EPIDEMIOLOGY AND CONTROL OF MALARIA IN IRRIGATED PARTS OF TANA RIVER COUNTY, KENYA

A thesis submitted in partial fulfillment of requirements for Masters of Science in Veterinary Epidemiology and Economics degree of University of Nairobi.

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Year: 2014

Declaration

This thesis is my original work and has not been presented for a degree in any other University.

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Dedication

I dedicate this work to my parents Mr. and Mrs. Muriuki. Thank you for your support throughout the time of my study.

Acknowledgements

I would like to thank Dr B. Bett for the research opportunity he gave me to carry out this work under the project "Dynamic Drivers of Diseases in Africa: Ecosystems, livestock/wildlife, health and wellbeing". This project was carried out under the thematic unit of food safety and zoonoses at the International Livestock Research Institute.

I thank my supervisors Prof P.M Kitala, Dr B. Bett, and Dr G. Muchemi for providing the expertise, guidance, and encouragement which made this project possible. I am also very grateful for the training opportunities offered to me at the Department of Public Health, Pharmacology and Toxicology, University of Nairobi.

A lot of appreciation goes to the farmers and their families at Bura Irrigation Scheme who gave their time to answer the various questions and provided the blood samples for malaria testing. I thank the community leaders for their cooperation in mobilizing and sensitizing the people.

I also thank the medical officers of health at Bura Health Centre and Hola District Hospital for allowing me to review clinical records. I appreciate the technical support received from the clinicians and the laboratory technicians from the two hospitals.

Finally, I thank my family for their encouragement and support during the period of my academic studies.

God bless you all.

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List of abbreviations

ACT: Artemisinin-based Combination Therapy

AIC: Arkaike Information Criterion

AL: Artemether-lumefantrine

AMREF-ESRC: African Medical and Research Foundation-Ethics and Scientific Review Committee

DFID: Department of International Development

DOMC: Division of Malaria Control

EIR: Entomological Inoculation Rate

ESRC: Ethics and Scientific Review Committee

GIS: Geographic Information System

GoK: Government of Kenya

HIV: Human Immunodeficiency Virus

ILRI: International Livestock Research Institute

IMM: Integrated Malaria Management

IRS: Indoor Residual Spraying

ITN: Insecticide-treated Net

IVM: Integrated Vector Management

KAP: Knowledge, Attitude and Practices

LLIN: Long-lasting Insecticidal Net

MOH: Ministry of Health

MoPHS: Ministry of Public Health and Sanitation

NIB: National Irrigation Board

ODK: Open Data Kit

SP: Sulphadoxine/Pyrimethamine

WHO: World Health Organization

Abstract

Irrigation schemes introduced in areas of high malaria endemicity often amplify malaria burden especially if no mitigation or adaptation measures are implemented. The development of Bura and Hola irrigation schemes (to enhance food security) in Tana River County, Kenya, might have escalated the baseline risk of the disease in the area. The objectives of this study were to: (i) assess the knowledge, attitude and practices (KAP) of the local communities in relation to malaria transmission and control; (ii) determine the prevalence of malaria and the associated risk factors; and (iii) develop and validate a deterministic model for analysing the effects of irrigation on malaria transmission.

A cross sectional study was conducted in Bura irrigation scheme between November and December 2013. A total of 48 questionnaires were administered to the household heads to collect information on KAP and potential risk factors of malaria. Concurrently, 160 people (maximum of five people randomly selected from each of the 48 households) were screened for malaria parasites using Rapid Diagnostic Test (RDT). A dynamical model made up of mosquito population module and disease transmission module was developed and validated using field data on the amount of water per unit area of irrigated land, rainfall and temperature and then fitted to the observed malaria prevalence data. The Entomological Inoculation Rate (EIR) was then estimated.

The community in Bura irrigation scheme demonstrated good knowledge on causes, symptoms, transmission and control of malaria. Almost all (98%) of the interviewed households owned at least one bed net, and 93% of them had their nets treated with an insecticide. The average number of nets per household was three (one net for every two people) with 98% of the household members reporting having used the net the night before the interview. Sources of the mosquito nets included government health facilities (69%), government campaign (19%), NGOs (19%) and the rest, through purchasing. Only 12% of the households practiced environmental management to control malaria transmission. Treatment of clinical cases was based on Artemether-lumefantrine (AL) which is freely available in the government health facilities. The prevalence of malaria at the community level was 5% while a review of clinical records indicated a decline in the prevalence. Households located ≤5kms from the nearest health facility had a lower risk of malaria infection (OR=0.104, p-value=0.0128) than those located >5kms. Household size was also associated with malaria infection (OR=1.685, P-value=0.0226). The model reproduced the observed prevalence data with a variance of 0.0002. The estimated EIR was five infectious bites per person per year.

This study showed that the high usage of Insecticide Treated Nets (ITNs) and Artemether-lumefantrine (AL) could have led to a decrease in malaria prevalence in irrigated parts of Tana River County despite the intensification of irrigated agriculture. This means that a larger population in this area is becoming susceptible to malaria infection suggesting the possibility of an epidemic if the current interventions are not sustained. Awareness should be created on the importance of integrated management of malaria. The developed model could be used to predict the prevalence of malaria in this area enabling decision makers to implement appropriate control measures in a timely manner. Data from non-irrigated areas and covering a longer period of time should be collected for more rigorous model validation and simulation of the effectiveness of various interventions.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Malaria is a major public health problem worldwide, where one million people die every year, 90% in sub-Saharan Africa (Breman, 2001; World Health Organization (WHO), 2008). It is one of the leading causes of morbidity and mortality in Kenya accounting for 30-50% of all outpatient attendance and 20% of all admissions to health facilities (Ministry of Health (MOH), 2012). An estimated 170 million working days are lost to the disease each year. Pregnant women and children under five years of age are the most vulnerable groups to malaria infections with an estimated mortality rate of 20% of all deaths in the children. In Kenya, there are four epidemiological zones whose diversity in malaria transmission and risk are mainly determined by altitude, rainfall patterns and temperature. These include the endemic Lake Victoria and coastal areas, epidemic-prone Western highlands, seasonal transmission in the arid and semi-arid areas, and low risk central highlands including Nairobi (Division of Malaria Control (DOMC), 2010)).

Food insecurity is a major problem for people living in arid and semi-arid areas. This has led to the implementation of irrigation development schemes as one of the most effective ways to reduce poverty and promote economic growth. Through irrigation schemes, crop production increases through enhanced yield, acreage and number of cropping cycles per year, as well as decrease the risk of crop failure (Hussain and Hanjra, 2004). Despite these socio-economic benefits, irrigation development schemes can aggravate the problem of mosquito-borne diseases by increasing the number of aquatic larval habitats and extending the duration of the transmission season (Ijumba and Lindsay, 2001) or by removing the seasonal cycling of the disease (Baeza *et al*., 2011). Land use changes such as irrigation are known to affect microclimatic conditions that influence the abundance and survivorship of mosquitoes by creating standing water masses which increases humidity (Foley *et al.,* 2005; Patz *et al.*, 2005). The introduction of irrigation schemes, and associated agricultural practices, are now considered to be among the primary factors driving the increase in the global malaria burden (Baeza *et al*., 2011). The mechanisms underlying this phenomenon remain poorly understood given the complexity of vector ecology, parasite transmission and human behavior.

The development of Bura and Hola irrigation schemes in Tana River County in Kenya might have escalated the baseline risk of the disease given that the area is infested with *Anopheles gambiae* complex which are efficient malaria vectors (Mutero and Birley, 1987). Other mosquito species such as *Aedes* and *Culicines* are also likely to emerge causing complications in management of febrile illnesses, which are often treated as malaria. In 1981 and 1982, a severe outbreak of cerebral malaria in Hola caused serious child mortality, leading to an increased desertion of the scheme but little was done to ascertain the risk factors involved. A study by Japan International Cooperation Agency (JICA) and Nippon Koei Limited (1995) identified that, the prevalence of *P. falciparum* at irrigated and riverine areas of Hola was 54 percent more than in the non-irrigated surrounding area.

The analysis of the potential for irrigation to influence malaria transmission is fundamental for the prevention and control of the disease, for evidence-based guidance of health policy and planning, and for the promotion of intersectoral action. This study aimed to understand; the knowledge, attitude and practices (KAP) of the community in Bura and Hola in relation to malaria transmission and control, seasonal patterns of malaria prevalence and the associated risk factors of malaria infection, and to develop and validate a deterministic model for analysing the effects of irrigation on malaria transmission.

1.2 Overall objective

To study the epidemiology and control of malaria in irrigated parts of Tana River County, Kenya.

1.3 Specific objectives

i. To assess the knowledge, attitudes and practices of the community in irrigated parts of Tana River County in relation to malaria transmission and control.
ii. To determine the prevalence and risk factors associated with malaria infection in irrigated parts of Tana River County.
iii. To develop and validate a transmission model for estimating the effect of irrigation on malaria transmission.

1.4 Hypothesis

Intensification of irrigated agriculture in Tana River County has led to increased prevalence of malaria.

1.5 Justification

Bura and Hola irrigation schemes are currently being renovated and expanded to ensure food security. Increase in potential mosquito-breeding habitats is expected with increase in irrigated agriculture. Employment and various commercial activities generated by an increase in both smallholder and irrigation schemes are expected to attract both immune and non-immune immigrants and this could lead to an epidemic.

Central to the future of malaria control is more effective understanding of the relationships between risk factors, the frequency and longevity of infection, and disease outcome (Greenwood, 1997). Given the development of the irrigation schemes, and the limited studies on the association between irrigation expansion and malaria transmission in the county, investigations are required to evaluate the impact of irrigation on malaria prevalence. The results would provide baseline data for the selection and implementation of appropriate malaria and vector control measures.

The thesis is organized into five chapters as follows: (1) introduction; (2) review of literature; (3) knowledge, attitude and practices and the associated risk factors for malaria infection; (4) dynamic models of malaria transmission; and (5) general discussions, conclusions and recommendations. Each of the chapters three and four, contain, introduction, materials and methods, results and discussion.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Etiology and transmission of malaria

Malaria in human is caused mainly by four species of protozoan parasite of the genus *Plasmodium* which include *Plasmodium falciparum, P. vivax, P. malariae* and *P. ovale* (Mueller *et al*., 2007). *Plasmodium falciparum* is the most prevalent parasite species in Kenya at 96 per cent, of which 16 per cent comprises mixed infections with *P.ovale*, *P. malariae* or both (DOMC, 2011). Untreated *P. falciparum* infection can lead to coma, renal failure, pulmonary edema and death (White, 1994).

The malaria parasites are transmitted to the human host through a bite by an infected female *Anopheles* mosquito. *Plasmodium* sporozoites are injected into a human when the mosquito takes a blood meal. The sporozoites travel to the liver and invade liver cells. After 5-16 days, depending on parasite species, the sporozoites reproduces asexually (tissue schizogony), producing merozoites. These infect red blood cells, undergo blood schizogony and produce new infective merozoites repeatedly over 1-3 days while bursting red blood cells (Schlagenhauf-Lawlor, 2008). Some of the merozoites develop into sexual forms of the parasite, the female and male gametocytes. The gametocytes get ingested by a feeding female *Anopheles* mosquito. They mature in the mosquito gut to form the male and female gametes that later fuse to form zygotes. The zygotes develop into actively moving ookinetes that burrow into the mosquito mid-gut wall and form oocysts. Growth and division of each oocyst produces sporozoites which travel from the body cavity and invade the mosquito salivary glands. The cycle of human infection re-starts when the mosquito takes a blood meal, injecting the sporozoites from the salivary glands into the human bloodstream (Cowman *et al*., 2012). Clinical symptoms such as fever, pain, chills and sweats may develop 8-25 days after an infected mosquito bite (Mandell *et al*., 2010).

The *Anopheles gambiae* species complex is the main vector of malaria in most of East Africa including the Kenyan coast (Mbogo *et al*., 2003). The species complex is represented at the delta of Tana River by a mixture of *An. gambiae sensu stricto* and *An. arabiensis* while the latter is the main or only species in Tana River County (Mutero and Birley, 1987).

The life cycle of the malaria parasite is maintained in relatively hot, humid climates, such as the coastal and western regions of Kenya (Mutero and Birley, 1987). In such areas, there is year-round transmission of malaria and residents actually develop a partial immunity to the disease, if they survive beyond the age of five.

2.2 Epidemiology of Malaria in Kenya

Malaria is one of the leading causes of morbidity and mortality in Kenya; approximately 28 million Kenyans are at risk of malaria (DOMC, 2010). It accounts for 30-50% of all outpatient attendance and 20% of all admissions to health facilities. An estimated 170 million working days are lost to the disease each year in the country (DOMC, 2010). The most vulnerable group to malaria infections are pregnant women and children under 5 years of age with an estimated mortality rate of 20% of all deaths in children under five (MOH, 2012).

The Kenya malaria indicator survey (KMIS) 2010 reported that children aged 5-14 years of age had the highest prevalence of malaria at 13% while the prevalence in children below five years increased from 4% in 2007 to 8% in 2010. It was also reported that malaria prevalence is nearly three times as high in rural areas (12%) compared to urban areas (5%) (KMIS, 2010).

There are four malaria epidemiological zones in Kenya whose diversity in malaria transmission and risk are mainly determined by altitude, rainfall patterns and temperature (DOMC, 2010). These are:

Endemic: A total of 29% of the Kenyan population live in a malaria endemic area. These include areas around the Lake Victoria in Western Kenya and coastal region where malaria transmission is high and intense throughout the year (entomological inoculation rate of 30 to 100 per year) with the *P. falciparum* malaria prevalence between 20% and 40%. Rainfall, temperature and humidity are the determinants of the perennial transmission of malaria. The vector life cycle is usually short with high survival rate due to the suitable climatic conditions.

Epidemic-prone: Approximately 20% of Kenyans live in these areas and have a malaria prevalence ranging from 1% to less than 5% but with some areas experiencing prevalence between 10% and 20%. This zone is mainly in the Western highlands where malaria transmission is seasonal with considerable year-to-year variation. Epidemics are experienced when climatic conditions (increase in minimum temperatures during the long rains) favors and sustain vector breeding.

Seasonal transmission: This is mainly experienced in the arid and semi-arid areas in Northern and South Eastern parts of the country where about 21% of Kenyans live (malaria prevalence less than 5%). These areas experience short periods of intense malaria transmission during the rainfall seasons. Temperatures are usually high and water pools created during the rainy season provide the malaria vector breeding sites. Extreme climatic conditions that cause flooding in these areas lead to epidemic outbreaks with high morbidity rates due to low immune status of the population.

