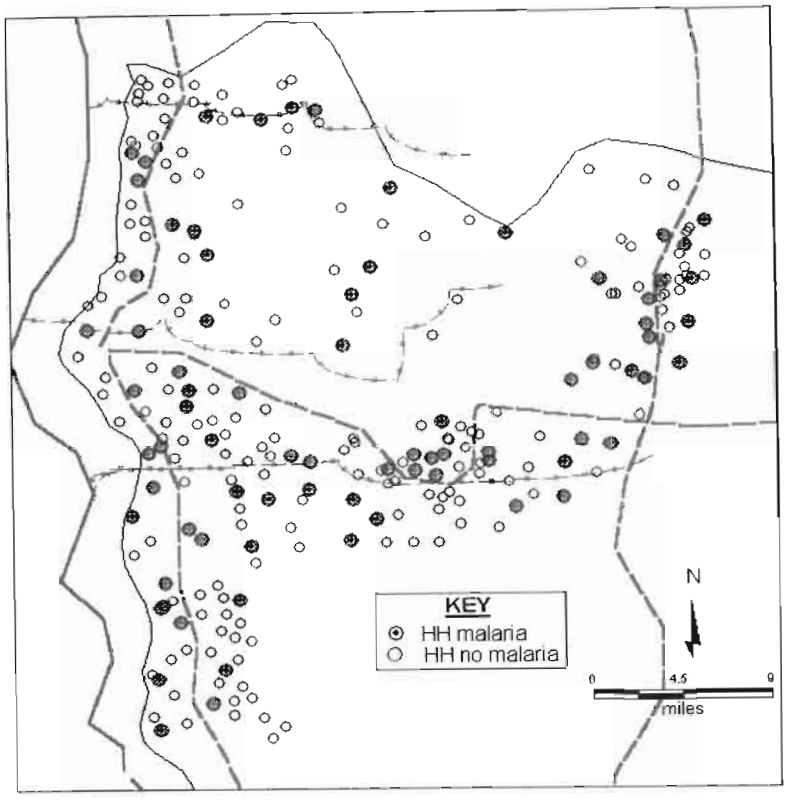

Figure 4.9. Distribution of malaria cases within Lukwesa village over the study period (2000-2001) based on attendance at the health facility for malaria.

Test	Mean distances (km)		t-value
	User	Non user	
Health centre	14.9	16.4	1.3636
Road	1.7	2.4	2.0544
Hospital	11.9	12.0	0.1705
Shop	13.3	14.7	1.3054
Water	5.7	6.4	1.1591
School	14.2	15.6	1.3384
Church	14.7	15.4	0.7205
CHW	20.1	17.7	-1.868
T/Healer	20.1	21.0	0.6295
T/Leader	13.4	12.2	-1.460

Table 4.1. *T*-values and mean distances from households to 10 reference points in the village for ITN user and non-user households.

Fisher's Exact Test was used to explore the relative risk of users and non-users of ITNs contracting malaria. For households using ITNs, the Relative Risk (RR) was 6% (RR=0.061, CI, 0.057-0.394; P<0.05), while for non-users it was 40% (RR=0.404, CI, 0.057-0.394; P<0.05). Households

without an ITN at Lukwesa village had a one in 2.5 chance of acquiring malaria, compared to households with ITNs who had 1 in 17 chances of infection.

Discussion

In Zambia mosquito net usage in the population was less than 5% prior to the ITN project, showing that there is little or no tradition of ITN use in the country. This would imply that with every ITN initiative there needs to be a community sensitization campaign. Malaria is often identified by community members as one of their pressing health problems; where this is not the case, the mosquito biting nuisance is often a key factor in net acquisition and utilisation. This perception should form the basis for improving access to and eventual utilization of ITNs, especially by vulnerable groups (e.g. children below the age of five years; pregnant women). Issues of sustainability are at centre stage in the global discussions on ITNs. This is in fact the basis for proposing the ITN model at the global level. The model recognizes that there those who cannot afford an ITN, and these should benefits from various subsidy public sector initiatives, involving NGOs, civil society, governments, and religious groups. There are those who can afford to contribute a little towards the cost of an ITN. The model recognizes these groups and suggests reaching them through other channels such as social marketing, ITN-for-work and cost-sharing coupons. Those who can afford are encouraged to obtain their ITN as far as possible from the commercial market. The role of behaviour change communications is acknowledged in the model, as a means for making net use become apart of people's culture (WHO/RBM, 2002).

ITN usage in communities where this programme began stood at 60% coverage and about 40% re-treatment rates at the time of the survey. These were encouraging results when one considers the prevailing poverty levels of >70% in the country according to the World Bank (1993) report. Poor rural communities in this study were able to prioritize malaria and in 40% of cases brought their nets back to get them re-treated after a year of use.

Within the study site although ITNs had only been available for less than 12 months, more than a quarter of the households had already acquired and were using them. The overall malaria caseload seemed to be declining (Figure 4.4). Das *et al.* (1993) documented a similar situation in Afghanistan. They noted that within a year of ITN use, the malaria incidence rate had dropped eight fold. Corresponding findings were made in China (Rowland *et al.*, 1997; Dapeng *et al.*, 1994). In Africa, there are many documented cases of positive use of ITNs, including The Gambia where the combination of ITNs

and chemoprophylaxis reduced all-cause childhood mortality by 63% (Alonso *et al.*, 1993; D'Alessandro *et al.*, 1995). This shows that malaria is responsible for the largest proportion of childhood mortality in Africa and its control should save more than half of the 1-2.7 million malaria-associated deaths (WHO, 1993; Choi *et al.*, 1995).

In attempting to address issues pertaining to the actual acquisition of ITNs by community members, a GIS analysis showed households to be randomly distributed within the study village (Figure 4.3), although slightly clustered near rivers and roads. Other clusters are around social services, such as schools and health facilities were situated in a similar pattern.

Within distance buffers at 2, 5 and 10km radii, there was a non-statistically significant difference in scattering between ITN user and non-user households. Despite this, a slight non-significant association existed between ITN ownership and residing outside the 5km but within the 10 km buffer. Malaria occurred significantly more often in ITN non-user households than in user households.

The data in this study suggest that both ITN users and non-users were getting malaria infection challenge albeit at different rates. This was an important observation relating to the development of protective immunity within a population. It was feared in the past that ITNs might be so effective that they would prevent the necessary sporozoite challenge essential for development of immunity which would result in delayed increased mortality effect or "rebound effect". However, this has been shown not to be the case (Lengeler, 1998). The fact that ITN users do contract malaria infection, albeit at low rate, proves that the community is getting an inoculation challenge that facilitates immunity development. Lengeler (1998) pointed out that the argument about the rebound effect should not delay implementing national level ITN programmes. In places with high transmission intensities, concern should not be about individuals not contracting malaria, but rather prevention of fatal outcomes. It is also suggested that in these places ITNs have no dramatic impact on preventing parasitological infection or the incidence of clinical disease. It is the impact of the ITN on mortality-related indices that make it an attractive health intervention (Alonso *et al.*, 1993). ITNs should not be used as anti-malaria interventions in isolation of other equally effective approaches to mortality prevention to enable communities to benefit from their synergistic effects (WHO, 1989).

As has been stated by Fiedler (1981) and Zwarenstein *et al.* (1991), a host of complex factors dictate community, family, and individual access to health services. The decision by households to purchase an additional ITN, even when one was provided to them, seemed to depend on factor which were not elucidated in this study. Even the use of the nets in the post-

purchase period follows another set of behavioural processes. Other behaviours dictate re-treatment and households opting for multiple net ownership or replacement.

In this inquiry, it has been demonstrated that the socio-economic status of a household was associated with the purchase and use of the ITN. Perhaps this is explained by the fact that those families with more disposable income (indicated by property ownership) were more likely to invest some of it in personal protection early in the intervention. This being the case, one would expect that over time, other household classes would eventually acquire ITNs, after saving or using the installment schemes available through the programme. Lack of cash income was also provided as the reason for not having bought an ITN prior to the survey. One would argue in favour of this theory being responsible for those countries with a culture or history of using mosquito nets. This is the case in Mali, Senegal and recently Tanzania. The assumption would be that, their current culture of sleeping under mosquito nets must have started at some point in time. It would seem that for households to have equitable access to ITNs, the government should create an enabling environment to make it easier for people to afford them.

The World Bank (1993) places Zambia's poverty in rural areas at 70%. This may call for the provision of subsidies for this intervention, just like indoor residual spraying was provided free of cost to the population. Schemes such as exchanging ITNs for commodities other than cash (barter) may be a viable option. In fact the barter system was tried in the pioneer communities at the start of this programme, but it was found to add a further burden to the supervisory capacity of the health system.

The level of formal education of the head of the household, irrespective of its economic status, was another factor whose influence on ITN acceptance by the household was examined. It was found that households whose heads had spent between 1-5 years in school tended to own more ITNs. The converse was also true; those without formal schooling owned the least ITNs. Household heads without formal education seemed to have a low level of awareness about malaria, about ITNs or their value. Although communication materials have been designed for the entire community, they seemed to reach only those who are literate and able to understand messages. The literate grasp the concepts quickly and use the acquired knowledge to protect their households from malaria. The ITN culture had to be learned, and this is usually a slow process.

This study showed that the major obstacle to ITN ownership appeared to be the cost (Figure 4.7). Elsewhere, Alonso *et al.* (1993), Curtis and Mnzava (2000) and Njunwa *et al.* (1991), have all also concluded that cost is a real issue and that it explains low coverage in ITN projects. Other studies

however, (MacCormack and Snow, 1986; Brinkman and Brinkman, 1995; Quinone *et al.*, 1998), consider that ITNs do not introduce new costs to families, but cognizance should be taken of existing costs of other frequently used protective measures, such as repellents, repeated fees at health facilities and transportation costs. Although ITNs were not yet due for re-treatment at the time of the study, it may be assumed that when they do, cost will also determine how many will be brought back for re-treatment. The demonstration in this study that non-ITN users are more likely to get malaria than users should be used as advocacy evidence of the effectiveness of ITNs in preventing malaria.

GIS has been employed to estimate the importance of distance between households and a number of reference points in the village. Statistically, the mean distance between households and the road was significantly correlated to ITN ownership. Households with ITNs were situated nearer to the roads (mean distance 1.7km), than those without ITNs, which were 2.4 km or more away. Generally, the rest of the tested reference points showed smaller distances between "ITN-owned" households than "non ITN owned" households. The exception to this observation was the traditional healer, 21km and 20.1 km and the Community Health Worker, 17.7 km and 20.1 km for net-owners and non-net owners, respectively.

Among the parameters considered, the shortest average distance was between households and roads ranging from 1.7 to 2.4 km, followed by distance to water bodies from 5.7 to 6.4km for net-owners and non net-owners, respectively. The traditional healer and the community health worker were the two community-based health providers found in Lukwesa village. Although they were the ones in the business of providing health services to the local community, they were on average situated furthest from the households. The community health worker was in fact the provider of ITNs in the community.

It should be noted that ITN sales by the community health worker were incentive-driven. For every net fully paid for by a household, 20% of the purchase price (US$ 0.50) went to the community health worker as commission from the sale. In addition, upon completion of training each trainee CHW received a bicycle, health education materials and a certificate. This could partly explain why they were able to cover their catchment populations more vigorously than before, they were remunerated. As the community health worker delivered ITNs door-to-door, the effect of distance on the uptake of ITNs was thus probably nullified. Higher sales close to roads may be a result of the community health worker frequently riding his bicycle along the roads.

The maximum walking distance to reach the community health worker was 40 km, which by Zambian and probably sub-Saharan standards is not insurmountable. Thus perhaps the distances considered in this study were lower than the threshold at which uptake of ITNs would be affected. Other opportunities for households to obtain an ITN presented themselves in public gatherings such as religious and traditional ceremonies. ITNs were also available for sale at the health centre on certain days, such as the antenatal and under-five year clinic days. Information could also be sent home through school children. Taken together, these mechanisms could have had an impact on masking the effect of distance on ITN consumption by households. It has been demonstrated in other studies that distance together with population density and economic deprivation, are some of the important determinants of access to health services by communities (Fiedler, 1981; Chetty, 1995; Laximi and Cleland, 2000; Tanser, 2000). As the community had only one option for obtaining ITNs, those who needed the service had no choice but to make the journey, irrespective of the distance involved.

The findings of this study are in agreement with those by other workers, which show that ITNs are a key intervention in malaria prevention. There is global consensus that ITNs do work and have been validated in many trials including the four major African research projects (Luxemburger *et al.*, 1994; Rowland *et al.*, 1997; Lengeler, 1998; Schellenberg *et al.*, 1998; Curtis and Mnzava, 2000). All these workers point out that ITNs are beneficial and that there should be no further delays in implementing national malaria control programmes using them. Despite this unanimity, up to the year 2000, there have been no examples of truly national ITN intervention programmes anywhere other than China and Cambodia (Rowland *et al.*, 1997).

For Africa the debate has now largely shifted from whether ITNs work to the best delivery mechanisms to benefit the poorest of the poor. At operational level, the debate about the best way to deliver ITNs to the populations is still continuing and there are many views on how best to implement ITNs in countries with intense malaria transmission (WHO, 1989). There are also strong views advocating placing this life-saving intervention in the hands of the private sector, which judging by the magnitude of the malaria problem, (1.2-2.7 million deaths in African children annually), is tantamount to placing children's survival at the mercy of the profit-oriented private sector (Cleland and Hobcraft, 1985; Grant, 1988; Krige, 1990).

There are a number of new initiatives in the ITN arena whose collective goal is addressing the problems associated with delivery of sufficient quantities of quality ITNs to communities. Studies such as this one contribute to the gathering of evidence that inform this process so that it is

based on scientific evidence rather than opinion, as has been the case in the past.

The global ITN framework aims at linking the public and private sectors to work in concert, each using its comparative advantage to release its full potential into the ITN market. NetMark is a USAID initiative, which is assisting a number of African countries in implementing the various aspects on the global framework. It catalyses both the public and private sectors to increase their investments in the ITN arena, at the lowest possible cost to the consumer, while still assuring quality.

Other organizations are supporting implementation of other aspects of the model such as delivery of free ITNs to deserving constituencies; include UNICEF and the rest of the civil society. Others are working on the demand creation aspect of the model where they are availing subsidized ITNs to popularize them to the communities. The model also recognizes the delivery of ITNs in emergency situations. There are institutions with the right competences to deal with this aspect.

As long as malaria continues to kill people at the magnitude it does currently, no effort should be spared in trying to understand what drives this disease. Trying to understand factors that influence the uptake of the ITN intervention is equally important in mitigating the negative impact of malaria on the population, and this was the objective of this inquiry.

Chapter Five: Evidence-based Malaria Risk Stratification in Zambia

Introduction

The survival and development of all arthropod vectors of human and animal disease is affected by climate change, especially rainfall, temperature and relative humidity (Hay *et al.*, 1996). These elements may exert a direct or indirect effect on the biology and survival of these vector populations. The last century witnessed a rise in the earth's temperature of between 0.3°C and 0.6 °C and this has had an important impact on some of the world's most important vector-borne diseases, such as malaria (Lindsay and Birley, 1997).

Nearly half of the world's population is at risk of one or more vector borne diseases as a result of living in tropical and temperate climates. For example, approximately 2.1 billion people in more than 100 countries are at risk of malaria alone (Washino and Wood, 1994). While the malaria situation has improved in some places, the overall prevalence of malaria in Africa, Asia and the Americas continues to deteriorate. This has led nations, institutions, organisations and agencies including the World Health Organisation (WHO) to call for development of new and innovative approaches to malaria control (WHO, 1993; Najera, 1989; Washino and Wood, 1994).

Malaria and climate

The distribution of malaria in Africa is not homogeneous. Small-scale spatial variations and temporal heterogeneities in the mosquito population can have important consequences for disease transmission (Lindsay and Birley, 1997; Cattani *et al.*, 1986; Smith *et al*, 1994; Sharp and le Sueur, 1996). Climate variability has been noted to be responsible for changing malaria endemicities globally (Nchinda, 1998) and hence affecting malaria transmission by its impact on the sporogonic cycle (n) and mosquito survival (p) in accordance with the MacDonald (1957) basic malaria reproduction formula (McMichael *et al.*, 1996; le Sueur and Sharp, 1996).

Prolonged droughts have often forced people to move closer to water bodies which in turn exposes them to higher malaria transmission potentials. Drought sometimes causes rivers to dry out producing discontinuous pools along riverbeds favouring certain malaria vectors to proliferate and others to diminish

(Lindsay and Birley, 1997). Deforestation and a number of other human activities contribute to increases in malaria transmission (WHO, 1996).

Global warming is expected to result in increases in both ambient temperature and rainfall, and at higher altitudes it would bring malaria into cities that have been protected from malaria by low temperatures, such as Harare and Nairobi (Connor *et al.*, 1997; Nchinda, 1998). Unless this is accompanied by increases in precipitation, it may affect longevity of vector mosquitoes negatively (Mc Michael *et al.*, 1996).

Spatial and Environmental determinants

Since Ross discovered the malaria parasite cycle in the mosquito in 1897 and subsequent progress in the understanding of the biology and ecology of malaria vectors, much effort has been expended defining local, regional and global spatial distribution of the disease (Hay *et al.*, 1996). Malaria distribution maps based on lay observations and expert opinions, often lacking clarity and reproducible definition, have been produced. In most cases opinion maps tend to use anecdotal data from limited observations to produce maps representing large areas. Such maps have resulted in distortions of actual distribution patterns and often masked the true nature of local malaria epidemiology (le Sueur *et al.*, 1997).

In nature, malaria transmission involves a complex interaction between vector, host, parasite and the environment. Environmental factors, such as temperature, rainfall and relative humidity, to a large extent determine and modify the amount of malaria disease in the human population (Onori and Grab, 1980). Once the actual situation is known, it can be compared with the "norm", leading to forecasting of events, resulting in early warning and prompt action.

Disease modeling is a method of studying the impact of determinants, such as climate variability, on vector-borne diseases. It enables the elucidation of interdependence between climate variability, vector population dynamics and human disease. While taking account of local realities, such as control measures, health services, parasite reservoirs and population densities. Models should be validated with historical data and expert opinion. The Famine Early Warning System (FEWS) programme of the Food and Agriculture Organisation (FAO) is one example of an early warning system and this is the result of disease modeling (Martens *et al.*, 1995; le Sueur and Sharp, 1996; McMichael *et al.*, 1996).

Satellite Information

Satellite datasets are increasingly becoming useful in mapping the extent to which environmental factors modify disease dynamics in both time and space (Connor *et al.*, 1997; Thomson *et al.*, 1997). Remote sensing is the science and art of obtaining information about an object through analysis of data acquired through devices not in contact with the object (Washino and Wood, 1994; Connor *et al.*, 1997). The liberalization of certain global datasets recently has allowed the manipulation of these data in Geographical Information Systems (GIS) in predicting disease patterns, including malaria (le Sueur *et al.*, 1997, Snow *et al.*, 1998).

The science of GIS has introduced new dimensions to the understanding, prediction, analysis and dissemination of spatial relations between disease, time and space (Connor *et al.*, 1997; Tanser, 2000). It allows the integration of satellite, environmental, and climatological data, together with local knowledge in relational databases to accurately display complex interactions in simple formats (Goodchild, 1992; Reader, 1994).

Applications of GIS

Recent developments in GIS represent significant improvement over the traditionally measured weather elements. Vectors usually exist in microhabitats that are not reflected by general average measured climate (Hay *et al.*, 1996). The use of these data sets in a GIS provides an opportunity to integrate up-to-date information, local knowledge and historical trends in a manner that draws attention to areas of change-associated problems and options for action. This makes GIS a tool not only for data analysis, but also for information management and decision-making (le Sueur *et al.*, 1997).

Among the pioneering applications of GIS to malaria in Africa has been the development of a Malaria Information System (MIS) at household level by the Malaria Research Programme of the Medical Research Council (MRC) of South Africa (Sharp *et al.*, 1998). This has resulted in improvements in the planning and implementation of community-based development programmes. The GIS capability has not only been applied to mapping malaria and to developing surveillance at district level, but has proven sensitive enough to monitor changes at household level. In this example, maps produced as a result of innovative application of GIS have resulted in excellent opportunities for simplifying the malaria problem by identifying factors that are responsible for both its proliferation and limitation. This has led to deployment of resources in the most cost-effective, systematic, equitable and sustainable way, resulting in evidence-based decision making and effective planning (MARA/ARMA, 1998; Sharp *et al.*, 1998). Recently, steps have been taken to apply this model and

technology to the whole African continent through an initiative called Mapping Malaria Risk in Africa (MARA/ARMA).

The MARA/ARMA Collaboration

The Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique (MARA/ARMA) is a continent-wide collaborative effort aimed at spatially establishing malaria distribution in Africa. The expected output is an evidence-based atlas of malaria distribution in Africa. This is being realized through establishment of a continental database on the epidemiology of malaria using historical malaria data sets (IPCC, 1998; Craig *et al.*, 1999). For the purpose of data collection, Africa has been divided into regional and sub-regional centres. The most commonly available data and best estimator of malaria intensity is the malaria parasite prevalence rates (Omumbo *et al.*, 1998). Preference is for parasite ratios in lower age groups (0-9 years), although in places with limited data, cross-sectional data are acceptable. Other parameters, such as the Entomological Inoculation Rates (EIR), Infant Parasite Rates (IPR) and Health facility based incidence data, are admissible only for four countries in Southern Africa. These are Botswana, Namibia, South Africa and Zimbabwe. These countries are on the transition fringe between stable malaria and epidemic malaria. In addition, they possess reliable health facility-based data which could be applied as a proxy indicator of parasite rates (le Sueur and Sharp, 1996; IPCC, 1998; MARA/ARMA, 1998).

