Outdoor Malaria Transmission: Human activities and the risks of mosquito bites in rural communities of Morogoro Region, Tanzania.

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A thesis completed by published work

Submitted to the School of Public Health, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfillment of the requirements for the degree of Doctor of Philosophy (by publication)

Student number 1197596

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Candidate Declaration

This thesis is submitted in the integrating narrative format, approved by the Faculty of Health Sciences, of published work.

I, Irene Richard Moshi, do solemnly declare that this thesis is my original work. It is submitted for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg, and has not been used as a submission for any other degree or submitted at any other University. I am aware that plagiarism (using someone else's work without their permission and without acknowledging the source) is wrong and strictly prohibited in University Laws. I confirm that the work submitted for assessment for the above degree is my unaided work except where I have explicitly indicated otherwise.

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Irene Richard Moshi Date 28th October, 2019

Dedication

This thesis is dedicated to all the respondents who agreed to work with me despite their experienced fatigue in research. However, I would like to dedicate this thesis to my aunt for her support throughout my life and her dedication to help me become an educated, responsible and fearless woman.

Also, I would also like to dedicate this thesis to my late mother:

In the Loving Memory of my Mother

Flora Amos Maro

1952-2001

Thesis Material

Original peer-review publications

For all of the listed publications, Irene Richard Moshi contributed to the study design, research management, training and supervision of field workers, data collection, data management including data entry, cleaning and coding, analysis and in 2 papers she is the first author while the 3rd paper she shares the 1st authorship with another researcher:

Moshi, IR, Halfan Ngowo, Angel Dilip, Daniel Msellemu, Edith P.Madumla, Fredros O.Okumu, Maureen Coetzee, Ladislaus L. Mnyone, Lenore Manderson. Community Perceptions on Outdoor Malaria Transmission in Kilombero Valley, Southern Tanzania. *Malaria Journal* 2017; 16:274 doi:10.1186/s12936-017-1924-7

Moshi, IR, Lenore Manderson, Halfan S. Ngowo, Yeromin P. Mlacha, Fredros O. Okumu, Ladislaus L. Mnyone. **Outdoor malaria transmission risks and social life: A qualitative study in south eastern Tanzania**. *Malaria Journal* 2018; 17;397 doi:10.1186/s12936-018-2550-8

Finda, M.F., **Irene R. Moshi,** April Monroe, Alex J. Limwagu, Anna P. Nyoni, Johnson K. Swai, Halfan S. Ngowo, Elihaika G. Minja, Lea P. Toe, Maureen Coetzee, Lenore Manderson, Fredros O. Okumu. **Linking human behaviours and malaria vector biting risk in south-eastern Tanzania**. *Plos One* 2019, 14 e0217414.

Other Publications

Swai JK, Marcelina F. Finda, Edith P. Madumla, Godfrey F. Lingamba, **Irene R. Moshi,** Mohamed Y. Rafiq, Silas Majembere, Fredros O. Okumu. Studies on mosquito biting risk among migratory rice farmers in rural South-Eastern Tanzania and development of a portable mosquito-proof hut. *Malaria Journal* 2016; **15**:564 https://doi.org/10.1186/s12936-016-1616-8**Conference proceedings**

Moshi, IR, Halfan Ngowo, Alex Limwagu, Fredros Okumu, Maureen Coetzee, Ladslaus Mnyone, Lenore Manderson: Misconceptions of the community towards

outdoor segments of transmission have hindered elimination of malaria transmission in Southern Tanzania: Oral Presentation at the PHASA Conference, East London, South Africa, October 2016

Moshi, IR, Halfan Ngowo, Fredros Okumu, Maureen Coetzee, Ladslaus Mnyone, Lenore Manderson: Sociocultural factors and their contributions to mosquito biting exposure and outdoor malaria transmission: Poster presentation at the American Society for Tropical Medicine and Hygiene, Atlanta, Georgia November 2016

Moshi, IR, Lenore Manderson, Emmanuel Kaindoa, Halfan Ngowo, Maureen Coetzee, Ladslaus Mnyone: House structure and outdoor malaria transmission risks in Kilombero Valley, South-Eastern, Tanzania: Poster presentation at the American Society for Tropical Medicine and Hygiene, Philadelphia November 2017

Fellowship

Consortium for Advanced Research Training in Africa (CARTA) Fellowship for PhD valued a total amount of $120,000 USD (2014-2018)

Service and Collaborations

Providing technical advice about qualitative data collection methods to different scientists at Ifakara Health Institute and teaching of Masters students at Nelson Mandela University, Bagamoyo Campus in Tanzania.

Collaborated in writing five grant applications and we secured/succeeded in receiving funding for one grant (for 4year project) that will focus on malaria research which we will be implemented in Tanzania and Mozambique.

Peer reviewed articles for BMC Malaria Journal, BMC Public Health and proposals for European Science Foundation -Fonds voor Wetenschappelijk Onderzoek (ESF-FWO)

Abstract

Rationale

Malaria prevention and control can be attained through a combination of strategies, including vector control, responsive health systems for prompt and accurate diagnosis and treatment, community access to information and interventions, and well-financed malaria control programmes. Disease prevention and control programmes depend mostly on the nature of disease transmission; therefore, this research (together with other research) helps to determine appropriate measures to prevent the target populations from the risks of acquiring infection. Historically, malaria control strategies had focused on indoor malaria transmission, with interventions aimed at reducing transmission from an endophilic and endophagic vector. In general, frontline interventions to reduce risk and prevent transmission included long-lasting insecticide Nets (LLINs) and insecticide residual spraying (IRS) but also prompt diagnostic tests and treatment. As a result of the roll-out of these strategies, many countries have experienced a tremendous decrease in malaria transmission, giving them hope to consider the possibility of malaria elimination.

Outdoor malaria transmission has always existed in forests, fields, and around houses and animals, depending on vector species and preferred habitat, behaviour and host availability (animal or humans). Notably, there has been an increase in malaria transmission as a result of the increased outdoor host-seeking behaviour of mosquitoes that previously fed indoors. This has been associated with an increased proportion of malaria mosquitoes biting outdoors, resistance to pyrethroids (commonly used on ITNs/LLINs) occupational factors including migratory farming activities and changes in land use. The change in vector habitat and behaviour, and consequent sustained transmission of malaria, is a growing public health concern that jeopardizes existing vector control strategies in malaria-endemic countries including those in Africa. Although there has been growing advocacy for new research on vector control and interventions, minimal consideration has been given to the contribution of human practices and behaviour to outdoor malaria transmission. Feasible malaria prevention and control programmes need integrative approaches that take into account all contributing factors to the risks of malaria transmission, both indoor and outdoor, and the allocation of appropriate and effective interventions.

In Tanzania, most malaria prevention and control programmes depend on donor funding and have focused on the prevention and control of malaria indoors. Despite research findings that indicate insecticide resistance and increasing outdoor biting by malaria vectors, outdoor malaria transmission has not been addressed within the aim and strategies for malaria control nor incorporated into the current strategies of the National Malaria Control Programme (NMCP). This reluctance to address "outdoor malaria transmission" is likely because it is a relatively new phenomenon and there are few funds available to be dedicated to interventions for preventing outdoor malaria transmission .

This doctoral dissertation addresses some of the factors driving outdoor malaria transmission in areas where frontline interventions such as LLINs are widely used. I hypothesize that community knowledge on outdoor malaria transmission and prevention, and a range of behaviours and practices, might contribute to risk of infection. The four broad aims of this PhD project were to describe and analyse: community perceptions on outdoor malaria transmission; the interventions that people use while outdoors; the activities and practices that people undertake outdoors that expose them to mosquito bites; and the reasons for such practices being conducted outdoors.

Methods

The study was conducted in four villages in Kilombero Valley (two villages from each of the two districts Kilombero and Ulanga, from February 2015 to September 2016. A mixed method study was undertaken, based on a convergent parallel design approach whereby both qualitative and quantitative data collection strategies were conducted concurrently in the same phases of the research process. The mixed methods included entomological collections of mosquitoes by using modified CDC light trap and miniaturized double net trap (DN-Mini), and a range of social research methods to provide data to allow for indepth understanding of this topic. Specifically, in addition to observations of community activities and informal conversations with participants from the study communities, a) 40 in-depth interviews were conducted, with ten respondents selected from each village, b) eight key informant interview were conducted, with leaders/respected individuals from the community, and c) focus group discussions which were conducted with members of the study communities. Semi-

structured interview guides were used to conduct all the in-depth interviews (IDIs), key informant interviews (KII) and focus group discussions (FGDs) (see guides at the end of the main texts). The interview guides were used to guide the researcher/data collectors during the conversations with adults/heads of selected household, leaders of the community and wider population respectively, to capture people's knowledge, perceptions, and attitudes toward outdoor malaria transmission.

Collection of entomological data was done by using the Centres for Disease Control and Prevention (CDC) light traps. However, the use of CDC light traps was not very efficient for indoor-outdoor biting risks comparisons so the data were complemented by additional mosquito collections using a miniaturized double net trap (DN-Mini). Mosquito biting rates of all *Anopheles* species collected were analyzed, and logistic regression (LR) was performed separately for each *Anopheles* species to determine the rate of exposure to the risk of malaria transmission as per identified activities. Using graphing and analysis in R statistical software, mosquito biting rates were analysed with the use of generalized linear mixed-effects models (GLMM) separately for each species, accounting for both fixed and random factors, with log-linked Poisson error distribution, using the *lme4* package in R statistical package. A structured observation guide was also used to document all activities that were conducted outdoors, and their frequencies were correlated with the host-seeking mosquitoes collected. Mosquito collection was conducted parallel to documentation of human outdoor activities hourly from 6:00 pm to 7:00 am. To assess community knowledge, identify interventions used and activities and practices in which people engaged, thematic content analysis was used for all interviews and focus group discussions, and for notes from observations, with themes identified and responses assessed as per identified themes.

Key Findings

The results show that there is limited knowledge on outdoor malaria transmission among people in the study villages. The emphasis on adherence to interventions has concentrated on the prevention of indoor transmission through the use of frontline interventions. The main sources of information on the prevention of malaria, which still focuses on indoor malaria transmission, are information from healthcare workers in

hospitals, road and radion advertisements, fliers, and media broadcasts by the National Malaria Control Programme (NMCP) in collaboration with different donors. Prevention of outdoor malaria transmission is not included in the strategies for malaria prevention within the NMCP. While everyday domestic activities take place outdoors throughout the year, other outdoor activities such as celebrations occur seasonally and are associated with different religious, social and cultural purposes. Those that take place on a daily basis at the household level expose people on a continuing basis to outdoor mosquito biting, thus increase the risks of malaria transmission. The study results show that peridomestic activities are conducted outdoors during the evening when the host-seeking mosquitoes (malaria vectors including both *Anopheles Gambiae s.l* and *Anopheles funestus*) were collected are prevalent and actively biting. The seasonality catch of host-seeking mosquitoes indicates that during the dry season, the highest biting peak was observed among *An. gambiae s.l.* at 20:00 hrs while among *An. funestus* the highest peak was observed at 21:00hrs. During the wet season the highest peak biting time among *An. gambiae s.l.* was observed at 22:00 and 19:00hrs, but there was very limited amount of mosquito density. For *An. funestus*, the biting rate was low throughout the night with a slight peak between 22:00hrs and 0:00hrs. When comparing biting patterns indoors and outdoors, the study found that during the dry season, the biting rates for *An. gambiae* indoor started to peak at 19:00hrs with the highest peak at 21:00hrs, while for *An. funestus* there was steady biting pattern with a slight increase between 2:00hrs and 3:00hrs. During the wet season, the biting rate among *An. gambiae s.l.* started to peak at 19:00hrs with highest peak at 22:00hrs hours, when there was a very limited amount of human activities indoors, while among *An. funestus* the biting rates were still low with a slight increase at 22:00hrs hours to 0:00hrs, again, when there was a very low frequency of human activity indoors since some families sleep around 21:00hrs to 22:00hrs. Activities that took place at these times exposed people to the risk of mosquito bites; frequent exposure increased their risks of infection.