Low-risk: Found in the central highlands of Kenya where about 30% of Kenyans live. There is little or no disease transmission since temperatures are usually too low to allow completion of the sporogonic cycle of the malaria parasite in the vector. However, increasing temperatures and changes in the hydrological cycle associated with climate change are likely to increase the areas suitable for malaria vector breeding.

Noor *et al*. (2009) developed a malaria risk map (Figure 2.1) that captures all the four epidemiological zones.

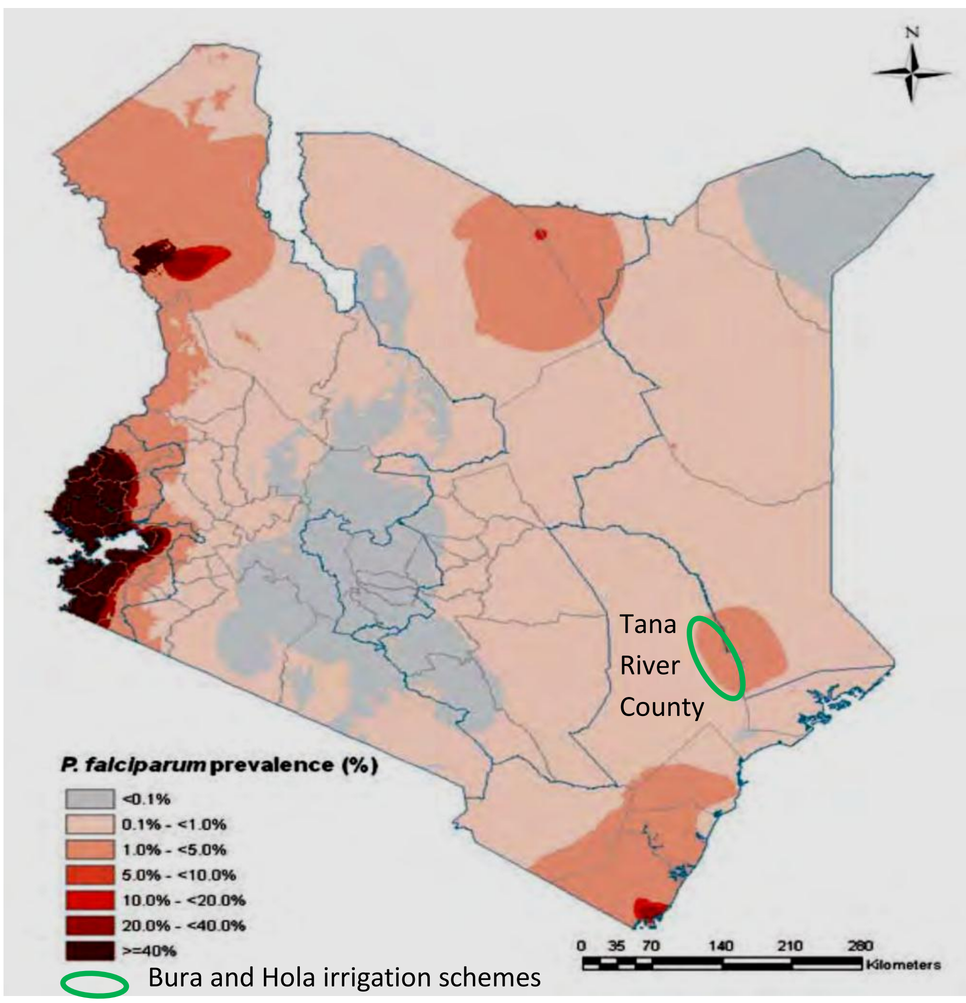

Figure 2.1: Kenya malaria risk map, 2009 (Noor *et al*., 2009)

2.3 Knowledge, Attitude and Practices about malaria

The knowledge, attitudes and practices (KAP) about malaria vary from community to community and among individual households (Rodriguez *et al*., 2003). Most health related beliefs and behavior stem from family background (Campbell *et al*., 2002). Efforts to address malaria menace largely depend on the community perceptions, beliefs, and attitudes about malaria causation, symptom identification, treatment of malaria, and prevention but these are often overlooked (Munguti, 1998; Deressa *et al*., 2003). Successful implementation and sustainability of malaria control efforts also depends on an understanding of who already knows about malaria and its prevention, who has adopted malaria prevention and vector control as well as who is at risk of malaria infection (Adongo *et al*., 2005).

Misconceptions about malaria transmission and its causes still exist. This creates a need for targeted educational programs to increase the communities' efforts to develop desirable attitude and practices regarding malaria and their participation for malaria control (Singh *et al*., 2014). An analysis of KAP in Mwea Division in Kenya showed that, an integrated management of malaria could have contributed to a reduction in malaria cases in the area (Okech *et al*., 2008).

2.4 Risk factors associated with malaria infection

Infection with malaria parasites is dependent on mosquito, *Plasmodium* parasite and human factors. Breeding of *Anopheles* mosquitoes is influenced by environmental factors such as land cover, rainfall, temperature and altitude thus affecting the density of mosquitoes and the seasonality of transmission (Macdonald, 1957; Molineaux, 1988). For instance, areas with greater amounts of precipitation and higher temperatures are expected to have greater malaria prevalence, as these conditions favour breeding of *Anopheles* mosquitoes as well as parasite reproduction within the mosquitoes (Mouchet, 1999). *Plasmodium* parasite and egg development within the mosquito are temperature dependent (Nikolaev, 1935; Detinova, 1962; Afrane *et al.*, 2005). Altitude plays an important role in determining malaria infection due to its effect on temperature (Githeko *et al.*, 2006); temperature decreases with increasing altitude. Very high temperatures may also increase human-vector contact through individual behaviour change, by discouraging bed net use and encouraging outdoor sleeping (Okoko, 2005). Land use change as a result of irrigated agriculture and human settlements modifies the local climate and microclimate, and also leads to creation of new habitats for malaria vectors (Munga *et al.*, 2006).

Socio-demographic and behavioural factors influence malaria transmission dynamics. A study by Ernst *et al.* (2009) indicated that, greater malaria risk was associated with lower levels of education of household heads, recent overnight travel, poor housing conditions and living near channelled swamp water, forests and maize fields. Housing characteristics (e.g. screening, roof materials and open eaves) indicate the level of protection residents have against indoor mosquito biting (Yé *et al.*, 2006). Ownership and/or usage of Insecticide Treated Nets (ITNs) and household wealth have also been reported to influence malaria: wealthy individuals have access to better healthcare compared to poor people while usage of ITNs substantially terminates malaria transmission (Lengeler, 2004; Graves *et al.*, 2009). Livestock kept near homesteads influence malaria transmission by providing alternative blood meal sources for zoophilic mosquitoes (Mahande *et al.*, 2007).

Human migration influences malaria incidence through several mechanisms such as: (i) movement of non-immune individuals to new settlement areas close to forests (Marques, 1987; Martens and Hall, 2000; Prothero, 2001); (ii) involuntary movements due to civil or ethnic conflicts, persecution and natural disasters (Bloland and Williams, 2003); and (iii) high human mobility of infected individuals, who act as carriers of the parasite (Castro *et al.*, 2006).

In endemic areas acquired immunity greatly influences how malaria affects an individual and a community (Doolan *et al*., 2009). After repeated attacks of malaria a person may develop a partially protective immunity. Clinically immune individuals often get infected by malaria parasites but may not develop severe disease, and, in fact, frequently lack any typical malaria symptoms (Tran *et al*., 2012). This protective immunity is good for an individual but may be detrimental to the population since these individuals are unlikely to seek medical attention leading to longer periods of infectiousness. However, it is not clear how the duration of untreated clinically immune infections compares to untreated symptomatic cases.

A study by Greenwood (1989) explains the micro-epidemiology of malaria and its importance to malaria control. The author observes that both genetic and environmental factors are likely to contribute to variations in malaria prevalence between villages and even within a village. Clustering in households of genetically determined red blood cells abnormalities, and possibly immune response genes, may contribute to differences in the prevalence of malaria within a village while differences between villages could probably be explained better by environmental factors. The position of a village in relation to mosquito breeding habitats, housing conditions, level of anti-malarial measures and attitudes to malaria treatment may contribute to local variations in the prevalence of malaria.

2.5 Malaria and irrigated agriculture

Malaria transmission dynamics in a particular region are defined by the interaction in time and space of intrinsic (human, parasite and mosquito) and extrinsic (environmental and socio-economic conditions, human behavior and control measures) determinants of the disease (Breman, 2001). Irrigation schemes introduced in areas of high malaria endemicity have generally led to an increase in diversity and abundance of the malaria-vector populations that, in turn has led to an escalation of the malaria problem (Renshaw *et al.,* 1998). For instance, irrigation in the Kano plain of western Kenya led to a 70-fold increase in the main malaria mosquitoes while both the Mwea and Hola/Bura irrigation schemes switched to perennial rather than to seasonal malaria transmission (Mutero *et al.,* 2000).

A study by Jaleta *et al*. (2013) in Ethiopia demonstrated the negative impact of large-scale irrigation expansion on malaria transmission through increased abundance of mosquito vectors. In their study, malaria prevalence and the risk of transmission by *An. arabiensis* assessed by the average human biting rate, mean sporozoite rate and estimated annual Entomological Inoculation Rate (EIR) were significantly higher in the irrigated sugarcane agro-ecosystem compared to the traditionally irrigated and non-irrigated agro-ecosystems.

Crop cultivation through irrigation has brought changes in the ecosystem which has affected the farmers' health in addition to creating habitats ideal for the breeding of *Anopheles* mosquitoes (Keiser *et al.,* 2005). The epidemiological pattern of malaria also changes from seasonal to perennial, consequently raising the disease incidence in communities with little prior exposure or immunity (Dolo *et al.,* 2004; Keiser *et al.,* 2005).

The building of dams in the Uasin Gishu Highlands in Kenya (Khaemba *et al*., 1994) and the irrigation of fields, e.g. in Rwanda (Jadin and Herman, 1946), particularly rice fields, created a profusion of breeding sites for malaria vectors. A malaria epidemic in Burundi was linked to the expansion of local rice fields and the creation of fish ponds (Marimbu *et al*., 1993). In this case, rice fields may have been a more important source of vectors, since it is well known that they can generate large numbers of *An. gambiae s.str.* Common farming practices associated with wet rice cultivation in particular, have been clearly linked to increased malaria transmission in some areas (Surtees, 1970).

In Bura and Hola irrigation schemes, the main crop under irrigation is maize. Maize cultivation has been associated with mosquito abundance and survivorship (Kebede *et al*., 2005). Maize pollen is a potent nutrient for mosquito larvae. Larvae develop to the pupal stage more rapidly, more frequently, and produce larger longer surviving adults where maize pollen is abundant than do those that have little access to this food (Ye-ebiyo *et al*., 2000).

Changing landscapes can significantly affect local weather more acutely than long-term climate change. Land cover change can influence microclimatic conditions, including temperature, evapotranspiration, and surface runoff (Foley *et al.*, 2005; Patz *et al.*, 2005), all key to determining mosquito abundance and survivorship. Variation in microclimatic conditions has a profound effect on the life of a mosquito and the development of malaria parasites (Bruce-Chwatt, 2011); hence its influence on the transmission of the disease and on its seasonal incidence. The most important climatic factors are rainfall, temperature and humidity.

Malaria parasites cease to develop in the mosquito when the temperature is below 16^0C. The best conditions for the development of *Plasmodium* in the *Anopheles* and the transmission of the infection are when the mean temperature is within a range of 20-30^{o}C, while the mean relative humidity is at least 60 percent (Bayoh and Lindsay, 2003). A high relative humidity lengthens the life of the mosquitoes and enables it to live long enough to transmit the infection to several persons (Patz and Olson, 2013). These conditions are currently witnessed in Bura and Hola irrigation scheme which are located in an arid and semi-arid area.

Afrane *et al.* (2005) found that, open, treeless habitats experience warmer midday temperatures than forested habitats and also affect indoor hut temperatures. As a result, the gonotrophic cycle (egg development) of female *An. gambiae* was found to be shortened by 2.6 days (52%) and 2.9 days (21%) during the dry and rainy seasons, respectively, compared with forested sites. Similar findings have been documented in Uganda where higher temperatures have been measured in communities bordering cultivated fields compared with those adjacent to natural wetlands, and the number of *An*. *gambiae* per house increased along with increasing temperatures (Lindblade *et al.*, 2000).

Higher maximum and mean temperatures of aquatic breeding sites found in farmlands hasten larval development and pupation rates (Munga *et al.*, 2006). Increased canopy cover in western Kenya was negatively associated with the presence of *An*. *gambiae* complex and *An. funestus* larvae in natural aquatic habitats (Minakawa *et al.*, 2002).

Malaria transmission in most agricultural ecosystems is complex and involves the interactions of the host-vector-parasite triad, environment and the socio-economic factors in the community (Patz and Olson, 2013). A review by Ijumba and Lindsay (2001) on the impact of irrigation on malaria in Africa reveals that, irrigation schemes do no always lead to increased malaria burden but can also reduce it. In the review, they show cases where increased number of vectors following irrigation can lead to increased malaria in areas of unstable transmission, where people have little or no immunity to malaria parasites, such as the African highlands and desert fringes. But for most of sub-Saharan Africa, where malaria is stable, the introduction of crop irrigation especially rice cultivation has little impact on malaria transmission. The explanation given for reduced malaria burden despite implementation of irrigation schemes include: (i) the displacement of the most endophilic and anthropophilic malaria vector *An. funestus* by *An.*

arabiensis with lower vectorial capacity, as the latter thrives more than the former in rice fields; (ii) among members of the *An. gambiae* complex, some cytotypes of *An. gambiae sensu stricto* are more vectorial than others (for example, the Mopti form has high vectorial capacity and breeds perennially in irrigated sites, whereas the savanna form is often sympatric but more seasonal); and (iii) many communities near irrigation schemes benefit from the greater wealth created by these schemes leading to increased possession and use of bed nets, and also better access to improved healthcare compared with those outside such development schemes.

2.6 Control and management of malaria in Kenya

Several methods have been used to control and prevent malaria by targeting either the vector population or the parasite (Utzinger *et al*., 2002). These include use of bed nets (insecticide treated or untreated), Indoor Residual Spraying (IRS), improved housing conditions and environmental control methods such as draining of stagnant water, clearing bushes, larviciding and pupaciding. Other methods that have been used to control malaria transmission include oil application on exposed body parts, use of mosquito coils and burning of cow dungs and herbs as mosquito repellants (Okech *et al*., 2008).