Apart from disease-related data, environmental variables (temperature and rainfall) are utilised to predict the suitability of an area to sustain malaria transmission. A climate-suitability mathematical model for stable malaria transmission (fuzzy logic) has been derived using the GIS software IDRISI (Craig *et al.*, 1999). This model has been verified with data from some localities on the continent. The resultant model fits well with both historical and expert opinion maps. The model produces superior results because it is empirically derived and therefore, reproducible (Lindsay and Birley, 1997; Snow *et al.*, 1998; Craig *et al.*, 1999).

The MARA/ARMA fuzzy logic model is not the first model to use climate data to predict malaria. The malaria reproductive model proposed by Macdonald in 1957 and the Malaria-Potential-Occurrence Zone (le Sueur *et al.*, 1997), are two other examples.

Despite some inherent limitations of the GIS-based approach to modeling, it is at least providing relatively reliable information on the geographical distribution of malaria risk, and estimates of malaria morbidity and mortality (Snow *et al.*, 1997). The value of a spatial information system in this case is not

only for advocacy, but also for providing an epidemiological basis for rational disease control planning and management (Snow *et al.*, 1998).

Application of GIS in Zambia

For resource-constrained sub-Saharan African countries, like Zambia, the need for a GIS-based malaria information system cannot be over-emphasized. Currently, decisions in the malaria programme in Zambia are taken on an *ad hoc* basis driven by personal opinions. Control efforts are haphazard, resulting in misdirection of the limited resources available. There is lack of understanding of the nature and extent of the malaria problem in the country. The national Health Management Information System (HMIS), which includes malaria, does not reflect the true malaria situation on the ground.

An evidence-based Malaria Information System (MIS) would create a more focused and purposeful approach to directing resources to areas of most need with reasonable returns for effort and resources invested.

For the purpose of the MARA/ARMA collaboration, Zambia is located in region six, the southern Africa region. Like all other regions, the distribution of malaria is not homogeneous. The rationale behind the collection of the Zambian data within the auspices of MARA/ARMA is to contribute data to this continental initiative and to develop a functional malaria information system for the country.

The purpose of this study was to apply GIS to enhance the understanding of the distribution of the determinants of malaria in the country and to utilise this knowledge to compare the situation on the ground to the government policy of equity of access to quality-assured health services close to the family.

The goal was to derive a number of GIS platforms for Zambia to demonstrate (for the first time) the relationship between policy and declarations, and reality on the ground. This will serve as an entry point to encourage the government to rationalize disease control by placing services where the need is greater.

The expected outcome of this study was to demonstrate the importance of evidence basis for decision-making in disease prevention and control in Zambia, with the following specific objectives:

- collate, analyse and present existing historical data on malaria prevalence in the country, especially drug efficacy surveys involving primary school-going children;
- use GIS to develop a malaria endemicity map (stratification) through verification of the MARA/ARMA fuzzy logic model, historical and expert opinions;
- identify the various endemicity zones of the country;

- prepare specific maps of malaria distribution in Zambia, including malaria survey sites;
- propose mechanisms for improved local response to the malaria situation especially in areas with potential for malaria epidemics;
- make available electronic district-specific GIS platforms of malaria endemicities to policy makers, planners and district programme managers.

Methodology

Data Collection

Malaria prevalence data were collated from all over the country where malariometric and other surveys, especially of children aged between 4 and 14 years, have been undertaken. Reports abstracted went back more than 30 years and altogether 364 reports were identified and found to contain 208 uniquely identifiable data points suitable for the study (MARA/ARMA 1998). Data were collected between March 2000 and September 2001. It was first abstracted to the 2000 version of the MARA/ARMA database proforma. A double entry system was utilized for inputting data into a Microsoft Access® database. It was re-entered and cleaned at the southern African node of the MARA/ARMA collaboration.

Reports containing malaria prevalence rates or parasite ratios but where the age of subjects could not be ascertained or assumed and those whose sample sizes were less than 50 individuals, were excluded from the analysis.

Geographical co-ordinates of each data source were established from paper maps, electronic maps or estimated from nearest known points or physical features. All included surveys were conducted within confined and named localities and for this reason, assumed to be point-referenced malaria prevalence data (Omumbo, *et al.*, 1998). Paper maps at 1:50,000 scale were obtained from the government survey department. Where a place could not be ascertained in this way, Africa Data Sampler® (World Resource Institute, 1995) was employed to locate names mentioned in survey reports. Approximately 25 sites were geo-positioned with a hand-held Global Positioning System (GPS).

Administrative boundaries for the first three levels (national, provincial and district) were obtained from Africa Data Sampler (ADS) software, while fourth level boundaries (constituencies) were converted into electronic format from a paper map at the MRC GIS centre in South Africa, this being

the first time that boundaries of this level became electronically available. It was digitized from a paper map at a scale of 1:1,500,00. The country is divided into nine provinces, which have remained consistent over a long time. The next administrative level districts, which were last altered in 1996. Below districts, there are 150 constituencies. Constituencies are a political rather than an administrative construct. The ADS software also defines GIS surfaces of rivers, lakes, and other natural resources.

Data from surveys conducted in exactly the same localities were combined (numerator and denominator) and the mean derived. In situations where multiple survey results were available for the same site, preference was given to the survey with a larger sample size and/or one in which children of 5-9 years were considered and/or the most recent survey and/or those where the methodology was most clearly outlined.

Data searches included use of relevant internet websites, national archives of Zambia, Mines archives, libraries of both public and private institutions and registries. In addition, correspondence was entered into with both health and archive officials in Britain and Zimbabwe. Both these countries were at one time interested in the health affairs of Zambia. Britain was the first to set up government in Zambia in 1922, while Zimbabwe was the seat of government and capital of the Federation of Rhodesia and Nyasaland between 1958 and 1963. Expert interviews were also conducted with a number of authorities, especially those who had worked in the public health department of the mines.

Malaria Classification

The best estimator of malaria endemicity in an area is the number of infective mosquito bites a population receives over a period of time, the Entomological Inoculation Rate (EIR). This parameter is not commonly available in much of Africa, as it requires special skill and high resource inputs to determine. In its absence, the next best proxy indicator of malaria transmission intensity is the malaria infection rate, especially in children 2-9 years old (Metselaar and Van Theil, 1959; Beier *et al.*, 1999; Craig *et al.*, 1999).

In this study, transmission intensity parasite ratio estimates were assigned to four arbitrary categories. These categories helped to divide the country into different malaria transmission zones. This was done to minimize the error of lumping together areas of different transmission rates which is a common practice in classifications based on expert opinion.

Stratum 1 (lowest) contained places where asymptomatic malaria infection rates ranged from 0% to approximately 15%. Stratum 2 contained

rates between 15% and 25% as moderate transmission; Stratum 3 between 25% and 40% (high), and Stratum 4 (highest) above 45% of the survey population with asymptomatic parasitemia. A similar classification was designated by Snow and collaborators (1997) and was later used by Omumbo *et al.*, (1998).

The epidemiological rationale behind these categories is that the lowest class includes all places where the chances of acquiring malaria infection is on average one in five and in the highest class the chances rise to almost five in five.

These definitions translate into observed disease presentations within all age categories of populations living in places of very low transmission intensity equally affected (Snow *et al.*, 1998) and the severe forms of disease are generally cerebral malaria cases. In highest transmission areas on the other hand, severe forms of malaria are common in children during their first two years of life and present as severe anemia. In places of moderate malaria transmission, the disease presents in the population as a mixture of the two situations above, with category two biased towards anemia, while category three leans towards cerebral involvement and severe disease affects older children in the 3-4 year age group. Older children and adults would have developed sufficient protective immunity to minimise malaria-specific mortality.

It was assumed for the purpose of this study that malaria prevalence and therefore endemicity in Zambia had remained relatively stable during the survey period. This was especially defendable in rural areas which have not experienced any large-scale control programmes. Urban areas have however, experienced variably successful control programmes between 1930 and 1980.

Statistical Analysis

The database containing parasite prevalence rates was created in Microsoft access and exported to Idrisi® (Idrisi 32) software in space delimited ASCII format as a point vector file and also to the MapInfo® environment. A Zambian boundary polygon was employed as the vector file. The two were then rasterised and displayed in Idris 32. Statistical analysis was performed on the parasite ratio layer of points to generate a continuous surface, using distance-weighted average surface interpolation to calculate the best-fit surface to the entire set of data points. The local interpolator using six sample points nearest to the pixel to be interpolated, was used in the calculation. The function draws a circle around each pixel to be interpolated. The search radius was set to yield six control points within a

circle, calculated by dividing the total study area by the number of points and determining the radius that would on average result in six points. This computation assumes an even distribution of points.

However, some flexibility is built into the programme. The attribute of an interpolated pixel should be most similar to that of its closest known data point. The function utilises the inverse square of distance ($1/d^2$) where d is the distance in map points. Therefore, for every pixel interpolated, the distance to every sample point is determined and the inverse square of the distance computed. Each sample point attribute was then multiplied by its respective inverse square distance term and all these values were then summed. The resultant sum was divided by the sum of the inverse square distance terms to produce the interpolated value (Eastman, 1999). The resultant raster surface was framed with the boundary layer and visually compared with the existing distribution maps and models (Craig *et al.*, 1999).

The chi-square statistic can be used to test for dependence although it is not a good measure of association between two variables, but its widespread use in tests of independence justifies its inclusion here. Cramer's V is one of the robust measurements based on the Chi-square that attempts to modify this statistic to minimize the influence of sample size and degrees of freedom. It also restricts the range of values to those between 0 and 1 (Marija, 1993). The statistic, Cramer's V is defined as:

$$V = \sqrt{\left\{\frac{\chi^2}{n(\nu - 1)}\right\}}$$

Where, V is the smaller of the number of rows and columns and n is the sample size. Cramer's V can attain a maximum value of 1 for tables of any dimension.

The application of a generalized linear model to the two-way table was considered realizing that there was a possible conclusion between the two variables (age and site) and parasite infection rates. Two models of the log-linear model were considered (Dobson, 1996), the independence and the maximal models.

The terms of the log-linear model under the independence model were:

$$\log E(Yij) = \mu + \alpha_i + \beta_j$$

And the terms under a maximal model were

$$\log E(Yij) = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij}$$

The hypotheses to be tested to measure goodness of fit for the contingency table were:

H_0 : the model of independence fits the data well.

H_1 :the maximal model fits the data well.
The statistics used to measure goodness of fit for contingency tables were the log-likelihood ratio statistics (D) and chi-squared statistic (χ^2).

Fuzzy Logic Model

In 1999, Craig and collaborators proposed a fuzzy logic model of the probability of malaria transmission occurring in a particular place. The model was improved on by the introduction of the start and end month of malaria transmission by Tanser (2000). The interpolated surface for Zambia was visually compared to these standards, in addition to expert and historical opinions. Both models utilize temperature and rainfall to predict the suitability of a particular place for malaria transmission. Other inputs include rainfall quantity, availability of breeding sites and suitability of temperature. Expert opinion, although sometimes questionable, is nonetheless an invaluable benchmark against which empirical evidence is verified.

Results

Parasite Ratio Records

A number of historical records containing parasitological data were identified from different places in Zambia. The bulk of these were from research and special surveys spanning over 3 decades from 1968 to 2001. The richest source of data was surveys involving primary school children aged 5-14 years, especially from the days of mass chloroquine distribution (1975-1982). A total of 161 surveys, representing 44% (n=364) of the total surveys were found to contain suitable data according to the inclusion criteria. Of these, 103 (64%), were school surveys, 26 (16%) were under-five children attending routine antenatal sessions without any clinical complaint. A further 17 (10.6%) were surveys of randomly selected community members 15 (9.3%) screened for drug efficacy testing, also in primary school children (Figure 5.2). Clearly school surveys contributed the majority of data points to this study.

The names of places of interest to this study, including rivers and lakes, are presented in Figure 3.1 of chapter three.

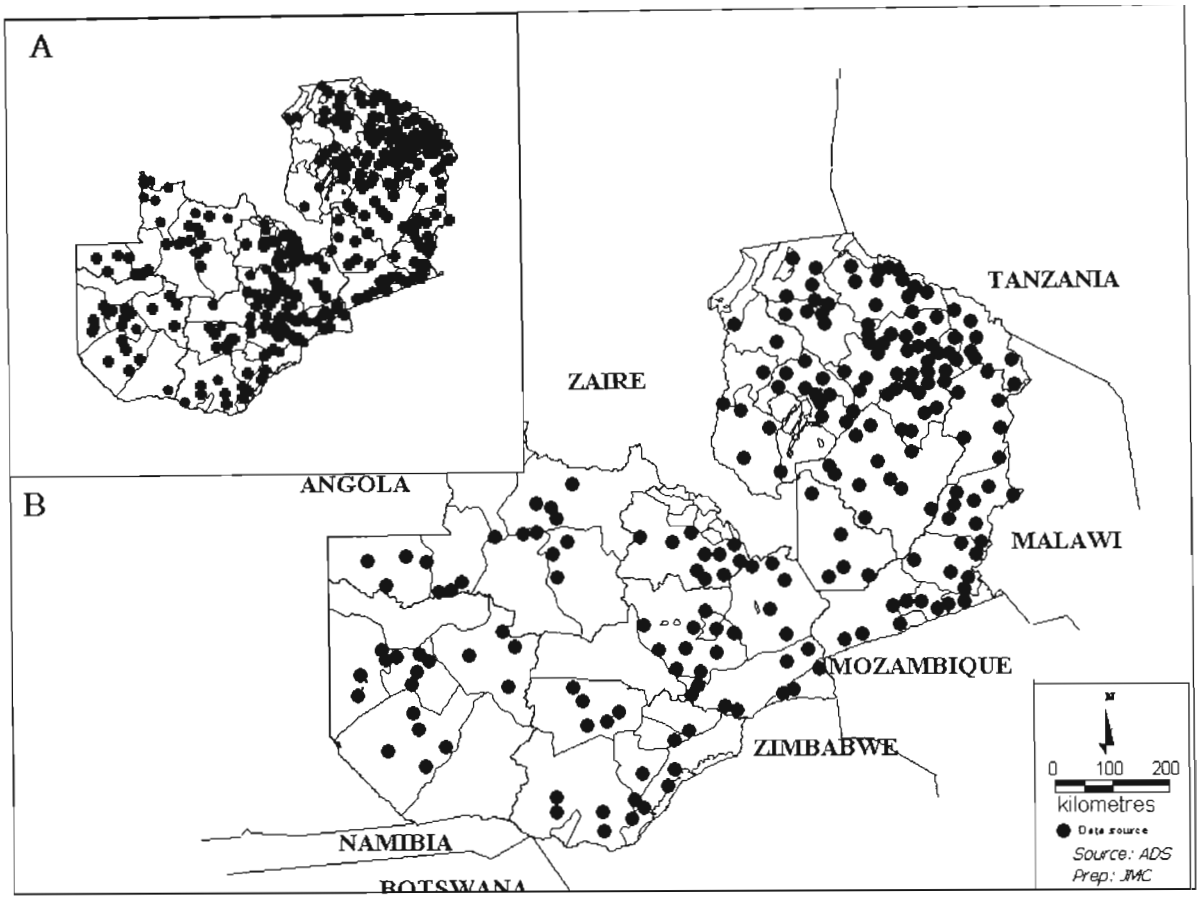

Figure 5. 1. Map of Zambia showing locations of all known surveys.
(A =All known surveys; B= Surveys with suitable parasite rates)

The search for information yielded a total of 161 geo-referenced data points. The northern half of the country has been surveyed more than the southern and western parts of the country (Figure 5.1). These reports included 21% published in peer reviewed journals, 5% were from nutritional survey reports, 57% were abstracted from Ministry of Health and related institutional reports, a further 5% from academic theses and 11% from various other sources.

The richest single source of suitable data was the Ministry of Health, especially the National Malaria Control Centre. Under the category "other", there were a number of one-off sources, such as the National Demographic Health Surveys (DHS) and baseline surveys for some developmental activities (Figure 5.3).

A number of places yielded multiple surveys and their admission criteria are discussed in the methodology section. These multiple points which were not separable in terms of space were discarded and this

process resulted a lesser number of data points included in the surface interpolation analysis (Figures 5.2 & 5.4).

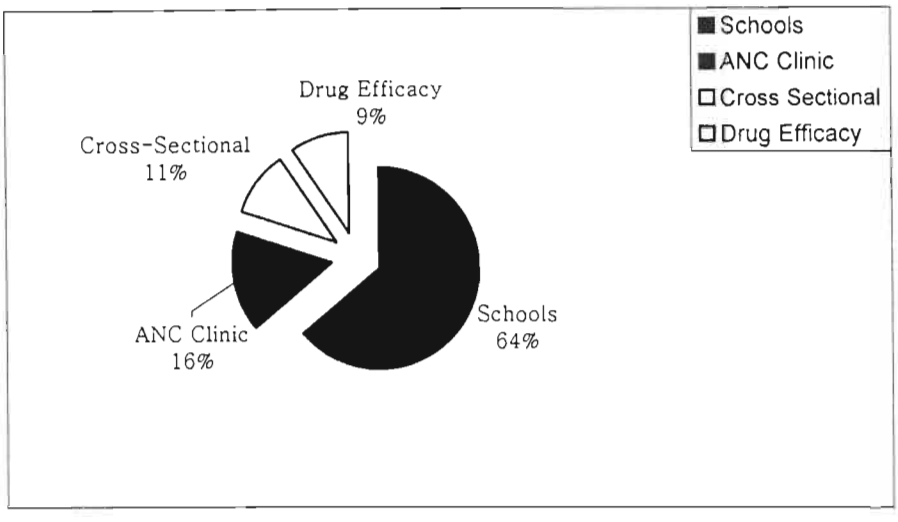

Figure 5.2. Parasitological ratios data sources.

There was much variation in the quality of data available in reports, methodologies used and in some situations certain information was not available. Sample sizes varied considerably and the timing of surveys were not always stated. In some cases, places had been sampled multiple times, while others had been sampled only once (Figure 5.1).

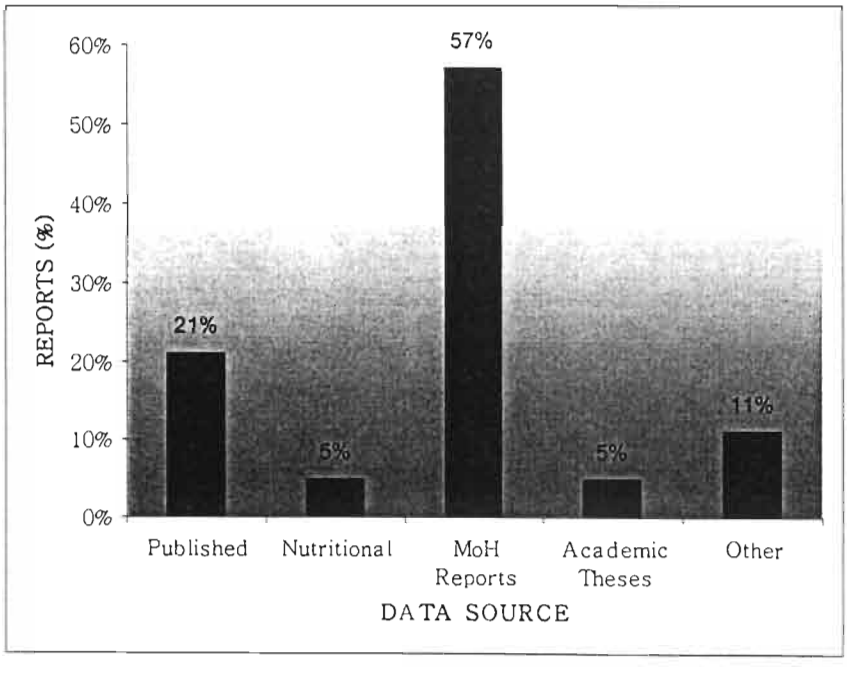

Figure 5.3. Report types containing parasite ratios utilised in the study.

Mapping Malaria Risk

The interpolated risk map (Figure 5.4) divides the country into four distinct malaria transmission zones.