Seasonal, cultural gatherings and ceremonies are mostly conducted outdoors during the times when the host seeking mosquitoes are actively outdoors. During these activities and ceremonies, people hardly use interventions to prevent themselves from mosquito bites, thus putting people at risk of malaria infection and transmission. Although most gatherings are conducted during the dry season when there is lower vector density, gatherings associated with mourning and funerals are conducted year-round. The wet

season has high mosquito density, so the risks of being bitten and infected are particularly high during this period. Attending social gatherings and ceremonies is of great importance to people in the study communities, and their engagement maintains unity, cooperation and social cohesion. There is poor access to interventions that can be used outdoors, despite the growing evidence of increased outdoor feeding and the risks of outdoor malaria transmission. House structures characteristically have minimal or no amenities like kitchens, bathrooms, and living rooms, this contributes to spending more time outdoor conducting activities such as cooking, eating, resting, conversing and, above all, socializing. Houses have poor ventilation and during the dry season, when the ambient temperature is especially high, the houses become very hot due to the absence of ceiling boards indoors. People often find it unbearable to spend time indoors, and so people spend most of their time outdoors. Additionally, most houses have unscreened windows, eaves, and doorways, thus allowing mosquitoes easy entrance into houses; this contributes to the risk of exposure to mosquito bites indoors.

Implications

Minimal knowledge of outdoor malaria transmission risks and little or no consideration of risk or prevention of infections contributes to people's exposure to mosquito bites outdoors. Lack of attention to aspects of outdoor malaria transmission by the NMCP further hinders the integration of appriopriate strategies for malaria prevention and control. The NMCP continues to be silent on integrating these risks in malaria prevention strategies, and this jeopardizes the reduction and elimination of malaria in the country. In the study community, cultural and religious gatherings for both Christians and Moslems were conducted outdoors, but this is less significant than the changes in host-seeking mosquitoes and increases in outdoor biting, which continue to put people at risk of malaria infections year round. Social practices that involve communities, during a range of celebrations bring about socialization, improve unity and cooperation, and provide members of the community with material and financial benefits. These practices enable the study community to maintain social cohesion. Such activities cannot be actively discouraged, since these are practices that are tied to people's identity. However, improved promotion of and access to interventions for both indoor and outdoor transmission will help to reduce the risk of malaria transmission and complement existing indoor interventions for malaria prevention and control.

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List of Abbreviations

ACT - Artemisinin-based Combination Therapy

BCC - Behaviour Change Communication

CDC - Centres for Disease Control

CQ - Chloroquine

HLC - Human Landing Catches

IHI - Ifakara Health Institute

IPTp - Intermittent Preventive Treatment in Pregnancy

IRB - Institutional Review Board

IRS - Insecticide/Indoor Residual Spray

ITNs - Insecticide Treated Nets

KINET - Kilombero Net

KV – Kilombero Valley

LLINs - Long-Lasting Insecticide-treated Nets

MCH - Maternal and Child Health Care

NGO - Non-Governmental Organization

NIMR - National Institute for Medical Research

NMCP - National Malaria Control Programme

SBCC – Social Behaviour Change Communication

THMIS - Tanzania HIV/AIDS and Malaria Indicator Survey

WHO - World Health Organization

Introduction

This doctoral dissertation was written through a publication route, with the thesis consisting of three published academic papers that are preceded by a 'cover story'. These are preceded by a general introduction comprised of a literature review and methods. The results are explained through the use of three emerging research themes, and this is followed by a discussion and conclusion.

The Cover Story

I will begin by presenting the background to this study (Chapter 1). This section includes the literature review on malaria in both local and global contexts, the relationship between human behaviour and malaria transmission, a discussion of the interventions that have been put in place in various settings, including in Tanzania, and their impact on current disease trends.

This literature review also identifies and elaborates on gaps in the prevention of outdoor malaria transmission, risks of malaria transmission in the local context, and the interplay of human behaviour, health behaviour and risks of transmission. This section also justifies why this study needed to be conducted.

The conceptual research framework is then presented. This framework was developed to assist in the explanation of the complex relationship between three main factors of knowledge, attitude and perceptions, which influence human behaviour and are, at the same time, determined or affected by the environment in which people live. This section illustrates the different factors that interplay and influence prevention or exposure to infection, and describes the other factors that have an impact on the way in which interventions have been formulated. It explains the effects of these on the continued risk of malaria transmission.

In this chapter, I also present the research aim and specific research objectives that this thesis aimed to address, and central thesis themes that arose from the empirical data, and that guided the analysis and the synthesis of the research findings. These themes are: community knowledge on outdoor malaria transmission, exposure to the risk of outdoor malaria transmission at household level (proportion of exposure to indoor and outdoor transmission) and social and cultural gatherings as maintenance of social

cohesion (meanings attached to the social gatherings, risk of infection, prevention and control measures).

In Chapter 2 of this narrative, I provide an overview of the methods applied to this research, the data that were collected, and the various analytic procedures.

I have organized the results section of this thesis (Chapter 3) into two subsections. The first subsection describes the social demographic characteristics of the participants. The second subsection presents the results of this study, with the three thesis themes that emerged from the synthesis of the data. Together with the results, I present the two published papers and one manuscript that has been submitted for consideration for publication as part of this doctoral research. Section 4 is the discussion section, which explained the results thematically, in relation to the three dominant themes and the existing literature. I have also used the discussion section to suggest the use of theories and models that are applicable, affordable and sustainable, and so are able to be used in planning and allocating interventions and strategies to minimize the risks of transmission. These approaches may be used for the control and elimination of malaria through taking into account the driving factors in disease transmission and prevention. In this chapter, I have also addressed the limitations and challenges, and provided the general conclusions of the study.

Copies of the study's ethics approvals, protocols, the published papers and the abstracts of presentations, are set out in the Appendices.

CHAPTER 1: BACKGROUND AND LITERATURE REVIEW

1.0 Background

Malaria is a serious public health problem that continue to affect low-income countries and under-resourced, specifically rural, areas. The impact of malaria is especially high in low-income countries for several reasons including poor housing, which increases the risks of exposure to vectors as well as infection, because unscreened houses provide easy indoor access for mosquitoes. Additionally, small and poorly-ventilated houses mean that people conduct most of their household chores and social activities outdoors. These include cooking, eating, cleaning cooking utensils, socializing outdoors, and sleeping outdoors during very hot weather. Amenities such as bathing and toilet facilities are also located outdoors, and using them involves frequent in-out movements which provide opportunities for mosquitoes to enter indoors and bite both indoors and outdoors.

Different cultural practices and gatherings conducted outdoors impact the use of interventions. Where interventions are poorly taken up, resisted, or are ineffective, the risks of exposure to malaria transmission are increased. Despite the existence of cultural and social beliefs that hinder the use of interventions in rural settings, there is also minimal access to affordable and readily available prevention methods as a result of poor transportation and costs of the materials or manufactured product. Apart from bed nets, no other malaria intervention has been subsidized, such as repellents, and it is very difficult for people to incur recurrent costs: a topical repellent bottle of only 50 ml, for example, cannot last for even two months. In addition, the relatively high cost of seeking care contributes significantly to poor access to prompt diagnostic tests and timely treatment. There is a need to understand peoples' lifestyle choices and a need to ensure that interventions are identified and developed to fit with their circumstances and the changing nature of the environment. This includes the human use of space in different settings, animal keeping, use of the surrounding environment for agricultural production and animal husbandry, and physical environmental change, including changes in precipitation and temperature.

In the Kilombero Valley, household activities generally take place outdoors, not indoors, on a daily basis. The majority of social and cultural practices and gatherings that take place outdoors are longstanding. These did not constitute a great threat to health five decades ago, when malaria vectors were predominantly endophilic and endophagic (that is, resting and biting indoors). Consequently, malaria interventions were directed to reduce the risk of transmission indoors. Additionally, in the 1990s and early 2000s, there were a number of campaigns for malaria prevention and control (NMCP, 2008, 2002, 1997), and education packages and improved access to interventions. The introduced strategies led to mosquito behaviour change and adaptation to interventions to increase their survival. Increasing access to education on malaria prevention and interventions contributed to the reduction in malaria transmission (Bonner et al., 2011, NMCP, 2010, Schellenberg et al., 1999). However, while the roll out of interventions have contributed to the decrease in malaria transmission, the increasing use of interventions, particularly bed nets, has also led to mosquito physical and behavioral resistance. Resistance of malaria mosquitoes to pyrethroids (mostly used in insecticide-treated bed nets), occupational and social activities have increased the risk of mosquito bites outdoors (Prapanthadara et al., 1995, Ranson et al., 2011, Matowo et al., 2017, Swai et al., 2016). Mosquito behavior avoidance to interventions such as LLINs increase the risk of biting among humans (Ojuka et al., 2015, Sokhna et al., 2013, Russell et al., 2011). However, increasing population growth has led to changes in the environment for settlement and human activities, such as agricultural practices to meet basic needs which contribute to environmental changes and increases in mosquito density (Patz et al., 2000). The increasing risks of outdoor malaria transmission in the study communities are due to the presence of active host-seeking mosquitoes at times when people are outdoors, from early evening and early in the morning. Studies have shown that people within this community are frequently re-infected with malaria, thus researchers have called for reconsideration of the importance of human behaviour in the community (Dunn et al., 2011).

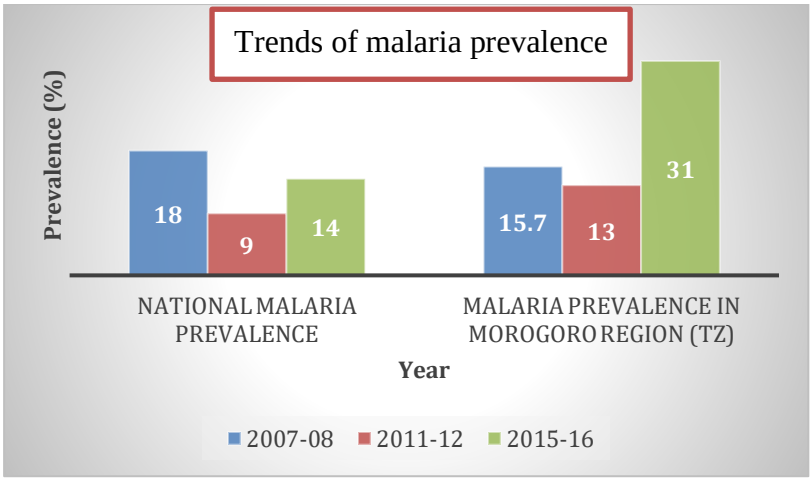
The National Malaria Control Programme (NMCP) has continued investing in interventions for malaria control and elimination by focusing on prevention of indoor malaria transmission. This has been through its public health programmes and

deployment with partners of interventions for indoor vector control, such as bednets. Other interventions such as indoor residual spraying (IRS) and larviciding, which can be used to reduce outdoor malaria transmission risks, continue to receive minimal investment. As noted by Killeen (2014), the study area experiences residual malaria transmission, and accordingly, the uncoordinated efforts to address the burden of malaria in these settings continue to increase the risks of both indoor and outdoor malaria transmission. These programmes give minimal consideration to the relationship of the intervention, human behaviour, and environment, so contributing to the causes of the changes and experiences of residual malaria transmission.

Vector control tools are important and a core aspect in preventing malaria transmission. However, human behaviour, and the social and cultural aspects of such behaviour, also need to be taken into consideration when dealing with the risks of malaria (and other infectious disease) transmission. The integration of these aspects for malaria prevention and control could contribute significantly to the reduction, control and elimination of malaria. Malaria elimination will be attained or will succeed through the use of applicable, feasible and attainable mitigation and intervention measures through national disease control health policies.