Use of Insecticide Treated bed Nets (ITNs) and IRS have been shown to be highly effective in preventing malaria among children in areas where malaria is common (Nahlen *et al*., 2003; Lengeler, 2004). The ITNs are estimated to be twice as effective as untreated nets and offer greater than 70% protection compared with no net (Raghavendra *et al*., 2011). They also have a two-fold effect on reducing malaria transmission compared to untreated bed nets: they offer a physical barrier between vector and humans while at the same time increasing the mortality rates of mosquitoes either by starving them or through the effects of the applied insecticides. Untreated bed nets reduce malaria transmission by reducing the contact rates between the mosquito and humans and also by starving them thus increasing their mortality rates (Mwangi *et al*., 2003).

The IRS kills mosquitoes entering the houses and also resting on sprayed surfaces. Unlike ITN, IRS protects communities and therefore must have a wider coverage; it further requires that a population accepts the spraying of its households once or twice a year (WHO, 2008). Larvicides are used to target the larval stages of the mosquitoes while pupacides target the pupal stages. Prophylactic drugs are mainly used by people travelling to malaria endemic areas. They reduce the probability of a person getting infected following a bite with an infectious mosquito. Malaria curative drugs reduce the duration of infectiousness of an individual host (Fryauff *et al*., 1995).

A combination of the above control methods constitute an Integrated Malaria Management (IMM) package and have been shown to be very successful in many tropical environments (Utzinger *et al*., 2002). A study by Okech *et al*. (2008) observed that implementation of IMM in a community in Mwea irrigation scheme in Kenya could have led to a drastic fall in malaria incidence.

According to Lalloo *et al*. (2006), community participation and health education strategies promoting awareness of malaria and the importance of control measures can be successfully used to reduce the incidence of malaria.

The primary malaria vector control methods used in Kenya are long-lasting insecticidal nets (LLINs) and IRS against mosquitoes (DOMC, 2011). A study in the malaria lake endemic zone in Kenya showed that the combination of IRS and universal coverage with LLINs as a vector control strategy yielded a protective efficacy of 61 percent compared with LLINs alone (Hamel and Mary, 2010).

In 2006, the Government of Kenya (GoK) launched a massive campaign to distribute 3.4 million nets free of charge to children under the age of five years in the whole country (Noor *et al*., 2007). The Mentor Programme with the support from Department for International Development (DFID) distributed 17,700 LLIN in 2007 to pre-empt the malaria epidemic effects of flooding in Tana River and Garissa districts (Mentor, 2007). In 2009, the government adopted the global strategy of ensuring universal coverage with ITNs (one net for every two people) for all persons at risk of malaria (DOMC, 2011).

The IRS has largely been used in Kenya for epidemic preparedness response in Western highlands (GoK, 2007). An extensive IRS campaign in Tana River and Garissa Districts was mounted in 2007 by the Mentor programme where both Fenona® (alphacypermethrin) and ICON® were used in spraying covering 36,337 households and providing protection for an estimated 267,551 people (Mentor, 2007). Larviciding and environmental management were also used in targeted areas as per the Integrated Vector Management (IVM) Policy Guidelines (DOMC, 2010).

Since 2006, the Government of Kenya policy recommends that all persons with fever, including children under five, be tested for malaria and if confirmed, treated with artemether-lumefantrine (AL) an Artemisinin-based Combination Therapy (ACT), which is provided free of charge in all government and faith-based facilities (DOMC, 2011). Pregnant women are vulnerable to the effects of malaria and are a specific target group for malaria interventions including ITNs given free of charge during antenatal care, intermittent preventive treatment in pregnancy with sulphadoxine/pyrimethamine (SP), and prompt and effective treatment of parasitaemia.

In areas infested with highly zoophilic *An. arabiensis*, livestock have been used to control malaria. The *An. arabiensis* can feed on livestock as alternative sources of blood meals if human beings are out of reach (by sleeping under mosquito nets). This phenomenon has been utilized to control malaria by sponging livestock with insecticides (Mahande *et al*., 2007). A study in an agro-ecosystem in Mwea division in Kenya suggested that zooprophylaxis was the most possible explanation for the observed decrease in malaria prevalence in the irrigated villages (Mutero *et al*., 2004).

The effectiveness of malaria control strategies can be improved by considering factors such as geographical distribution of malaria, developmental strategies such as irrigated agriculture and human settlements, and availability of health services (Molineaux, 1988; Binka *et al.,* 1998). Proper timing of these control measures would be important in preventing escalation of malaria burden especially in areas undergoing development of irrigation projects.

2.7 Dynamical models of malaria transmission

Modelling malaria transmission has been well established starting with the work of Ross and Macdonald (Ross, 1911; Macdonald, 1957). These models showed that, the mosquito population plays a major role in malaria transmission dynamics. Meteorological variables such as rainfall, temperature and humidity determine biological processes of the mosquito and the parasite development (Detinova, 1962). Development of weather-driven malaria variables, therefore, allow for a better understanding of the dynamics of malaria transmission. The construction of dynamic vector models has enabled the simulation of a time-dependent mosquito population (Depinay *et al*., 2004; Pascual *et al*., 2006).

Ermert *et al*. (2011) described a fuzzy distribution model to determine the suitability of a mosquito breeding site using a 10-day accumulated water. The fuzzy distribution, therefore, affects the mortality rate of eggs, larva and pupa as well as the oviposition. Gonotrophic (egg development within mosquitoes) and sporogonic cycles (parasite development within the mosquito) are temperature dependent (Nikolaev, 1935; Detinova, 1962). Hoshen and Morse (2004) have modelled the effects of temperature and rainfall on malaria transmission dynamics. The effects of irrigation schemes on malaria transmission remain a complex phenomenon that is worth investigating. Very few studies have endeavoured to address this problem (Ohta and Kaga, 2014).

CHAPTER THREE

3.0 KNOWLEDGE, ATTITUDE AND PRACTICES AND THE ASSOCIATED RISK FACTORS FOR MALARIA INFECTION

3.1 Introduction

One of the difficulties associated with achieving a reduction in malaria incidence is that a combination of many diverse factors contributes to the maintenance of its transmission. These include environmental and geographic features of the area such as climatic factors, land use patterns, development of irrigation schemes, the movement and habits of people, and the creation of new human settlements in relation to development schemes (Molineaux, 1988).

People in different societies hold a variety of beliefs about the causes of illness and its transmission that vary according to cultural factors, and hence have a direct consequence for both preventive and treatment seeking behavior (Musyoka, 2011). Understanding community's perceptions of malaria, its cause and transmission, and the factors which influence these perceptions, must be a central part in formulating a successful intervention for malaria treatment and control. In this chapter, analysis of Knowledge Attitude and Practice (KAP) and associated risk factors for malaria was done at Bura irrigation scheme in Tana River County, Kenya. Malaria prevalence in the community was also determined and clinical records reviewed in both Bura and Hola district hospitals.

3.2 Materials and Methods

3.2.1 Study area

Tana River County is situated in the upper coast of Kenya bordering Kilifi, Lamu, Taita Taveta, Kitui, Isiolo and Garissa counties (Figure 3.1). It is generally dry and prone to drought. Rainfall is erratic, with rainy seasons in March-May and October-December. It is situated in a semi-arid area with annual relief rainfall varying between 400mm and 750mm with a mean annual temperature ranging between 30^0C and 33^0C. Flooding is a regular feature, caused by heavy rainfall in upstream areas of the Tana River.

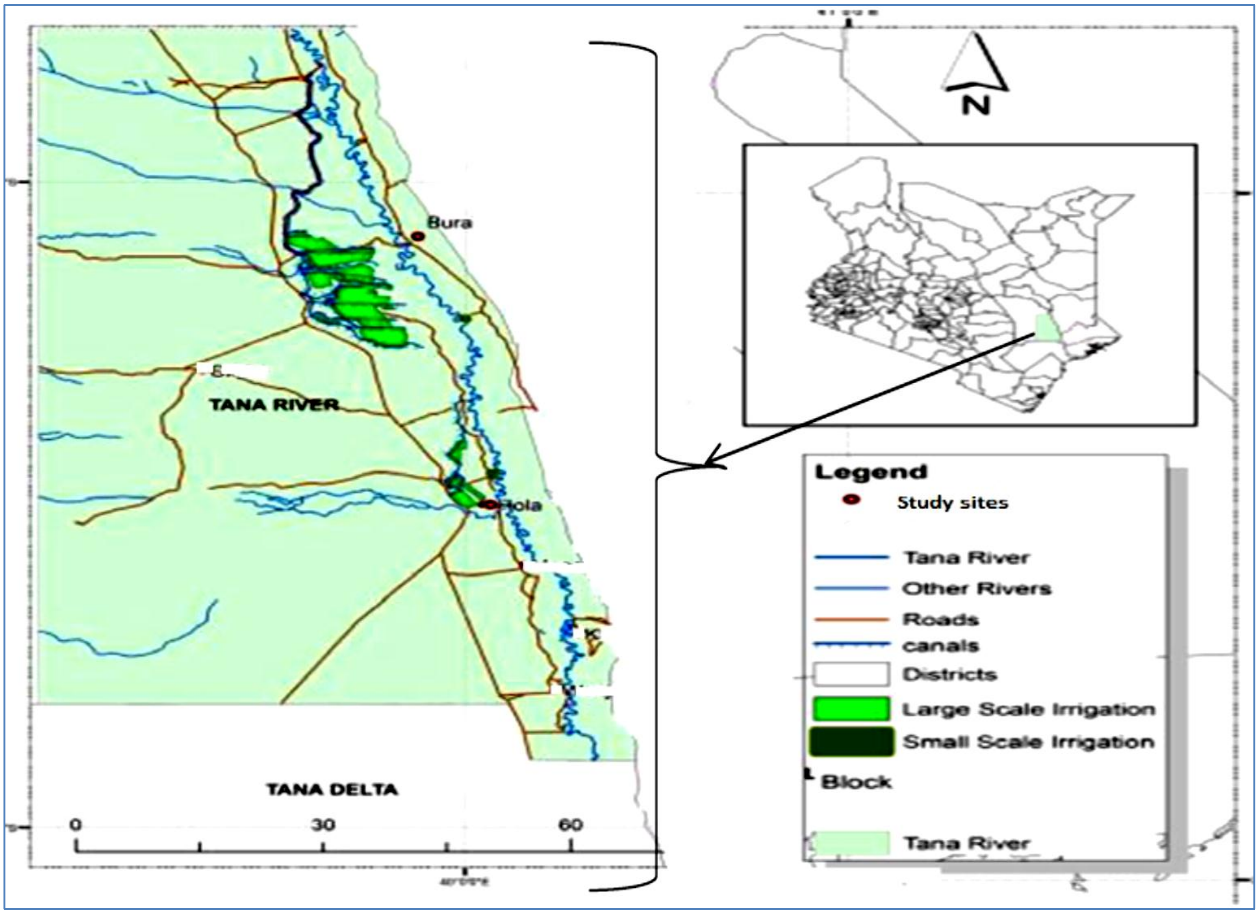

Figure 3.1: Map of Tana River County-Irrigated areas (ILRI GIS Map)

The study was conducted in Bura Irrigation Scheme in Tana River County during the period November and December 2013. The Irrigation scheme covers about 6250 acres of land out of which, 3000 acres are under maize cultivation while the rest are mainly used for horticulture (National Irrigation Board, personal interview). According to 2009 Kenya Population and Housing census, the population residing within the irrigation scheme is about 82,545 people.

Settlement in the schemes is organized in 10 villages. River Tana, the longest river in Kenya is the source of water for irrigated agriculture in the County. The irrigation scheme is currently under expansion. Malaria is endemic in the County and the major malaria vector species is a mixture of *A. gambiae sensu stricto* and *A. arabiensis* while the latter is the main or only species in the County (Mutero and Birley, 1987).

3.2.2 Study design

A cross-sectional study was carried out using a two-stage sampling method. Households were randomly selected from a list of all households obtained from the National Irrigation Scheme at Bura. The minimum number of households and individuals required for the study was determined using equation 1 and 2 (Dohoo *et al.*, 2003). A maximum of five people in each selected household were then randomly selected for screening of malaria parasites.

$$n = \frac{Z_{\alpha}^{2} pq}{L^{2}} \qquad \text{(Equation 3.1)}$$

Where:

n is the required sample size.

Z_{α} is the value of the Z statistic that corresponds to a level of confidence of 95% (1.96).

P denotes the prevalence (10%) of malaria obtained from the records at Bura Health Centre, and $q=1-p$

L is the precision of the estimate set at 0.05.

With solution:

$$n = \frac{1.96^{2} \times 0.1 \times 0.9}{0.05^{2}}$$

n **= 138 people**

Adjusting for clustering:

$n' = n(1+\rho(m-1))$ ……………………………………….. (Equation 3.2)

Where:

n' is the adjusted sample size

n is the unadjusted sample size (138)

ρ is the intra-household correlation coefficient set at 0.04 (Correa *et al*., 2012)

m is the average household size of five.

With the solution:

$n' = 138(1+0.04(5-1))$

n'=**160 people (or 32 households)**

3.2.3 Malaria prevalence

Clinical records were reviewed at Bura Health Centre and Hola District Hospital to determine the seasonal patterns of malaria prevalence. This was done after obtaining consent from the medical officers of health in the hospitals.

At the household level, the purpose of the study was explained to the household members and consent sought from household heads. Median cubital venous blood was obtained using a sterile vacutainer from a maximum of five randomly sampled members of a selected household by a licensed laboratory technician. Each participant was adequately prepared for blood sampling after signing a consent form (Appendix I); the form describes the procedure to be performed including the amount of blood to be drawn. An independent witness signed the consent forms. A total of 160 samples from 48 households were tested using Carestart^{TM} malaria HRP2 (pf) kit, a Rapid Diagnostic Test (RDT). Participants with positive rapid tests were offered immediate treatment by a clinician. A short questionnaire was administered to collect individual information such as relationship to household head, age, sex, occupation, whether the person had suffered from malaria within the last two months and the RDT result. This was done using Open Data Kit (ODK) collect software in a smart phone.

3.2.4 Knowledge, Attitude and Practices (KAP) and associated risk factors for malaria

A survey was conducted to capture the knowledge, attitude and practices of the community in Bura Irrigation Scheme. A structured questionnaire (Appendix II) was administered to the household heads in the same households where malaria screening was done. The questionnaire was pre-tested in a village outside the study site. The information gathered through the questionnaire included demographic data of the households, knowledge of malaria disease, control/prevention measures for malaria and mosquitoes and the treatment regimens of malaria. Household characteristics such as house construction materials, activities of the occupants, source of drinking water and environmental factors in homesteads thought to influence human mosquito contact were also collected. The data were collected using ODK collect software in a Samsung galaxy Tablet 7.