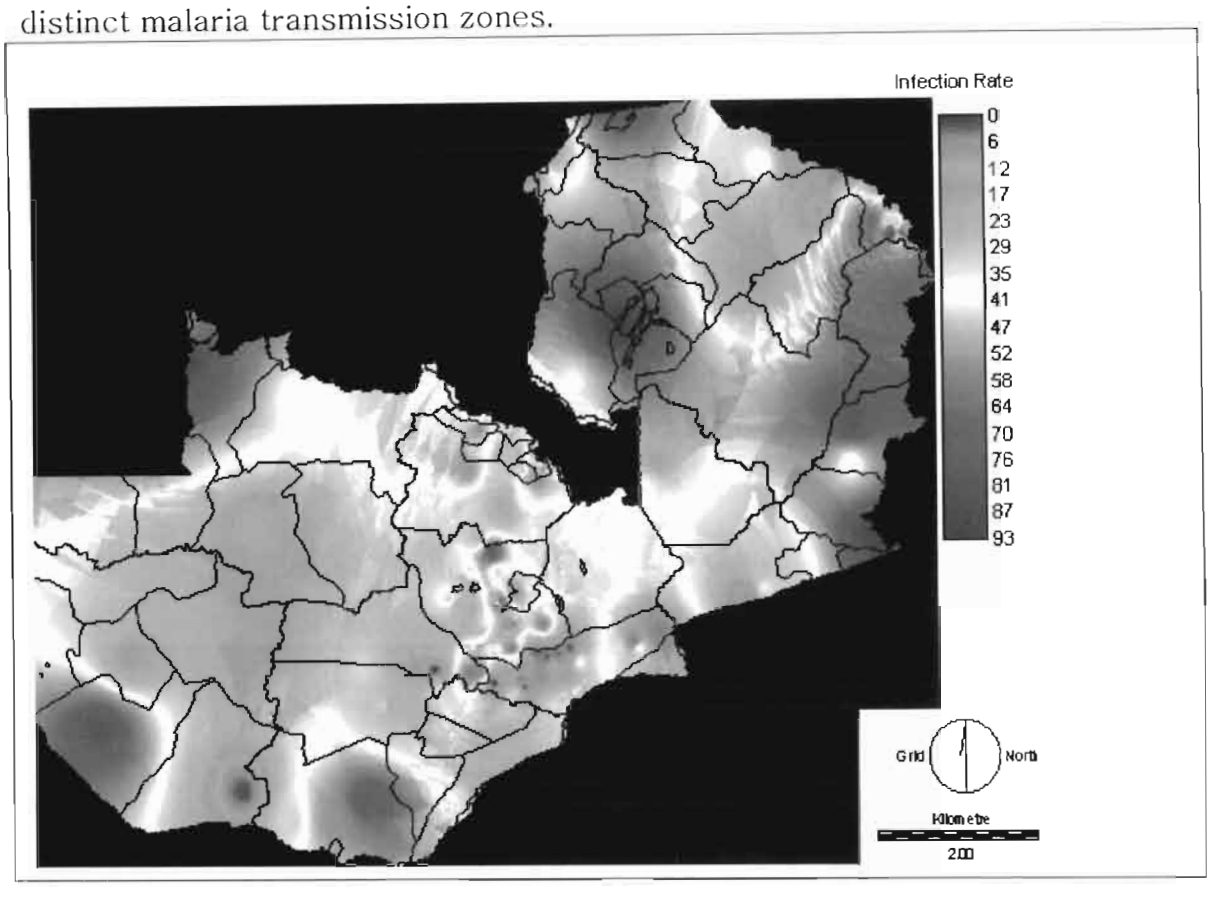

Figure 5.4. Zambia malaria risk map.

The lowest parasite infection rates were observed in stratum 4 the urban areas. Urban areas showed infection patterns similar to those in Western and Southern provinces, but at a lower threshold (Figure 5.6). Malaria infection rates generally lie below 15% and occur equally across all age groups. In this stratum, the impact of control is probably a major contributor to the relatively low infection rates and there are limited breeding sites because of absence of surface water or pollution.

Stratum 2 (Plateaux) comprises the highland plateaux of the Northern, North-western and the rural parts of Copperbelt province. Here infection rates in children lie between 24% and 40%. There was some evidence of declining prevalence rates with age (Figure 5.4 & 5.5). Similar infection rates were also observed in association with the country's highlands. The Muchinga escarpment lying in the north-

easterly direction stretching from central parts of Central province to the Malawian and Tanzanian borders, forming the Nyika plateau and the Mbala highlands respectively. The Kalene hills in the North-western province where Angola, the Democratic Republic of the Congo and Zambia meet, extend southwards to the Northern parts of Central and Southern provinces.

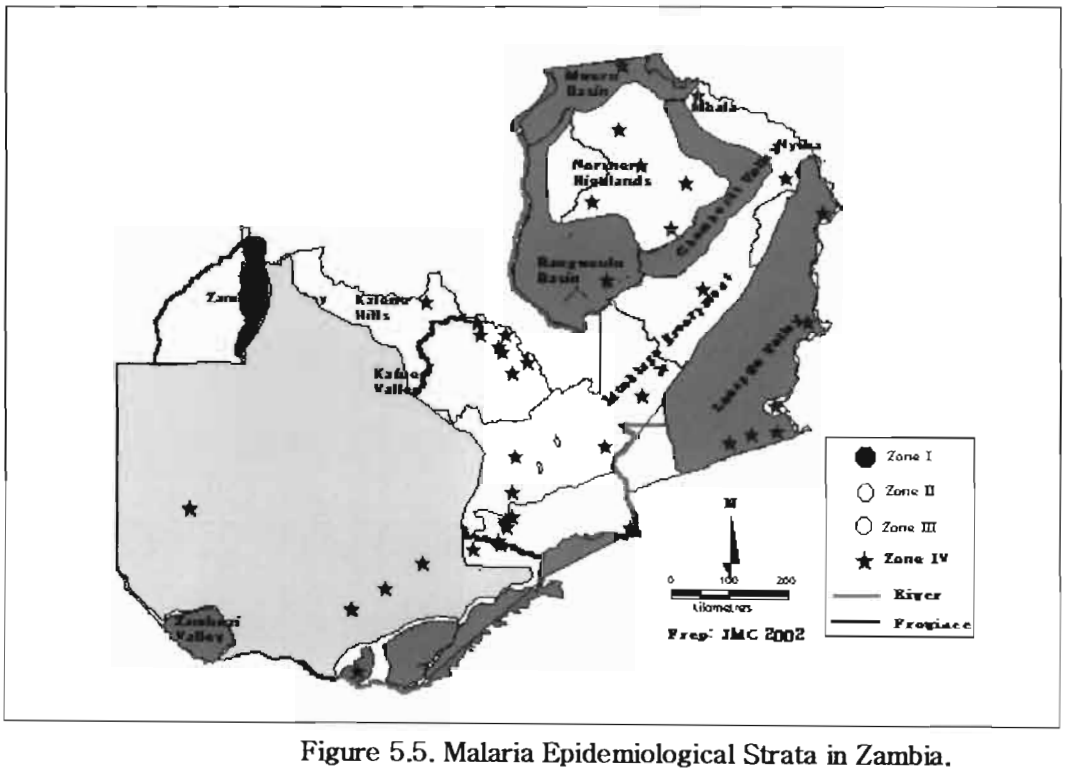

Figure 5.5. Malaria Epidemiological Strata in Zambia.

Stratum 3 (Relatively arid) is the ecological zone covering most of Southern and Western provinces. This represents infection rates ranging between 15% and 23%. Parasite infection rates remain constant across all age groups. Adults and children thus exhibit roughly similar infection patterns (Figures 5.4 and 5.5).

Stratum 4 (Hot river valleys) represents high infection rates among children 5-14 years of more than 45%. This stratum comprised the basins of lakes Tanganyika, Bangweulu, Mweru and Mweru-Wantipa. Similar rates were observed along valleys of the main rivers: Chambeshi, Luangwa, Luapula and some parts of the Zambezi river (Figure 5.5).

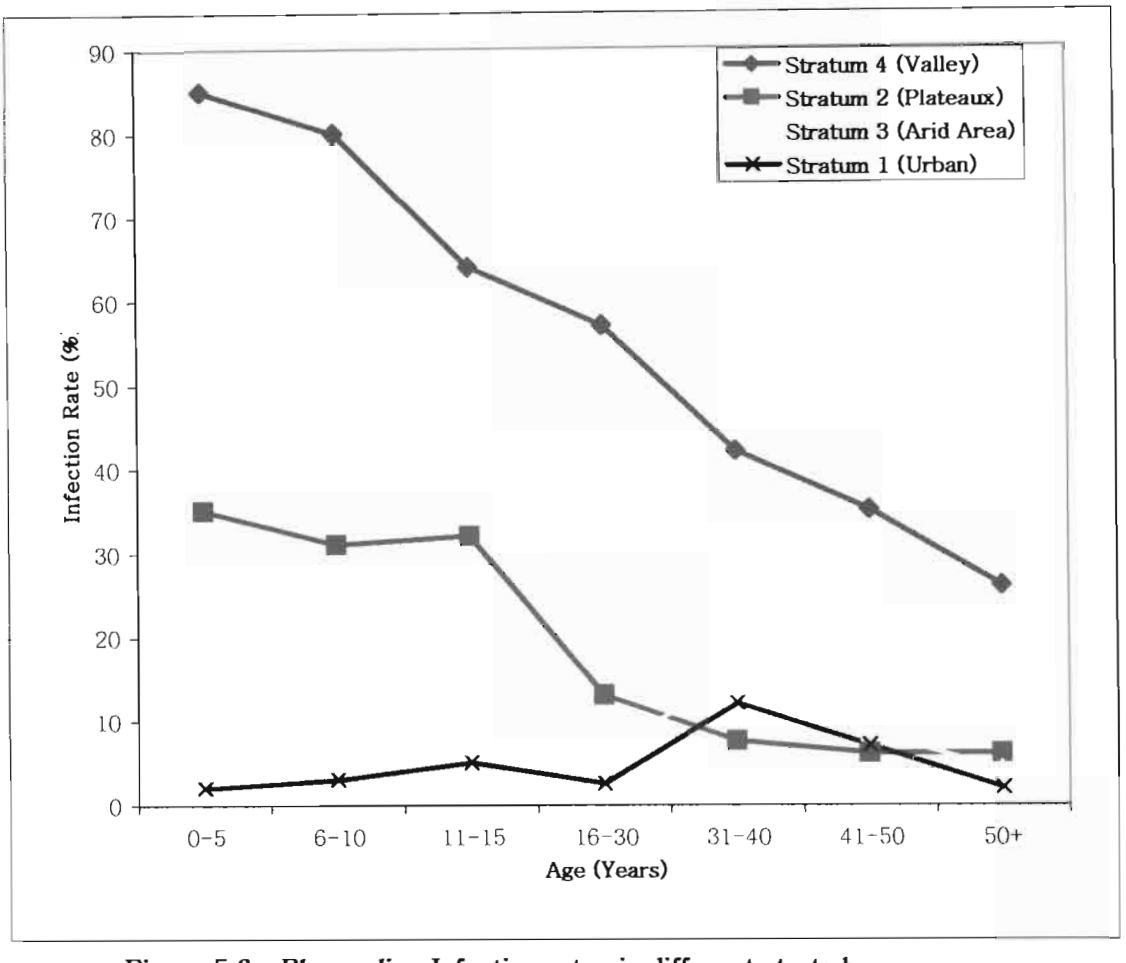

Figure 5.6. *Plasmodium* Infection rates in different strata by age group.

The Kafue, Zambia's second largest river traverses the central part of the country in a north-south direction but has not featured much in the discussion in relation to large river valleys due to its unique nature. It passes through the most urbanised parts of the country (from Copperbelt to Southern provinces) and this influences its contribution to malaria transmission. Its rural parts cut across unpopulated places such as the Kafue and Lochnivar National parks (Figure 5.5). Stratum 4 presents a situation where parasite infection rates in local populations seemed to decline rapidly and continuously with age (Figure 5.6).

There was a statistically significant association the parasite infection rates within different age categories and site ($P < 0.0001$), with a contingency coefficient of 0.266.

A log-linear model was fitted under the two hypotheses above and obtained $\chi^2 = 42.1438$, $D = 39.46$, degrees of freedom (dof) = 12, and hence significant at $p < 0.0001$. The estimates of the main effects are

shown in Table 5.2. The log linear regression model shows how the categories of age and location were associated.

Malaria Infection by Age

Human *P. falciparum* infection rates were examined and classified according to two variables, age of the population and area of residence at the time of the survey. Cross-tabulation of age and location is displayed in Table 5.1.

Age (Years)	Parasite Rate by Site			
	Valley (%)	Plateaux (%)	Arid area (%)	Urban Area (%)
0-5	85	35	4	2
6-10	80	31	5	3
11-15	64	32	8	5
15-30	57	13	6	2.5
31-40	42	7.5	15.5	12
41-50	35	6	8.5	7
>51	26	6	4	2

Table 5.1. Parasite ratios by site and age category.

The malaria parasite infection rate in the age category 0-5 years was correlated with the area of domicile (Corr. Coef. 1.2; 0.8-1.6; $P<0.05$) (Table 5.2). The same was true for a broader age group ranging from 0-30 years. Above 30 years, there was marginal significance up to 40 years (Corr. Coef. = 0.6; 02-1.0; $P<0.05$), beyond which there was no longer any significance in the relation between parasite infection rates and age at different sites (Corr. Coef. = 0.3; -0.1-0.2; $P>0.05$) (Table 5.2).

Age (Years)	Coefficient estimation	95% Confidence interval	Standard error
0-5	1.1688	0.75 - 1.59	0.2136
6-10	1.2368	0.87 - 1.61	0.1893
11-15	1.1701	0.80 - 1.54	0.1908
16-30	1.0609	0.68 - 1.44	0.1934
31-40	0.7472	0.35 - 1.14	0.2023
41-50	0.5909	0.18 - 1.00	0.2078
51+	0.3185	-0.11 - 0.75	0.2190

Table 5.2. Correlation coefficients between age groups and different sites.

Discussion

Until the 1980s, Geographic Information Systems (GIS) use was largely the domain of specialists. The mastery of the graphical nature of its application and the intense computational requirements for spatial data manipulation needed considerable expertise. This restricted GIS to academic and other specialised sectors (Deichmann, 1996). The health sector is just realising the possibilities in which this technology can benefit the millions who are afflicted with ill health, especially in sub-Saharan Africa. This technology possesses the potential to change for the better, the way health planning is conducted through introducing greater efficiency and cost-effectiveness (de Savigny *et al.*, 1995).

One of the tenets of the social movement of Roll Back Malaria is the use of empirical evidence as the basis for decision-making and GIS is providing that evidence in an area that was dogged with potentially biased expert opinions (Omumbo *et al.*, 1998; Craig *et al.*, 1999; Nabarro, 1999). Precise knowledge about the extent and the nature of the distribution of malaria or any other disease is critical for selecting and planning interventions and their implementation.

This study presents for the first time, an empirically derived malaria risk map for Zambia. In terms of malaria transmission, it represents the fringe zone between the extreme unstable southern Africa region and the high intensity stable transmission patterns of central Africa, encompassing the equatorial belt. Much of the country lies north of the -16.4° S effective temperature isoline (le Sueur and Sharp, 1996). The whole population is exposed to malaria to varying degrees.

According to opinion-based continental models, Zambia as a whole is classified as an area of intense perennial transmission. On the contrary, the risk map in figure 5.4 shows different endemicities and risk depending on location in the country.

One of the reasons malaria eradication was not seriously attempted in Africa was because some schools of thought contended that it was too difficult to deal with because of super-infection rates across the continent (Sharp, 1990; Bradley, 1994; Sachs and Malaney 2002). It has now become clear that malaria (even in Africa) is far from uniform. There are many places with zero transmission, just as there are others with higher transmission rates and a whole range in between (WHO, 1996; Lengeler *et al.*, 1998; Omumbo *et al.*, 1998; Craig *et al.*, 1999). Needless to state therefore, that targets and interventions should be locally defined when formulating malaria strategies. The availability of GIS-backed empirical evidence on the distribution of malaria, complimented by improved

epidemiological understanding of the disease, will enhance better targeting of intervention delivery at local level.

Existing expert opinion on the stratification of malaria in Zambia divides the country into three regions: river valleys, urban areas and plateaux. This is in accordance with the paradigm of accumulated experience, based on the dependence of malaria transmission on climatic and geographical conditions of an area. In addition, some social-economic imperatives and population dynamics have often influenced assignment of places to endemicity classes. The risk surface presented here identifies areas of the country associated with different levels of malaria transmission intensity and divides the country into four rather than three distinct zones (Figures. 5.4 & 5.5).

Stratum 1 recognizes the valleys of major rivers: The Chambeshi, Kafue, Luangwa, Luapula, Lunga, Lunsemfwa and the Zambezi rivers. It also includes the basins of Lakes Bangweulu, Kariba, Mweru, Mweru-Wantipa and Tanganyika. These areas average 900m above the mean sea level. Summer temperatures soar to 34°C (October-April), while in winter (May-July) it averages above 20°C. In these areas, breeding sites are likely to be available throughout the year and therefore, malaria transmission is assumed to occur all year round with only limited winter reductions. Malaria transmission ranges between hyper- and holo-endemicity (Teklehaimanot and Beljaev, 1993). The risk map presented here (Figure 5.4) shows a striking resemblance to this situation. Parasite infection rates from surveys in these sites were the highest (>50%). The exceptions being the Kafue valley and parts of the Zambezi river valley. Malaria in these places is also modified by other factors, such as urbanization, limited human population and control measures. However, it should be noted that even with these exceptions, edges of rivers represent higher transmission potentials. The fact that the endemicity map is a mathematical model, may have provided a smoothening effect of places between data points.

The implications for malaria control in this stratum would be to focus on mortality prevention, especially among the vulnerable, such as young children 1-3 years of age, pregnant women, and the chronically ill. Visitors from other parts of the country should be encouraged to take appropriate prophylaxis in this stratum.

The major portion of the country lies in stratum 2 which is a plateaux lying at an average altitude of 1000-1200m above sea level. In this stratum, there is marked seasonality in malaria transmission. Higher transmission is experienced during hot summer months (November to March) and lowest transmission in dry winter months of May to August (Teklehaimonot & Beljaev, 1993; Taylor and Mutambu, 1986). Malaria disease classification

here is mesoendemic. The stratum is characterized by lower parasite infectivity rates in the population (Figure. 5.5). It represents a zone of lower transmission intensity and is potentially prone to malaria epidemics.

Malaria is more pronounced in children and the development of their immunity is delayed. Malaria related mortality would tend to concentrate in 5-7 year olds (Snow *et al.*, 1998). Control measures targeting young children under the age of ten years would be beneficial. This stratum is of particular importance as it affects most of the arable farming area. Incidentally, these are also places of higher population density.

The interpolated model classifies the western and southern parts of the country together with the protruding peaks above the plateaux, as places of lower malaria endemicity (stratum 3). These are represented by the Muchinga escarpment, Mbala highlands, Kalene hills, Nyika plateau and the convergence point of the Central, Copperbelt, Northwestern, Southern and Western provinces (Figure. 5.4). This situation was not derivable from the opinion maps, but was demonstrated by the risk map presented here. The epidemiology of malaria in these places is similar to the epidemic-prone highlands of east Africa.

Stratum 4 represents urban centers, which present a unique malaria situation compared to the rest of the country. This consists of major cities and towns including provincial centres. These are areas of economic importance, especially with regard to copper mining. Malaria is classified as hypo-endemic to absent, as one moves from the periphery to the center of a typical town. The disease burden has been reduced to a great extent through long-term successful control programmes and urbanisation. It may also represent a positive demonstration of successful partnership between public and private sectors.

The malaria risk map (Figure 5.4) portrays stratum 3 and 4 as places where malaria affects all age groups. Uniformity of infection across age groups is a typical indicator of malaria epidemic potential. Therefore, in urban areas and highlands, entire populations should be targeted for malaria prevention. A focus on epidemic forecasting, preparedness and control would be a useful intervention.

Generally, expert opinion on the distribution of malaria in Zambia was similar to the classifications that have been empirically derived in this study. It was believed that malaria transmission was highest along river valleys and lowest in urban areas and on the plateaux (Ministry of Health, 1993). However, these opinions were not accurate when it came to transmission intensities in Southern and Western provinces along the Zambezi valley. It was also inaccurate along the Kafue river valley, where this study has shown malaria to be limited by urbanization and low population densities. There is

thus a need to adopt this new empirically derived endemicity map as the basis for decision-making and future planning for malaria prevention and control.

The malaria risk map derived in this study constitutes an important entry point into local level (country) malaria distribution modeling. This represents the third level of national and regional scale modeling identified by Craig and co-workers (1999). The first being at continental scale; the second at sub-continental level; the third at regional and country level, and the fourth level would cover areas of about $30km^2$.

Third level modeling takes into account local ecological conditions and other disease determinants to produce a disease risk map. The Zambia risk map has demonstrated a simple evidence-based malaria stratification approach. It emphasises the need to define malaria endemicity at local and regional levels. Working at national and regional levels explains and demonstrates small-scale differences that affect malaria distribution but which could not otherwise be explained by global and continental models (Craig *et al.*, 1999; Tanser, 2000).

In conclusion, the malaria risk map for Zambia generated from parasite ratios is the first of its kind for the country and allows an evidence-based approach to malaria planning. The map compares well with climate-based predictive models and historical experience. In most parts, the image is more relevant to what is happening at the local level (Snow *et al.*, 1998; Craig *et al.*, 1999; Tanser, 2000). The work here confirms that climate predictions, while invaluable at continental and regional levels, present many limitations at local level. This is because the influence of parameters, such as water bodies are usually not taken into account and transitional zones between stable and unstable situations are not easily recognisable. To be meaningful at the local level, these climate prediction models have to be verified with both expert experiences and local models like the one presented here.

The malaria risk map for Zambia demonstrates how GIS can be a tool for constructing a body of evidence for policy decision making by policy makers, programme managers and implementers. On the global and regional levels, it adds to the MARA/ARMA objectives of collaboration within Africa to accumulate empirical spatial information platforms using GIS. This in turn is supporting the integration of digital and attribute data to understand malaria distribution across the continent at both regional and local levels. Kleinschmidt and collaborators (2001) propose a number of interventions for each endemicity level, delimited through the interpolation process, to limit malaria-related mortality. This model provides momentum to the process of moving from the hypothetical to the quantifiable in malaria stratification (Craig *et al.*, 1999).