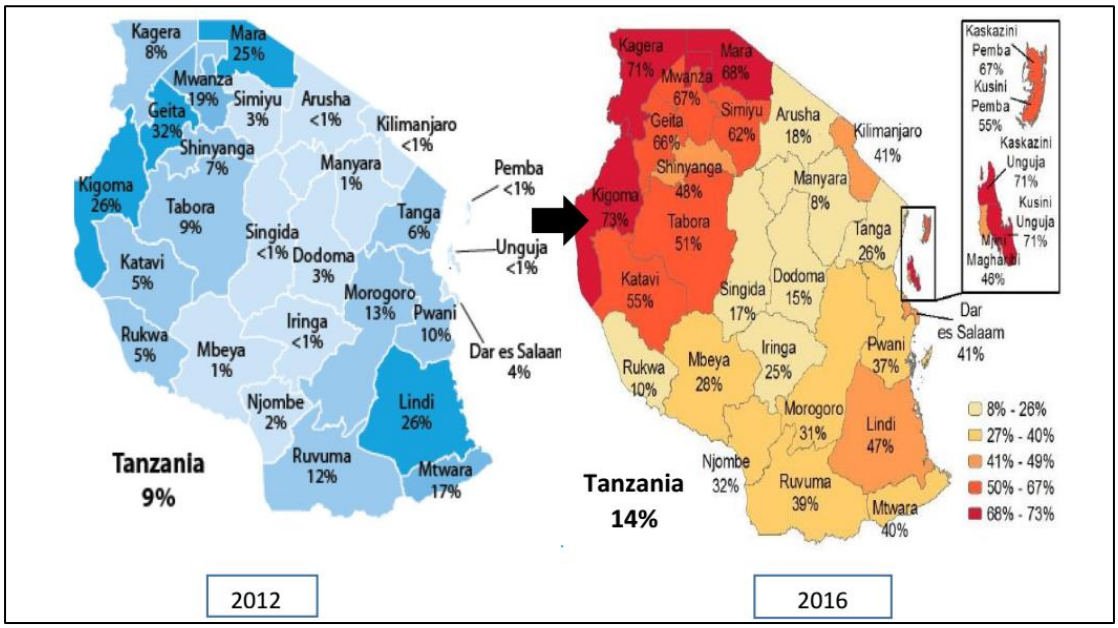
The consideration of human behaviour and practices in disease control offers a significant contribution to disease prevention, where such knowledge can be translated to enable the use of appropriate country-specific interventions. For instance, countries like South Africa and Rwanda have used knowledge on the nature of the vector and breeding sites to identify possible interventions and strategies to eliminate the disease (Sharp et al., 2007, Muheki et al., 2004). In Tanzania, the use of bed nets was particularly relevant and effective, given habitat and biting patterns of the vector, and historically bed nets have significantly contributed to the reduction of the burden of malaria. Unfortunately, the increasing use of such interventions have contributed to changes in mosquito (vector) feeding behaviour, and to an increase in the population of other species that transmit malaria that were not targeted by this one intervention. In Tanzania, as discussed in section 1.3.2 and as indicated in Figures 1.1 and 1.2 (below), there was an increase in malaria prevalence. Current prevention and control strategies still rely on earlier information on mosquito feeding patterns, without amendments in

response to updated data on changes in the vector and vector feeding patterns. Continued investment in and use of bed nets alone will not eliminate malaria due to vector resistance to existing interventions, and this will not help the country to reach its desired goal of malaria eradication. On the other hand, the current malaria changes indicate a significant increase in malaria prevalence (Figure 1.1), even in areas that were about to reach elimination targets (Figure 1.2). This increase indicates the limited effectiveness of the existing interventions in controlling and eliminating malaria in Tanzania and in malaria endemic countries, and is a threat to all stakeholders including people in the community, the NMCP, and funders. Given this, the government needs to rethink its investment in other measures for malaria prevention and elimination. Enhanced understanding of the nature of the risks of outdoor malaria transmission and prevention, as provided by this thesis, help to consider other factors that might lead to increased risk of otdoor malaria transmission and suggestions that can reduce such risks. The use of real-time data (existing updated information on malaria transmission trends) on vector feeding behaviour by malaria control programmes may contribute significantly to disease control and elimination. There is also a need for more community programmes on malaria prevention, with programmes that are based on current knowledge and information on changes in mosquito biting patterns and therefore changes in risk to being infected.



Sources: (TDHS-MIS, 2016, THMIS, 2013, 2008, THMS, 2013)

Figure 1.1**:** Trends of malaria prevalence in Tanzania and Morogoro regions, 2007 to 2016



(Source: THMIS 2012 and TDHMIS 2016)

Figure 1.2**:** Changes in malaria prevalence in children by regions in Tanzania, 2012 and 2016

There is little uniformity in how people live throughout the country, with cultural differences, beliefs, and practices distinctive of particular societies and with differences in wealth, assets, and urban/rural variation. These factors may impact the use of intervention and risks of exposure to risks of mosquito bites (Pulford et al., 2011). However, other factors such as the presence of wetlands and weather conditions provide a conducive breeding habitat in various settings and in vector survival, so influencing risk of malaria in different areas. The presence of floodplains and irrigation schemes have highlighted the need for a strategy that extends beyond the use of bed nets for controlling mosquito breeding and malaria transmission risks. There is a need to understand these diverse ecologies, communities and their impact on disease transmission risks, to allocate and support the use of interventions appropriate to the risks and patterns of transmission.

As described further below, this study used a mixed method approach to gather social and demographic data (both qualitative and quantitative) and entomological methods (CDC Light Traps and miniaturized double net trap (DN-Mini)) to obtain data on the biting patterns of vectors in this particular area. These methods were of great importance for the identification of domestic activities, social and cultural practices,

and in estimating risks of exposure to outdoor malaria transmission, as per identified activities, from early in the evening to late at night and again early in the morning. This combination of data was important to understand the factors that are associated with the risk of exposure to outdoor malaria transmission, including practices and living arrangements, and to identify the patterns and possibilities of intervention use at household and community levels. The data collected, as I will describe in this thesis, enabled me to identify gaps in intervention use and to consider how to develop and allocate appropriate interventions that target the existing risk factors of malaria transmission. Understanding these risks in the context of a changing environment and biting patterns is of great importance for malaria control and elimination. In this study, the focus was on the estimation of risks of exposure to mosquito bites at a household level in both dry and wet seasons, and the risks associated with ceremonies and social gatherings that are mostly conducted outdoors during the dry season. Logistic regression was performed separately for each species of mosquito to determine the rate of exposure to the risk of malaria transmission as per identified activities, to provide evidence of such exposure in human outdoor activities.

The main contributions of this thesis were to (i) address a gap in studying the relationship between human behaviour, knowledge of intervention use, and in understanding risks in the environment on outdoor malaria transmission, (ii) identify and describe human outdoor activities and their contribution to exposure to outdoor malaria transmission, (iii) identify and describe community gatherings and ceremonies that contribute to outdoor malaria transmission risks, and (iv) address the importance of using a multisectoral approach to prevent and control malaria through the use of updated/current data on vector biting patterns, feeding behaviour, and environment differences.

1.2 A Conceptual Framework

Social ecological theory helps to explain the importance of taking into account the wide range of environmental and societal aspects of prevention, maintenance, and control of disease. This model was developed by American sociologists, but was later changed and developed by Bronfenbrenner (1994). The theory focuses on providing people with an opportunity to understand the dynamic interrelationships of various personal and environmental factors. People's behaviour is influenced by different factors that exist

in the environment in which they live, including range of social norms and cultural beliefs context, political and economic conditions. The model helps to explain the importance of above factors and how it affects peoples' relationships and impact to the community. The model identifies important factors and illustrates their interrelationships, so providing insight into the dynamics that influence the presence of diseases in particular settings. The inclusion of social, institutional and cultural contexts enables us to develop interventions that are based on local factors, and so have the potential to lead to a sustainable solution to a particular problem. This theory goes beyond social cognitive theories that are based on three main dimensions including: person, behaviour and environment, which are central factors to the way an individual behaves (Bandura, 1991). All these factors contribute to how an individual behaves, but to develop interventions applicable to a community, there is a need to consider wider contextual factors that interplay with, impact on and influence human behaviour.

Awareness is crucial in behaviour change, so when people are made aware of particular practices that expose them to infection or illness, the expectation is that they will change their behaviour. Several theories of human behaviour assume that access to adequate information on health risks will influence behaviour, but such information sometimes only creates the preconditions for change without necessarily leading to change. This is partly because personal influence is required to overcome the obstacles which might prevent the desired health behaviour. This approach overlooks the importance of the social environment and the role that this plays in influencing behaviour and so enabling (or inhibiting) behavioural change. Another crucial element which influences such change is perceived self-efficacy which Bandura (1997) refers to as one's ability to formulate a certain behavior and adhere to a set of actions that are appropriate to produce a certain required goal. Individual belief to attain certain goals is crucial in facilitating change, although even if people have the skills required to change, they may not believe they can change their circumstances or that it is necessary to do so, and in consequence the whole process of change is jeopardized. Bandura emphasizes that what matters is the cognitive belief in the ability to perform or overcome certain challenges, because this may facilitate change. However, this approach assumes that changes are embedded in and depend on individuals. This approach minimizes the role of society as a whole. Individual understandings of disease, including vulnerability and

susceptibility to malaria, have successfully influenced people's behaviour and their uptake of interventions.

In addition, mosquito behaviour changes and insecticide resistance have been observed to be a major problem including in the Kilombero Valley in Tanzania and elsewhere in SSA (e.g. Bioko in Equatorial Guinea) (WHO, 2013, Reddy et al., 2011, Russell et al., 2011). So, with changes in ecology and the increase in outdoor biting, the social-ecological model appears to be the best approach for reducing, controlling and elimination of the disease. To reduce and eliminate malaria, Panter and colleagues (2006) have proposed that programmes for malaria control should adopt and use the social-ecological model. The approaches embedded in the model do not focus only on human behaviour, as one factor which is subjected to change in order to reduce diseases, but rather they also focus on different factors such as the community, family, infrastructures, physical and social environment, politics and culture. The model recognizes that there are constraints on human behaviour, and these need to be addressed to facilitate community mobilization and target those willing and able to change. In addition, this model emphasizes that in formulating, implementing and evaluating health interventions, there is a need to take into consideration all the necessary factors that affect or impact on human behaviour in a particular setting. In this way, the model provides an opportunity to develop interventions that are culturally compelling and appropriate to the social, economic and environment.

It is important to link what might be regarded as people's actual behavior, the need/purpose to change behaviour and expected health impacts that lead to behaviour change. Panter-Brick and colleagues (2006) have added that, in each strategy, there is a need to formulate and use a framework in which other interventions and strategies can be able to use the design or implementation and evaluation methods in a wider context (Panter-Brick et al., 2006).

People and societies change, cultures differ even in the same country and environment. As a result, the intensity and risks of disease transmission are also different. So, health interventions should consider social and economic landscape as well as the local ecology of the target communities (Panter-Brick et al., 2006). This approach will lead to successful behaviour changes which are acceptable, affordable, effective and sustainable. Figure 1.3 below shows the social and ecological aspects that disease

control agencies need to take into account when prevention, maintenance and control of disease is concerned.

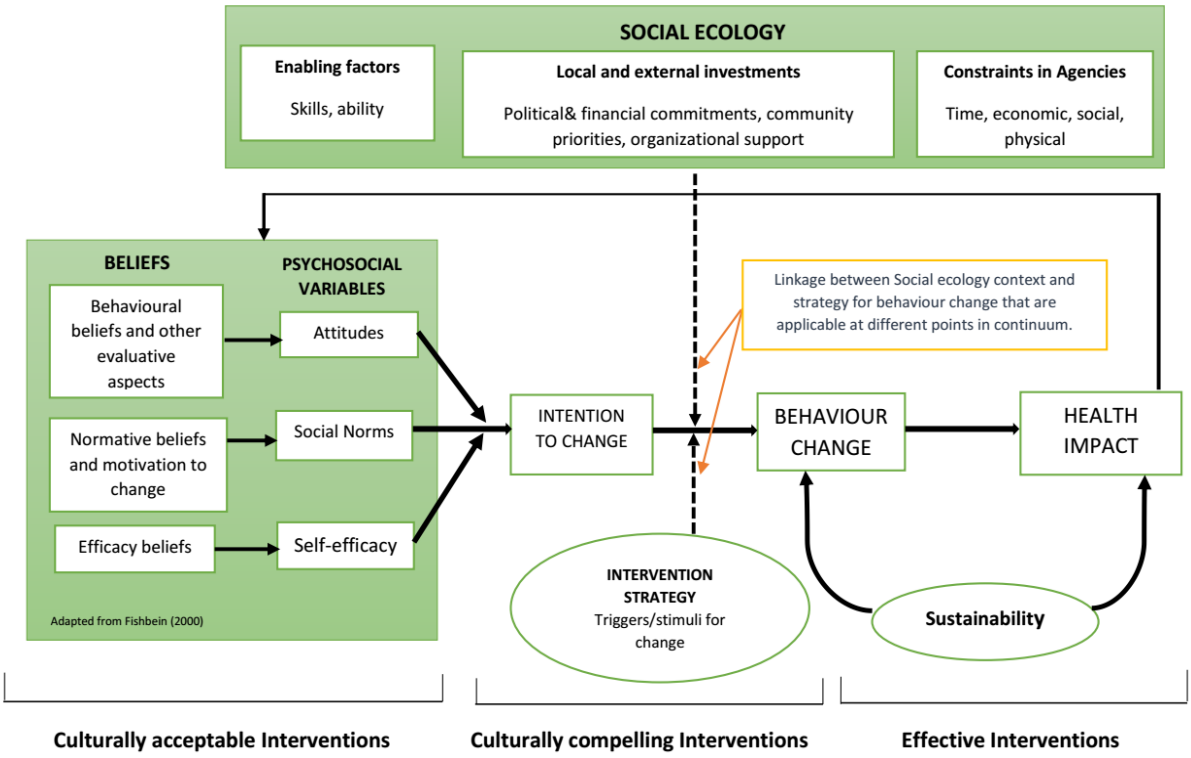


Figure 1.3: A conceptual framework as adopted from the social ecological model of behaviour change, for culturally appropriate, culturally compelling and effective interventions. Adapted from Panter-Brick and colleagues (2006) to be used for prevention and control of outdoor malaria transmission.