3.2.5 Ethical considerations

Ethical clearance was sought from African Medical and Research Foundation-Ethics and Scientific Review Committee (Ref: AMREF-ESRC p65/2013). Informed consent was sought from the subjects selected for the survey. All diagnostic bouts of malaria were treated by a registered clinician.

3.2.6 Data analysis

Data were cleaned in excel before being imported to R statistical software version 3.0.2 for analysis. Descriptive statistics were used to examine the data. The KAP analysis was done using proportions, frequencies and means. The prevalence was determined by dividing the total number of people who tested positive by the total number of people tested.

Generalized linear models (GLM) were used to determine the association between malaria infection and the risk factors. Two response variables were used: one was the RDT result and the other was whether a household had at least one member who had suffered malaria within the last two months before the implementation of the study. The independent variables comprised the socio-economic and demographic variables that included age, gender, occupation, household size, main source of drinking water, main material of the room's wall, main material of the room's roof, main material of the room's floor, use of IRS in the past 12 months, distance to the nearest health facility, use of mosquito nets and total number of nets. The RDT result, age and sex were collected at individual level while the rest of the variables were collected at household level.

Univariate analysis was first conducted for each potentially explanatory risk factor. Multivariable models were then developed by backwards stepwise logistic regression analysis. Starting with all potentially significant variables, explanatory variables were sequentially dropped if their effect on the model was not significant ($p>0.05$). In addition to the main effects, possible combinations of up to three-way interaction terms were added and assessed to further avoid and mitigate the problem of confounding. The model with the lowest Arkaike Information Criterion (AIC) was considered as the most parsimonious. The goodness-of-fit of the final model was tested using residual deviance chi-square.

3.3 Results

3.3.1 Household demographics and characteristics

A total of 48 households (shown in Figure 3.2) participated in the KAP study. Fifty-six percent (27/48) of all the household respondents were females while the rest were males; their average age was 49 years. The average household size in Bura irrigation scheme was six people with an immigration rate of 0.054 persons per household per year (13 people immigrated to the area within the last five years before the implementation of the study). Almost all (98%) households kept at least one species of livestock within their homestead. This could suggest an alternative blood meal source for mosquitoes. Most (90%) houses in Bura irrigation scheme were built using muddy walls, iron sheet roofs and earth floor. Irrigation water canals were the major source of water for domestic use.

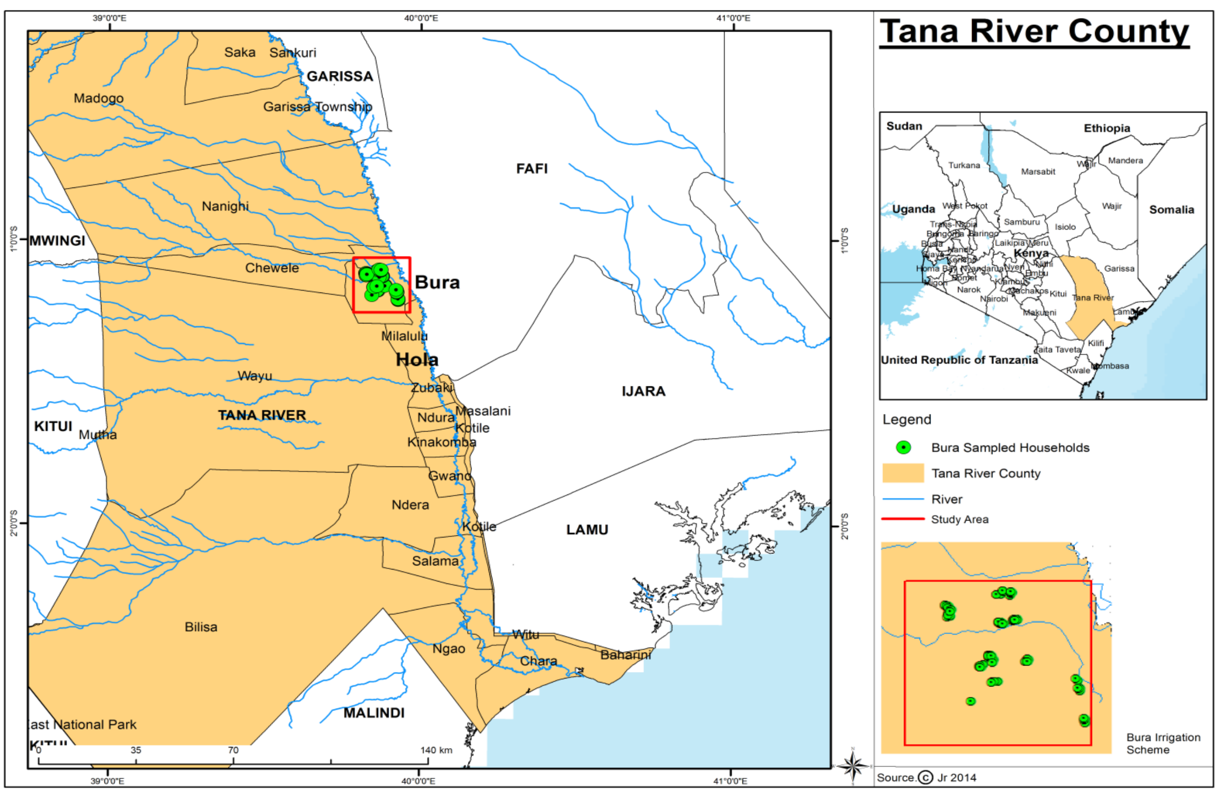

Figure 3.2: Sampled households in Bura irrigation scheme

3.3.2 Community knowledge of malaria disease

All the respondents knew malaria and 98% (47/48) said that malaria is caused and transmitted by mosquito bites. The household respondents identified malaria symptoms including fever (81%), headache (73%), vomiting (54%), body weakness (52%), body pains (44%) and shivering (44%). Eighty-eight percent of the respondents associated malaria with stagnant water in water canals, farm depressions, ponds, dams, hoof prints and tyre tracks.

3.3.3 Case management of malaria

Nighty-four percent (45/48) of the respondents reported having access to healthcare. The average distance a malaria victim travelled to the nearest healthcare facility was 5.5 Kilometres with the nearest health facility at 200 meters away and the farthest at 12 kilometres away. Eighty-one percent of the respondents reported seeking treatment from the government health facility, 17% from private clinic and 2% used medications from local chemists/pharmacy and retail shops. Free medication provided by the government health facility, was reported to be the main reason for using the facility. Sixty-nine percent of the households reported having at least one family member who had suffered malaria within the last two months of this study. Within 24hrs of sickness, 62% of the respondents sought treatment from the hospital, 17% took paracetamol self-medication, 14% did nothing and 7% took Artemether-lumefantrine (AL) self-medication. After one day of sickness, 30% of the respondents went to the hospital, 23% had AL self-medication, 20% took paracetamol self-medication, 17% took other home-based medication and 10% did nothing. Eighty-two percent of those who sought treatment reported using AL, 21% quinine, 19% paracetamol, 13% fansidar, 4% Amodiaquine and 2% chloroquine.

3.3.4 Control and prevention of malaria

Respondents reported that they used a variety of measures to control/prevent malaria in their homes. All the respondents reported having at least one bed net, 93% of which were treated with insecticides. The average number of nets per household was three (range: 1–7 per household) with one net for every two people. Ninety-eight percent of the household members used the nets the night before the interview. The sources of the mosquito nets included government health facility (69%), government campaign (19%), NGOs (19%), retail shop (6%), chemist (4%), NIB (2%) and private clinic (2%).

Twelve percent of the respondents reported that they used environmental management to control/prevent malaria and this included clearing of bush/vegetation (15%) and removal of stagnant water bodies (19%) around the homestead. In addition, the respondents used several methods to lower the numbers of mosquitoes in their homes including burning cow dung/herbs (6%) and mosquito coils (8%). Forty percent of all the interviewed households had their houses sprayed with an insecticide within the last 12 months before the implementation of this study.

3.3.5 Annual patterns of malaria prevalence

Figure 3.3 (a) and (b) shows the observed trends of malaria prevalence between the years 2010 and 2013 from a review of clinical records in Bura and Hola government health facilities. Figure 3.3 (a) compares the prevalence from both hospitals while Figure 3.3 (b) shows the combined malaria prevalence from the two hospitals. The prevalence from Bura Health Centre was decreasing while that from Hola decreased and then rose in the year 2012. The combined prevalence from both hospitals shows a decreasing trend in malaria cases.

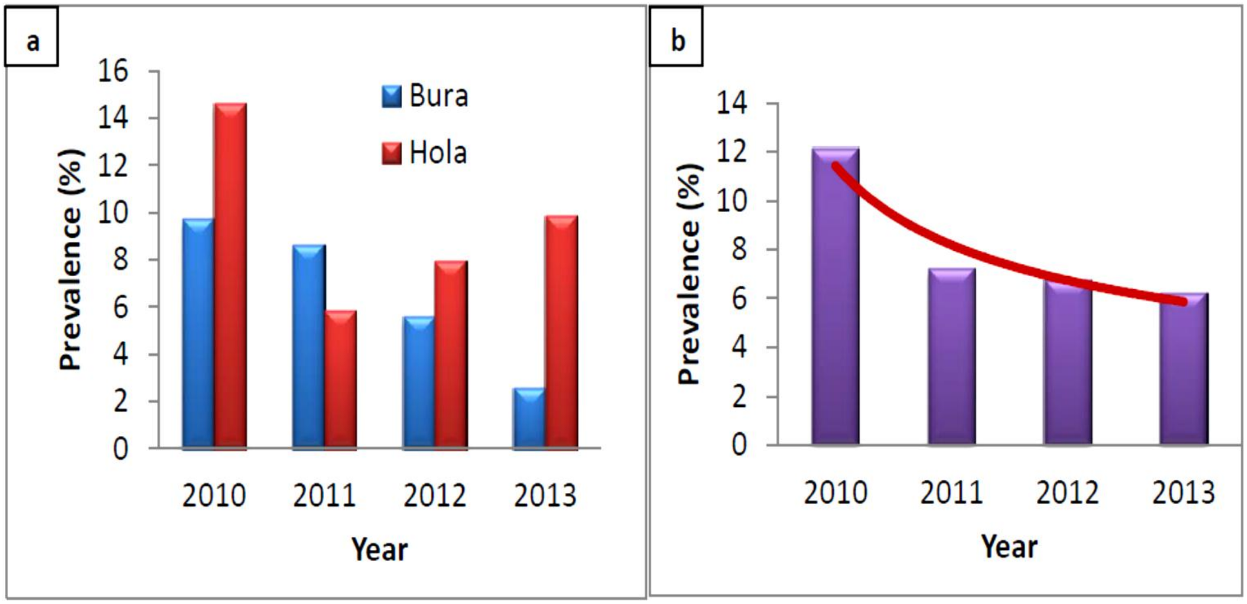

Figure 3.3: Trend of malaria prevalence in Bura and Hola between 2010 and 2013: (a) shows the yearly trend in each hospital while (b) the trend in both hospitals.

3.3.6 Malaria prevalence in Bura and Hola irrigation schemes

Using Carestart^{TM} malaria HRP2 (pf) kit, eight out of 160 people tested positive (prevalence of 5%). The prevalence of households that had at least one member positive for malaria was 10.4% (5/48).

3.3.7 Risk factors associated with malaria infection in Bura irrigation scheme

At individual level, age, sex and occupation of the subjects were not significantly associated with Rapid Diagnostic Test (RDT) result or whether a person had malaria infection within the last two months of the study. Tables 3.1 and 3.2 shows the univariate analysis at household level with RDT result and whether an individual had malaria infection within the last two months before the implementation of the study, respectively, as response variables. Using RDT result as the outcome variable, only water canals were statistically (p-value=0.021) associated with malaria infection. People fetching water from water canals were less likely (OR=0.093) to get malaria infection compared to those fetching water from dams. On the hand, when the outcome variable was whether an individual had malaria within the last two months of this study, distance to the nearest health facility was associated with malaria infection.

At 95% level of confidence, none of the independent variables explained the RDT result in a multivariate analysis. Distance to the nearest health facility (p-value of ≤5km=0.0128) and household size (p-value=0.0226), were significantly associated with whether a person had malaria infection within the last two months before implementation of the study (Table 3.3). Based on the result, households located ≤5km to the nearest health facility (OR=0.104) were at a lower risk of malaria infection compared to households located >5km. Furthermore, for a unit increase in household size, the odds of having a person who had malaria infection within the last two months of this study increased by 68.5% (OR=1.685). All the other variables were not statistically associated with malaria infection as shown in Table 3.3.

Table 3.1: Univariate analysis using Rapid Diagnostic Test result as the response variable at household level

Variable	Estimate	Odds Ratio	95% CI		P -value
			Lower	Upper	
Main material of wall (ref=grass)					
Iron sheets	-14.487	5.111e-7		9.165e172	0.995
Mud	-0.189	0.8276	0.091	17.991	0.877
Stones with cement	0.470	1.600	0.547	4.713	0.758
Main material of roof (ref=grass)					
Iron sheets	17.74	5.070e7	2.267e-138	_	0.995
Main material of floor (ref=cement)					
Earth/sand	-1.634	0.195	0.015	4.728	0.220
Household size	-0.103	0.902	0.547	1.366	0.652
Main water source (ref=dams)					
Water canals	-2.380	0.093	0.010	0.682	0.021
Water tanks	-17.055	3.917e-8	_	2.62e181	0.995
IRS within last one year (ref=no)					
Yes	-16.649	5.880e-8	_	1.272e153	0.996
Ownership of ITN (ref=no)					
Yes	16.56	1.563e7	1.749e-118		0.995
Bed nets per person	-3.330	0.036	2.454e-4	2.245	0.141
Distance to nearest health facility (ref=>5km)					
≤5km	-1.909	0.148	0.007	1.109	0.100
Key: IRS=Indoor Residual Spraying, ITN=Insecticide Treated Nets					

Table 3.2: Univariate analysis using whether a household had at least one member who had suffered from malaria within the last two months before the implementation of the study as the response variable

Variable	**Estimate**	**Odds Ratio**	**95% CI**		**P -value**
			Lower	Upper	
Main material of wall (ref=grass)					
Iron sheets	-17.819	1.825e-8		1.644e204	0.994
Mud	-0.315	0.730	0.096	3.758	0.725
Stones with cement	-1.253	0.286	0.025	2.587	0.274
Main material of roof (ref=grass)					
Iron sheets	0.619	1.857	0.458	7.277	0.372
Main material of floor (ref=cement) Earth/sand	0.102	1.107	0.049	12.514	0.936
Household size	0.286	1.331	0.979	1.921	0.092
Main water source (ref=dams)					
Water canals	-0.445	0.641	0.086	3.253	0.615
Water tanks	15.468	5.217e6	8.056e-91		0.993
IRS within last one year (ref=no)					
Yes	0.519	1.680	0.194	35.758	0.666
Ownership of ITN (ref=no)					
Yes	0.109	1.115	0.142	6.501	0.906
Bed nets per person	-2.375	0.093	0.004	1.264	0.092
Distance to nearest health facility (ref=(>5km))					
≤5km	-1.447	0.235	0.047	0.904	0.048
Key: IRS=Indoor Residual Spraying, ITN=Insecticide Treated Nets					

Table 3.3: Multivariate analyses with significant variables and whether a household had at least one member who had suffered from malaria within the last two months before the implementation of the study as the response variable

Variable	Estimate	Odds Ratio	95% CI		P -value
			Lower	Upper	
Household size	0.522	1.685	1.126	2.800	0.0226
Distance to nearest health facility (ref=>5km)					
≤5km	-2.266	0.104	0.014	0.524	0.0128

Figure 3.4 shows the association between bed nets ownership and the distance to the nearest health facility. This shows a pattern of decreasing bed nets possession and use with increasing distance from the nearest health facility.