Chapter Six: Malaria Vectors in Zambia

Introduction

Despite the large number of mosquito species that occur in the world, only a small proportion are involved in transmitting disease to humans. Malaria is only transmitted by mosquitoes of the genus *Anopheles*. In Africa where the malaria per capita burden is highest, the most important malaria vectors belong to only two species groups; *Anopheles gambiae* Giles sensu lato (s.l.) and *Anopheles funestus* Giles s.l. both of which are species complexes.

For malaria transmission to occur, the female vector mosquito must feed on at least two independent occasions. The first is on malaria-infected blood to acquire the parasite and the second to transmit the parasite.

Malaria parasites are unicellular blood-dwelling protozoans belonging to the genus *Plasmodium*, four species of which have evolved compatibility with humans, namely *Plasmodium falciparum, P. malariae, P. ovale* and *P. vivax*. Of these, *P. falciparum* is responsible for the great majority of malaria-related morbidity and mortality, especially in children in sub-Saharan Africa. The other three species are not nearly as important as *P. falciparum* in terms of causing disease and death.

In nature, maintenance of malaria involves a complex interaction involving the vector, definitive host and parasite. An understanding of vector's bionomics and the environment in which they occur is crucial in planning and implementing of effective malaria programmes. Such an understanding ought to include knowledge on species and their spatial dispersal in a geographical area. It should include an understanding of factors that bear upon the questions of:" When?", "Where?", and "How?" malaria occurs.

With few exceptions sub-Saharan Africa countries, have limited information on the bionomics of local malaria vectors. Zambia is one of these countries with limited information about malaria vectors. There are only a handful of records documenting vector studies conducted in Zambia.

This study attempts to identify and study the behaviour of malaria vectors at two epidemiologically and geographically distinct sites in Zambia; one located in the high rainfall northern half of the country and the other in the drier southern sector.

Literature review

In 1902, Giles working in The Gambia, identified and described *An. gambiae* Giles and *An. funestus* Giles. Davidson and Jackson (1962) established through crossing experiments that *An. gambiae* Giles was not a single species (Fontenille and Lochouarn, 1999) but a complex consisting of several morphologically indistinguishable species. This followed field observations in which *A. gambiae* s.l. from different locations was found to behave and respond differently to control interventions (White, 1974; Sharp, 1990). As a result, *An. gambiae* Giles was split into two species called A and B by Paterson (1964). A third species called C, had already been discovered and described by Theobald in 1911 (Paterson, 1964). In addition, two salt water-breeding species, *An. melas* and *An.* var *gambiae,* were described by Davidson and Jackson (1962). The number of distinct species in the *An. gambiae* Giles complex at this stage came to five (Davidson, 1964; Paterson, 1964). White (1973) found and described yet another species. He found it breeding in mineral water swamps in the Pare forest in Bwamba County in Uganda. He called it species D (Sharp 1990).

Species A, B, C and D have all been given full names (Mattingly 1977). The specimen which was described by Giles in 1902, from west Africa and later designated species A, has retained the name *An. gambiae* Giles ss. Species B is called *An. arabiensis*, as it had been described by Paterson in 1964. Species C has retained Theobald's 1911 name of *An. quadriannulatus* and species D is called *An. bwambae,* the name White gave it in 1973. *An. melas* Theobald, is still named as Theobald described it in 1903. It is the salt water breeding species found along the West African coastline and elsewhere. Donitz (1902) described another salt-water breeder this time on the east coast of Africa, and called it *An. merus*, bringing the number of cryptic species in this group to six. *An. gambiae* Giles *sensu stricto* has recently been split further into *mopti, Bamako* and *savanna* (Gilles and Coetzee, 1987; Sharp 1990; Fontenille and Lochouarn, 1999).

The second epidemiologically important member of the genus *Anopheles* is the species *An. funestus* Giles. Giles described it in 1902 and it has remained as such, although it was suspected to be a complex made up of closely related siblings since the 1930s. Using larval stages, it has been divided into five morphologically indistinguishable groups: *An. funestus, An. confuses, An. leesoni, An. rovulorum and An. brucei* (Paterson, 1963; Bushrod, 1981; Mosha and Petracca, 1983; WHO, 1984;

Gilles and Coetzee, 1987; Sharp, 1990;). The sub-group *An. funestus* is further divided into four indistinguishable members: *An. funestus* Giles, *parensis, aruni,* and *vaneedeni* (Gilles and de Meillon, 1968; Gilles and Coetzee, 1987; Sharp, 1990; Fontenille and Lochouarn, 1999). Of all the members of the *An. funestus* Giles complex, only *An. funestus* Giles is an efficient vector of malaria. All others are largely zoophilic (Wilkes *et al.*, 1996).

Malaria Vectors in Zambia

Anopheles distribution data for Zambia has been derived from regional and continental extrapolations, such as the Ethiopian zoological region, now called the Afro tropical region (Davidson and White, 1972). The first evidence of the existence of *Anopheles* mosquitoes in Zambia comes from identifications made when malaria control activities commenced on the Roan Antelope Copper Mine in Luanshya in 1929 (Watson, 1953). De Meillon visited the Copper mines in 1937 and conducted a number of entomological evaluations. He determined the flight range of the *Anopheles* species, and recovered *An. gambiae* Giles s.l. 4.2 kilometers from the point of release, while *An. funestus* Giles was recovered 4.5 km from the release site (Coetzee, 1945). Paterson (1963) drew a distribution map showing the dispersion of fresh and salt-water breeding members of the *An. gambiae* Giles s.l. group on the African continent (Figure 6.1). He makes reference to material collected in Zimbabwe formerly Southern Rhodesia as being proof for existence of new members of the *An. gambiae* Giles complex. He went on to describe the characteristics and bionomics for all the then known members of the complex in this area. He mentions them as being present at Chirundu (in northern Rhodesia) which he erroneously refers to as being in southern Rhodesia. With such confusion, it is possible Paterson could have been referring to work done in Zambia (Northern Rhodesia) as being in Zimbabwe (Southern Rhodesia). The species A found at Chirundu was endophilic and anthropophilic (Paterson, 1963). He concluded by emphasizing that for malaria control to succeed, entomological work should guide the choice of control methods and approaches based upon the known behaviours of particular species. Paterson (1963) reported that *An. gambiae* Giles species A, B and C were found in sympatry at Chirundu.

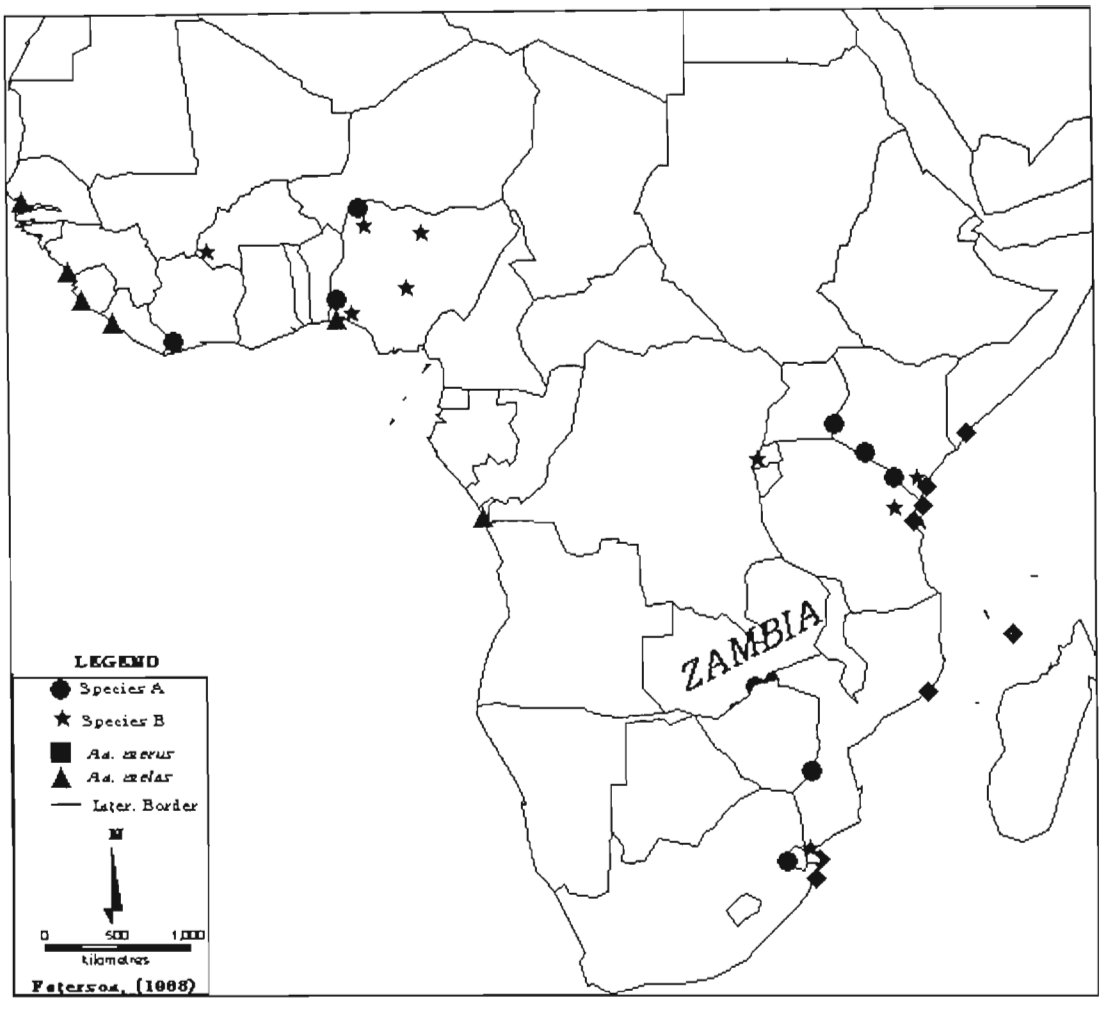

Figure 6.1. *Anopheles gambiae* s.l. Giles distribution in Africa (Source: Giles and Coetzee, 1987).

The Coetzee *et al.*, (2000) vector distribution map for Zambia is based on specimens collected at Chirundu (28.93333E; -16.0000S) by Paterson (1962; 1963; 1964), Davidson (1964) and Shelly (1972; 1973). They reported the presence of *An. arabiensis*, *An. gambiae* s.s. and *An. quadriannulatus*. Collections of *Anopheles* vectors by Hadjinicolou (1963), Paterson (1963), Shelly (1973), Bransby-Williams (1979) and Siachinji (2000), were all performed in the southern part of the country. Hadjinicolou made the first observations on the behaviour of *An. gambiae* Giles s.l. at Chirundu in Zambia in 1963. He found *Anopheles* larvae breeding in pools along the Zambezi river throughout the year and in rain puddles during the rainy season. He conducted some experiments on the evaluation of an insecticide (HCH). This is the only record of insecticide

application at this site, albeit on experimental basis only (Shelley, 1973). On the southern bank of the river Zambezi (Zimbabwe), Green (1970) made larval collections at a location -16° 20"S; 30° 57"E and 1000 feet above sea level. He identified three members of the complex, namely *An. gambiae* s.l. species A, B and C.

Apart from the Luanshya studies in the 1930s and collections on the Copperbelt in the 1970s, there is no other mention of the presence of *An. funestus*. Possibly this was because it was absent, or incorrectly identified as *An. gambiae* Giles s.l. group, or excluded from the study altogether.

Sporozoite Rates by Site

Bransby-Williams (1979) conducted out indoor human-biting collections of species B at Chipata, Eastern province at a site situated 1032m. He did the same at Lusaka at 1154m above sea level. At these two sites, despite expecting to capture *An. gambiae* Giles s.s., he only found *An. arabiensis*. He carried out hand dissections for sporozoites on these specimens and found 0% in the Lusaka collection and 1.1% in the Chipata sample. This resulted in an overall rate of 0.4% in 981 female mosquitoes dissected. This was despite the fact that precipitin tests performed on the same sample had a 98% Human Blood Index (HBI). Both Chipata and Lusaka fall in the low rainfall zone of the country. Based on this result and the earlier studies by Shelly (1973) at Chirundu, Bransby-Williams (1979) concluded that *An. arabiensis* might be the only species transmitting malaria in Zambia. It was the only species identified from polytene chromosomes on collections from southern, eastern, copperbelt, and central parts of Zambia (Shelly, 1973; Bransby-Williams, 1979; Zahar 1985).

The Malaria Research Laboratory made some observations on the behaviour of *Anopheles* in the period 1969-1970 at Chirundu and Ndola rural, and captured *An. funestus* Giles (Zahar 1985).

The Malaria Research Laboratory collections were tested for sporozoite infectivity. The Chirundu indoor collection showed *An. gambiae* Giles s.l. with a 3% sporozoite infection, while the outdoor rate was 7.2%. The mosquitoes collected off bovines outdoors had an infection rate of 0.4%. *An. funestus* Giles indoors showed 0% infection, outdoors, 1.2% and 0% caught off bovines outdoors. At Ndola, *An. gambiae* Giles 0% sporozoite infectivity in mosquitoes biting animals out doors, none were caught feeding in the other two situations. *An funestus*, Giles biting indoors had sporozoite rate of 1.6%, biting outdoors 1.2%, resting indoors

1.9%, and resting out doors 2.6%. At Livingstone *An. gambiae* Giles s.l. was infected at a rate of 2.4%. This was higher than Shelly's (1973) or Bransby-William's (1979) sporozoite rates (Zahar, 1985).

In pursuance of reinforcing the mosquito extermination act (GRZ, 1966), local authorities had banned the growing of certain crops such as maize near residences, allegedly because mosquitoes bred in the maize fields or mosquitoes hid among crops. To dispel this belief, Watts and Bransby-Williams (1979) conducted a study to prove that it was not possible for malaria vectors to breed in maize leaf axils. They searched for larvae but found none. They concluded by advising local authorities that slashing of maize plants should not be conducted in the name of malaria control (Watts and Bransby-Williams, 1978). In fact, this same question had been answered 46 years earlier by Watson (Watson, 1932).

As can be seen from the foregoing account, Zambia remains largely poorly studied in terms of vector varieties and their spatial distribution. This study will assist in shedding some light on possible vector species present in the country and their population dynamics.

This study is an attempt to add to the body of knowledge about malaria vectors in Zambia. It aims to identify *Anopheles* species at the two study sites; to identify vectors of malaria; seasonal variability in their abundance; resting habits, and their parasite infection rates. An attempt was also made to identify their sources of blood meals.

Specific objectives of the study were:

- identification of *Anopheles* species in the study villages
- identification of malaria vectors
- estimation of seasonal vector population dynamics
- estimation of *Plasmodium* infectivity rates in the vectors
- identification of non-human hosts for Anophelines, and
- estimation of seasonal Entomological Inoculation Rates.

Methodology

Study sites

The study was conducted at two sites representing two distinct strata; Kapululila village, representing low rainfall southern Zambia, and Lukwesa in the high rainfall northern half of the country.

Kapululila Village

Kapululila village is located within Lusaka province in Kafue district. It is situated within the Zambezi valley at an altitude of 386m above mean sea level at the confluence of the Kafue and Zambezi rivers (grid reference 28.833333°E; -15.870500°S). Situated at the southern part of the country on the border with Zimbabwe to the south, as it was described by Shelly (1973). The Zambezi river forms the international boundary between the two countries. The vegetation type is savannah and common tree species are *Commiphora, Combretum, Pterocarpus, Markhamia, Acacia* and *Adansonia.* Other vegetation includes sedges, ferns and phragmites on the banks of both the Kafue and Zambezi rivers. The area receives marginal rainfall averaging only 700mm annually, and droughts are not uncommon, with associated crop failures. Monthly mean temperatures vary from 19.5°C in July to 40°C in October, with a 24-hour range of up to 18°C in cooler months. The mean daily relative humidity is at its lowest in October (37%) and highest in February (87%). The predominant ethnic group is the Goba-speaking people of Chieftainess Chiawa. Both the Kafue and Zambezi rivers play important roles in the lives of inhabitants, in terms of fishing, transport and farming. The main economic activities are commercial flower (Marigold) and banana farms, fishing and subsistence farming. Tourism is centred on water activities and the Lower Zambezi National Park. Kapululila village is linked to the nearest border town of Chirundu and is in turn linked to the district headquarters by an all-weather road and is accessible by water transport. Expert opinion classifies this site as holoendemic for malaria (Hadjinicolaou, 1963; Shelly, 1973). The area has never experienced malaria control activities, other than case management in health facilities and experiments that have been conducted by various workers.

Lukwesa Village.

Situated in the Luapula valley of Luapula province, Mwense district is in the high rainfall zone at grid reference -10.226667°S and 28.790000°E, at 900m altitude. The site lies on the northeast edge of the country on the border with the Democratic Republic of the Congo (DRC), where the Luapula River forms the international boundary. The vegetation is predominantly Miombo woodlands characterized by *Jubernardia, Isoberlinia* and *Brachystegia* species. *Sagitaria, Ludesia* and *Phragmites* are found along river valleys. Rainfall averages 1500mm per annum, mainly falling between November and April. Mean annual temperatures

range from 18°C in the cooler months to 28°C in October, with high relative humidity throughout the year varying from approximately 50% to close to 100%. The main ethnic groups are the Lunda-Luba speaking people of various dialects under chief Lukwesa and others. The economic mainstay of the population is fishing along the Luapula river and farming for communities on the plateau. Trading forms a significant component of the community's activities especially with the DRC. There are no records of malaria control activities other than curative services and more recently drug efficacy trials and insecticide treated mosquito net activities covering the entire district including Lukwesa village. Expert opinion classifies this area between hyper- and holo-endemicity for malaria.

Mosquito Collection Techniques

Two techniques were employed for sampling adult *Anopheles* mosquitoes. Morning Pyrethrum Spray Sheet Collection (PSC) and exit Window Traps (WT). Mosquitoes collected were identified as far as possible on the day of collection using Gillies and De Meillon (1968) keys for mosquito identification. Confirmation of identification was performed in Durban at the Malaria Research Programme of the Medical Research Council (MRC), South Africa laboratories.

PSCs were conducted in 20 houses, 10 at each site, on a monthly basis from March 2000 to April 2001. Although specific houses were varied, the number sampled was always 10 per site, per month following the techniques described by WHO (1963, 1975). Natural pyrethrum concentrate was diluted with kerosene to a 0.3% solution mixed with 0.1% pyperonyl butoxide. Two hand-held spray pumps with a cone spray nozzle were used to apply the knockdown insecticide. This procedure was conducted early in the morning between 06.00 hours and 08.00 hours local time. White calico sheets were used to cover all surfaces in the houses, including furniture. Two spray-men (one on the inside and the other on the outside of the house applied the insecticide mixture, starting at the door covering eaves, windows and other openings, synchronizing their movements with regard to direction and speed, ending again at the door. The one on the outside stopped spraying, while the inside one would then apply the chemical to all interior surfaces. Following insecticide application, an allowance of ten minutes was made before removal of sheets to ensure the knockdown effect. Each sheet was taken outside and examined for knocked down mosquitoes. The knocked down mosquitoes were picked up with a pair of fine-tipped forceps and placed in a petri

dish lined with moist filter paper. Collected mosquitoes were transported to the field laboratory for preliminary identification and preservation.

Exit Window Traps were used to sample adult mosquitoes exiting dwellings as described by WHO (1975). A total of 25 traps were employed per site each month. After obtaining the necessary permission from owners, one person within the household was trained to set up and empty traps. Traps were set up at 18.00 hours local time and left in place until 06.00 hours the following morning. Mosquitoes from traps were removed with an aspirator and sorted.

Upon capture, mosquitoes were classified according to their gonotrophic condition; categories being blood engorged, unfed half gravid and gravid females. Mosquitoes collected and identified morphologically as *An. gambiae* Giles s.l. were for species identification and CSP detection.

Mosquito Identification

Using the preserved heads of *An. gambiae* s.l., the Polymerase Chain Reaction (PCR) method was employed to identify three members of the *An. gambiae* s.l. complex; *An. arabiensis*, *An. gambiae* s.s. and *An. quadriannulatus* in accordance with the method described by Paskewirtz and Collins (1990) and Paskewirtz *et al.* (1993).

Deoxyribonucleic Acid (DNA) was extracted by first macerating the mosquito tissues in a tube containing 10 microlitres (μl) of PCR water and boiled at 100° C. The boiled samples were cooled down on an ice bath for 10 minutes and preserved at ordinary fridge temperature (4°C) over-night. From the preserved specimens, DNA was extracted and processed in accordance with Paskewirtz and Collins (1990).

Individual mosquito samples were identified into species, viz *An. arabiensis* Patton, *An. gambiae* Giles s.s. and *An. quadriannulatus* Theobald, by comparing the migrational distances of the unknown with the control samples of this species complex. The samples were read using the transilluminator.

Sporozoite Detection

Identification of *P. falciparum* circumsporozoite protein in *Anopheles* mosquitoes was achieved by the direct Enzyme Linked Immunosorbent Assay (ELISA) method described by Beier *et al.* (1987), using preserved *Anopheles* thoraces. Each individual mosquito was crushed in a single specimen tube to which 200 μl of sterile water was added. The mixture

was then boiled for 10 minutes at 100° C, and then cooled down on ice for 30 minutes. This was then subjected to the ELISA technique. The plates were read at a wavelength of 414 nanometers (nm), using an ELISA reader (Dynotech-MR-5000 Quincy, channel Islands).