1.3 Literature Review

1.3.1 Global overview of malaria

Mosquito-borne diseases including lymphatic filariasis, dengue fever, Rift Valley fever as well as malaria are major public health concerns, affecting millions of lives (Table 1.1). Bites from infectious female *Anopheles* mosquitoes with *Plasmodium species* (*spp)* that transmit malaria to humans (Miller et al., 1994). The disease affects people worldwide, the majority living in tropical and subtropical areas where environmental conditions favour the existence of the vectors. However, the four species of *Plasmodium* parasites namely: *P. vivax, P. malariae, P. ovale and P. falciparum* cause variations of malaria worldwide (Gillies and De Meillon, 1968, WHO, 2011a). Among

these, *Plasmodium falciparum* was proven to be the most life-threatening, and is responsible for 86% of all severe cases and mortality, primarily in sub-Saharan Africa (WHO, 2009). However, another type of *Plasmodium* species has recently been identified in Asia, called *Plasmodium knowlesi.* This species has been identified as having a much higher fatality rate, and results in malaria cases that are much more severe, than those caused by *P. vivax* and *P. malariae* (Kantele and Jokiranta, 2011, Collins, 2012, Cox-Singh, 2012, Cox-Singh et al., 2008, Ahmed et al., 2014).

Table 1.1: Mosquito-borne diseases worldwide and estimated DALY (in thousands).

	DALYs 2013	95% confidence interval
Malaria	65493.1	53064.9–79960.7
Lymphatic filariasis	2022.1	1096.3–3294.4
Dengue	1142.7	727.6–1978.2
Yellow fever	30.7	25.3–37.1
Other neglected tropical diseases* (including other mosquito-borne viral fevers)	3132.7	2328.1–4208.7
Encephalitis** (including mosquito-borne viral encephalitis)	4804.2	4022.4–5926.9

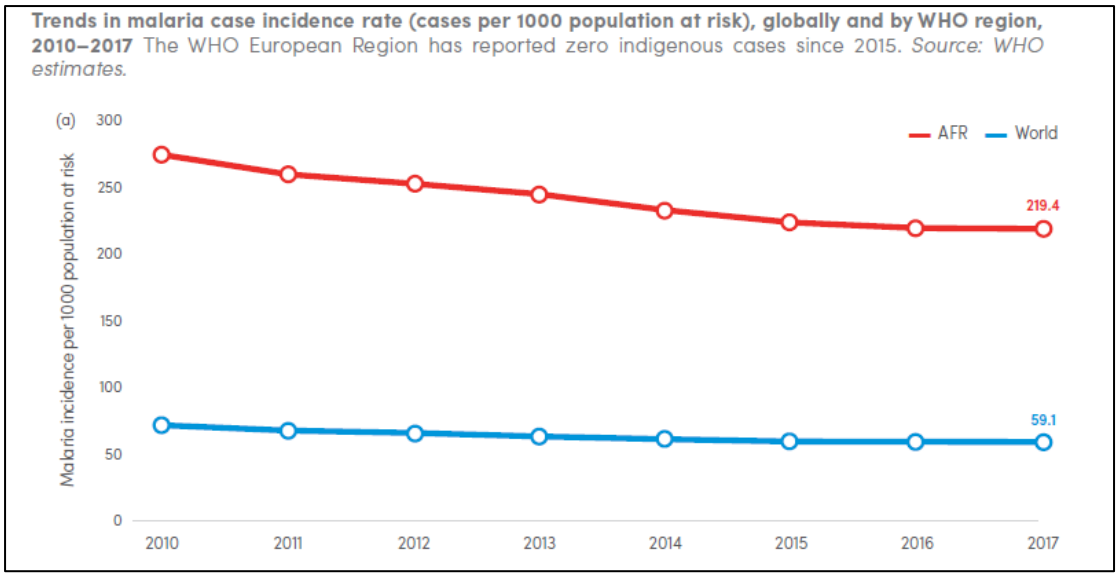
Source: (Murray et al., 2013)

Notes: DALYs are the sum of years of healthy life lost to premature death and years lived with disability. *Including also tick-borne disease and several minor helminthiases (complete list of diseases in Annex of GBDS 2013), (Murray et al., 2013).

To reduce the effects of malaria and saves lives, for well over a century, a range of measures have been put into place. Early public health interventions included environmental management (clearing streams, putting oil on water); more recent interventions have included long-lasting insecticide-treated bednets (LLINs), indoor residual house spraying (IRS), preventive treatment methods for pregnant women as well as timely diagnostics and treatment with artemisinin-based combination therapy (ACTs) (WHO, 2010). The above measures and strategies led to the recent successes in the global decline of morbidity and mortality. These strategies were successful in attracting political commitment and government financial support to the fight against the disease in malaria-endemic countries including Tanzania. However, the financial

commitment from the Tanzanian government has not been enough to sustain programmes countrywide, and so most of the programmes still depend on donor funding (NMCP, 2014).

In 2000, malaria caused approximately 300 to 500 million clinical cases worldwide where Sub-Saharan Africa accounts for 90% of all total cases (WHO, 2003). In 2010, WHO indicated that malaria had caused approximately 237 million cases, which decreased to 211 million cases in 2015 but then began to rise again: 216 million cases in 2016, 219 million cases in 2017 (WHO, 2018). In 2000 the estimated deaths due to malaria was 839,000; this had dropped to 446,000 in 2015 and continued to decrease to 445,000 in 2016 and 435,000 deaths in 2017 (WHO, 2016, 2018). The significant portion of all malaria cases and deaths were from WHO African countries which accounted 88% and 90% of all cases and 90%, 91% and 93% of all deaths in 2015, 2016 and 2017 respectively (WHO, 2015b, 2016, 2017) as indicated in Figure 1.4. The reduction in mortality is contributed by the use of vector control tools such as ITNs, prompt diagnostic tests and treatment by ACTs. Despite this substantial decrease, as indicated in Table 1.2, the disease has significant contribution to child death, which accounted for 303,000 deaths in under-five children in 2015 and 266,000 estimated deaths in 2017 and disease burden in many developing countries (WHO, 2018).



Source: WHO, World Malaria Report 2018.

Figure 1.4**:** Trends in malaria case incidence worldwide

Table 1.2**:** Estimated number of malaria deaths according to world regions.

Estimated number of malaria deaths by WHO region, 2010–2017 *Source: WHO estimates.*

	Number of deaths							
	2010	2011	2012	2013	2014	2015	2016	2017
African	555 000	517 000	489 000	467 000	446 000	432 000	413 000	403 000
Americas	480	450	400	400	300	320	460	630
Eastern Mediterranean	8 070	7 280	7 340	6 750	8 520	8 660	8 160	8 300
European	0	0	0	0	0	0	0	0
South-East Asia	39 800	32 800	28 400	21 800	24 100	25 200	25 600	19 700
Western Pacific	3 770	3 340	3 850	4 600	4 420	2 860	3 510	3 620
World	**607 000**	**561 000**	**529 000**	**500 000**	**483 000**	**469 000**	**451 000**	**435 000**
World (children aged under 5 years)	**444 600**	**405 000**	**371 000**	**344 000**	**322 000**	**302 000**	**283 000**	**266 000**

WHO: World Health Organization.

Source: WHO, Malaria Report 2018

Investment for malaria control and elimination is crucial to reduce malaria infection, cases and deaths, but investment has not yet reached the estimated annual budget in 2008 by the Global Malaria Action Plan of about US$ 5.6 billion to reach the targets for malaria control (Malaria, 2008). There is a substantial increase in malaria investment from US$ 2.5 billion in 2009 to US$ 2.9 billion in 2015, US$ 3.1 in 2017; the estimated annual budget is US$ 6.6 billion for 2020 (WHO, 2016, 2018, Malaria, 2008, Patouillard et al., 2017). Thus, governments in malaria-endemic countries need to increase funds for malaria programmes to maintain malaria prevention and control activities, including to address several existing problems such as inaccessibility to interventions such as ITN or IRS for vulnerable groups and the general population, and to ensure effective surveillance systems. Together with other interventions such as environmental management and use of malaria prophylaxis, these activities are essential to maintain the earlier attained success. The integrated approach is of great importance to reduce malaria transmission but it will also have a significant contribution to health and socioeconomic development in most malaria endemic countries as it is considered to be a contributory cause of poverty (WHO, 2011b, Gallup and Sachs, 2001) in malaria-endemic countries.

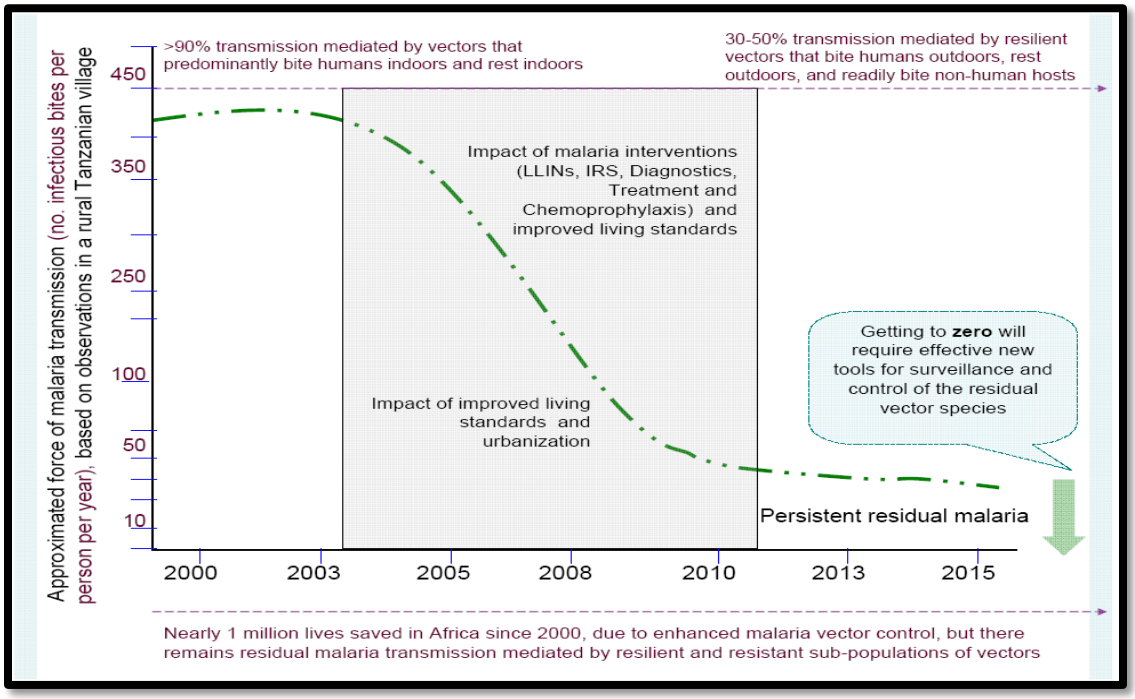
Malaria has been among the leading cause of morbidity and mortality in Tanzania (MoHSW, 2013) where more than 50% of the total population is at risk of malaria infection (Mboera et al., 2007). Even with the scale-up of frontline interventions, more than 90% of Tanzania population (54,551,284 people out of 55,155,473) is at risk of malaria infection. In 2016 there were 5,188,505 confirmed malaria cases and 5,046 reported malaria associated deaths (WHO, 2017). Due to the increasing behavioral resistance of mosquitoes to existing interventions such as LLINs, currently malaria endemic countries are shifting from pyrethroid insecticide for IRS to other expensive insecticides (WHO, 2017). New developed interventions should consider the use of organophosphate pirimiphos-methyl for IRS since no vector resistance have been reported. Although this new formula is expected to be more effective, it is extremely expensive and exceeds the annual budget of the NMCP in the country (WHO 2015). So, the implementation of the widespread use of IRS in Tanzania is still in question;other methods and interventions, such as insecticides which are not pyrethroid based, cheap and affordable, are highly encouraged to address risks of disease transmission.