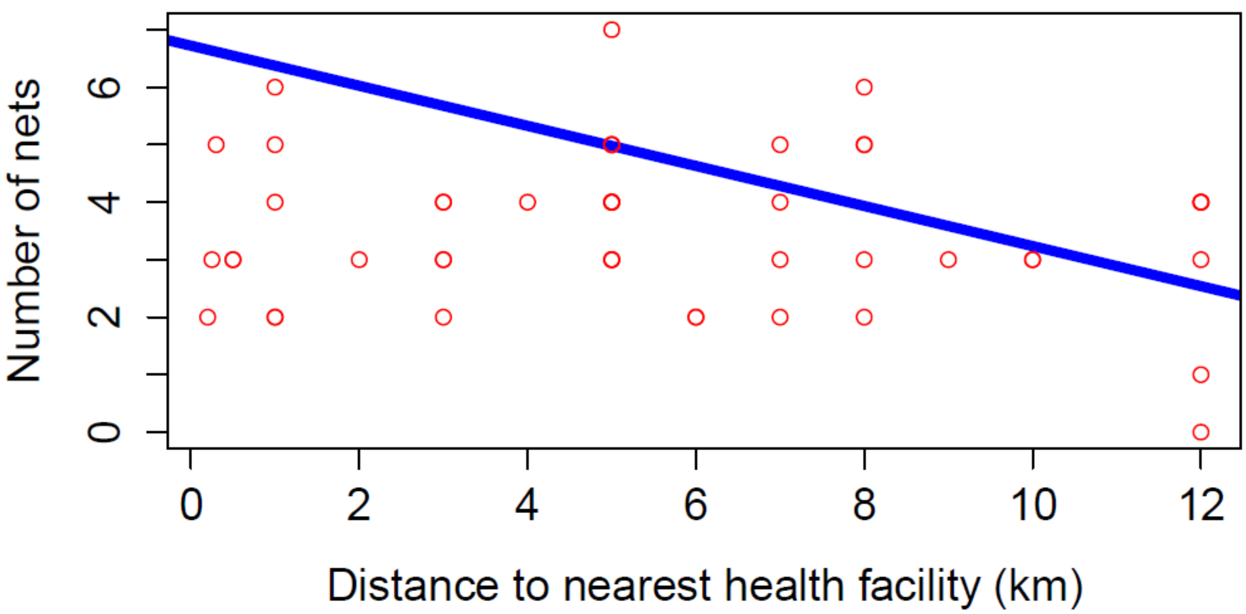

Figure 3.4: Relationship between bed net ownership and distance to the nearest health facility

3.4 Discussion

The housing conditions in most households consisted of muddy walled houses roofed with old and rusting iron sheets. Residential house status or structure has some implications in malaria transmission as poorly constructed houses expose individuals to mosquitoes by providing suitable resting places or shelter and therefore attacking the occupants (Kirby *et al*., 2008). Nevertheless, in poorly constructed houses where cooking and sleeping take place in the same room, smoke could repel mosquitoes through the eaves at the time that cooking is taking place (WHO, 2008). Most households cooked within their residential houses and this could have probably repelled most mosquitoes. Yé *et al*. (2006) observed that, children living in houses with mud roofs had significantly higher risk of getting malaria infection compared to those living in iron-sheet roofed houses. A possible explanation for this scenario is that iron sheet roof is not a suitable resting place for blood-engorged mosquitoes as opposed to cracks in the mud roof. In Bura irrigation scheme, almost all houses were built using corrugated iron sheets.

Almost all interviewed household owned at least one type of livestock species. Livestock can influence malaria transmission by providing alternative blood meals for *Anopheles* mosquitoes that is necessary for oviposition (Mahande *et al.,* 2007). This observation is of critical importance in Bura irrigation scheme where the prevalent malaria vector is the *An. arabiensis* which is highly zoophilic (Mutero and Birley, 1987). A study by Mutero *et al.* (2004) in Mwea division in Kenya suggested that zooprophylaxis was the most possible explanation for the observed decrease in malaria cases in villages with rice irrigation.

The community members in Bura irrigation scheme demonstrated good knowledge about malaria disease; its causes, symptoms, treatment and its prevention by using bed nets. Insecticide treated nets (ITNs) are the most practical method of mosquito control that are used to protect at-risk individuals from mosquito bites and hence malaria infections (Lengeler, 2004). Through interviews, the community members revealed a very high ownership and usage of bed nets regardless of whether it is treated or not. The use of untreated mosquito nets has been found to have some protective measures against mosquito bites while ITNs increases the mortality of vectors in addition to reducing vector-host contact, and therefore reducing the transmission of malaria (Mwangi *et al*., 2003).

In this study, the major sources of the bed nets were the government health facility and government campaigns both of which could have resulted in the observed overwhelming possession and use of bed nets by the community. In 2007, the Mentor Programme with the support from Department for International Development (DFID) distributed 17,700 Long Lasting Insecticide Treated Nets (LLIN) to pre-empt the malaria epidemic effects of flooding in Tana River and Garissa Districts (Mentor, 2007). Free distribution of ITNs in Kenya also takes place through antenatal and child welfare clinics to pregnant women and children under one year of age and through comprehensive care clinics for people living with Human Immunodeficiency Virus (HIV) (DOMC, 2011). In 2009, a global strategy of ensuring universal coverage with ITNs (one net for every two people) for all persons at risk of malaria was adopted by GoK (DOMC, 2011). This target seems to have been met in Bura irrigation scheme but there were possibilities of over reporting.

Only a few households practiced environmental management such as bush clearing around homesteads and draining of stagnant water as methods of controlling malaria. Environmental management has been shown (Kibe *et al*., 2006) to be a cost-effective method of reducing mosquito abundance which, if coupled with other vector and malaria parasite control methods, would substantially reduce malaria. These constitute an Integrated Malaria Management package (IMM) and have been shown to be very successful in many tropical environments (Utzinger *et al*., 2002). Okech *et al*. (2008) observed that, implementation of IMM in a community in Mwea irrigation scheme in Kenya could have led to a drastic fall in malaria incidence. Thus, there is a need for the residents of Bura irrigation scheme to be educated on other methods of malaria control if the prevalence of the disease is to be further reduced.

Government health centers are a backbone in case management of malaria. In the study site, the major government facility is the Bura Health Center and the drug of choice in the treatment of malaria was Artemether-lumefantrine (AL). This is the recommended drug for malaria in Kenya by the Ministry of Health since 2006 after increasing resistance levels to sulphadoxine/pyrimethamine (SP). The AL is freely available in government and faith-based health facilities and since its introduction the trends of malaria infection cases in Kenya have been decreasing (MoH, 2012). Most people in Bura irrigation scheme are aware about the drug and its use. It is also worth noting that the use of quinine (21%) is relatively high in this community. According to the national guidelines of malaria treatment in Kenya, quinine is the recommended drug for severe malaria (MoPHS, 2011). This could be an indication of the severity of malaria infection in Bura irrigation scheme. Sixty-nine percent of the households reported having at least one member who had suffered from malaria within the last two months of this study yet the observed prevalence was 5%. This might indicate the possibility of misdiagnosis of other febrile illness leading to exaggerated treatment of assumed malaria. Significantly high prevalence of Q fever and West Nile virus are being reported by an ongoing project (Dynamic Drivers of Diseases in Africa: Ecosystems, livestock/wildlife, health and wellbeing) yet the community does not know about these other febrile diseases. This appears to support the hypothesis that anthropogenic changes observed in Tana River County could have changed the diversity of mosquitoes leading to emergence of other vector-borne diseases.

A review of the hospital records showed a declining trend in malaria which was confirmed during the community screening of malaria parasite in this study. The use of AL together with the high usage of ITNs is likely to have reduced malaria transmission in the area.

Using RDT result as the outcome variable, people fetching water from water canals were less likely (OR=0.093) to get malaria infection compared to those fetching water from dams. The reservoirs created by dams provide larger areas of stagnant water compared to water canals. Dams also provide a steady source of water, sustaining mosquitoes that may have otherwise died during the dry season (Jobin, 1999).

The distance to the nearest health facility and the household size were significantly associated with having at least one member of the household who had suffered from malaria within the last two months before the implementation of this study. Households located less than or equal to five kilometres to the nearest health facility were at a lower risk (OR=0.104) of malaria infection compared to households located more than five kilometers. Households near health facilities (<5km) had more nets compared to households located far away (>5km) and this observation is in agreement with a study done by Larson *et al.* (2012) in Malawi. This indicates the important role that health services can play in controlling/prevention of malaria. However, there is need to enhance community-centered ITN distribution models by utilizing community health workers to deliver the nets directly to the households and also pass the information about their usage and malaria control.

For a unit increase in household size, the odds of having a person who had malaria infection within the last two months of this study increased by 68.5% (OR=1.685). A similar observation was made by Ayele *et al*. (2012) where family size was significantly associated with malaria infection. An increased household size could have led to a higher probability of a mosquito feeding on a person thus increasing the transmission if infected. Contrary to other studies (Sintasath *et al*., 2005; Ayele *et al*., 2012), age, sex, housing condition (main materials of wall, roof and floor), number of mosquito nets per person and IRS were not significantly associated with malaria infection.

CHAPTER FOUR

4.0 DYNAMIC MODELS OF MALARIA TRANSMISSION

4.1 Introduction

Mathematical models have been used to explain malaria transmission dynamics in human and vector populations starting with the work of Ross (1911) and then Macdonald (1957). Some studies (Ohta and Kaga, 2014) have tried to incorporate irrigation into a malaria transmission model but there are a lot of challenges due to the lack of precision in quantifying the vector breeding sites. In this study, the breeding site is modeled by quantifying the amount of stagnant water brought about by rainfall and irrigation in a fuzzy distribution model described by Ermert *et al*. (2011). To analyse the effects of irrigation on malaria transmission risk, a one-vector one-host deterministic model made up of a mosquito population sub-module and disease transmission sub-module was used.

4.2 Materials and methods

4.2.1 Model development

The model structure involves three sub-modules: mosquito breeding suitability, mosquito population dynamics and disease transmission modules. The model was implemented in Microsoft Excel 2010.

4.2.1.1 Mosquito breeding suitability model

The model assumes that breeding sites for *Anopheles* mosquitoes are presence of open water bodies that are created either by rainfall or water pumped from River Tana for irrigation in the study area. The suitability of breeding sites affect the number of produced eggs (β) that are oviposited (Paaijmans *et al.*, 2007). Ermert *et al.* (2011) described a function that can be used to estimate the number of oviposited eggs as well as the survival of immature stages depending on the availability of suitable mosquito habitats.

Here, the 10-day cumulative rainfall and daily irrigated water was modeled with the following concept: (i) a small amount of eggs are oviposited when little/no rainfall and irrigation activity is ongoing; (ii) rainfall and intensified irrigation lead to a higher proportion of oviposited eggs; and (iii) breeding sites are washed out by excessive water. The following conditions are therefore set in the fuzzy distribution model: dry unsuitable conditions (threshold U_1), most suitable condition (S) and unsuitable conditions due to excessive water (threshold U_2). A fuzzy suitability (*f*) function of 10-day cumulative rainfall and irrigated water (aw) was computed as follows (Ermert *et al.*, 2011):

$$f(aw) = \begin{cases} 1 - COS^2\left(\frac{aw-U_1}{S-U_1} \times \frac{\pi}{2}\right), & \text{if } U_1 < aw < S \\ COS^2\left(\frac{aw-S}{U_2-S} \times \frac{\pi}{2}\right), & \text{if } S < aw < U_2 \\ 0, & \text{else} \end{cases} \qquad \text{.............. (Equation 4.1)}$$

The daily amount of water pumped from the river during the year 2013 was obtained from the records at the National Irrigation Board (NIB) in Bura. The irrigation water was added to that from 10-day accumulated rainfall after harmonizing the units (mm) by calculating the water per unit area of irrigated land. During the study, the area under irrigation was 6520 acres of land. Rainfall data were obtained from the weather station at Bura irrigation scheme.

The effective number of viable oviposited eggs per female mosquito (*e*), which forms the basis of the modeled immature mosquito population, was determined as (Ermert *et al.*, 2011),

$$e = \beta \times f\,(\text{aw}) \qquad \text{…………………………………………… (Equation 4.2)}$$

The Fuzzy distribution was also used to estimate mortality rates of eggs, larvae and pupa.