Bloodmeal Identification

A census for mosquito hosts revealed that apart from the human population, almost every household at both sites kept domestic animals. Sheep and goats were common in both areas. They were usually tethered in pens near houses. Cats and dogs were present in some homesteads and almost every household possessed poultry. Ducks and turkeys were observed in Kapululila village. Cattle were conspicuously absent from both sites. Wild animals were observed or reported in both areas, including lechwe, hare, tortoise, snake, lizard and frog. Bird life, included wild duck, egret, kingfisher, heron, kite, nightjar, hawk, falcon, dove, guinea fowl and partridge.

Preserved bloodmeals from engorged *Anopheles* females were processed to identify their sources as outlined by Beier *et al.* (1988). The abdomens of field-collected mosquitoes were cut off and preserved. Immunised rabbit serum with total proteins of goat/sheep, bovine and human were used. The bloodmeal was diluted at 1: 10 in PBS 0.01 M at pH 7.2 (Beier *et al.*, 1988). Negative controls were obtained using unfed mosquitoes, while positive controls were from human-fed laboratory colony material, and goat and bovine blood. The plates were analysed by an ELISA microplate reader at 414 nm. Results were interpreted by comparison with the cut off baselines established by the product of the mean of negative control readings, +/- 3 standard deviations (Beier *et al.*, 1988).

Entomological Indices

Entomological indices were estimated from the analysis of various datasets obtained in the study. *P. falciparum* circumsporozoite protein rates were obtained using the PCR technique (Beier *et al.*, 1987; Paskewitz & Collins 1990) as an estimate of mosquito infection. Vectors found resting in human dwellings by the PSC method were computed into house resting and human biting densities per night (Charwood *et al.*, 1997; Thomson *et al.*, 1997; Mendis *et al.*, 2000). Only those identified as either *An. gambiae* complex sibling species or *An. funestus* s.s. were employed for further analysis. The identity of the remaining fraction could not be

ascertained with any confidence as either *An. gambiae* s.l. Therefore, the denominators employed in all computations refer only to the proportion identified to species level. All mosquitoes collected and classified as *An. funestus* were assumed to belong to the *An. funestus* s.s. group and therefore the whole collection was used as the denominator in the computations.

The calculation of daily, monthly, seasonal and annual infective bites was possible for the *Anopheles* vector species found at both sites during this study. Entomological Inoculation Rate (EIR) was estimated from the product of *Anopheles* female mosquito bites per person per night and the proportion of those bites which were positive for *Plasmodium* sporozoites by ELISA (MFI, 2000), as:

EIR = mas. Where ma, is the number of *Anopheles* mosquito bites per person per night and s the proportion of those mosquito bites that are positive for CSP protein.

Climate Data

Rainfall and temperature data were obtained from the Zambia Meteorological Department. Both rainfall and temperature surfaces were 10-year averages, derived from the nearest national meteorological station (Lukwesa from the Mansa station and Kapululila from Lusitu station). Temperature was recorded in °C as monthly averages covering the decade 1990-2000. Rainfall was collected as monthly averages in mm over the same period (Zambia Meteorological Department, 2001). Both temperature and rainfall data sets were comparable to long-term averages obtained from global datasets (WRI, 1995).

RESULTS

Anopheles Species Identification

Three Anopheles species: *An. arabiensis, An. gambiae* and *An. funestus* were identified at the two study sites (Figures 6.2 and 6.3).

6.2. Map of Zambia showing Mwense District.

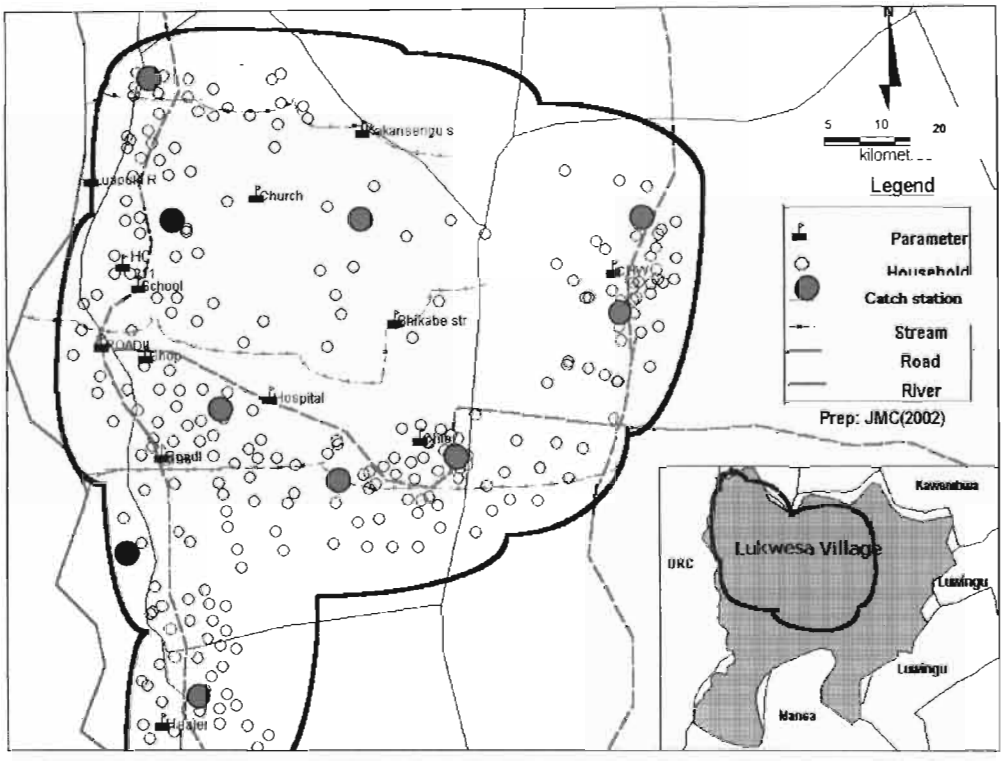

Figure 6.3. Map showing the Lukwesa study site and mosquito collection houses.

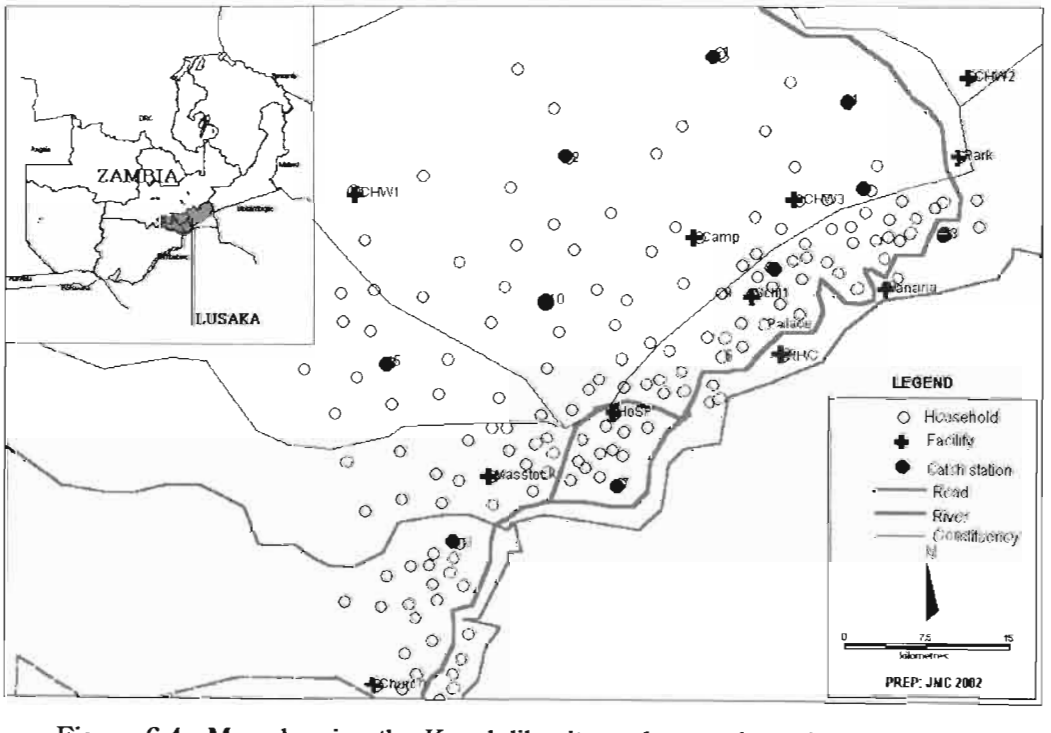

Figure 6.4. Map showing the Kapululila site and mosquito collection houses.

A combined total of 3,638 *An. gambiae* s.l. females were caught from the two study sites. *An. arabiensis* and *An. gambiae* s.s. (both efficient vectors) occurred at both sites in different proportions, in time and space. In addition, the two study sites also yielded 834 specimens morphologically classified as *An. funestus*.

At Lukwesa, 2,693 female mosquitoes belonging to the *An. gambiae* s.l. complex were caught and a sub-sample of 35% (n=939) were subjected to PCR test, with 32% (n=300) successful DNA amplifications. Two hundred and seventy one (n=300) mosquitoes were conclusively identified as *An. gambiae* s.s. and 29 as *An. arabiensis*. At this same site, a total of 667 mosquitoes were morphologically classified as *An. funestus* s.l. in the field. A PCR discrimination test was run on the whole sample of *An. funestus* (n=667). The test confirmed 97.2% (n=648) as *An. funestus* s.s.

At Kapululila, 945 *Anopheles* mosquitoes were identified as *An. gambiae* s.l. in the field. A total of 352 (37%) female mosquitoes were tested using the PCR technique. Of these, 40% (n=140) had successful DNA amplification, comprising 85% (n=119) *An. arabiensis* and 15% (n=21), *An. gambiae* s.s. All 167 specimens morphologically classified as *An. funestus* were subjected to the discrimination test and thus resulted in 100% (n=167) confirmation of *An. funestus* s.s.

Table 6.1 shows the numbers of *Anopheles* females tested and identified at both study sites. A proportion of the extracted DNA of all female mosquitoes that tested negative for PCR were again preserved to be re-tested for sporozoite infection status.

SITE	SPECIES	TOTAL
Lukwesa	*An. arabiensis*	29
	An. gambiae s.s.	271
	An. funestus s.s.	648
Kapululila	*An. arabiensis*	119
	An. gambiae s.s.	21
	An. funestus s.s.	167

Table 6.1. Species composition of adult *Anopheles* mosquitoes collected at the two sites.

Population Dynamics

Using the proportions of *An. gambiae* s.l. and *An. funestus*, identified above, the population dynamics of indoor resting species are presented in Figures 6.5 and 6.6 for Lukwesa and Kapululila, respectively.

For *An. gambiae* s.l., only 32% and 40% of the collection for Lukwesa and Kapululila, respectively, could be successfully identified to species level. Consequently, sporozoite infection rates were determined on the basis of these sub-samples only. Using the ELISA technique, the presence of pfCSP as a proxy indicator of *Plasmodium* infection was utilized in both *An. arabiensis* and *An. gambiae* s.s.

At Lukwesa, the 300 specimens, comprising 271 *An. gambiae* s.s. and 29 *An. arabiensis,* formed the basis for all computations and subsequent tests. Furthermore, a total of 648 were confirmed as *An. funestus* s.s. As a result of this high proportion, it was assumed for the purpose of this study, that only *An. funestus* s.s. was present and all 100% (n=667) was utilised. *An. funestus* was the most abundant vector species, making up 69% (n=667) of the sample at this site. *An. gambiae* s.s. was the second most abundant making up 28% (n=271) of the *Anopheles* sample. *An. arabiensis* was least and made up only 3% (n=29) of the *Anopheles* population.

At Kapululila, 40% of the *An. gambiae* s.l. sample tested was successfully identified with 119 *An. arabiensis* and 20 *An. gambiae* s.s. females, respectively. Additionally, all 167 specimens morphologically classified as *An. funestus* proved to be *An. funestus* s.s. Overall, 306 *Anopheles* females were available for determinations of entomological and parasitological parameters. As at Lukwesa, *An. funestus* was the most abundant *Anopheles* mosquito, making up 55% (n=167). The numbers of *An. gambiae* s.s. complex however, demonstrated relative abundance, with *An. arabiensis* at 39% (n=119), while *An. gambiae* s.s. 6% (n=20).

Using mosquitoes successfully identified to species level, monthly indoor house resting populations were determined (Figure 6.5). *An. funestus* was the numerically dominant species at both sites, although the majority was collected in a single month in both settings (Figures 6.5 and 6.6). Monthly species collections were significantly different at the two sites (X^2= 349.6, dof=2, P<0.00) and Cramer's V= 0.6 at (P < 0.001).

At Lukwesa, *An. arabiensis* presented in low numbers throughout the year, with an exception of a small peak (11 mosquitoes) in March. Numbers were negligible the rest of the year, including May-July when it was not found at all. *An. gambiae* s.s. numbers were lower during winter

(May to August) when they averaged 3.8 mosquitoes per month. The number of *An. gambiae* s.s. increased with rising temperatures from September through to November with a monthly mean of 42 mosquitoes. It peaked in November after which a gradual reduction was recorded with decreasing temperature and rainfall (April/May), with an average of 9.5 per month. *An. funestus* during the cool months (July and August) was found with a monthly average of 70 female mosquitoes. This species was rarely found during the rainy season (December-March) when it averaged 3.5 female mosquitoes per month.

At Kapululila, *An. funestus* showed a similar seasonal profile (Figure 6.6) with a peak during the cool dry months (July -August) at a monthly rate of 37 mosquitoes. It was rare during the hot and wet months (December to March) decreasing to a low of 2.5 per month. Outside these seasons, this species was collected at a monthly mean of 3.7 per month. *An. gambiae* s.s. presented with low monthly numbers throughout the collection period at this site. It only showed a small peak of 6 mosquitoes per month in the cool season (July-August). It was virtually absent the rest of the year, averaging 0.8 per month. *An. arabiensis* was present throughout the year with the exception of the cool dry months of May and June (Figure 6.6). It averaged 20 mosquitoes per month, with a peak above 25 mosquitoes per month during October to December.

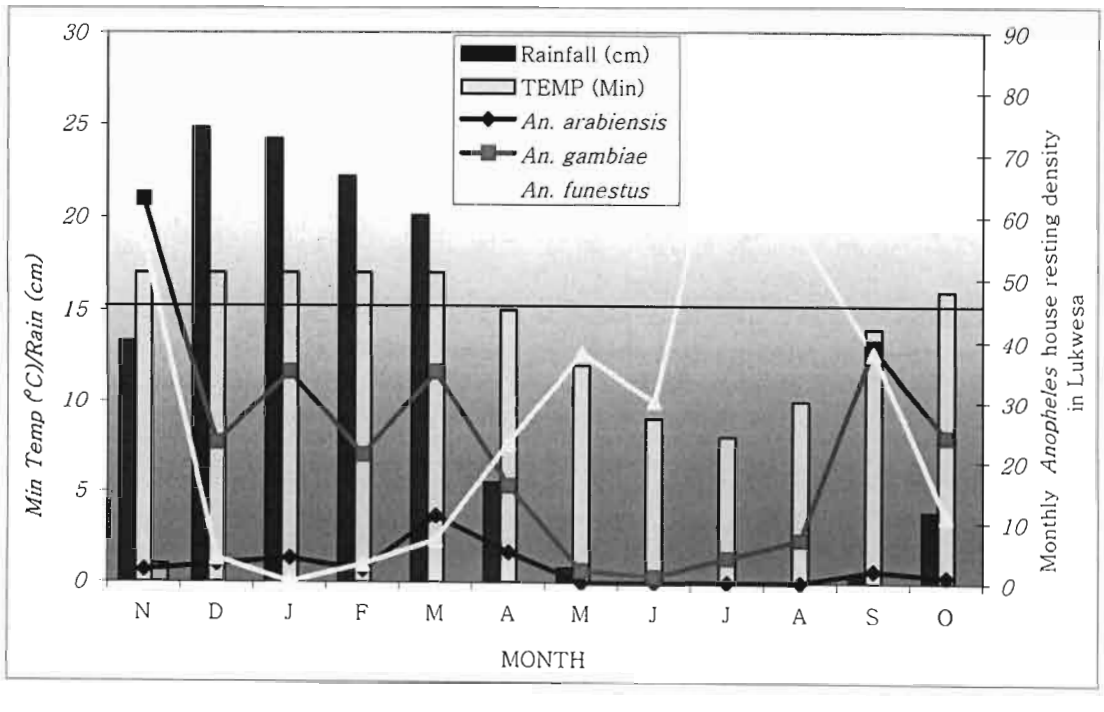

Figure 6.5. Monthly *Anopheles* catches, rainfall and minimum temperatures at Lukwesa.
(Based on PCR species identifications).

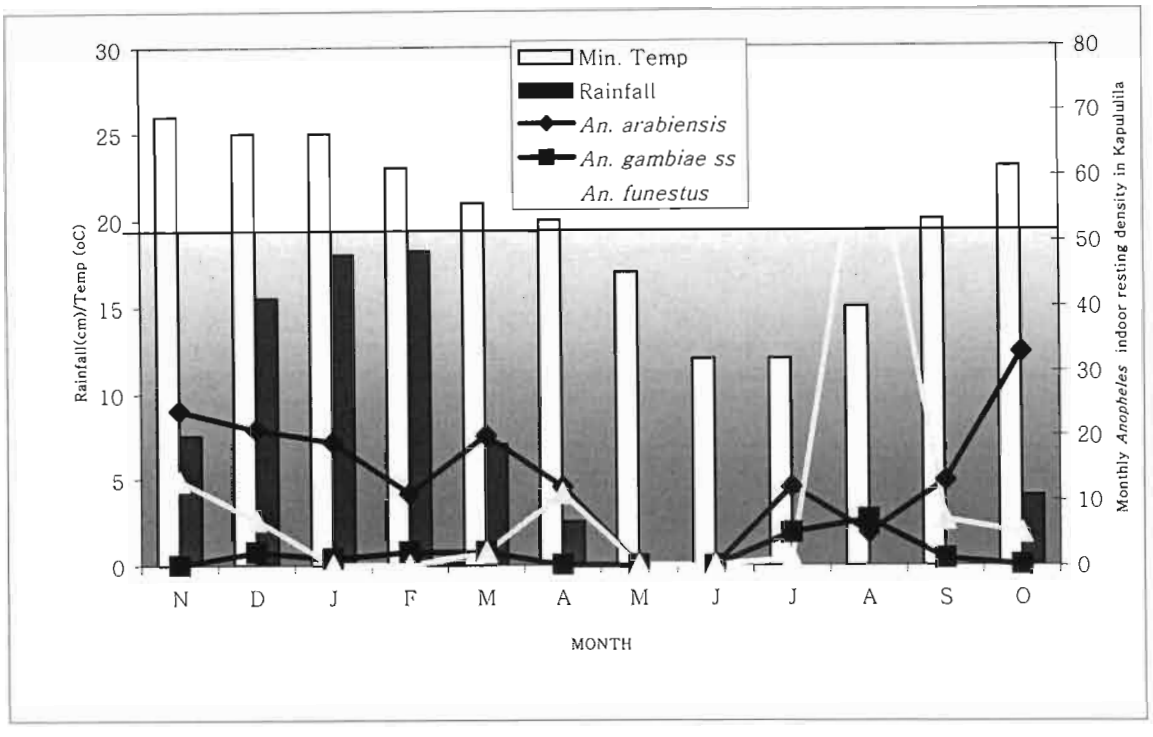

Figure 6.6. Monthly indoor *Anopheles* catches, rainfall and minimum temperatures at Kapululila. (Mosquito numbers based on PCR species identification).

Effect of Temperature on Vector Density

The relationship between monthly *Anopheles* house-resting density and the monthly minimum temperature (°C) was examined using a linear logistic regression for both sites.

At Lukwesa, *An. gambiae* s.s. density was positively and significantly correlated with the prevailing average minimum temperatures (r^2=0.500, P=0.009, Correlation Coefficient (CC) = 4.01, Confidence Interval (CI) = 1.2-6.8). *An. arabiensis* density, on the other hand, was marginally correlated with minimum temperature (r^2=0.400, P=0.03, CC 0.58, (CI = 0.046-1.12)). *An. funestus* density was not significantly correlated with temperature (r^2=0.013, P=-5.33, CC -5.33, (CI =-9.2- [-1.4]).

At Kapululila, *An. gambiae* s.s. monthly population density was not significantly correlated with minimum temperature (r^2=0.100, P=0.33, CC = 0.44, (CI =-1.4-0.53). *An. arabiensis* density on the other hand was significantly correlated with minimum temperature: r^2=0.830, P=0.0001 and CC of 1.7 (CI = 1.1-2.2). There was no significant correlation between

temperature and *An. funestus* population density at this site (r^2=0.038, P=0.56, CC -0.81(CI =3.8- 2.2).