1.3.2 Distribution and impact of intervention measures in place

As already argued, disease control measures that target both humans and vectors have a significant contribution to disease reduction and control. In rural settings, patterns of disease transmission and means of prevention may be different from those that apply in urban areas due to different living conditions, breeding habitats and, locational benefits of people living in urban areas in accessing drugs, services, education (Geissbühler et al. (2009) and benefits from disease control and prevention activities (Alirol et al., 2011). However, there are different ways that people interact with the environment in rural and urban areas in terms of land use for income generation, such that in rural areas agriculture is among the main activity for subsistence and income generation. In some areas, agriculture practices, resulting in the continued presence of breeding habitat, lead to increase in mosquito density (Lindblade et al., 2000) especialy in rice and sweet potato farming. In Kilombero Valley, seasonal farming that involves farmers living in shamba huts in the fields expose them to a greater risks of mosquito bites than is the case when they are in villages (Swai et al., 2016). However, most houses in the villages/rural areas are not screened, compared to improved screened houses in urban areas which reduce mosquito entry and contribute to reduction in

malaria transmission (Ogoma et al., 2010, Lindsay et al., 2003a, Lwetoijera et al., 2013). Also, people in rural areas are more likely to be exposed to mosquito bites and malaria infection, because of environmental factors which favour mosquito breeding habitat, minimal access to interventions and inability to afford various interventions due to financial constraints (Bousema et al., 2010). Although access to interventions and services alone does not guarantee disease prevention and its elimination, it contributes significantly to disease control. But the rate and possibility of infections depends on the existing vectors, species distribution, habitat and mosquito biting behavior.

Generally, despite differences according to location, interventions have made a remarkable contribution to disease control, prevention and reduction in malaria cases in Tanzania, as indicated in Figure 1.5 As already described, these interventions include LLINs, IRS, prompt diagnosis and improved access to effective treatment, usually artemisinin-based combination therapy (ACT) as the first-line malaria treatment. These combined approaches have contributed to more than 50% decrease in child mortality associated with malaria in many countries, Tanzania, inclusive which was the main target for the Millennium Development Goals (THMIS, 2012). Other strategies including chemoprevention, particularly intermittent preventive therapy for pregnant women (IPTp) through the use of sulphadoxine-pyrimethamine (SP) (antimalarial drug), which is administered twice during the second (20^{th} -24^{th} week) and third trimester. Other strategies including house screening (THMIS, 2013) and larval source management have reported successes in some settings, but are given little attention by NMCP and other stakeholders in Tanzania (De Castro et al., 2004, Geissbühler et al., 2009). On the other hand, weak health systems, poor preparation and interpretation of diagnostic results, limited community involvement and inadequate local budgets for NMCP continue to limit progress in disease control.



Source: (Okumu, 2014)

Figure 1.5: Diagrammatic representation of progress made against malaria over the past decade and the role of residual vectors on persistent malaria transmission. The approximate values are based on observations in the Kilombero Valley, south eastern Tanzania.

Whereas historically, *Anopheles gambiae* was the dominant vector in Kilombero Valley (Kaindoa et al., 2017), currently, other *Anopheles* species, such as *Anopheles funestus*, have become significant malaria vectors in parts of Tanzania. There is now an increasing risk of transmission both indoors and outdoors before going to bed, which cannot be targeted by existing interventions (Milali et al., 2017). This indicates the need for new interventions that can target the remaining risks of transmission.

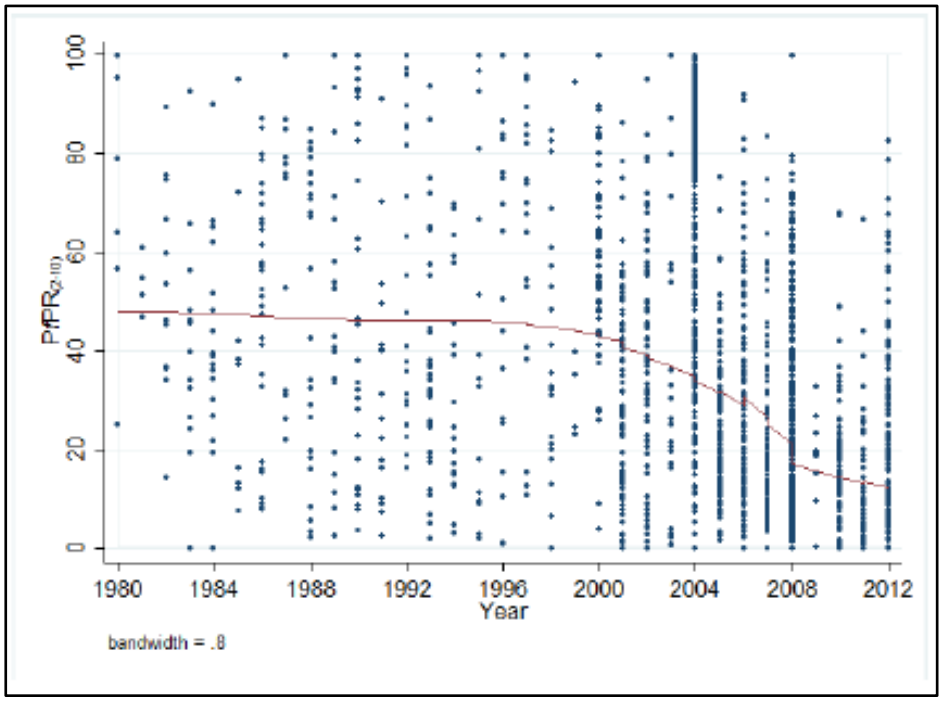
Public health researchers have been involved in studies on human behaviour and behaviour change in understanding disease transition, control and prevention (Atkinson et al., 2010, Beer et al., 2012, Chibwana et al., 2009, Dadzie et al., 2013, Hlongwana et al., 2009, Mwenesi, 2005). These include behaviour change studies based on different models to explain the role and importance of human behaviour in transmission and prevention of diseases as far as health behaviour is concerned, as described above. Different studies have used ethnographic methods to understand the factors that

underpin behaviours in several geographical and social locations. Other studies have used knowledge, attitude and practice instruments to establish and relate different disease transmission risks (Rutta et al., 2012, Mazigo et al., 2010), prevention, and the use or non-use of interventions in different societies (Panter-Brick et al., 2006).

Currently, there is a growing interest in understanding human behavior that contributes to disease transmission or prevention by using multiple methods or approaches. In this study, both qualitative and quantitative approaches were employed to help describe and analyze the contributions of human behaviour, practices and activities to malaria transmission risks. We assessed community knowledge, views, and perceptions regarding outdoor malaria transmission, and interventions that people used outdoors to protect themselves from mosquito bites. As explained in Chapter 2, these data were complemented by documented overnight biting pattern of host-seeking mosquitoes, which were collected at the times that people were conducting different activities outdoors. The correlation of mosquito biting pattern data, and the frequency of evening human outdoor activities help to understand risks of malaria transmission (as a proxy of risk of malaria transmission) as a result of outdoor activities.

1.3.3 Malaria status in Tanzania

In the first decade or so of this century, malaria prevalence in Tanzania declined by 50%: from 18.1% in 2000 to 9% in 2012. This has been explained to be the result of several strategies such as LLINs, IRS, and prompt diagnosis and treatment (THMIS 2012), although the decline was said to have started even before the scale-up to intervention in 2000, as indicated in Figure 1.6. The prevalence estimation over the years was established by using the Locally Estimated Scatterplot Smoothing (LOESS) method. This tool used to generate data to enable the creation of a smooth line through scatterplots, to allow visualization of trends and relationships between variables (Cleveland, 1979).



Source: (NMCP,WHO,IHI 2013)

Figure 1.6: Loess regression line of 2193 survey data points (from parasite cross-sectional survey data) assembled between 1980 and 2012.

Major efforts that account for the initial decline in malaria prevalence focused on prevention and control of malaria through the Hati Punguzo scheme, whereby people used vouchers, with a very small contribution of their own, to get bednets from accredited shops at a very low price (Hanson et al., 2008). The Hati Punguzo scheme was introduced in 2004 in Kilombero Valley and was extended to other parts of the country in 2006 ((Tanzania), 2002, Hanson et al., 2008, SMARTNET, 2005). It was then followed by universal free bed-net distribution, which aimed to ensure that nets covered all sleeping places in the country (Renggli et al., 2013). However, in 2016 the HIV/AIDS Malaria Indicator Survey (THMIS) showed that the malaria prevalence rate had increased by over 50%, from 9% to 14% (as indicated in Figure 1.2), despite the universal distribution of interventions. The survey results also indicated a decrease in bednet use from 72% to 54% among children under the age of five years, and a decline in bed net use also among pregnant women from 75% to 54% (TDHS-MIS, 2016). Although this indicates that there may be individual behavior resistance to bed net use, the reasons for such decline are still unknown.

Bednets were the leading contributor to the decline in malaria prevalence, incidence and deaths until 2012, and remained the leading intervention despite their decline in use and questions about their effectiveness. Several challenges exist, such as insecticide resistance, which threaten the performance of bed nets (Ranson and Lissenden, 2016). Mosquito avoidance behaviour to pyrethroid-based interventions such as insecticide-treated bed nets and IRS, and other factors such as environmental changes have contributed to increasing outdoor biting early in the evening and early in the morning (Russell et al., 2011). Other challenges that hinder malaria elimination include weather changes, poor and uncoordinated responsive systems for detection, surveillance and disease management due to insufficient funding for malaria programmes, which affect drug stocks in health facilities, poor infrastructure (health facilities that are not of good conditions and poor accessibility due to presence of seasonal roads), and unskilled personnel (the presence of health workers who are not well qualified as in rural areas most health facilities are headed by medical attendants and not doctors). These factors all affect existing efforts in the management, prevention, control and elimination of malaria (NMCP, 2014). Population increase, increases in land use and poor agricultural methods have all contributed to increases in mosquito density, and other species such as *An. funestus* who are becoming more significant in malaria transmission (Kaindoa et al., 2017). In addition, a study by Milali et al. (2017) has indicated that the risk of malaria transmission from mosquito bites can occur any time regardless of time of day. So, high concentration on bed net use only, will continue to put people at risk of exposure to malaria. Thus, indicates the need for area-specific interventions for existing malaria vectors that are not targeted by existing interventions, as indicated above in Figure 1.2.

1.3.4 Malaria control strategies and their impact

As already described, nearly two decades ago, malaria-endemic countries adopted several malaria control measures and management, including the distribution of untreated bed nets (Killeen et al., 2007b). Later, from 2004-2011, ITN and LLINs were distributed, with a major bed net use and scale up campaign from 2009 targeting all sleeping places in Tanzania (NMCP et al., 2013, Mulligan et al., 2008, Alba et al., 2011), These strategies led to an increase in bed net ownership and use (TDHS-MIS,

2016, THMS, 2013), and this, together with increasing use of insecticide residual spraying (IRS), contributed to the reduction of indoor malaria transmission.

These vector control measures were estimated, by treatment, if required, with the use of antimalarial drugs such as chloroquine. Chloroquine was replaced by SP (sulfadoxivne/pyrimethamine) as the first-line antimalaria drug in Tanzania in 2001 (Eriksen et al., 2005), due to increased parasite resistance to chloroquine (Taverne, 2001, Abdulla et al., 2000, Breman et al., 2004, Mutabingwa et al., 2001). Later, due to increased drug resistance, the first line antimalaria drug was changed from SP to ACTs. The introduction of ACTs led to the reduction of malaria morbidity and mortality in most malaria-endemic countries, including Tanzania (Bhattarai et al., 2007, Ceesay et al., 2008, O'Meara et al., 2008, Chizema-Kawesha et al., 2010, WHO, 2014).

As already described in sections 1.1.5 and 1.1.6, in the early 2000s, bed nets were distributed country wide. In 2004 a survey conducted in Ifakara in the Kilombero Valley and reported that household net ownership was more than 80%, rising from 37% in 1996 and indicating a rapid increase in net ownership as a result of a social marketing programme (NMCP, 2013). The social marketing campaign, focusing on increasing distribution of bed nets and insecticides, was managed by a private organization but under the directives of the Ministry of Health and with the involvement of researchers based in Ifakara in Kilombero Valley. This social marketing approach had already been used in health programmes in the area in the 1980s and 1990s to influence changes in human behaviour associated with malaria transmission (Kortler and Roberto, 1989). The Kilombero Net Project (KINET) was based on information from studies on human behaviour, transmission, disease trends and prevention methods conducted within the area (Abdulla et al., 2001, Abdulla, 2000, Lalvani et al., 1996). That information led to an understanding of people's knowledge of malaria, perceptions, and interventions used, which led to a proper set of programme goals. This understanding provided a base for designing the message behind the products, so achieving high product acceptability, as described by Minja et al. (2001b).