4.2.1.2 Aquatic vector stages

The aquatic part of the mosquito lifecycle consists of an egg stage, E, larval stage, L and a pupal stage, P. On average each female mosquito will lay β eggs per day, which undergo a per capita daily mortality at a rate m_E, that depends on the fuzzy function and the surviving eggs will hatch into larvae at a rate d_E. These larvae will undergo a per capita daily mortality at a rate m_L influenced by the fuzzy function. Larvae surviving the developmental period of dL days (where the reciprocal of d_L is the rate of progression to the next stage) will develop into pupae. A carrying capacity of 100,000 larvae was used to control their exponential growth and also the number of eggs oviposited (larvae density influence oviposition). The developed pupae will undergo a per capita daily mortality at a rate m_P that is again affected by the fuzzy function while those that survive development will emerge as adults at rate given by the reciprocal of development period, d_P. A daily time step using the following set of ordinary differential equations was used to describe the mosquito aquatic stages,

$$
\begin{aligned}
\frac{d}{dt}(E) &= e - d_E E - m_E E \times f(aw) \\
\frac{d}{dt}(L) &= d_E E - d_L L - m_L L \times f(aw) \\
\frac{d}{dt}(P) &= d_L L - d_P P - m_P P \times f(aw)
\end{aligned}
\qquad \text{(Equations 4.3)}
$$

It is assumed that half of all emerging adult mosquitoes are females (Kirby and Lindsay, 2009). Male adult mosquitoes are ignored, only assuming there are enough males for successful mating with females. Emerging susceptible adult female mosquitoes will search for a blood meal and begin their temperature-dependent gonotrophic cycle (egg development within the mosquito). Model parameters were obtained from the literature (Table 4.1).

Table 4.1: Model parameters

Parameter	Description	Value	Source
U_1	Unsuitable condition-no water	0	fitted
S	Suitable condition	44mm	fitted
U_2	Unsuitable condition-flushing effect.	50mm	fitted
β	Number of eggs laid by mosquito per day	12.7	Service, 1971
d_E	Period of development of eggs (days)	6.67	Bayoh and Lindsay, 2003
d_L	period of development of larva (days)	4.17	Bayoh and Lindsay, 2003
d_P	period of development of pupae (days)	1	Bayoh and Lindsay, 2003
m_E	per capita mortality rate of eggs (day^{-1})	0.035	Bayoh and Lindsay, 2003
m_L	per capita mortality rate of larva(day^{-1})	0.035	Bayoh and Lindsay, 2003
m_P	per capita mortality rate of pupae (day^{-1})	0.025	Bayoh and Lindsay, 2003
m_A	Per capita mortality rate of adult mosquito(day^{-1})	0.913	Bayoh and Lindsay, 2003
K	Larvae carrying capacity	100,000	Subjective
DdGc	Degree day gonotrophic cycle	37	Detinova, 1962
Tc	Temp threshold gonotrophic (°C)	18	Detinova, 1962
DdSc	Degree day sporogony	111	Nikolaev, 1935
Tmin	Temperature threshold _*P. falciparum* (°C)	16	Nikolaev, 1935
BMI	Blood meal index	0.8	Ermert *et al*., 2011
Phv	Human to mosquito transmission efficiency	0.2	Ermert *et al*., 2011
Pvh	Mosquito to human transmission efficiency	0.5	Ermert *et al*., 2011
Inc	Incubation period in days (*P. falciparum)*	14	Warrel, 2002
Inf	Infectious period (days)	14	Warrel, 2002
r	Loss of immunity (days)	30	Warrel, 2002
b	Human birth rate (day^{-1})	0.015	Subjective: used to maintain a constant population
d	Human death rate (day^{-1})	0.015	

4.2.1.3 Mature mosquito dynamics

Gonotrophic (a cycle of egg development) and sporogonic (a cycle of parasite development within mosquitoes) are determined using frameworks described by Hoshen and Morse (2004). Detinova (1962) detected a "degree-day" dependence of the time for the preparation of a brood in *An. maculipennis* (the gonotrophic cycle, *Gc*) and hence also of the time for biting, which may be expressed as,

$Gc = \frac{1+DdGc}{T-Tc}$ where T is the daily mean temperature. (Equation 4.4)

A daily progress rate (part of gonotrophic cycle covered in one day) is calculated as,

$$G_R = \frac{1}{G_c} \qquad \text{(Equation 4.5)}$$

The completion of a cycle may be established when the sum of daily G_R values reaches one. Thirty seven "boxes" (corresponding to the 37 degree days) are constructed, between which the mosquitoes progress in steps of G_R. At the end of each day, the number of mosquitoes that progress to the next stage is dependent on the survival rate ($1-m_A$). At the end of a gonotrophic cycle (upon arrival at box 37), each mosquito oviposits and then begins a new cycle. The success of oviposition is dependent on the existence of water-bodies, and hence on 10-day accumulated rainfall and/or daily irrigation water.

The preference for human biting over cattle by a mosquito is described by the blood meal index (BMI, the proportion of bites on humans, of total bites). A proportion of mosquitoes that bite infective humans become themselves infected at a probability *Phv.* It was generally assumed that infected mosquitoes stay so for life.

The sporogonic cycle (Sc, the process of fertilization of the macrogametocyte, formation of the oocyst, ookinete, penetration of the midgut and then the subsequent development of the sporozoites which dwell in the salivary glands) for *P. falciparum* lasts 111 degree-days above 16°C (Nikolaev, 1935). The daily sporogonic progress is thus $S_R = 1/Sc$ where Sc was calculated by Detinova (1962) as,

$$Sc = \frac{DdSc}{T - Tmin} \qquad \text{(Equation 4.6)}$$

To combine the gonotrophic and sporogonic processes each of the 37 box-stages of the gonotrophic cycle are subdivided into 112 sub-sections, numbered zero to 111, representing progress in degree-days. The zero subsection reflects an uninfected mosquito. At the same time t (in calendar days) and in each day, an infected mosquito sub-population progresses by gonotrophic rate G_R and by sporogonic rate S_R. A finite fraction (m_A) of the mosquito population dies and thus does not make the transition.

Upon the completion of the sporogonic cycle the mosquito remains at the infectious stage. If the mosquito is not infected while feeding, it remains uninfected throughout the gonotrophic cycle. After biting an infectious human, an uninfected mosquito has a probability (*Phv*) of either becoming infected or not (1-*Phv*). The force of infection is a product of *Phv*, BMI and the proportion of infected humans (Ih/Nh). A mosquito has a chance of feeding on cattle or other hosts and these alternative sources of blood meals are not expected to be infectious. Mosquitoes may arrive at the uninfected biting stage by two processes, either just after maturation or else by completing an uninfected gonotrophic cycle. New eggs are laid by mosquitoes completing a gonotrophic cycle thus; all mosquitoes located less than G_R from the end of the gonotrophic cycle will oviposit and their number was summed over all infection states, zero to 111.

4.2.1.4 Human population dynamics

Susceptible humans, *Sh*, can be infected when they are bitten by infectious mosquitoes at a rate *λh* to join the exposed class (*Eh*). This force of infection is a product of mosquito feeding rate per day (*BMI/Gc*), proportion of infected mosquitoes (*Iv/Nv*), mosquito to human transmission efficiency (*P*vh) and the ratio of mosquito to human population (*Nv/Nh*).The exposed individuals incubate the parasite at a period *inc* (whose reciprocal is the rate of progression) until they become infectious, *Ih*. Infectious individual's progress to the recovered, *Rh*, class at a rate *1/inf* while assuming no disease induced deaths. Since malaria is endemic in the area under the study, it was assumed that the recovered class gain partial immunity which they later lose at a rate *r* to join the susceptible class. A constant human population was assumed and therefore the birth rate (*b*) was equal to the death rate (*d*). The parameters (Table 4.1) were obtained from the literature and the following differential equations describe the human population dynamics:

$$\begin{aligned}
\frac{d}{dt}(Sh) &= bNh + rRh - \lambda hSh - dSh \\
\frac{d}{dt}(Eh) &= \lambda hSh - \frac{Eh}{inc} - dEh \\
\frac{d}{dt}(Ih) &= \frac{Eh}{inc} - \frac{Ih}{inf} - dIh \\
\frac{d}{dt}(Sh) &= \frac{Ih}{inf} - rRh - dRh
\end{aligned} \qquad \text{(Equations 4.7)}$$

$$Nh = Sh + Eh + Ih + Rh \qquad \text{(Equations 4.8)}$$

$$\lambda h = \frac{BMI}{Gc} \times \frac{Iv}{Nv} \times Pvh \times \frac{Nv}{Nh}$$

A baseline malaria prevalence of 0.7% in humans was assumed.

The above models are summarized in a compartmental model shown in Figure 4.1

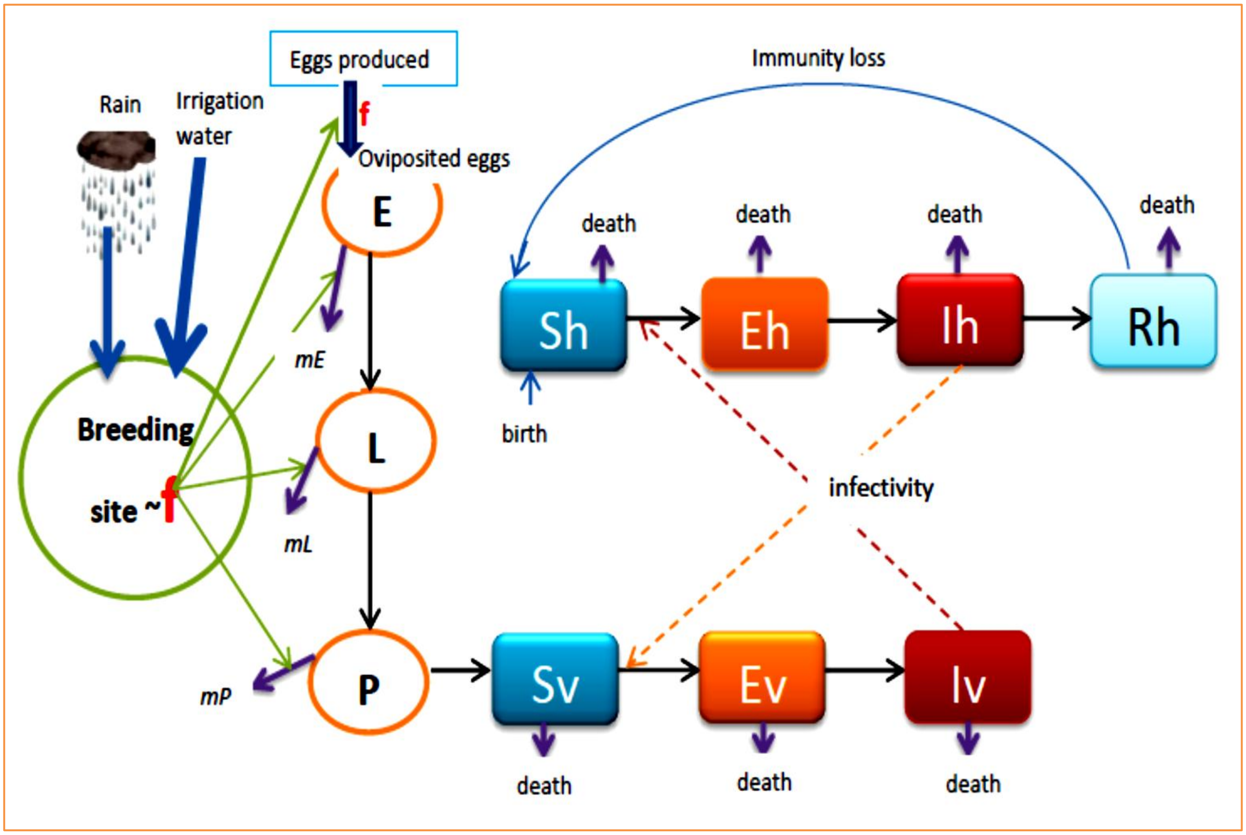

Figure 4.1: Model Structure

The fuzzy function, f is calculated from decadal rainfall and irrigation water and used to determine the suitability of the breeding site which then influences oviposition and mortality rates m_E, m_L and m_P of eggs (E), Larva (L) and pupae (P), respectively. Pupae develop and emerge as susceptible (Sv) adult mosquitoes (half of which are females). Susceptible mosquitoes take a blood meal from infectious humans (Ih) and move to the exposed (Ev) class where they incubate the *Plasmodium* parasite before becoming infectious (Iv). All adult mosquitoes are assumed to undergo a constant mortality rate. A susceptible human (Sh) gets bitten by mosquitoes in class Iv and move to the exposed (Eh) class where they incubate the parasite before becoming infectious (Ih). Infectious humans recover (Rh) and gain partial immunity which is later lost and they join Sh. Human beings are assumed to die at a constant rate with no disease-induced death rate.

4.2.2 Model validation

Data on malaria prevalence for the year 2013 were obtained from the local hospitals while rainfall and temperature data were obtained from weather station at Bura irrigation scheme.

The model was fitted to malaria prevalence data obtained from Bura and Hola hospitals by varying the parameters of the Fuzzy distribution function. Parameter values that gave the least variance between predicted and observed prevalence were used.

4.2.3 Entomological Inoculation Rate

Entomological Inoculation Rate (EIR) is the number of infectious bites per person per unit time and it is used to measure the intensity of malaria transmission in endemic areas. It is the product of the human biting rate and the sporozoite rate, that is, a function of the number of mosquitoes per host, the daily rate of mosquito biting and the proportion of infectious mosquitoes. Reducing any of these values would decrease the EIR and therefore having a direct reflection of vector control and antigametocytocidal drugs. The EIR was calculated as:

$$EIR = \frac{BMI}{G_c} \times \frac{N_v}{N_h} \times \frac{I_v}{N_v} \qquad \text{(Equation 4.9)}$$

4.3 Results

Figure 4.2 shows the fuzzy distribution model that represents the breeding conditions by determining a suitability function which was then linked to the malaria transmission model. The model shows that the most suitable conditions for mosquito breeding during the year 2013 were between March and April, and October and December. These coincided with the known rainy seasons in Tana River County. However, Figure 4.3 shows that the mosquito population appeared to be abundant through-out the year despite the seasonality of rainfall. It also shows a year-round presence of sporozoite-infected vectors suggesting the effect of irrigation.