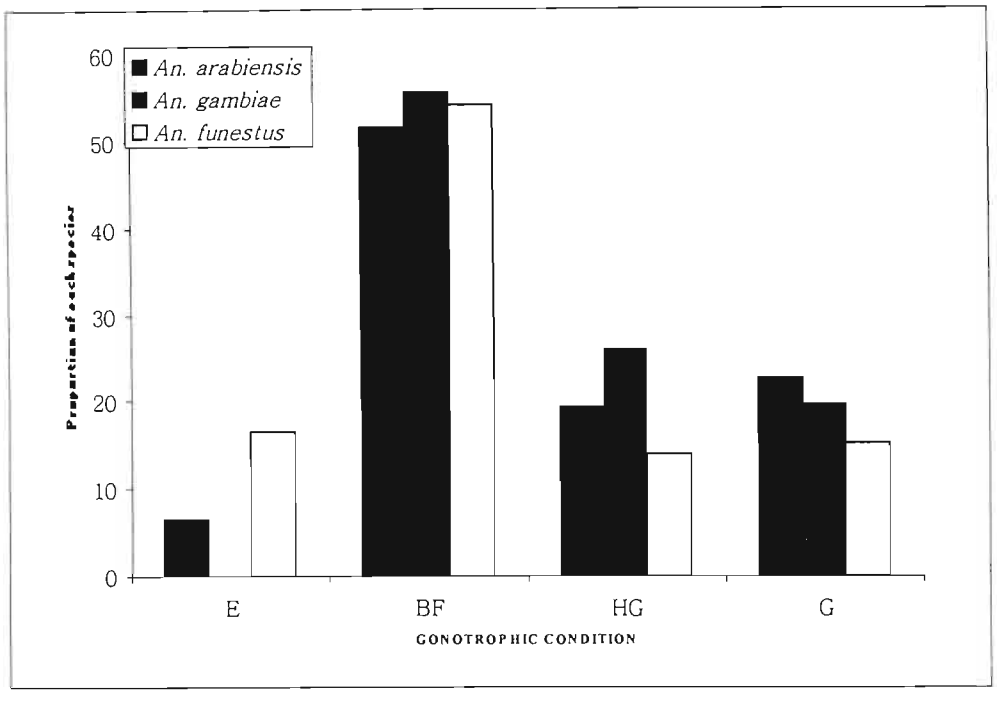

Figure 6.7. Combined gonotrophic condition of indoor resting *Anopheles* females for both sites.
E=Unfed; BF=Bloodfed; HG=Half gravid; G=Gravid

Gonotrophic Condition

Working with the sub-sample identified to species level, blood-feeding patterns at both sites were examined and the results are presented in figure 6.7 and table 6.2.

An examination of *Anopheles* species found resting indoors and identified as *An. arabiensis* at Kapululila showed that out of a total of 29 specimens tested for identification of bloodmeal source, 51.6% were bloodfed, 20% each were half gravid and fully gravid, while 6% were unfed (Table 6.2). Of the 271 *An. gambiae* s.s. specimens, 56% were bloodfed, 26% gravid, 20% were fully gravid and 0% were unfed. Of *An. funestus* at this site, 667, 54% were freshly fed, while the remaining three conditions were almost equal.

At Kapululila, 58.3% of *An. arabiensis* were bloodfed, 16% half gravid, 16% fully gravid and 10% unfed (Table 6.2). Both remaining species showed similar indoor resting gonotrophic conditions.

Site	Species	Bloodfed	Half gravid	Gravid	Unfed
Lukwesa	*An. arabiensis*	51.6%(15)	20% (6)	20% (6)	6% (2)
	An. gambiae s.s.	56% (152)	26% (5)	20% (54)	0% (0)
	An. funestus	54% (360)	17% (113)	15% (100)	14% (93)
Kapululila	*An. arabiensis*	58.3% (69)	16% (19)	16% (19)	9.7% (12)
	An. gambiae s.s.	51% (11)	20% (4)	22% (5)	7% (1)
	An. funestus	50% (84)	21% (35)	21% (35)	8% (13)

Table 6.2. Gonotrophic status of indoor resting *Anopheles* species by site.

Species	Bloodfed	Half gravid	Gravid	Unfed
Lukwesa	53% (1427)	21% (566)	17% (458)	9% (2420
Kapululila	51% (482	24% (227)	20% (189)	5% (47)
TOTAL	52%	22.5%	19.5%	7%

Table 6.3. *An. gambiae* s.l. gonotrophic status for the entire sample from both sites.

The gonotrophic condition of the entire *An. gambiae* s.l. sample representing the sum of all Anophelines captured throughout the study period showed comparable results (Table 6.3).

The majority of mosquitoes (52%) were bloodfed. Half-gravid females made up 21% and fully gravid represented 17% of the sample, while unfed mosquitoes were least represented in indoor collections (Table 6.3). Figure 6.7 is the graphic representation of the divisions between fed status for species showing similarity in gonotrophic condition between species and this was confirmed statistically with no significant difference between sites (X^2=0.653, dof= 1, P>0.05).

SITE	SEASON	SPECIES	n	BLOOD MEAL SOURCE (%) Human	Sheep/Goat	Bovine
Lukwesa	Dry season	*An. arabiensis*	75	46.4	53.6	0.0
		An. gambiae s.s.	75	55.4	44.6	0.0
		An. funestus	75	100.0	0.0	0.0
	Wet season	*An. arabiensis*	75	43.2	56.8	0.0
		An. gambiae s.s.	75	81.5	18.5	0.0
		An. funestus	9	36.0	64.0	0.0
Kapululila	Dry season	*An. arabiensis*	50	42.1	57.89	0.0
		An. gambiae s.s.	50	-	-	
		An. funestus	36	96.4	3.67	0.0
	Wet season	*An. arabiensis*	55	53.3	46.7	0.0
		An. funestus	13	51.1	16.7	0.0

Table 6.4. Bloodmeal sources of *Anopheles* females during the study.

Feeding Preference

Feeding patterns and host ranges for *Anopheles* species found during the study and tested by direct ELISA are shown in Table 6.4. Blood meal sources were from either human or goat/sheep. All tests conducted at both sites were negative for bovine blood.

During the dry season, the Lukwesa samples showed proportions of human feeding as presented in table 6.4.

At Kapululila, *An. arabiensis* turned more to non-human hosts from which it took 58% of its bloodmeals during the dry season. During the rainy season, the trend was reversed and this species fed more on humans (53%). *An. funestus* fed almost exclusively on humans during the dry season (96%). This was partly reversed during the wet season with a reduction in the tendency to feed on humans, which was similar to Lukwesa area, where there were few specimens. *An. gambiae* s.s. could not be included in the analysis at this site because of low numbers.

Evidence of bovine feeding was not found at either site (Table 6.2). A within-site comparison of sources of bloodmeal for the three *Anopheles* species showed a statistically significant association between season of collection, mosquito species and bloodmeal source in the Lukwesa

samples (X^2= 55.5, dof= 2, P<0.001), validated by a Cramer's V value of 0.497, P<0.001, showing a strong association of 0.5. Data for Kapululila village failed to demonstrate a significant association between season, species and bloodmeal source. However, the association was observed in the wet season (X^2= 32.24, dof= 2, P <0.001). The data clearly demonstrated a preference for human blood feeding by *An. funestus,* particularly in the dry months.

Sporozoite Infection Rates

P. falciparum CSP infection rates in vector mosquitoes were derived from the *Anopheles* sample identified by PCR (Table 6.1). *P. falciparum* sporozoite CSP positive rates by site and species were confirmed by direct ELISA (Figures 6.8-6.10).

At Lukwesa, there were infections demonstrated in *An. gambiae* s.s. and *An. funestus*, not *An. arabiensis* (Figure 6.8).

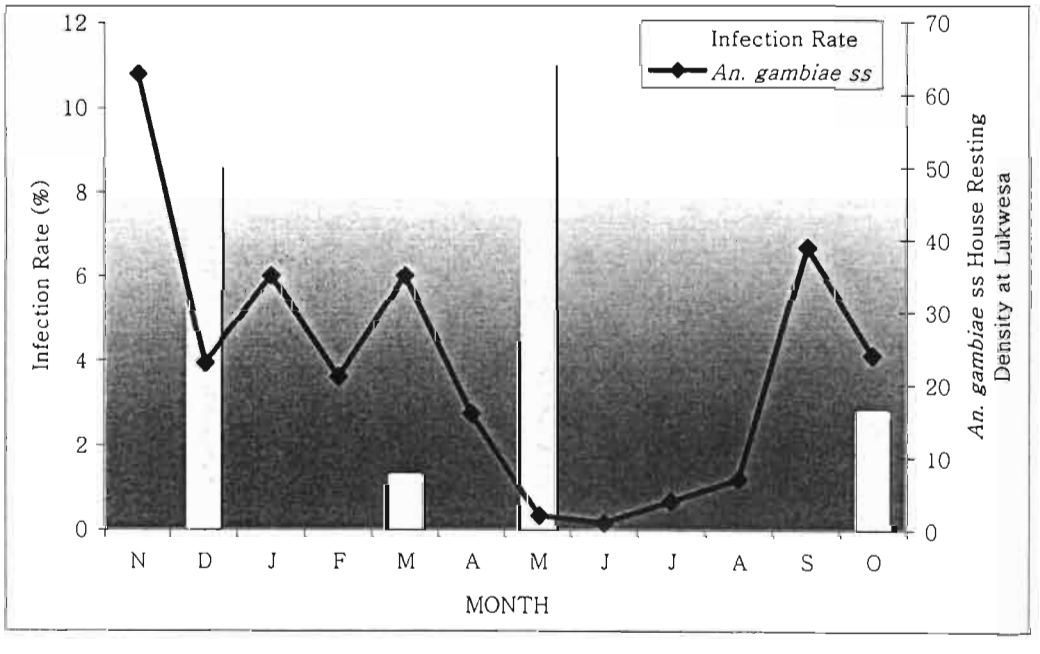

Figure 6.8. *An. gambiae* s.s. identified from monthly indoor resting catches and pfCSP infection rates at Lukwesa village.

An. gambiae s.s. was found positive for pfCSP protein in all three seasons; November-February, March-June and July-October, with the most infections occurring during the cool season in May at the end of the rainy season, when an overall infection rate of 11.1% was recorded. The infection rates detected during the wet season, in December was 8.7%,

the dry hot season (October) was 2.7%, and 1.23% in March at the end of the rainy season (Figure 6.8). The overall annual weighted mean of pfCSP infection rate for *An. gambiae* s.s. at this site was 5.9%. At the same site, *An. funestus* was found pfCSP positive only during the cool dry season, or soon after the rains in April a rate of 4.4% (Figure 6.9). *An. arabiensis* was not found infected during sampling period at this site.

Figures 6.8 and 6.9 display that *An. gambiae* s.s. and *An. funestus* positivity occurred during the transition period between the end of the hot, rainy season and the beginning of the cool dry season from March to April.

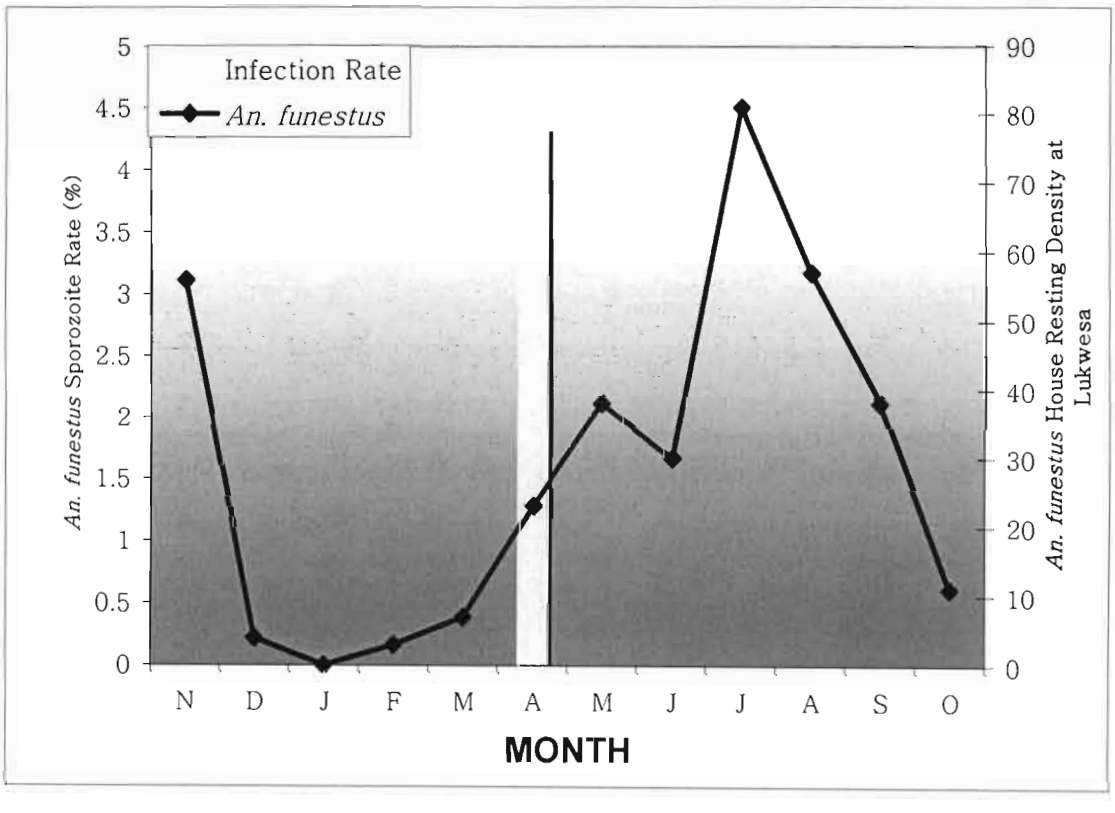

Figure 6.9. *An. funestus* identified from monthly indoor resting catches and pfCSP infection rates at Lukwesa village.

At Kapululila, neither *An. gambiae* s.s. nor *An. funestus* were found infected with *Plasmodium* circumsporozoites in any season during the study. Only *An. arabiensis* displayed a seasonal sporozoite infection rate of 5.56%, at the end of the warm rainy season during April (Figure 6.10).

P. falciparum sporozoite infection rates could not be compared between sites because there were no infected mosquito species common to both sites.

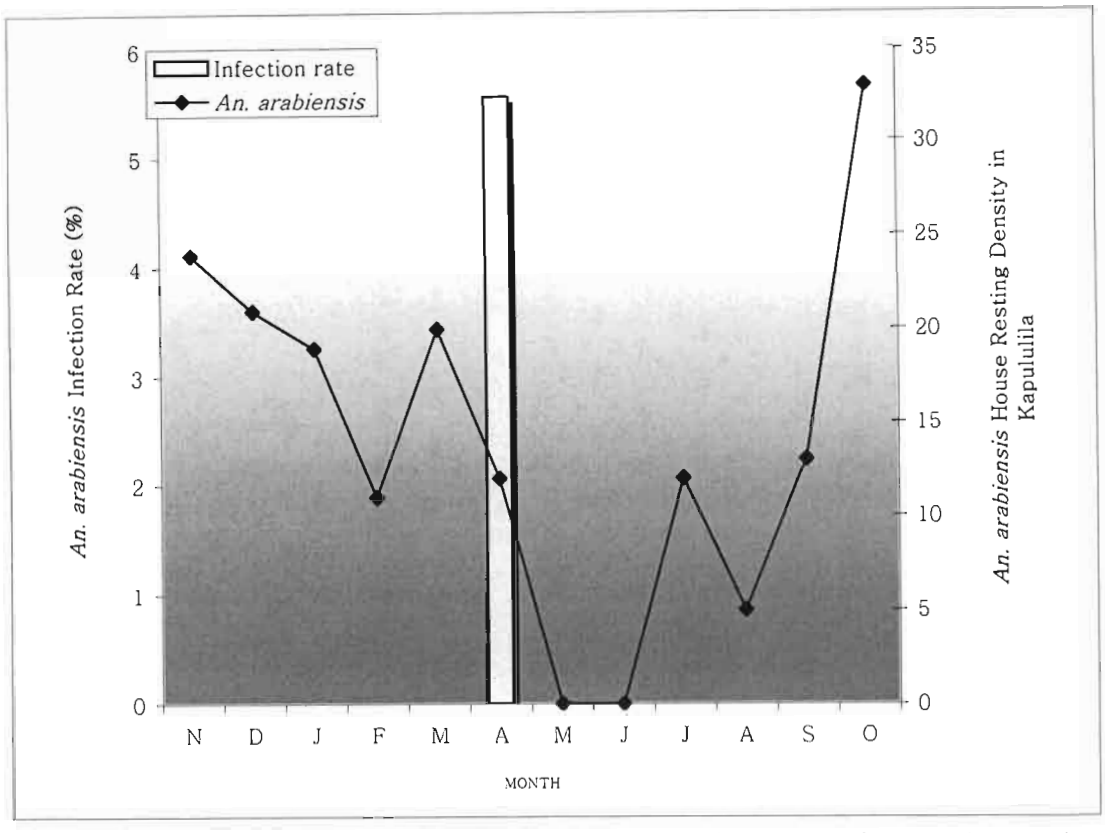

Figure 6.10. *An. arabiensis* identified from monthly indoor resting catches and pfCSP infection rates at Kapululila village.

Overall, Figures 6.8-6.10 demonstrate that the period with the lowest indoor resting vector density was the period in which the *Anopheles* females presented with the highest sporozoite infection rates. Higher sporozoite rates also coincided with cessation of rain and on set of the cool dry season.

Entomological Inoculation Rates

Results show that Lukwesa village had multi-season pfCSP positivity in two infected vector species, resulting in a high Entomological Inoculation Ratio (EIR). Kapululila village had evidence of single season infected vectors and only a single vector infected (Table 6.6). *An. funestus* at Lukwesa was an important vector during the cool dry season in terms of EIR, despite exhibiting a lower pfCSP ratio of 4.35% than *An. gambiae* s.s. with a ratio of 5.94% (Table 6.5). *An. funestus* showed a higher daily indoor biting rate of 0.51 bites per person per night, compared to 0.21 for *An. gambiae* s.s. (Table 6.6).

While *An. funestus* was a successful vector at Lukwesa it was not incriminated in malaria transmission at Kapululila during the current

survey (Table 6.5). The sample size for *An. arabiensis* at Lukwesa was low (n=29) as was the case for *An. gambiae* s.s. at Kapululila site (n=21). As a result of these low numbers, it is possible to meaningfully interpret their contribution. Monthly vector infection rates comparisons are not possible due to low monthly numbers found. However, an attempt is made to perform seasonal analyses when the collections are pooled (Figures 6.11 and 6.12).

Site	Parameter	*An. funestus* monthly collection											
	Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Lukwesa	Numbers	56	4	0	3	7	23	38	30	81	57	38	11
	Infection(%)	0	0	0	0	0	4.4	0	0	0	0	0	0
Kapululila	Numbers	13	7	0	0	2	11	0	0	1	73	7	5
	Infection(%)	0	0	0	0	0	0	0	0	0	0	0	0

Figure 6.5. *An. funestus* monthly density and pfCSP infection rates at both sites.

SITE	Species	Sample Size	Persons /House	Man Biting Rate	Daily Biting Rate	Monthly Biting Rate	Seasonal Biting Rate	PfCSP %	EIR Ib/p/n	Annual Ib/p/n
Lukwesa	*An. arabiensis*	29	3.6	8.06	0.02	0.67	2.68	0.000	-	-
	An. gambiae s.s.	71	3.6	75.28	0.21	6.27	25.09	5.942	1.248	456
	An. funestus	667	3.6	185.2	0.51	15.44	61.76	4.350	2.218	810
								TOTAL	3.466	1266
Kapululila	*An. arabiensis*	119	3.4	35.0	0.096	2.92	11.67	5.56	0.533	195
	An. gambiae s.s.	21	3.4	6.18	0.017	0.52	2.06	0.00	-	-
	An. funestus	167	3.4	4.12	0.113	3.43	13.71	0.00	-	-
								TOTAL	0.533	195

Table 6.6. Infective *Anopheles* bites per person per year with resultant EIR per site.