In 1997 and 2004, evaluation studies were conducted in the Kilombero Valley: after the massive distribution of bednets through the KINET social marketing programme in 1996, and before the mass distribution of insecticide-treated bednets (Abdulla, 2000, Lalvani et al., 1996, Abdulla et al., 2001, Kabanywanyi et al., 2008, Killeen et al.,

2006), to estimate the contribution of bednets in the reduction of malaria transmission risks. This study used the human landing catches (HLC) method which was conducted by Killeen and colleagues (2007b), in different villages in the Kilombero Valley. The study established that bednets provided about 75% protection from disease transmission, not only to the individuals using nets within the households but also within the community, through reduction of parasite transmission within the human population, mosquito abundance and vector survival (Killeen et al., 2007b).

However, evidence suggested a significant contribution of IPTp in the reduction of maternal and neonatal deaths (Menéndez et al., 2010, Menéndez et al., 2007, WHO, 2013). Despite the IPTp contribution in reducing the risk of transmission among vulnerable groups, mass education was not provided as it was for bed nets. The dissemination of information on the importance of IPTp was left to health workers, particularly those in the Maternal and Child Healthcare (MCH) section, even though sometimes they may not even provide the dose to pregnant women. A study conducted by Nganda et al. (2004) in Kibaha District Hospital in 2003 found little additional impact of IPTp in reducing transmission compared to bed nets, because pregnant women were not receiving the required dose. A similar study was conducted in the Tanga Region of Tanzania (Anders et al., 2008), observed that pregnant women who visited the clinic had no information or knowledge about the importance of the drug or the dose to be administered. The authors also found that the required dose in the twentieth to twenty-fourth week was not being administered in the study clinic. Despite the importance of this S/P dose at that stage, it was advised that the dose instructions should be revised and that the drug should be provided earlier than the twentieth week because at that stage, pregnant women are already at risk of malaria infection, and the infection contributed to anaemia in pregnancy (GBCHealth, 2012). The study also revealed that the irregular treatment of pregnant women with chloroquine was contributed by drug stock-outs and poor adherence to CQ medication (pregnant women did not finish the required dose). These factors contributed to drug resistance, leading to the use of sulfadoxine-pyrimethamine (SP) as the primary treatment drug for malaria prevention among pregnant women (Anders et al., 2008). Although SP was found to have low therapeutic value in many parts of Tanzania, it continue to be used because of its good safety profile (Mugittu et al., 2005) as compared to chloroquine. It has also

een found to reduce the risks of placental malaria and anaemia among pregnant women (Schultz et al., 1994, Sirima et al., 2003).

In 2013, the trends for IPTp administration were still observed to be low (Thiam et al., 2013), even though antenatal care attendance was high (WHO, 2014). For required health care services, health workers are expected to be knowledgeable on reasons for such changes, but in these settings, this was not the case. Therefore, it is not surprising that the use of IPTp in 2012 had increased only to 31.4 % from 22% in 2005 (THMIS, 2012), while in 2015 only 35% of the pregnant women received one dose and only 8% received all recommended three doses (TDHS-MIS, 2016). This is a clear indication of the poor implementation of agreed strategies for malaria prevention, and control will take long time to materialize. The timely availability and arrival of funds to the facilities, as well as education and training to the health providers on the importance of use and provision of education to users, are of great importance (Mubyazi et al., 2005). These practices have significant impact on increasing the uptake of IPTp in order to reduce malaria among pregnant women.

1.3.5 Changes in mosquito behaviour and malaria transmission risks

As noted, the effective protection provided by ITNs and IRS can only be realized when transmission occurs indoors, primarily while people are in bed (Russell et al., 2011). However, the increasing use of ITNs and IRS has resulted in insecticide resistance among *Anopheles* species mosquitoes, as observed in Mwanza and others in Tanzania (Kweka et al., 2013, Mboera et al., 2013). However, other factors such as environmental changes, the existence of behavioral resistance among mosquitoes to existing interventions, has contributed to increased outdoor biting rates and early peak biting behaviour of mosquitoes in endemic areas in Tanzania and elsewhere in SSA [e.g. Equatorial Guinea (Russell et al., 2011, Reddy et al., 2011)]. Outdoor biting is not a new phenomenon, but the increased outdoor biting rates has become an important factor to be well evaluated to prevent malaria transmission risks. Even though Bradley and colleagues (2015) claims that there is no transmission associated with outdoor biting, in areas where there is high use frontline interventions and continued frequent malaria infections, it is important to evaluate the possible causes and find immediate solutions *to save lives. On the other hand, McLaughlin et al. (2019) explained that, the risk of*

outdoor biting exist and requires other interventions to target mosquitoes who cannot be targeted by existing interventions.

However, studies have also noted an increase in outdoor biting among *An. funestus (Kaindoa et al., 2017).* These changes indicate the limited ability of the interventions in place in preventing and controlling malaria. Traditionally, *An. funestus* prefers to bite indoors and to be active when people are asleep, but by 2009, indoor biting tendencies had reduced compared to outdoor biting, and their peak biting activity had moved from late at night to early evening. Similarly, a study done in Zanzibar Island in Tanzania, have also identified that, there is a major shift toward outdoor biting by *Anopheles Arabiensis(Björkman et al., 2019)*. In addition, biting early in the evening and early in the morning among malaria vectors in Solomon Island was also noted to occur among *Anopheles farauti* which was also observed to bite indoors late at night (McLaughlin et al., 2019).

In the Kilombero Valley, where this study was conducted, the primary vectors were members of the *An. gambiae* complex. This group of vectors comprises several sibling species including two behaviorally distinct species, *An. gambiae sensu stricto (s.s.)* and *An. arabiensis*. *Anopheles gambiae sensu stricto* is originally a forest dwelling mosquito which is mostly endophilic, while *An. arabiensis* prefers mostly the dry savanna and most often exophilic, but is also opportunist (Gillies and Coetzee, 1987, Gillies and De Meillon, 1968). Mosquito behaviour was again observed to have changed from indoor to outdoor biting, with a shift in peak biting time from post-midnight to biting later at night, when it was almost dawn (Moiroux et al., 2012). These studies suggest the need for outdoor measures to protect people from infection and disease transmission.

Although the strongest evidence of mosquito behaviour change relates to insecticide resistance, the observed resistance and changes in mosquito behaviour may also be influenced by other factors, such as climate and environmental changes. For example, a study conducted in the Kabale District in south-west Uganda observed an increase in the number of *An. gambiae s.l.* as a result of ongoing human activities which contributed to increase in environmental temperature. The changes involved replacing the swampy vegetation with agriculture land, leading to changes in temperature from moderate to high temperatures that facilitated malaria transmission in that area

(Lindblade et al., 2000). Deforestation and human activities contribute to the greenhouse effect, thus, led to the rise in temperature and changes in precipitation, influencing mosquito breeding habitats, survival and distribution (Norris, 2004, Patz et al., 2000, Martens et al., 1995). This is because clearing land leads to changes in the ecosystem (temperature, humidity, vegetation and sunlight) which lead to high temperatures that favours mosquito breeding habitat (GBCHealth, 2012). Changes in vegetation affect even the existing microbes in the areas as a result of land use modifications such as dam construction, irrigation systems schemes (monitored and unmonitored), and deforestation. These land use practices also make significant contributions to the increase in mosquito population densities and changes in distribution. However, majority of irrigation schemes create a conducive environment for mosquito breeding and survival. In addition, despite the significant contribution of pesticides in agriculture activities and biotechnology farming in agricultural produce, the use of insecticides also contributes to the increasing risks of malaria transmission (GBCHealth, 2012). Thus, better and safe agricultural practices are highly encouraged to reduce the risks of malaria infection.

1.3.6 Malaria in rural Kilombero Valley, Tanzania

In the 1990s, malaria transmission in Kilombero Valley was very high, with an average entomological inoculation rate of about 300 infectious bites per person per year (Smith et al., 1993a), and an expected malaria prevalence of more than 70%. Despite the presence of other diseases such as tuberculosis, yellow fever, lymphatic filariasis, and HIV (Geubbels et al., 2015), malaria was the leading health problem in the area. In 1996, the Kilombero and Ulanga Net Project (KINET) was introduced to try to reduce human-mosquito contact in order to minimize the effects and impact of malaria (Marchant et al., 2002, Minja et al., 2001b). KINET was introduced after a survey study was conducted which identified the risks of malaria transmission and barriers to intervention use (Schellenberg et al., 1999, Minja et al., 2001b). The distribution of nets, supported by a social marketing campaign that distributed bed nets and insecticide kits, as described above, led to a significant reduction of malaria prevalence and associated mortality. Nevertheless, in other part of the country, high bed net use was associated with facilitating people to sleep well due to the reduction of mosquito nuisance at night (Koenker et al., 2013). Subsequently, in the early 2000s, bed nets were rolled out countrywide, supplemented by other interventions and strategies for

malaria reduction such as IRS and prompt diagnosis (NMCP et al., 2013). A study conducted from 2009 to 2011 indicated that the prevalence rate of malaria for the Kilombero Valley, using the malaria rapid diagnostic test (MRDT), was 14%, which was a tremendous reduction from the previous prevalence (estimated to be 78% by microscopy, as noted above) (Harchut et al., 2013). In Morogoro region (where Kilombero District is located), malaria prevalence was 13% in 2011 (NMCP 2012).

Despite the success of these interventions, malaria transmission still exists, and different malaria endemic areas, including the Kilombero Valley, experience residual malaria transmission (Killeen, 2014). In 2016 the NMCP report indicated a marked increase in malaria prevalence in most of the country; in Morogoro, malaria prevalence rose from 13% in 2014 to 31% in 2016. It is likely that there is also an increase in prevalence in Kilombero Valley, due to increasing mosquito outdoor biting at times when people are not protected by bed nets (TDHS-MIS, 2016). As noted, countrywide and in Kilombero Valley, the increasing outdoor biting (indicating behavioral resistance among malaria vectors) is believed to be associated with several factors including resistance to pyrethroid insecticide, climate and environmental changes as well as human activities and associated ehaviours. Thus, increasing outdoor feeding indicates that existing interventions alone cannot be used to control and eliminate malaria in this area, and so there is a need for other interventions to target the changed mosquito biting patterns (Ferguson et al., 2010).

A study done by Milali et al. (2017) indicated that, regardless of the timing of a bite, any bite from a mosquito puts people at risks of transmission. So, together with other studies, they argue that malaria elimination is only possible if existing risks of transmission are addressed, and that multiple strategies are required to target the remaining risks of transmission (Killeen, 2014, Milali et al., 2017). Given the geographical location of Kilombero Valley, people continue to be at risk due to available breeding sites in existing floodplains. People who spend time outdoors and away with minimal use of interventions are at great risk of malaria infection. In addition, unscreened houses have also been identified as contributing factor to disease transmission risks as noted earlier. However, this valley is characterised with unscreen houses which have substantial mosquito entry points due to open eaves, unscreened

windows. Moreover, Ogoma et al. (2009). noted that, house improvement contribute significantly to the reduction of risks of indoor biting . Unfortunately, the value of housing improvement has not been emphasized in rural areas, however, perhaps because majority of the population could not afford to do so.

Continue malaria transmission is associated with increasing outdoor biting because people have been observed to spend a significant amount of time outdoors while not using interventions. However, in Kilombero valley, time spent outdoors is influenced by house structure, since most houses in the area lack amenities and facilities indoors, thus most chores are conducted outdoors (Moshi et al., 2017). Approaches for preventing outdoor malaria transmission are yet to be considered by the National Malaria Control Programme, except for larval source management (LSM) which is used only in a few selected areas due to its difficulty in implementation. This method was noted to be more effective in areas with seasonal transmission, where there are few areas of breeding habitats in fixed locations and accessible (Tusting et al., 2013). Additionally, despite the potential contribution of LMS in controlling outdoor biting, it can be implemented only in very few localities within the country. In areas like Kilombero which is characterized by a widespread and varying breeding habitat, with poor accessibility, the control measure cannot be used. Thus, the government needs another intervention that can be used to prevent mosquito bites outdoors. To date, minimal or no investment has been made on interventions for preventing outdoor malaria transmission.