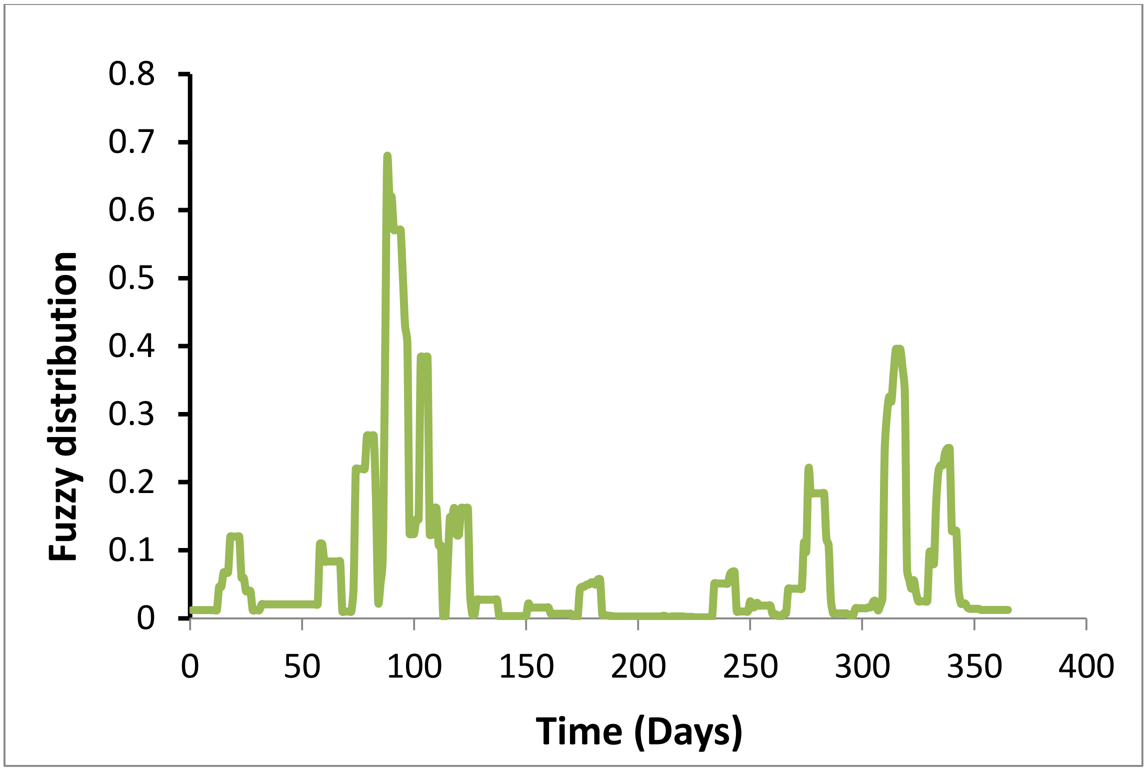

Figure 4.2: Fuzzy distribution model used to determine oviposition and mortality rates of aquatic stages of malaria vectors.

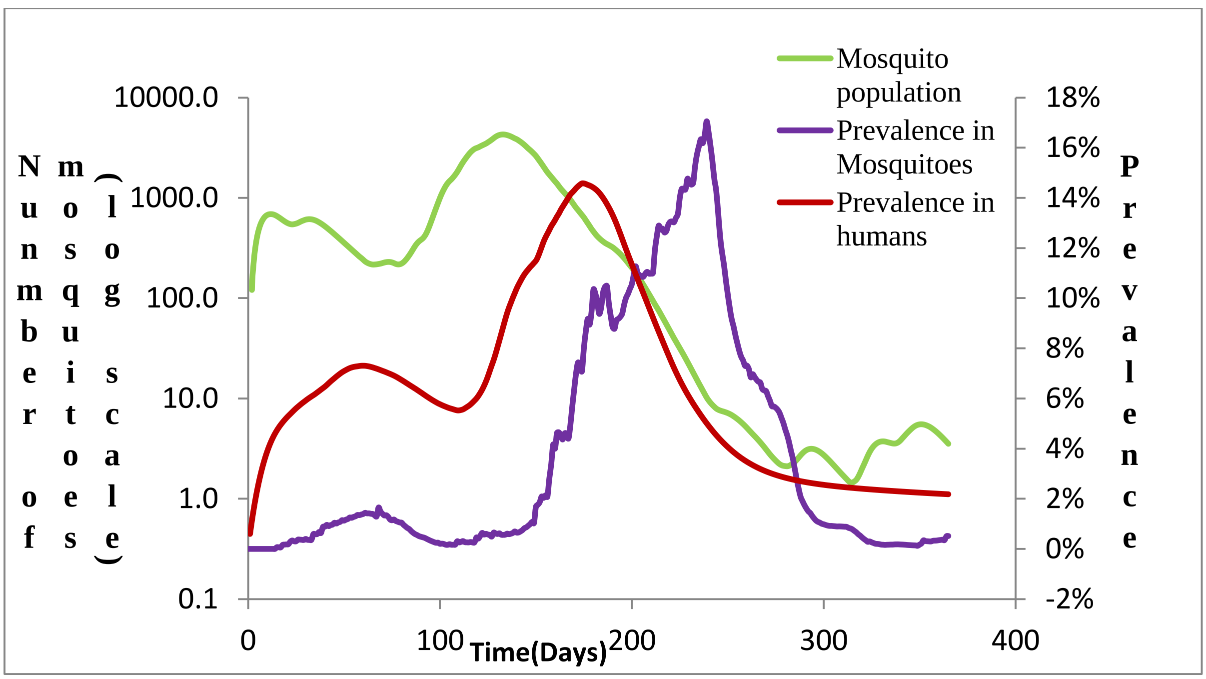

Figure 4.3: Mosquito population and prevalence of malaria parasite in humans and mosquitoes

Mosquito population density was very high immediately after the optimum conditions for mosquito breeding followed by a reduction during the unfavorable conditions (Figure 4.3). There was a time lag between peak density of mosquito population and the prevalence of malaria in humans and mosquitoes.

The fitted model (Figure 4.4) was obtained after varying the fuzzy distribution parameters and fixing baseline prevalence at 0.7%. This model had the least variation (0.0002) between the observed and the predicted prevalence. The upsurge of malaria cases appeared to occur three to four months after the optimum conditions for mosquito breeding.

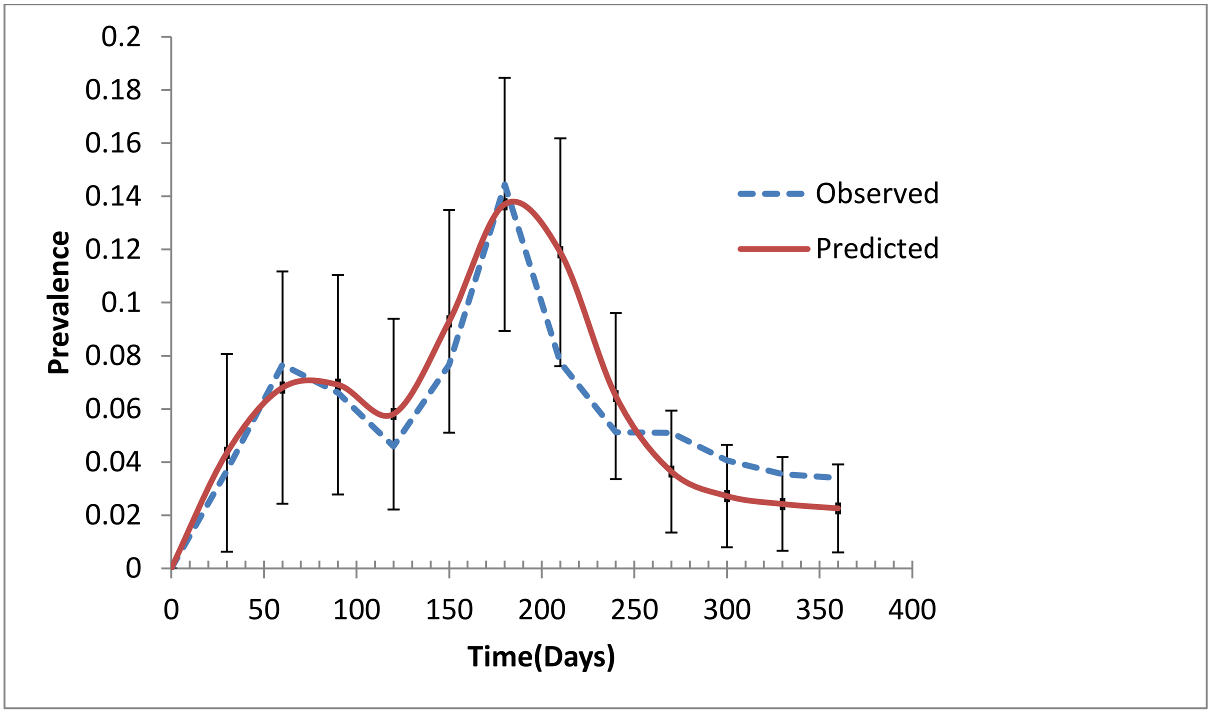

Figure 4.4: Predicted and observed malaria prevalence. The vertical lines show the 95% level of confidence.

The predicted EIR (the infectious bites received per person per unit time) shows some relationship with the prevalence of malaria parasite in humans and mosquitoes (Figure 4.5); the

EIR and prevalence in humans peaked at the same time, while that the prevalence in mosquitoes picked later. The EIR was estimated to be five infectious bites per person per year.

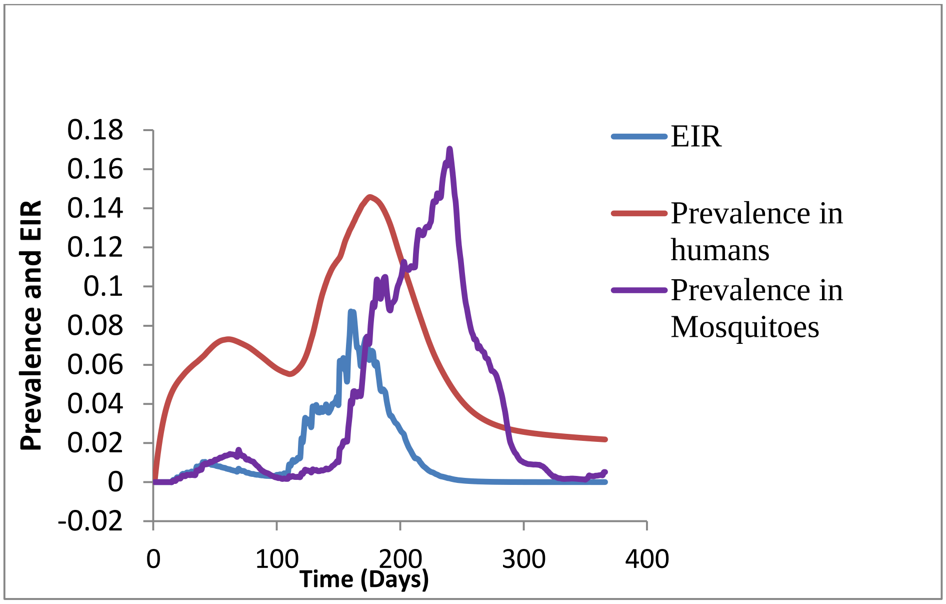

Figure 4.5: Predicted Entomological Inoculation Rate and malaria prevalence in humans and mosquitoes

4.4 Discussion

Malaria transmission largely depends on the size of mosquito population which in turn depend on breeding conditions (Kirby and Lindsay, 2009). The parameters for the fuzzy distribution model were arbitrary such that those that gave the least variance between the predicted and the observed prevalence were used. Ermert *et al.* (2011) used a similar approach but only with 10-day accumulated rainfall. In this study, the daily irrigation water per unit area of land was added to the 10-day accumulated rainfall.

The most suitable conditions for mosquito breeding during the year 2013 were between March and April, and October and December. However, the upsurge of malaria cases occurred between May and July. This is in agreement with a study done by Githeko and Ndegwa (2001) that suggest that malaria incidence lags onset of rains by 3-4 months. In Tana River County, rainfall occurs around March-May and October-December and its additive effect to the irrigation water was visible in the model. Data from non-irrigated areas will be necessary to quantify the extra malaria cases due to irrigation.

The mosquito population appears to be abundant through-out the year despite the seasonality of rainfall with the year-round presence of sporozoite-infected vectors suggesting the effect of irrigation. Irrigation increases the number of suitable breeding sites persisting throughout the year, leading to increased and persistent vector abundance (Keiser *et al.,* 2005; Jaleta *et al*., 2013). Higher vector population densities mean increased human biting rates, parous rates and sporozoite infections, resulting in increased EIRs if appropriate control measures are not undertaken (Jaleta *et al*., 2013).

The fitted model was obtained after varying the fuzzy distribution parameters and fixing baseline prevalence at 0.7%. This model had the least variation (0.0002) between the observed and the predicted. Generally, the model could be used to predict the prevalence of malaria in irrigated areas of Tana River County.

The quantitative relationship that exists between the proportion of people who are infected with *P. falciparum*, and the rate at which people are bitten by infectious mosquitoes (EIR) is an important aspect in malaria control (Beier *et al.,* 1999). The EIR was estimated to be five infectious bites per person per year in 2013 in irrigated parts of Tana River County. Beier *et al.* (1999) observed that substantial reductions in malaria prevalence are likely to be achieved only when EIRs are reduced to levels less than one infective bite per person per year. They also highlight that the EIR is a more direct measure of transmission intensity than traditional measures of malaria prevalence or hospital-based measures of infection or disease incidence. The effectiveness of various intervention measures should therefore be evaluated using the EIR to devise the appropriate malaria control measures in this area. Increased mosquito breeding site has a second order effect on EIR by allowing the human prevalence to rise earlier in the season, which increases the infectivity of the human population to vectors. A similar observation was made by Eckhoff (2011) by increasing the larval habitat.

CHAPTER FIVE

5.0 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

This study finds a reduction in malaria prevalence despite the intensification of irrigated agriculture in Tana River County. A review of the clinical records also show a decreasing trend of malaria prevalence in Bura irrigation scheme where the study was done. The epidemiology of malaria in Kenya has been changing with reported reductions in malaria associated hospital admissions (Snow *et al.,* 2009). A report by DOMC (2007-2009) suggested that, these changes have been in part, attributed to the increase in coverage and access to malaria control interventions, such as ITN, AL and IRS. In Bura irrigation scheme, ownership and usage of ITNs was reported to be very high probably more than any other area in the country. The AL is freely available in the government facilities in the area which could have led to its high usage. About 40% of all the interviewed households had their houses sprayed with an insecticide within the last 12 months of this study. A combination of these control measures could have resulted in the observed decrease in malaria prevalence.

Excessive use of malaria drugs is also suggested by the proportion (69%) of households having members who suffered from malaria within the last two months of this study. Fever was highly associated with malaria suggesting that all febrile cases are treated as malaria. The use of AL clears malaria parasite from the bloodstream and overtreatment can lead to parasite resistance to the drug.

Distance to the nearest health facility was significantly associated with malaria infection with persons located more than 5km to the nearest health facility being at a greater risk. Malaria infection was also associated with bed net ownership such that households within 5km to the health facilities owned more bed nets compared to households located more than 5km away from the health facility. A similar observation was made by Larson *et al.* (2012) in Malawi. This shows the importance of health services in management and control of malaria. Increased family size was also associated with history of malaria infection as observed elsewhere (Ayele *et al*., 2012). A higher household size could have increased the probability of a mosquito feeding on a human being thus increasing the rate of transmission if infected.