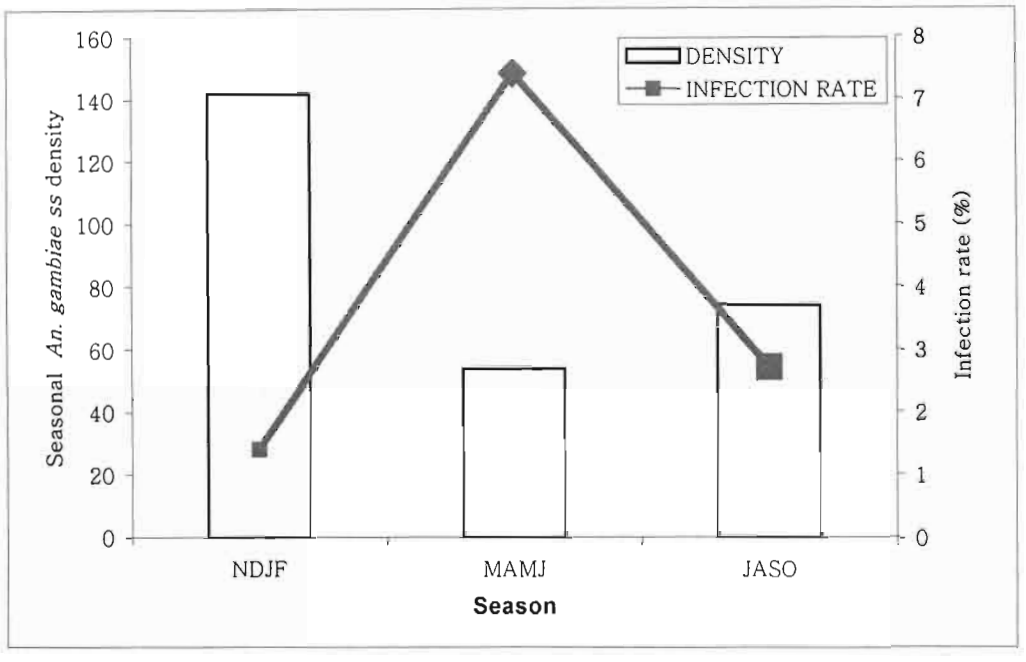

Figure 6.11. Seasonal *An. gambiae* s.s. indoor resting density and seasonal pfCSP infection rates at Lukwesa village. (abbreviations in X-axis represents first letter of month)

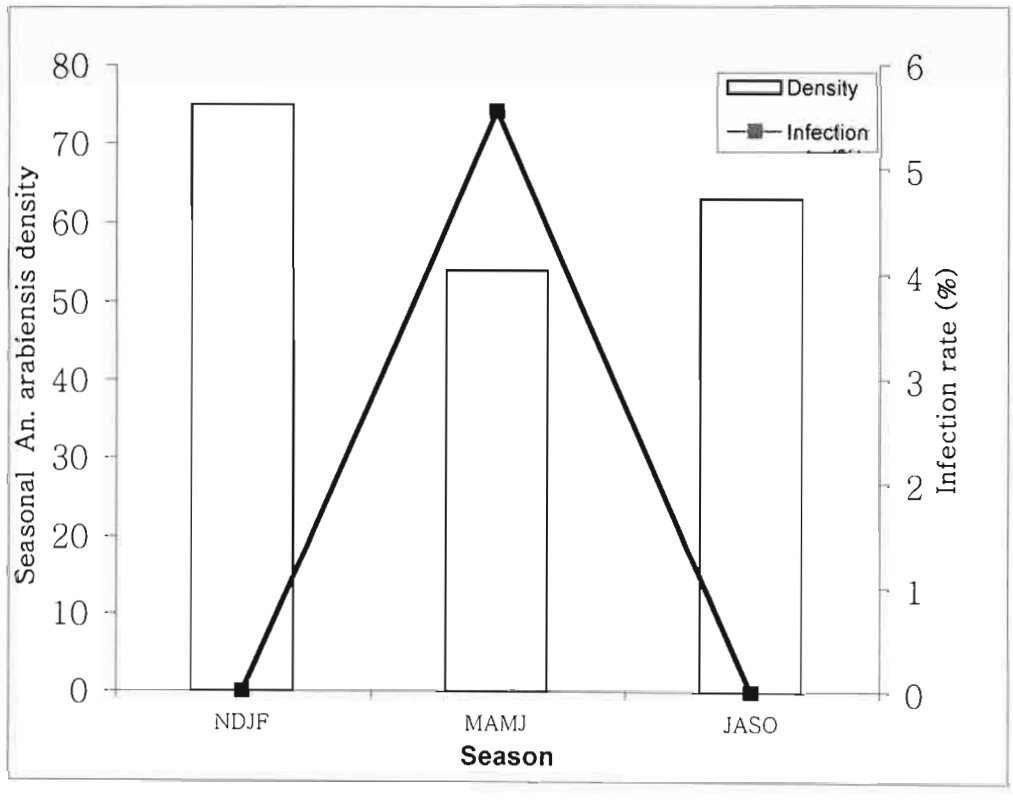

Figure 6.12 Seasonal *An. arabiensis* indoor resting density and seasonal pfCSP infection rates at Kapululila village.

Malaria Disease Incidence

Annual malaria cases per 1000 patients attending health facilities during the study are shown in Figures 6.13 and 6.14. The data were obtained during March/April 2000 from the national health information system database as preliminary national averages for the period under review (October 2000 to November 2000).

At Lukwesa, the peak in malaria disease reporting at health facilities was between December and May. *Anopheles* female mosquito house-resting densities were not directly correlated with the malaria cases reported at health facilities. Each vector species density showed peaks at different times of the year. The highest population peak for *An. gambiae* s.s. occurred at the start of the rainy season in November and high numbers were maintained through to April with decrease during cooler dry season from May to August. The density of *An. funestus* started to rise in May and peaked in July. Monthly house-resting densities of *An. arabiensis* at this site were low, only showing a small rise in numbers during March at the end of the hot wet weather (Figure 6.13).

There is approximately a one month lag between the time of maximum *An. gambiae* s.s. house-resting density in November and the peak of malaria clinical cases in December. The *An. gambiae* s.s. vector peak spanned the period January to April, with clinical cases occurring with a peak shifted to the right by a month. This is probably related to the time taken for the vector to build up its population density and the period of development of the parasite in infected mosquitoes, which are both dependent on temperature (Craig *et al.*, 1999).

The population density of *An. funestus* was visually related to the outpatient attendance at health facilities in an inverse manner; as the population density of the vector was building up in May, malaria cases had already started to decline. By the time *An. funestus* reached its maximum density in June/July, malaria cases had reached their annual minimum in health facilities (Figure 6.13). The temperature would have decreased during this period and may have affected parasite development in the vector.

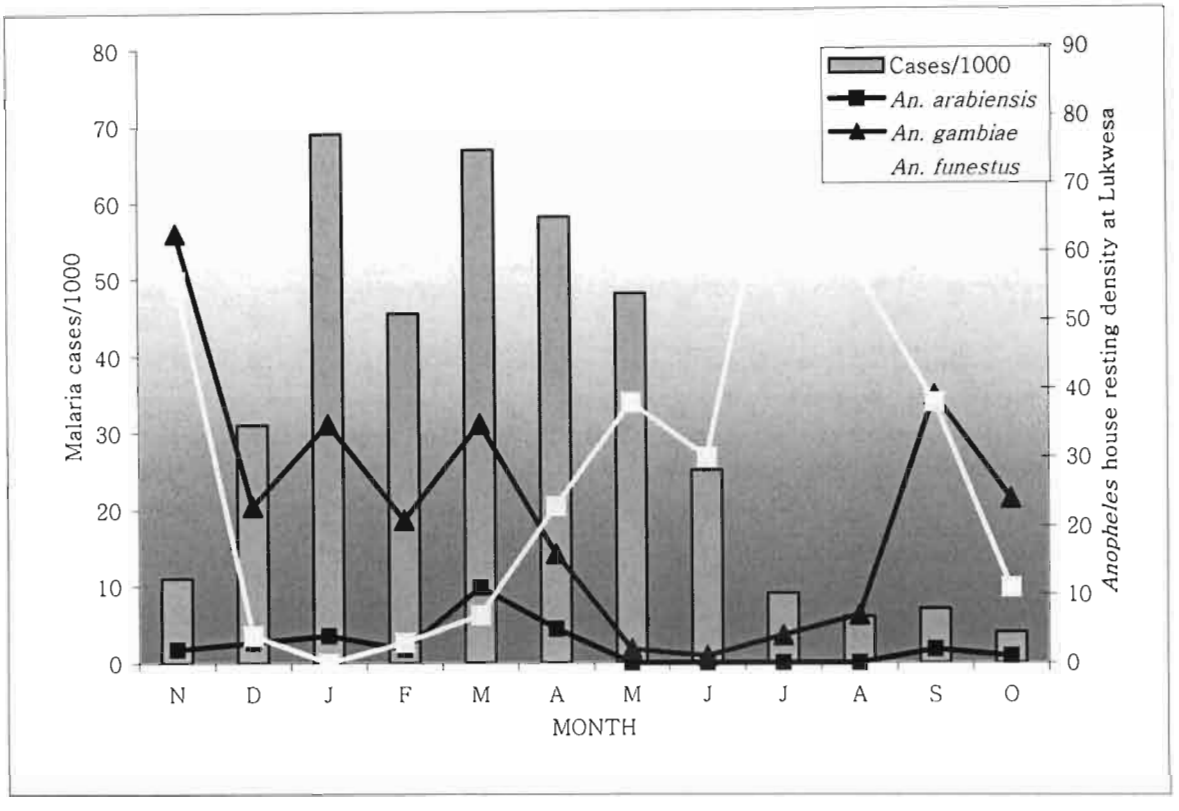

Figure 6.13. *Anopheles* indoor-resting and malaria incidence rate at Lukwesa.

The Kapululila site demonstrated a similar pattern to Lukwesa with the exception that the population density of *An. gambiae* s.s. at Kapululila was mirrored by *An. arabiensis* as the dominant species at Lukwesa. *An. funestus* appeared to play a similar role at both sites. The numbers of *An. gambiae* s.s. females captured at this site were insufficient to allow satisfactory analysis, but showed a small peak in July and August (Figure 6.14).

Although both *An. arabiensis* at Lukwesa and *An. gambiae* s.s. at Kapululila were considered potential vectors, catch numbers were too low to allow infection detection with any reliability.

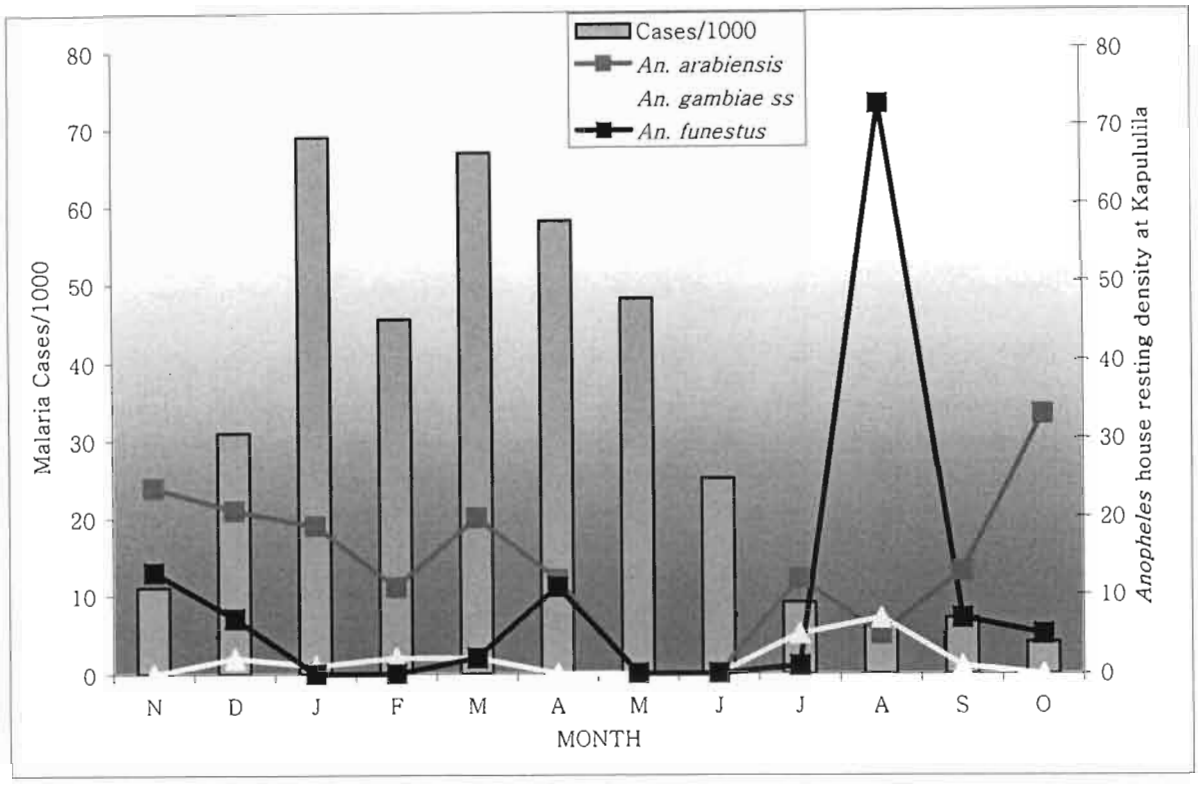

Figure 6.14. *Anopheles* indoor-resting vs malaria incidence rate at Kapululila.

Discussion

Three *Anopheles* species were identified at the two study sites; *An. arabiensis*, *An. gambiae* s.s. and *An. funestus*. *An. arabiensis* and *An. gambiae* were the only members of the *An. gambiae* s.l. complex sibling species identified. The remaining freshwater breeding species (*An.quadriannulatus and An. bwambae)* have been identified in the country by a number of researchers, especially at Chirundu, near Kapululila village (Hadjinicolou, 1963; Paterson, 1964; Shelly, 1973), and recently, Siachinji (2000) in an unpublished report identified *An. arabiensis* and *An. quadriannulatus* from this same site.

Kapululila village within the Chirundu catchment area has been surveyed most over the years (Zahar, 1985). Studies at this site have examined vector identification and the bionomics of the *An. gambiae* complex sibling species. In the present study, three *Anopheles* vector species were found to occur at this site. This is only the second time that *An. funestus* has been documented from the site: the first being by the Malaria Research Laboratory in 1970 (Zahar, 1985). The area is situated in the Zambezi river valley, which is a typical habitat for *An. arabiensis* as

noted during previous mosquito collections from this site (Paterson, 1964; Shelly, 1972; and Zahar, 1985). Although all three species were present throughout the study period, *An. arabiensis* predominated in indoor collections made using PSC. Elsewhere, Service (1970) and Highton *et al.* (1979) found this same species dominating on valley floors, especially in the arid lands near Lake Victoria in Kenya (Omer and Cloudsley-Thompson, 1970; White, 1972; 1974). White (1972) refers to the hot river valley as a major selective influence through climatic factors, such as relative humidity on adult mosquitoes; determining which species would predominate in an area. At this site, *An. gambiae* is approaching the limit of its distribution at -20° S latitude (Gilles and de Meillon, 1968).

The second site, Lukwesa, was examined for vector species for the first time during the present study. The presence of predominantly *An. funestus* and *An. gambiae* s.s. indicated that environmental factors such as rainfall and/or temperature and relative humidity might have been present at levels which did not favour the proliferation of *An. arabiensis* (White, 1972).

An. funestus and *An. gambiae* s.s. were found in higher densities throughout the collection period and in densities similar to those observed in the Copperbelt province by Shelly (1972).

An analysis of *An. gambiae* s.s. in relation to the average monthly minimum temperature (°C) showed that as long as the right breeding sites were present, the population densities were closely controlled by the minimum monthly average temperature. Logistic regression indicated that the two variables were closely related. As long as the minimum temperature remained above 15°C, the vector population remained high. This was the case from August/September, when temperatures were rising, no rain had fallen but the population had started to build up rapidly (Figure 6.5 & 6.6). The numbers stayed high as long as temperature averaged above 15°C. By March/April, temperatures started to decline to 15°C or below, and the vector population density decreased and remained low to August, when the temperatures again reached 15C°. In South Africa, le Sueur (1991) noted that below 16.5 °C, *Anopheles* larval development becomes indeterminate.

An. funestus also responded to the cue of minimum monthly temperature, this species' abundance was inversely correlated to the minimum temperature (r^2=5.33), again as long as suitable breeding sites were present (Figure 6.5). The critical temperature for this species also seemed to be 15°C. When the temperature exceeded 15°C population density of *An. funestus* was lower, while the opposite was also true, below the 15°C mark, the population increased as shown in figure 6.5. During

the hot humid months of September to March, the minimum temperatures were well above 15°C and the *An. funestus* population density was low. When the minimum temperature fell below 15°C, in the cooler dry months from March and April, the population built up reaching its peak in June/July, the cooler time of the year. By September/October after the temperature had risen above the threshold, the population density decreased dramatically. This cold-adaptation was also demonstrated by le Sueur (1991) in his study on larval populations in South Africa.

Examination of the population density curves for *An. gambiae* s.s. and *An. funestus* revealed a potential for year-round malaria transmission. The vector population densities seemed to respond to different environmental and possibly intrinsic cues, which resulted in maintenance of the malaria transmission cycle throughout the year.

With regard to vector species dynamics in the study sites, environmental elements including temperature and precipitation had a definite influence on population densities and consequently on malaria transmission. Apart from the classical impact of climatic factors on malaria transmission as explained by the Macdonald's model for malaria transmission (Macdonald, 1957), le Sueur (1991) noted that adult mosquito population density is regulated by larval instar duration, which is regulated by temperature and other factors. At lower temperatures, larvae took longer (up to 3 weeks) to emerge as adults. The same process took only one week in summer, implying that the vector population is present in the environment but in its immature form. As soon as the limiting factor is removed (in this case temperature), the vector population built up rapidly. Results of the present study with regard to *An. arabiensis* and *An. gambiae* s.s. meant that in winter (<15°C), most of the population was in larval form, in line with le Sueur's (1991) observation. Conversely, when temperatures averaged above 15°C, larval development to maturity was more rapid, resulting in higher population densities, comprised mostly of young mosquitoes, less likely to be infected. However, the opposite applied in the case of *An. funestus*. The population density was highest at lower temperatures and did not coincide with the rainy season (November-April). It should be noted that this species breeds in permanent water bodies, as opposed to mainly rainy puddles that are favoured by *An. gambiae* s.l. sibling species.

At Kapululila, *An. gambiae* s.l. was present in lower numbers than the other two species and was not included in further analyses for this site. *An. arabiensis* dominated collections here. *An. arabiensis* population density was significantly correlated with the minimum temperature (r^2=0.83), with a threshold of about 20°C, in keeping with *An. arabiensis*

favouring hot and humid climates. The population declined at the start of winter (March/April) and remained low until August when temperatures increased, with a rapid population growth from September to March/April of the following year (Figure 6.6). These findings are similar to those of Shelly in 1973 at Chirundu. Gradual population increases followed seasonal rainfall patterns. The population increased from December to March in concert with the peak. Numbers then decreased rapidly during April and stabilized at a lower level from May to October. Shelly (1973) attributed this sudden population density increase during the rainy season to the presence of numerous breeding places in the form of rain puddles, whereas for the remainder of the year *Anopheles* breeding was limited to pools in the sand banks along the Zambezi river. *An. arabiensis* was the only species showing positive correlation to temperature changes at this site.

Other fluctuations observed in population curves may be explained by inter-annual variations in the minimum temperature, as the 10-year averages employed here would have had a smoothing effect.

This study found general tendency for bloodfed mosquitoes to remain indoors, at least until the following morning at both sites, by both techniques, PSC and WTs. Although the WT technique captured negligible numbers of mosquitoes. All three species displayed similar indoor resting habits. There was no significant difference in the gonotrophic condition within sites or between different species from both villages. Half of the collection from indoors were bloodfed. The remaining 50% was divided equally between half gravid and fully gravid female mosquitoes making up approximately 25% each. Unfed females made up the remaining 5-10%.

These findings are similar to those reported by Shelly (1973), at Chirundu near Kapululila. He recorded indoor collections comprising of 75% of bloodfed females and equal proportions (20%) of half and fully gravid females. Unfed females were the least common group (5.9%) suggesting a tendency for blood-fed females to remain indoors. Bloodfed females belonging to *An. gambiae* s.l. group generally out-numbered gravid and half gravid females in indoor collections. Similar results were noted by Service (1970), who noted that *An. gambiae* s.l. exhibited a tendency to spend part of the gonotrophic cycle outdoors.

Hosts fed on by *Anopheles* species in this study were human and goat/sheep (Table 6.4). The tendency to feed on human blood is defined as anthropophilism, while that of feeding on animals is called zoophilism. Direct ELISAs were negative for bovine blood at both sites. This was expected, as no cattle occurred in either study area. In addition, some bloodmeals *An. arabiensis* (23%), *An. gambiae* (12%) and *An. funestus*

(4.8%) did not react with reagents, perhaps due to sample degradation or the possibility that the mosquitoes were feeding on other hosts.

In the literature, *An. arabiensis* demonstrates a mixed feeding behaviour, whereas *An. gambiae s.s.* is mainly anthropophilic (Shelly, 1973; Highton *et al.* 1979; Petracca *et al.*, 1991). White (1972) found a Human Blood Index (HBI) of 38% in *An. gambiae* s.s. and 28% in *An. arabiensis* at Kisumu, in Kenya. The same author in 1974 noted that where there were no other hosts, the (HBI) of *An. gambiae* s.s. could be assumed to be 100% human blood since this species exhibits compulsive endophily, which results in HBIs of 80-90%. Beier *et al.* (1988) in Kenya found similar HBIs to those reported here, and noted that where bovines out-number humans, low HBIs were noted in *An. gambiae* s.s., ranging from 28% to 50%. Ijumba *et al.* (1990) in Kenya made similar observations. In fact in Segera, Tanzania, White (1974) recorded HBIs as low as 4% in *An. gambiae* s.s. and 0.4% in *An. arabiensis*. White (1974) explains that contrary to the popular belief that goats and sheep are not important bloodmeal sources, malaria vectors, easily divert to them in the absence of bovines, as was found during this study. At Kapululila, Shelly (1973), had concluded that *An. arabiensis* would feed more readily on cattle when they were available, than they would on humans.

It was not clear from this study why there was a proportional reduction in human feeding, other than the fact that at Lukwesa in some instances during the rainy season an appreciable number of families move away from their permanent villages to fishing camps along Luapula river. These movements may have had a temporal effect on blood meal sources for mosquitoes. At Kapululila, most community members spent a number of nights away from their houses while working in their gardens, situated more than 15km from villages. However, the elderly and young did not generally participate in these population movements.

The seasonal nature of *P. falciparum* infection rates in *Anopheles* species has been documented in many studies (Krafsur, 1977; Ijumba *et al.*, 90; Taylor *et al.*, 1990). Results reported here show that pfCSP infection rates varied widely during the study in the three vector species.

At Kapululila, only *An. arabiensis* was found infected at the end of the rainy season during the month of April, at an annual ratio of 5.6%. It coincided with decreasing rainfall and low *An. arabiensis* population density. Sharp *et al.* (1988) in South Africa obtained similar results. The implication of this observation was that at this time of the year the vector was surviving long enough for the parasite to successfully complete the sporogonic cycle. The other vector species, although present, were uninfected at this site. The reasons for this were uncertain but may have

been related to environmental factors as that this is an arid area, a more suitable site for *An. arabiensis* (White, 1972).