1.4 Malaria research in Kilombero Valley

For over six decades, malaria research has been conducted in Kilombero Valley region, out of what was previously known as the laboratory of the Swiss Tropical Health Institute, founded in 1956. In 1991, it was renamed as the Ifakara Centre and in 1996 it was renamed the Ifakara Health Research and Development Centre (IHRDC). After ten years of research and operation, the Centre was renamed the Ifakara Health Institute in 2008. The main research of this centre has been on malaria, although the programme has expanded to include research on tuberculosis, HIV, maternal and infant health, and testing different technologies for preventing, reducing, controlling and elimination of various diseases. As an aspect of the institute's dedication to reduce malaria and its

adverse effects, it established a Health Demographic Surveillance System (HDSS) to help the smooth running of the Kilombero and Ulanga Net Programme (KINET). Although it no longer operates, KINET contributed significantly to the reduction of malaria prevalence, incidence and mortality in all age groups, with the highest contribution in the reduction of infant and under-five mortality through various interventions and strategies. The HDSS site also helped to track and document other diseases in the area, with the data used as a basis for research to increase access to information on prevention, diagnosis and treatment. The IHI also works in collaboration with the St. Francis Referral Hospital and the Tanzania Training Centre for International Health. These three institutions (IHI, TTCIH and St. Francis Hospital) are all located in Kilombero Valley and their main focus is to train health providers, provide health care services, conduct research and test different innovations that can be used to reduce disease transmission and improve peoples' health. The trained professionals and researchers offer their expertise in different health sectors. IHI has contributed significantly to health sector disease prevention through different research, development and test of interventions such as bed nets. Community trust and cooperation contributed to the success of the interventions and evaluation studies, projects and programmes, which have led to the reduction of exposure to diseases and improved access to prevention and treatment, in Kilombero and within the country (Mossdorf et al., 2011, Geubbels et al., 2015, Killeen et al., 2007a, Masanja et al., 2008). However, with continued presence of malaria in the valley, community trust is currently reducing.

The social marketing programme, as well as other government campaigns, led to the increasing use of IRS and LLINs and contributed to the increased reduction in malaria transmission. However, as discussed above, the increasing use of these interventions led to increases in outdoor biting (Milali et al., 2017, Russell et al., 2011, N'Guessan et al., 2007, Ojuka et al., 2015, Ranson et al., 2009). The increased risk of outdoor transmission is in part associated with the minimal number of interventions that can be used outdoors, and the fact that people spend more time outdoors without using interventions (Moshi et al., 2018, Moshi et al., 2017). In addition, parents move to *shamba,* located near breeding sites, to work on the farms during the cultivation and harvesting period; farmers end up exposed to mosquito bites due to minimal use of interventions (Swai et al., 2016). Absence of parental supervision during farming

seasons, and young children's practices of sleeping in groups without protection, expose them to mosquito bites and risks of infection (Dunn et al., 2011). Thus various social and economic activities contribute to the increasing risks and frequent malaria infection among people in this community (Huho et al., 2013). Also, (Milali et al., 2017), added that, the risks of transmission are high due to the increasing unpredictability of vector behaviour and biting especially with increasing outdoor bites by vectors such as *An. gambiae* and *An. funestus* (Kaindoa et al., 2017, Lwetoijera et al., 2014). Efforts to reduce the risks are challenging by loss of trust and community suspicion toward IHI because of its inability to eliminate malaria in the valley, leading to a common belief that the Institute uses people in the community for financial benefit, not necessarily to eradicate malaria and improve health of the community. This perception has contributed to resistance to interventions (Moshi et al., 2017). Yet at the same time, people feel that the institute is more capable than the government in disease elimination.

1.5 Structural factors in health systems

Since independence in 1961, the Government of Tanzania has put considerable effort to fight against two main enemies of development, which are diseases and poverty (Wangwe et al., 1998). Since then, different strategies have been put in place, such as health policies and economic policies to alleviate the problems. The main focus of these policies was disease reduction that focused on the reduction of disability, morbidity and mortality among children and the entire population; and increasing life expectancy through the provision of adequate and equitable maternal and child health services. Some of these strategies were to be achieved through the promotion of adequate nutrition and control of communicable diseases, vaccination against major infectious diseases, and the prevention and control of epidemics through the provision of essential drugs and required equipment at health facilities and hospitals, as well as training of healthcare workers (URT (MoH), 1990). Since independence, the Government of Tanzania has been the major provider of health care services together with NGOs but the severe economic hardships which affected the provision of services in 1980s (COWI et al. 2007) led to health sector reform. The reform aimed to ensure provision

and access to healthcare services through the development of sustainable and equitable healthcare based on the efficient use of available financial resources and health care providers, with amendment for the Private Hospitals Act, 1991 (URT, 1991). Through the health sector reforms, other changes were management reforms which involved the decentralization of health services, the introduction of charges in public facilities under financial reforms, organizational reforms, health research reforms, and public/private mix reforms (private sector to complement public health services) (MoH, 1994). Decentralization in the health sector puts a number of stakeholders as responsible across the government structure. For example, Council Authorities, Health Service Boards, Facility Committees, and Health Management Teams at the district level are given the responsibility for the management and administration of health services. So, the health system of Tanzania is based on a hierarchical system as used for the political system of the country. The Tanzanian health care system is highly decentralized into three levels: district level, secondary/tertiary level, and the central level. Responsibilities at each level are outlined in Table 1.3.

Table 1.3. Tanzanian health system levels and responsibilities

Level	**Responsibilities**
District & Local	The district hospital, health centers, dispensaries, and community health services
Secondary & Tertiary	Secondary and tertiary hospitals, providing specialty care, and other tertiary-level institutions (teaching institutions);
Central	Provides support services such as policy-making, donor coordination, and monitoring and evaluation.

The provision of health care services in Kilombero Valley is guided by national practice, but the services in small towns like Ifakara in Kilombero Valley, and in outlying villages, are very poor and characterized by minimal provision of health

information, lack of reliable and accredited sources of information, poor health care services, drugs stock-outs, and poor infrastructure (Swere, 2016), including an unreliable ferry service. However, the existence of dual systems in provision of health services (private and public facilities) and introduced charges for health care services intensify the gap between the "haves" and "have nots" and differences on the available and quality of services provided between private and public facilities. So, socio-economic factors have a significant influence in access and use of health care services. In the case of malaria, despite the fact that the government has subsidized malaria treatment, both diagnosis and treatment require financial contribution, limiting the ability of most poor people to access proper treatment for malaria. As a result, many rely on self-medication (Mnyika et al., 1995, Marealle and Kirutu, 2018, Chipwaza et al., 2014, Uzochukwu and Onwujekwe, 2004).

1.6 Human behaviour and disease transmission

Considerable attention has been given to contribution and importance of human behaviour in public health, including in its contribution to increases in disease transmission, the emergence of new, and reemergence of older infectious diseases. A significant decline in communicable and the growing importance of non-communicable diseases had been expected to occur in low and middle-income countries in recent decades due to increased access to medical care, economic development, growth of towns and cities (urbanization), and improved access to reliable information on prevention and control of diseases. Unfortunately, millions of lives continue to be lost each year globally due to several factors including human behaviour, and the continue spread and reemergence of diseases such as malaria (Martens and Hall, 2000, McMichael, 2004, Rogers and Packer, 1993)

As noted by Funk et al. (2010), human behaviour plays a significant role in the spread of infectious disease. Infectious diseases have been successfully reduced through the improved application of interventions, improved access to medical services, and in recent decades, the introduction of community programmes for behaviour change. In malaria prevention, apart from increasing access to prompt diagnostic tests and treatment, and the wider distribution of established interventions, behaviour change communication has been widely used, leading to the increasing use of interventions and

an associated decrease in disease burden (Mwenesi, 2005, Koenker et al., 2014, Mushi et al., 2008). However, as noted by Halstead, there has been an increase in outbreaks of infectious diseases as a result not only of the presence of the vector and pathogen, but also of individual behavioural responses to disease outbreaks (Funk et al., 2009, Halstead, 1996, Lindahl and Grace, 2015, Soto, 2009, Roche et al., 2016). So, understanding the link between human behaviour and practices in the ongoing spread, prevention, and control of infectious diseases in different areas is important to prevent the risk and effect of diseases. For instance, during the bubonic plague in the nineteenth century in Britain, and in China and other countries in Asia, people isolated themselves from those who were already infected to prevent the spread of especially pneumonic plague (Scott and Duncan, 2001, Glass et al., 2006, Lau et al., 2005). Much more recently, isolation was an important strategy used by villagers, international organizations and local non-governmental organizations (NGOs) in containing and interrupting the transmission of Ebola (Pandey et al., 2014, Mbonye et al., 2014). However, preventive behavior was also observed in response to measles outbreak in India (Philipson, 1996) and wearing of masks to prevent the spread of infection that led to severe acute respiratory syndrome in China (Lau et al., 2005, Glass et al., 2006). In relation to the above observed behaviours, Ferguson (2007) has noted that individual self-initiated behaviour could determine an outbreak of an infectious disease or its prevention. Thus, since humans have an important role in the prevention or continued spread of diseases, it is highly important to understand their contribution and determine ways to reduce such risks.

Changes in human behaviour in relation to infection, disease and transmission depend on peoples' awareness of the health risks they are exposed to, because such awareness helps them to protect themselves from such risks through available knowledge and the use of interventions. Peoples' resistance to preventive behavior, or challenges faced while adhering to advised prevention strategies, may expose them to the risk of diseases infection. Ferguson (2007) emphasized the need to understand peoples' interactions and disease dynamics in order to understand the underlying factors for disease onset. Even though behaviour change has been noted to reduce the spread of diseases, these changes do not occur easily; people need to be motivated to change based on their own decisions, supported by their perception on the importance of prevention (NAS, 2003). Most people in malaria-endemic areas have adopted the use of bed nets to prevent

mosquito bites at night, reflecting the success of health education on people related to the risks of disease transmission that were posed when people were not sleeping under bed nets. Although other behavioural interventions, such as wearing protective clothing, have also been advocated, the adoption of bed nets in particular led to a reduction of malaria and malaria related morbidity (Funk et al., 2009).

Disease prevention and control require a clear understanding of the mechanisms by which disease spreads among the human population. The social cognitive causal structure explains that awareness is crucial for human behaviour change (Bandura, 1991). Access to adequate information about the risks of diseases, including the mode of transmission, risk behaviour, and the impact or effect of acquiring the disease, are crucial for behaviour change. Even though studies have illustrated a significant contribution of behaviour change to disease prevention and control (WHO, Fenichel et al., 2011, Koenker et al., 2014), a supportive environment also plays an important role in preventing diseases. This environment includes the presence of and easy access to preventive means such as interventions, treatment, and required skills. Several studies have managed to explain the effect and significant contribution of human behaviour to disease transmission (Killeen et al., 2006, Martens and Hall, 2000, Norris, 2004, Patz et al., 2004), but more studies on the role and contribution of human behaviour in disease transmission are needed. This includes attention to human behaviour activities and practices to provide a clear picture of their role in outdoor malaria transmission risks.

1.6.1 Human behaviour and malaria transmission

Several human behaviours, social and cultural practices and livelihood activities are associated with malaria transmission. These risk behaviours include patterns of and shifts in sleeping patterns which hinder the use of bednets or render bednets ineffective, and social and cultural beliefs which interfere with bednet use and have been demonstrated to be associated with the risks of malaria transmission in the Kilombero Valley (Dunn et al., 2011). In this setting, Huho and colleagues emphasized the need to study human behaviour because of the frequent occurrence of people being re-infected with malaria parasites in areas where bed nets and artemisinin-based combination therapy (ACTs) have been scaled-up (Huho et al., 2012). Their study estimated the proportion of human exposure to malaria vectors, indicating that the continuous

interactions between humans and mosquitoes have led to changes in the behaviour of malaria vectors. Such findings indicate the importance of identifying the range and frequency of human-vector contacts in order to find ways to reduce such frequency to decrease transmission. However, Huho and colleagues also noted increasingly frequent episodes of malaria among people within the community, suggesting that existing interventions were inadequate to prevent all existing transmission risks. Early observations in the same study setting indicated that people spent a considerable amount of time outdoors early in the evening and early in the morning, performing various domestic and social activities, with little or no protection from mosquito bites (Moshi et al., 2018). These practices and activities increase the risks of exposure to mosquito bites and malaria transmission, as I describe in this thesis. The risks of outdoor malaria transmission may be higher due to increases in outdoor biting by the host-seeking mosquitoes (Kaindoa et al., 2017, Lwetoijera et al., 2014, Matowo et al., 2013, Monroe et al., 2015, Meyers et al., 2016), thus contributing to frequent re-infection with malaria. Studies done in Kilombero Valley have indicated an increase in outdoor feeding among malaria vectors such *An. funestus* and *An. arabiensis* (Kaindoa et al., 2017, Lwetoijera et al., 2014). However, an evaluation study to determine the ability of a mosquito landing box as a device for killing malaria vectors also found that there was early host-seeking activities outdoors at the times when most people were outdoors, indicating the risk of mosquito bites and hence malaria infection (Matowo et al., 2013). Moreover, the current research study found out that the early hours of the evening, when people are outdoors, conducting peri-domestic activities, correlates with the times when host seeking mosquitoes were also active outdoors, thus indicating the need for appropriate interventions to reduce the risks of malaria transmission (Finda et al., 2019).