To analyze the effects of irrigation on malaria transmission dynamics, a one-host one vector deterministic model was developed. The irrigation scheme was represented by a fuzzy distribution that is a function of unsuitable conditions due to desiccation or flushing effect of a lot of water and a suitable condition created by the additive effect of rainfall and irrigation water. This approach was used by Ermert *et al*. (2011) to refine the malaria model parameters in the growth of vector population. A validation of the model using climatic variables and an estimated amount of irrigated water fits the model to the observed malaria prevalence data for the year 2013. The small variation between the observed and the predicted prevalence could have been masked by the effects of ITNs and treatment as observed in KAP.

A possibility of over reporting of control methods especially ITNs could have been experienced. Further, a comparison of households with and without livestock could have given a better picture about the role of livestock in malaria transmission. More reliable rapid diagnostic test result could have been obtained using a finger prick. This study used blood obtained from the median cubital vein since more blood was required for multiple tests including malaria and other febrile illnesses in another study.

5.2 Conclusions

The prevalence of malaria in irrigated areas of Tana River County has decreased despite the large-scale intensification of irrigated agriculture. The high ownership and usage of Insecticide Treated Nets (ITNs), coupled by the free availability of Artemether-lumefantrine (AL) could have contributed to the observed decline in malaria prevalence. The ITNs and AL were mainly obtained from the government health facilities indicating the important role that healthcare services play in controlling/preventing and managing malaria.

Households located nearer to the health facilities had a lower risk of malaria infection than households located far away. In addition, smaller household sizes were associated with lower rate of malaria parasite infection.

The model fits the observed prevalence of malaria well and, therefore, it could be used to predict the prevalence and entomological inoculation rate of malaria transmission. This would enable decision makers to implement appropriate control measures at the optimum time.

5.3 Recommendations

More awareness should be created to the community on the importance of Integrated Malaria Management (IMM) which if coupled with the current control measures could reduce malaria cases further. The role of livestock in the irrigation scheme on malaria transmission requires further investigations. Further, a study is necessary to investigate the possibilities of overtreatment of malaria cases in the irrigated parts of Tana River County.

Data from non-irrigated areas and covering a longer period of time should be collected for more rigorous model validation, quantification of effects of irrigation and simulation of the impact of various interventions on malaria transmission.

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Appendix I: Consent form

Assent/Consent for: ______________________________ **University of Nairobi**

…. who is participating in a survey to determine the prevalence and risk factors of malaria under the project: Dynamic Drivers of Disease in Africa: Ecosystems,livestock/wildlife, health and wellbeing (DDDAC)

Project Information

I am _____________________ and I work with __________________ as a researcher.

We are doing research on malaria. The results obtained will be used in devising the appropriate mitigation measures to control and prevent malaria transmission in this area. You have been selected randomly to participate in the study and your participation is voluntary. This means that you are free to decline participation without any penalty. You do not have to decide now whether or not you will participate; you can consult anyone you feel comfortable with before making the final decision. Irrespective of whether you choose to participate or not, you will continue receiving medical services from any clinic in this area whenever you need them. That means you will not be denied access nor get preferential treatment in these facilities.

I will now take time to explain more about the research, please stop me whenever you need clarifications or to clarify meanings of words that you don't understand.

This work involves asking a few questions about you and your household and collecting a blood sample. We will draw about 2 ml of blood (half tea spoonful) from your arm. The blood will then be tested for malaria parasites using a Rapid Diagnostic Test. If positive for malaria, you will be treated immediately by a licensed clinician. This information that will be will be kept confidential.

I will also administer a questionnaire (to the household head) and this is expected to take about 10-15 minutes.

If you agree to be in the study but change your mind later, that is still OK; you can stop any time.

Will you be a part of this study? Yes No

Certificate of Consent

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate as a participant in this research.

Name/ID of the participant______________________________________

Signature/thumb print of participant _____________________ Date _____________

Witness

I have witnessed the accurate reading of the consent form to the above, who has had the opportunity to ask questions. I consent voluntarily to participate in this research.

Name/ID of a witness _________________________ID No.________

Signature/thumb print of the witness __________________ Date _____________

Researcher

I have accurately read or witnessed the accurate reading of the consent form to the potential subject, and the subject has had the opportunity to ask questions. I confirm that the subject has given assent freely.

Name/ID of the participant _____________________________ ID No.__________

Signature/thumb print of participant __________________ Date____________

Appendix II: A questionnaire survey on KAP and associated risk factors for malaria infection

UNIVERSITY OF NAIROBI

TANA RIVER COUNTY MALARIA SURVEY

HOUSEHOLD QUESTIONNAIRE

Date: ………………………

Name of interviewer: …………………………………………………...

NOTE TO INTERVIEWERS

For all pre-coded answers, simply circle the number of the choice which applies. Where the question is open-ended – meaning no pre-coded answers have been offered, then enter the respondent's answer in the space provided. Do not prompt the respondent for an answer.

IDENTIFICATION

Division ……………………………….. Location ……………………………….

Sub-location ………………………………………………………..

Village/number …………………………………..

Name of household head …………………………………… Phone no. ……………………

Household number ……………………………..

GPS reading ……………………………………

HOUSEHOLD SCHEDULE						
LINE NO.	USUAL RESIDENTS AND VISITORS	RELATIONSHIP	SEX	RESIDENCE		AGE
1	2	3	4	5	6	7
	Please give me the names of the persons who usually live in your household and guests of the household who stayed here last night, starting with the head of the household.	What is the relationship of (NAME) to the head of the household?	Is (NAME) male or female?	Does (NAME) usually live here?	Did (NAME) stay here last night?	How old is (NAME)? IN YEARS

01			M F 1 2	Y N 1 2	Y N 1 2	
02			1 2	1 2	1 2	
03			1 2	1 2	1 2	
04			1 2	1 2	1 2	
05			1 2	1 2	1 2	
06			1 2	1 2	1 2	
07			1 2	1 2	1 2	
08			1 2	1 2	1 2	
09			1 2	1 2	1 2	
10			1 2	1 2	1 2	

CODES FOR RELATIONSHIP TO HEAD OF HOUSEHOLD

01 = HEAD
02 = WIFE OR HUSBAND
03 = SON OR DAUGHTER
04 = SON-IN-LAW OR DAUGHTER-IN-LOW
05 = GRANDCHILD
06 = PARENT
07 = PARENT-IN-LAW
08 = BROTHER OR SISTER
09 = OTHER RELATIVE
10 = ADOPTED/FOSTER/STEP CHILD
11 = NOT RELATED

11	What is the occupation of household head?	1. Farmer 2. Pastoralist 3. Herdsman 4. Casual labor 5. Business person 6. Other …………………………..	
12.	Does this household own any livestock?	1. Yes 2. No	
13	How many of the following animals do this household own?	COWS/BULLS ………………. GOATS ………………………. SHEEP ……………………….. DONKEYS …………………… CHICKEN ……………………. DOGS ………………………… CATS …………………………	
14	Are the animals housed within the homestead?	1. Yes 2. No	

<table>
<tr><td>15</td><td>Type of house (record observation)</td><td><table><tr><td>Main material of the floor</td><td>1. Earth/sand
2. Wood
3. Cement
4. Carpet
5. Ceramic tiles</td></tr><tr><td>Main material of the roof</td><td>1. No roof
2. Grass thatch
3. Old clothes
4. Nylon papers
5. Wood planks
6. Iron sheets
7. Cardboard
8. Cement
9. Ceramic tiles
10. Other (specify) …...…………</td></tr><tr><td>Main material of the exterior walls.</td><td>1. No walls
2. Cane/trunks
3. Mud
4. Stone with mud
5. Stone with Cement
6. Bricks
7. Wood planks/shingles
8. Grass
9. Nylon papers
10. Other (specify) ………………..</td></tr></table></td><td></td></tr>
<tr><td>16</td><td>What is the main source of water for domestic use in your household?</td><td>1. In-house tap
2. Piped to the compound
3. Rivers/streams
4. Water canals
5. Water tanks
6. Borehole
7. Unprotected well
8. Protected well
9. Dams
10. Bottled water
11. Other …………………………</td><td></td></tr>
<tr><td>17</td><td>Is any member of your household an immigrant to the irrigation scheme, in the last 5 years?</td><td>1. Yes
2. No ⟶</td><td>19</td></tr>
</table>

18	If yes, how many?	Number …………………………...	
19	Is any member of your household an emigrant from the irrigation scheme, in the last 5 years?	1. Yes 2. No	
20	If yes, how many?	Number …………………………	
21	What are the household members' main reasons for immigration?	<table><tr><td>Immigrant</td><td>Reason (s)</td></tr><tr><td>I</td><td></td></tr><tr><td>II</td><td></td></tr><tr><td>III</td><td></td></tr><tr><td>IV</td><td></td></tr><tr><td>V</td><td></td></tr></table>	**Reasons** 1.Employment 2. Irrigation 3. Business 4. School 5. Visitation 6. Other (specify)
	KNOWLEDGE ABOUT MALARIA		
21	Do you know malaria?	1. Yes 2. No	
22	What causes malaria? (*multiple options possible)*	1. Mosquito bite 2. Long rains/being rained on 3. Stagnant water 4. Dirty home surroundings 5. Cold and wet weather 6. Eating raw food 7. Taking of dirty or polluted water 8. Witchcraft 9. Others…………………………..	
23	Can malaria be transmitted?	1. Yes 2. No ⟶ 3. Do not know	25
24	If yes, how? *(main reason only)*	1. Taking contaminated water 2. Infected mosquito bite 3. Sharing food 4. Direct contact with sick person 5. Blood contact 6. Other …………………………..	
25	What are the most common symptoms of Malaria? (*multiple options possible)*	1. Fever/hot body 2. Shivering 3. Weakness 4. Muscle/Joint pain 5. Headache 6. Loss of appetite 7. Vomiting 8. Cough 9. Others ………………………..	
26	What are the mosquito breeding sites? (*multiple options possible)*	1. Stagnant water 2. Rice paddies 3. Water canals	

<table>
<tr><td></td><td></td><td>4. Hoof prints and tire tracks
5. Ponds
6. Vegetation outside houses
7. Rubbish/pit latrines
8. Animal pens
9. Don’t know
10. Others ………………………..</td><td></td></tr>
<tr><td>27</td><td>What is the season for malaria infection in this region?</td><td>1. All year
2. Rainy season
3. After rainy season
4. Dry season
5. Other ………………………….</td><td></td></tr>
<tr><td>28</td><td>What group of people is mostly affected by malaria in this area?</td><td>1. Children under five
2. Elderly people
3. Pregnant women
4. Adult men
5. All adults
6. Others ………………………..</td><td></td></tr>
<tr><td colspan="4">TREATMENT AND HEALTH CARE SEEKING BEHAVIOUR</td></tr>
<tr><td>29</td><td>Do you have access to health facility?</td><td>1. Yes
2. No</td><td></td></tr>
<tr><td>30</td><td>What is the distance to the nearest health center?</td><td>Distance (in Km)……………</td><td></td></tr>
<tr><td>31</td><td>Is there any person in your household who suffered from malaria during the past one month?</td><td>1. Yes
2. No</td><td></td></tr>
<tr><td>32</td><td>If yes, what action was taken?
(ask action before period)</td><td><table><tr><th>Period</th><th>Action</th></tr><tr><td>Within 24 hrs</td><td></td></tr><tr><td>After one day</td><td></td></tr><tr><td>After two days</td><td></td></tr><tr><td>After three days</td><td></td></tr></table></td><td>Possible action
1. Taken to hospital
2. AL tablet self-medication
3. Paracetamol tablet self-medication
4. Home prepared Herbal medication.
5. Nothing
6. Other</td></tr>
<tr><td>33</td><td>(If NOT within 24 hrs)What was the main reason for the delay in the treatment?</td><td>1. No drugs at home
2. No money to buy drug
3. Not serious
4. No drug supplier around
5. No health facilities open
6. Usually first wait and see
7. Others…………………………</td><td></td></tr>
</table>

34	What drugs did they take?	1. ACT/AL 2 Fansidar/SP 3. Chloroquine 4. Amodiaquine 5. Quinine 6. Paracetamol 7. Herbal medicine 8. Religious healing 9. Don't know 10. Others ………………………..	
35	Which is the **most** used source of care for person presenting with malaria symptoms?	1. Government health center 2. Government dispensary 3. Private clinic 4. Local healers 5. Religious leaders 6. Other…………………………	
36	Why is it the most frequently used source? (*multiple options possible)*	1. Free medication 2. Prompt and better treatment 3. Nearby home 4. Other ………………………..	
37	***(If self-medication at home)***Where did you get these drugs that you gave at home?	1. Pharmacy/chemist 2. Ordinary shops 3. Traditional healer 4. Others …………………………	
PREVENTION AND CONTROL			
38	How do you prevent/control malaria? (*multiple options possible)*	1. Using mosquito nets 2. Draining/leveling of breeding sites around houses 3. Clearing of bushes and vegetation around houses and canals 4. Oil application 5. Taking drugs 6. Lighting fire and mosquito coils 7. Burning cow dung and local herbs 8. Good nutrition 9. Use indoor spraying 10. Others …………………………	
39	How many mosquito nets does your household have?	1. Number of nets ☐ → 2. None	41
40	**If none**, what would be the pertinent reasons of not having it?	1. High cost 2. Lack of confidence on the net 3. They were not available 4. They were not fairly distributed among community at large	

		5. Lack of awareness about its use 6. Low mosquito density 7. Others …………………………..	
41	Where did your household get this net?	1. Government campaign 2. Government health center/dispensary 3. Private clinic 4. Neighborhood 5. NGO 7. Retail shop 8. Pharmacy/chemist 9. NIB 10. Not sure 11. Other …………………………	
42	Where do you use the net in your household?	1. Bed 2. Fence 3. Windows 4. House walls 6. Other …………………………	
43	Was the net treated with an insecticide?	1.Yes 2.No 3.Not sure	
44	What is the time in which the bed net is retreated?	1. Not retreated 2. Once a year 3. Every six months 4. Other ……………………………	
45	Who slept under the mosquito net last night? (*multiple options possible)*	1. All people 2. Father 3. Mother 4. Young children 5. Girls 6. Boys 7. Visitors 8. Other	
46	At any time in the past 12 months, has anyone come into your dwelling to spray the inside walls of the house against mosquitoes to control malaria?	1. Yes 2. No 3. Don’t know	