At Lukwesa, *An. gambiae* s.s. was found infected during the periods when its population density was low. It was infected during March when both the quantity and quality of external resting sites had deteriorated due to falling winter temperatures. This forced mosquitoes to remain indoors, which may have contributed to their longevity and higher sporozoite rates. The overall annual infection rate for this species was 5.9%. *An. funestus* was found infected at the time of its lowest population density, during April. The infection rate in this species was 4.4%. A*n. arabiensis* did not test positive for pfCSP at this site. The infection rate in *An. gambiae* s.s. was highest at the end of the rainy season at the beginning of the cool dry season, between March and June, and in the hot dry season (July to October). The lowest sporozoite infection rate was recorded during the hot rainy season between November and February, confirming that despite low densities, mosquitoes were living long enough to acquire infection.

Plasmodium infection rates were negatively correlated to the house-resting density of vectors (Thomson *et al.,* 1994). Gillies (1954) and Muirhead-Thompson (1951) showed that large vector populations tend to comprise young females and hence sporozoite rates tend to be low, but following a decrease drop in population density, the infection rate would increase by reducing the denominator. A similar explanation may be valid here but further investigations into mosquito infection rates and population dynamics across seasons may be necessary to validate these findings further. In addition, a number of sites geographically located between the two studied may be useful in evaluating the impact of weather elements on relative abundance of the three species.

In this study, sporozoite rates indicate that *An. gambiae* s.s. was probably the most important vector at Lukwesa. *An. funestus* and *An. arabiensis* did not appear to be of much epidemiological importance as malaria vectors. At Kapululila, however, environmental conditions were considered suitable for *An. arabiensis* and it was found to carry a higher sporozoite rates. Based on vector infection rates, Lukwesa presented a higher risk of malaria transmission than Kapululila.

The infection rates found in this study are similar to those found in Zambia by other researchers. At Chirundu, Shelly, (1973) hand-dissected *An. gambiae* s.l. and found a 1.2% sporozoite infection rate. *An. arabiensis* samples from Eastern and Lusaka provinces (Bransby-Williams, 1979), revealed 0% infection in the Lusaka collections and 1.1% in the Eastern province collection. Hadjinicolou, (1963) at Chirundu found a 2.3%

infection rate in *An. gambiae* s.l. and pointed out that malaria in Zambia may be transmitted only by *An. arabiensis*. Similar observations on *An. funestus* in Copperbelt province found indoor resting populations uninfected (0%), while exophilic mosquitoes were infected at 1.2%. At the same site, *An. gambiae* s.l. caught indoors and outdoors were both infected at a rate of 1.6%. The current results are based entirely on indoor resting vectors, as exit window traps did not yield sufficient numbers of mosquitoes (Zahar, 1885).

Elsewhere, *An. arabiensis* has been reported to carry lower plasmodial infection rates than either *An. gambiae* s.s. or *An. funestus* (Service *et al.*, 1978). The infection rates of *An. arabiensis* reported here were generally higher than those reported in the literature. However, similar values have been reported in a number of instances elsewhere. Service *et al.* (1978) recorded a 5.0% sporozoite infection rate for *An. arabiensis* in an unsprayed area in Kisumu, Kenya, while Joshi *et al.* (1975) also in Kenya, found *An. arabiensis* infected at the rate of 7.8%. In Nigeria, Service (1970) recorded a 6% sporozoite rate. However, the commonly reported infection rates for this species in Africa range between 1% and 1.5%. In Pare, Tanzania, White (1972) reported *An. arabiensis* be infected at a rate of 0.9%. Fontenille *et al.* (1997) found 0.6% and Githeko *et al.* (1993) recorded 1.08% in Kenya.

In the present study, *An. gambiae* s.s. was found to have a mean annual sporozoite rate of approximately 6%. Similar rates have been reported by a number of workers. Service *et al.* (1978) found 6% in Kenya. At Pare in Tanzania, White (1972) found *An. gambiae* (4.8%). with only 0.4% infection rate, while Service (1970), in Nigeria recorded 6%, and noted that *An. arabiensis* and *An. gambiae* s.s. exhibited similar infection rates. Fontenille and others (1997) noted a 1.4% in Senegal, while Shililu *et al.* (1998) reported 6.3%, and Service *et al.* (1978), found a sporozoite rate of 6%-8% through hand dissections in Kisumu, Kenya.

An. funestus was only found positive for sporozoites in a single month at one site at a rate of 4.4%. This compares well with literature values reported for this species. In Matola, Mozambique, Mendis *et al.* (2000) reported a 2.5% infection rate, while in 1970 in Nigeria; Service recorded a sporozoite rate of 6%. Shililu *et al.* (1978) recorded 9.5% in western Kenya. Ijumba *et al.* (1990) in Mwea-Tebere irrigation scheme also in Kenya found this species infected at the rate of 1.6% and in West Africa (Senegal), Fontenille *et al.* (1997) noted a 2.6% infection rate and 4.3% was reported by Githeko *et al.* (1993) in Kenya.

The *An. arabiensis* rate was on the high side, similar to that reported from areas exhibiting hyper-endemic malaria. At Lukwesa, *An.*

gambiae s.s. and *An. funestus* were involved in malaria transmission, as both were found pfCSP positive. They were found infected at different times of the year, implying that the two vectors complimented each other in seasonally maintaining malaria transmission. The data indicate that at the second site (Kapululila), malaria was being transmitted exclusively by *An. arabiensis*.

During this study, an adult human resident at Lukwesa was exposed to approximately 3.5 infective bites per night or 1,266 infective bites per year, comprising 1.2 (456 per year) from *An. gambiae s.s.* and 2.2 (810 per year) by *An. funestus*. At Kapululila, an EIR of 0.5 infective bites per person per night or 194 per person per year, and attributed solely to *An. arabiensis,* was computed.

The EIRs calculated during this study are within the range recorded in Africa, which are known to vary from 0.01 to 1000 infective bites per person per year (Fontenille and Lochouarn, 1999).

There were differences in malaria transmission potential between the sites. There is a higher malaria risk in the Luapula valley, high rainfall zone of the country, also demonstrated by the Geographical Information System (GIS) stratification maps. They categorise this area as a hyper-endemic stratum 4 (Chapter 5).

The Zambezi valley belt, where Kapulilila is situated, experience lower rainfall, favoured by *An. arabiensis*. This site had 7 fold lower malaria risk compared to Lukwesa with an EIR of 0.5 infective bites per person per night.

Three members of the *Anopheles* complex were identified and implicated in malaria transmission, these being the most important vectors of malaria in sub-Saharan Africa (Gillies and Coetzee, 1987; Collins and Paskewirtz, 1995). The study also shows that malaria transmission should be defined locally (Craig *et al.,* 1999).

Malaria transmission at both sites was dependent on the densities and bionomics of the three species found. Infections of both human and vector populations were occurring more in the cooler dry season than the warmer, wet or hot and dry seasons of the year. Expert opinion generally holds that the cooler dry season is the time of low malaria transmission. The findings are generally in support of the over-wintering phenomenon discussed by le Sueur (1991). During this season, it appears that winter minimum temperatures below 20°C (Craig *et al.*, 1999) play a significant role in triggering the change in population behaviour. In turn, this produces much more robust *Anopheles* adults which can survive longer and are hence capable of surviving the sporogonic cycle. This is

supported by finding all three species infected during the cool/dry season (Table 6.4).

Kapululila village situated in the Zambezi valley was dominated by *An. arabiensis*. This vector is normally associated with unstable malaria transmission (Fontenille and Lochouarn, 1999). To some extent this was the case in this study. Chapter 5 has demonstrated that the lower Zambezi valley (Chirundu) is an area where malaria affects all age groups, a phenomenon associated with unstable malaria (Snow *et al.*, 1998). Lukwesa village is situated along the Luapula valley, associated with the *An. gambiae* s.s. and *An. funestus*, and demonstrated stable malaria transmission (see chapter 5).

A number of important malariometric indices related to malaria transmission have been estimated at the two study sites. These are essential precursors for realistic and effective programme planning for malaria prevention and control as they quantify potential risks and numerically describe the dynamics of malaria transmission. Although the EIRs estimated in the study are not an absolute measure of malaria transmission risk, they nonetheless represent an index of relative transmission potentials at the two sites.

The three vectors identified from the two sites have demonstrated bionomic patterns comparable to those known from the literature for each species. Although *An. arabiensis was* present at Lukwesa near to the equatorial belt, it is a more important vector in the arid southern part of the country where malaria transmission is unstable (Chapter 5). *An. funestus* was the most abundant indoor-resting mosquito at both study sites, although its population was concentrated in only two months of the year. *An. gambiae* s.s. was the important vector close to the equator, where it had the highest sporozoite infectivity rate.

It should however, be noted that these conclusions are based on limited observations and it would therefore be important to increase the sampling period and number of sites. While most studies in Africa focus on *An. gambiae* s.l. complex because of its wide distribution and relative ease with which it can be cultured under laboratory conditions, an equally if not more potent vector of malaria in Africa, *An. funestus*, should not be neglected.

The amount of variation in the intensity of malaria transmission observed within and between sites in this study demonstrates inherent in data that neglects the diversity of epidemiological conditions existing in localised areas. The current study demonstrates that an understanding of local vectors and their bionomics is key to the successful control of this important public health problem.

The study has shown that the periods of peak vector population numbers did not coincide with peak malaria transmission at either site. Thus, the promotion of interventions such as ITNs, which depend to a great extent on the intensity of mosquito biting, may be promoted at the wrong time of the year. Malaria transmission occurs more when the vector densities are at their lowest. According to this anecdotal data, it may seem that malaria programmes erroneously associate malaria disease simply with mosquito abundance but the results of this study indicate that ITNs should be promoted throughout the year with Indoor Residual Spraying (IRS) performed out at the end of the hot wet season. However, considering the limits in the data, this would be a premature conclusion until more data is collated and analysed in the subject.

The evidence gathered and presented in this study contributes to the body of knowledge about malaria vectors in Zambia. It opens other possible lines of scientific inquiry in an attempt to further understand the biological interactions among the three incriminated mosquito species. Continued sampling at the two sites, in addition to other intermediate areas, should yield particularly interesting information on the distribution of vectors and their determinants in Zambia. The epidemiology of malaria in the semi-migration of communities between their villages and temporal farming homes would be another interesting area to explore. The possible behaviour of *An. arabiensis* with regard to resting and feeding following the introduction of bovines in the area would be another interesting line of inquiry.

Chapter Seven: General Conclusions

The goal of this study was to contribute to an understanding of malaria and its determinants in Zambia. The study attempted to collate information about the possible options available for controlling malaria in the country. In this final section, main findings are extracted and discussed in terms of their role in malaria epidemiology. A number of issues requiring further research are.

Introductory notes

Chapter one, being the general introduction, notes the advances made in malaria control globally. It also raises the key technical and policy challenges facing malaria prevention and control today, at both global and local level.

History of the problem

Chapter two deals with the historical perspectives of malaria control in Zambia and shows how a scientific approach can prove effective in addressing the malaria problem irrespective of the initial endemicity level. It demonstrates how malaria control was used to protect capital investments when malaria was addressed as a developmental issue. For example, copper mining was made profitable through minimizing the impact of the malaria disease burden on the work force. The proportion of resources that went into malaria control compared to the total capital investment was less than 1%. The control of malaria not only reduced mortality due to malaria, but also appeared to reduce mortality due to a number of other diseases, such as diarrhoea, dysentery, anemia and upper tract infections.

The history of the malaria control activities in Zambia is traced by means of a case study of malaria control in one of the copper mining towns. The case study demonstrates that it is possible to minimize the impact of malaria on the population through the use of low-cost technology, such as environmental management or species sanitation, even in a high intensity malaria transmission situation. The so-called "death valley" consisting of a mixed human population from different immunological backgrounds ranging from the immunologically naïve Europeans to semi-immune local Africans. Malaria control was able to

improve the general health status of the whole population living on the mines. Although not quantifiable, it is reasonable to expect that the mine's productivity must have increased as a result of a healthier workforce. In later years, from the 1930s to the 1970s, this productivity became the backbone of the national economy; Zambia then had one of the most vibrant economies in sub-Saharan Africa. Profits from this and other mines in Northern Rhodesia were also invested into other countries that were members of the Federation of Rhodesia and Nyasaland, especially Southern Rhodesia which was the capital of the Federation.

The study documents how the malaria programme embraced new control techniques as they became available, including untreated mosquito nets, wearing thick clothing, mosquito-screening of dwellings, and species sanitation. These measures had a telling impact on malaria-related deaths and burden of disease. Next came oil-based and chemical larvicides and eventually the introduction of DDT for indoor residual application. There was added synergy and efficacy each time a new intervention was added to existing measures. For example, following the introduction of DDT for malaria control, human mortality on the mine was reduced to nil and clinical cases became a rare occurrence, especially after the Second World War.

Policy changes at local and global levels have had an important effect on malaria control over time. From 1929 when the mines consulted the Ross Institute for expert advice on malaria; through introduction of larvicides for vector control; the introduction of adulticides; the abandonment of residual spraying and then its re-instatement hiring private contractors to clear water drains; each of these represented an important policy decision with far-reaching implications for the future of malaria control. Political will is therefore important. This chapter demonstrates how policy change can both build and damage a disease control programme.

Therefore salient principles from historical experience should be embraced and new methods and technologies cautiously introduced. New strategies such as the social movement to roll back malaria must be applied in the context of local realities based on sound scientific evidence.

Health system development

The third chapter examines health systems development in Zambia, especially Primary Health Care. The analysis presented shows that the health systems in Zambia are well developed by sub-Saharan African standards. Access to health services range from a few minutes walk to 6-

8 hours' walk. Coincidental with the economic boom of the period prior to 1975, the country developed its health infrastructure commensurate with the size of the population. Areas of high population concentration received proportionately more facilities. However, following the economic collapse, this development paradigm was no longer possible. Population growth has overstretched the capacity of current facilities which were adequate 20 years ago. The adequacy of facilities in relation to the population growth has resulted in differentials in service provision between rural and urban areas. While rural communities cover long distances to access health services, urban areas are faced with problems related to congestion. Important indicators of access to services are ratios of population: facility and client: provider. In this study, it was found that the population: facility ratio mirrored population density patterns. Provinces with higher population densities also tended to have a higher consumer: facility ratio. Shortages of drugs and equipment further complicated access to services.

Health systems are examined in relation to fulfillment of global and national policy pronouncements over time. These include Roll Back Malaria's goal of controlling malaria based on population access to facilities or services within 30 minutes on foot and Zambia's vision of equity of access to quality-assured health services close to the family. Both these declarations are difficult to attain considering the current situation where health facilities are inadequate, congested or poorly supplied. This chapter also deals with the goal of reducing malaria-related mortality by half by 2010. Up to the year 2003, not much has happened to realize these goals.

Chapter three suggests possible means for achieving some of these ambitious goals including placing trained and motivated providers at community level to deliver the basic health care package to the population.

Determinants of access to health interventions

The study then focuses on factors that dictate the uptake of insecticide-treated mosquito nets at community level. This concept is discussed in Chapter four. The study examines a community initiative where community members decided to invest in malaria prevention. The attention of the reader is drawn to the fact that historically, malaria prevention and control interventions, especially indoor residual insecticide application have always been paid for by governments. However, with regard to ITNs, apart from a few dissenting voices, there is almost global

consensus that ITNs should be paid for by the consumer. The implications of this are discussed in the light of failure over the past 20 years to effectively deliver this intervention to the population in a sustainable fashion. Many factors affecting access to ITNs for community members are identified and discussed. The study attempts to identify the important ones that affect the uptake of the intervention by individual households.

Distance between the household and a number of village features are tested as possible associated variables affecting decision making for acquisition of ITNs. The study also considers the impact of socio-economic status of household and the time spent in formal schooling by the heads of households, as possible determinants. Distance between the household and services, in this particular community was not a factor in determining ITN acquisition by households. Wealth and education were positively correlated with ITN ownership. The cost of ITNs was found to be a major barrier to the up-take of this intervention.

Given the poverty rates in sub-Saharan Africa and if the Abuja declaration is taken seriously, then investment should be made to subsidize the intervention. Bed nets should preferably be free of charge for children and others who cannot afford them. Investments should also be made in the area of population education, as the results of the study show that education in the household correlated positively accessing health services more appropriately. Compared to those with relatively less education. Consideration should be given to the fact that the burden being exerted by malaria appears to keep Africa poor. To expect a family which lives on less than one US dollar per day, to purchase a 7 US $ ITN (3$-net + 1$-insecticide + 1$-delivery + 2$-profit) delivered by the commercial sector, shows that many intended users of ITNs may not be able to afford them. There is possibly room for partnership with the commercial sector, but their profit margins in the ITN should not be the driving force, but rather the greater good to come out of a healthier and wealthier community. While development of general health services and integration are slowly taking place, children are dying (1-2 million annually). There is an urgent need to focus on short or medium term vertical approaches to significantly bring down the scourge and then work to transform them into integrated health system delivery. Considering the magnitude of malaria, it should be used as a pathfinder in health system development.

Malaria stratification in Zambia

Chapter five focuses on the use of GIS technology to document and quantify the magnitude of the malaria problem in Zambia. Spatial surface analysis, employing the inverse square of distance in an Idrisi GIS environment has been used to interpolate parasite ratios from various localities in the country and generate a continuous layer malaria risk map. The interpolated surface identified four main malaria zones depending on site. Four major river valleys and all natural lake basins are places of high malaria risk. At these sites, malaria transmission was found (i) to be perennial, with the major burden concentrated in young children 1-3 years old and (ii) immunity of the population develops early. However, even at these sites local conditions might modify the definition of endemicity. The southern, western and urban parts of the country have lower transmission levels. In these places the disease affects the whole population equally. Local modifications in transmission patterns occur along rivers. Intermediate between the two extremes are highland areas mainly in the northern sector of the country, where malaria-related mortality is concentrated in the age group 2-5 years.

This study demonstrates that malaria transmission patterns cannot only be estimated globally, continentally, regionally or even nationally, but should be validated at district level or lower. The study proposes local level, particularly district-based, planning and implementation of malaria interventions.

Chapter five considers local expert opinion and compares these with the malaria risk map and shows a close resemblance between the two. The risk map also shows a striking similarity between the Zambian risk map and the continental fuzzy logic predictive model by Craig and collaborators (1999).

This section concludes with a proposal to carry out a national malariometric survey, which should be conducted specifically for the purpose of verifying the malaria risk map and increasing the number of data points included in the surface interpolation.

Malaria vectors

Malaria vectors from two sites representing the two major malaria strata in the country were identified and their dynamics followed over a 12-month period. The results of chapter six expand the limited information available on this subject. The identified vectors are analysed in relation to climatic factors and their numbers found to be affected by the minimum temperature once breeding sites are available. This is in agreement with over-wintering by some *Anopheles* species. He found

that temperature was a critical factor allowing vector populations to survive winters in their larval form.

Three different vector species were identified and all found infected with the malaria parasite protein. However, this does not prove that they were involved in malaria transmission. In the high rainfall zone, *An. gambiae s.s.* Giles and *An. funestus* Giles were the principal vectors. The situation in the arid south was different with malaria being transmitted by *An. arabiensis* Patton. This is in agreement with literature which shows that -16° S is the southern limit for *An. gambiae s.s.*, because of its preferred arid habitat. However, it is the main domain for *An. arabiensis* which thrives in relatively dry environments. The site, where *An. arabiensis* dominated in this study is situated around -16° S within the Zambezi valley. The second site where both *An. gambiae s.s.* and *An. funestus* dominated is situated around latitude -08°S. Transmission potentials were estimated for the three species and entomological inoculation rates calculated.

The study represents an opportunity to systematically document vectors present in the country, at two sites. Further work in this area is needed to produce an evidence-based malaria distribution map for Zambia. The district map would identify the transition zones between various vector species.

This body of work has contributed to tracing the history of malaria prevention and control in Zambia. Commencement of malaria control on the mines and other urban areas was among the earliest in sub-Saharan Africa. Using skilled human resource, the Roan was able to systematically and sustainably address the scourge of malaria. The gains made over more than 4 decades were only lost following poor performance in the national economy. However, institutional memory that malaria can be effectively fought, at least in urban areas still exists. It should also be noted that in Zambia, malaria was tackled as an economic rather than health problem.

The systems that were set up initially for malaria control were transformed into provision of general health facilities and services to the population as part of the development agenda. Zambia has done relatively well in improving general access to physical facilities; increasing the infrastructure stock from 14,000/facility in 1964, to 10,000/facility by 1990, despite a population growth rate of approximately 3.2 per annum. However, the quality of services offered has not been addressed in this study.

A comparison of the population at risk of malaria in Zambia has revealed that to some extent, the distribution of malaria based on expert

opinion to a greater extent is accurate. The malaria risk map also demonstrates that malaria in Zambia is not uniformly distributed in the country, both spatially and in magnitude. The interpolated surface provides a basis upon which control measures can be selected depending on the stratum.

Like most sub-Saharan African countries, the study reveals vectors favouring different ecological zones dependent on the amount of precipitation received. It also reveals the need for further research to delimit the existence of vector species and their bionomics, and thus their epidemiological importance.

A combination of the various aspects raised in this study would form the basis for evidence-based malaria programming.

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