The social cognitive theory by Bandura is particularly helpful in understanding human behaviour. Bandura argues that human behaviour is a product of the active interplay of behaviour, a person (including their cognitive ability) and environment (Bandura, 1991, 1995, 1997). According to this theory, people change or adopt behaviours appropriate to the environments in which they live, to survive. Bandura further explains that in most cases, people change behaviour as a result of being influenced by other people's behaviour. For example, in an environment with high mosquito density, when people are aware of the risk of malaria and its impact, they will adopt and use available

interventions to protect themselves from mosquito bites and disease transmission (NAS, 2003). Behaviour change will also facilitate educating each other on the benefits of intervention use and different preventive methods.

However, human behaviour theory (HBT) suggests that certain behaviours are said to be ‘a goal’, while social cognitive theory behaviours are ‘a process.' In this case, the goal could be a reward for behaving a certain way. Interventions used for preventing disease transmission to gain health benefits are, according to Green, Eriksen, Schor (Green et al., 1987), based on three factors - *predisposing* factors, *enabling* factors and *reinforcing* factors. In this model, known as the *PRECEDE model*, the predisposing factors are those that will motivate an individual towards performing a particular health behaviour; enabling factors are those that will facilitate change, such as the resources and skills needed for performing particular behaviours; and reinforcing factors are those that support or reward a particular behaviour. The motivating factors (predisposing factors) have to be in place before the facilitating factors, and these have to be present before there are reinforcing factors (Green et al., 1987). Hence, factors such as education on the risks of transmission, prevention and impact of the disease (motivating factors), availability and easy access to interventions (facilitating factors), and the benefits of using the interventions (reinforcing factors) are anticipated to contribute to significant changes and decreases in disease prevalence. In the context of this study, the decline in malaria brings with it several benefits, including good health, reduced morbidity and mortality, and downstream, economic growth. However, another school of thought has added that human behaviour is influenced by socio-economic factors, cultural values and practices, as well as the education level of individuals (Walsh and McPhee, 1992). Wilkinson and Marmot argue that the socio-economic status of an individual and individual membership of a particular group also influence or facilitate the way individuals behave, impacting on the types of illnesses to which people are vulnerable and their ability to access medical treatment when infected or afflicted (Wilkinson and Marmot, 2003). In high income settings as well as in low and middle-income countries, people living in poor economic conditions are more prone to disease than their counterparts. But, despite their economic status, there is a need to understood how the education level of an individual affects their capacity to analyze situations, the influence of this on their behaviour with regard to disease risk, and their decisions on disease prevention (Rosenstock, 2005).

However, as noted, personal benefits were also observed to be among the factors that facilitated the use of bednets which focus not on malaria prevention but facilitating better sleeping environment by reducing mosquito nuisance (Koenker et al., 2013, Uzochukwu and Onwujekwe, 2004).

Cultural factors cut across all aspects of society, including the ways people think, feel and act (Asp, 1999). In the Kilombero Valley, soon after the harvesting period, people sell their products and spend that income on new clothes and food for ceremonies and music, and they are free and able to participate in various ceremonies. These ceremonies are often held for more than one day. This may lead to different health impacts, including exposure to mosquito bites but, as I illustrate below, they are important to people in these communities. Despite minimal awareness of the risks of malaria infection while outdoors during these events, participation in such activities provides community solidarity and reinforces positive social relations. People conduct these gatherings according to religious, cultural and social expectations, and in doing so, they reinforce a sense of community with the effect of maintaining social cohesion. For instance, sleeping overnight at the household of a bereaved family member is important. This act portrays unity, love, and support, and failure to do so may lead to rejection and sometimes isolation (Moshi et al., 2018).

A range of risky behaviours affects school-aged children. This includes the non-use of mosquito bednets and staying outside in the evening when they are likely exposed to mosquitoes. This is compounded by parents moving to less substantial *shamba* (simple shelters located on farms) (Swai et al., 2016) to take care of crops, leaving children behind to take care of themselves (Makungu, 2011).

The activities and behaviours that involve people in Kilombero Valley have implications for disease transmission. However, occupational activities have been noted to contributed to the risks of exposure to mosquito bites and minimize the use of interventions such as rubber farming within the forest (Edwards et al., 2019, Tangena et al., 2016) as recreational activities such as watching television which expose them to the risk of mosquito bites (Leake Jr and Jeffrey, 1994). In addition, malaria transmission depends on vector behavioUr, ecology and the degree on contact between human and anopheles mosquitoes (Hii et al., 2013). These authors also noted that the agricultural activities such as rubber plantations provides ample habitats for mosquito breeding

which might be similar to rice farming activities and ecological factors facilitate breeding habitat and mosquito survival. However, Edward and colleagues (2019) used both entomological and social behaviour methods to investigate the magnitude of residual malaria transmission on the Thailand-Myanmar border, found high exposure to mosquito bites due to high mosquito abundance and minimal and non-use of intervention such as LLINs. However, sleeping late and waking up very early correlates with the peak biting hours of anopheles mosquitoes. Additionally, LLINs could only provide the required protection when used within the village setting and not within the forest or farms where people conduct most of their activities. Similarly, in Kilombero Valley, studies have shown that a considerable proportion of migrant farmers who spend time in shamba huts are exposed to mosquito bites. However, there is also high proportion of people who spend time outdoors during early evening and early outdoors at a household level. The study conducted for this dissertation focused on investigating why people spend longer times outdoors during the evening, what activities do they engage themselves into during the evening, identify a range of differences on the activities, engagement and meaning attached to them as well as the extent to which these activities or behaviour contribute to the risk of mosquito bites and existing residual malaria transmission in Kilombero Valley.

This study is among the studies that were conducted to help understand the relationship between human activities and biting patterns of host seeking mosquitoes. However, there is a considerable difference between this study and other studies as it described and analyzed not only the daily activities but seasonal interactions, the meanings attached to them and the use of interventions during those times. The study data indicated that, malaria infections outdoors can occur while conducting domestic activities and during community gatherings where there is minimal use of interventions as a result of both environmental, social and cultural factors. The use of a socio-ecological approach in this study helped to illustrate the environmental, ecological, social and cultural factors that cut across or facilitate increasing exposure to outdoor biting and minimal use of interventions which contribute to the risk of malaria transmission/infection. Additionally, community knowledge and perception and common understandings of the timing for malaria transmission, were identified as impacting the use of interventions. Community perceptions on malaria transmission

was based indoor biting from midnight which influenced the difference in the use of interventions and control measures both indoors and outdoors.

Studies have indicated that the increasing outdoor biting of malaria vectors, together with other factors (Kaindoa et al., 2017, Lwetoijera et al., 2014, Russell et al., 2011), provide an insight into observed frequent malaria infections among people in Kilombero Valley, despite presence of frontline interventions. It was important to understand different factors that contribute to existing residual malaria transmission. This study aimed to examine how human behavior contributes to outdoor malaria transmission risks, by evaluating different activities and associated behavior as well as examining local understandings on outdoor malaria transmission. Understanding how malaria transmission occurs, and where and when people are outdoors in this particular setting, will provide the necessary data to contribute to planning for malaria prevention, management, and control of malaria.

1.6.2 Human behaviour and behaviour change in disease transmission

To be able to explain the contribution of human behaviour in disease transmission, there is a need to understand that such behaviours are a result of range of factors that influence patterns of disease transmission, prevention, treatment, and control. Different human practices, education level, knowledge of infection and preventive methods, might all impact people's opinions, belief systems, and attitudes towards particular diseases. Human behaviour is not static but is, rather, subject to change, and any of the above factors may cause changes at individual or group level. Sources of information, including direct community outreach, print and radio media, and increasingly, social media, and type of information regarding diseases, have a huge effect on change in human behaviour (Marteau et al., 2012, Walsh and Simonet, 1995). If the aim is to intervene in disease transmission, then such information should be based on research findings which relate theoretical aspects of the disease to everyday experience. Individual access to information on particular diseases enables them to be aware of the risks of transmission and to avoid infection. Such access may influence an individual to change a particular behaviour toward exposure or prevention of a particular disease, but this also depends on how they perceive particular diseases, susceptibility and adverse effects.

Socio-economic factors such as education, economic level, social norms, behavioral factors and social activities of particular ethnic and social groups significantly contribute to the way people behave regardless of the presence of diseases in a particular area (Mora-Ruiz et al., 2014, Adler et al., 1994, de Castro and Fisher, 2012, Rosenstock, 2005). Therefore, disease prevention is believed to be successful if mediators of transmission, transmission mechanisms, the behaviour of the host, and other related factors for transmission, prevention and control, are all taken into account. But as Lewin and Kurt pointed out decades ago, individual health behaviour change is strongly associated with the seriousness of the disease and individual susceptibility, not necessarily with professional perspectives (Lewin, 1936, Becker and Maiman, 1975, Lakhan, 2006). This means that whether an individual feel susceptible to the disease and the effects of the disease are important in behaviour change, with emotional as well as cognitive elements having a significant contribution to healthy behaviour change. The perceived benefits and barriers also have significant contributions to health behaviour. In order for any health behavior change to be able to succeed, the approach should be multilevel, involving not only the health sector but also culture, political will, community, psychology and policies that influence health (Bonnie). Additionally, the perceived benefits that influence bed net use among people are prevention of mosquito nuisance and sleeping well (Koenker et al., 2013).

1.7 Justification of the problem

Despite global efforts, malaria has not yet been eradicated. The existing public health strategies for malaria prevention and control concentrate on the prevention of indoor transmission. As noted, this includes LLINs, IRS in selected endemic areas, the use of chemoprevention for pregnant women and infants, and the development and distribution of prompt diagnostic tests and treatment (TDHS-MIS, 2016). It also includes larvae source management, but this has never been used in Kilombero Valley, and has been administered only in a few urban areas (Geissbühler et al., 2009). As already argued, the existing challenge that jeopardizes the effectiveness of these interventions includes insecticide resistance and increased outdoor biting (Russell et al., 2011). Species such as *An. funestus* are also becoming important in malaria transmission in Kilombero Valley since they bite both indoors and outdoors, and cannot

be targeted by existing interventions alone, (Kaindoa et al., 2017, Killeen, 2014), thus contributing to residual malaria. Further, there is an increase in malaria prevalence even in areas with the highest coverage of indoor interventions such as LLINs. The NMCP still emphasizes the use of bednets and has not developed specific plans for fighting outdoor malaria transmission, except for the limited application of larviciding in Dar es Salaam, Zanzibar, and in Geita, northwestern Tanzania (Geissbühler et al., 2009, TDHS-MIS, 2016) - that is, in the national capital, in the major tourist province, and in the largest gold mine area in the country.

For outdoor prevention, there is evidence that interventions used even at a small scale could reduce the risks of malaria transmission. These include: topical repellents, insecticide-treated clothes and sandals, and the treatment of other items such as sisal mats and curtains. Scaling these products is still uncertain due to the associated costs of production and distribution, and cost-sharing of these interventions, as initially used in bed nets, would significantly contribute their uptake.

Although larviciding has proven to work best in areas with low transmission and areas with few accessible breeding sites where monitoring is easy, as in Dar es Salaam (Geissbühler et al., 2009), it can still be used in other areas with low transmission. For example, in rural areas where breeding sites change according to rainfall and the level of water, the effectiveness of larviciding will not yield better results, as indicated in Ghana (Majambere et al., 2010, Tusting et al., 2013). So, understanding the risks of mosquito bites and quantification of possible transmission risks is crucial for allocation of interventions to complement the existing indoor interventions.

Human activities and behaviours are important as contributing factors to malaria transmission (Lindblade, 2013) and to changes in vector behaviour and insecticide resistance (Nkya et al., 2014, Ojuka et al., 2015, Ranson et al., 2009, Reddy, 2012, Sokhna et al., 2013, Sougoufara et al., 2017), as already argued. Transmission is still high indoors in some areas (Seyoum et al., 2012b) and there is growing insecticide resistance (Moiroux et al., 2012). Changes in weather impact the local ecology and, as already explained, these contribute to an increasing proportion of infections now occuring before people go to bed, and early in the morning when people are outside of

their houses and are not protected by LLINs and IRS (The malERA Consultative Group on Vector Control, 2011, Govella et al., 2010, Reddy et al., 2011).

In addition, human behaviours and outdoor activities, including practices such as shifts in sleeping arrangements in response to livelihood needs, are observed to increase the risks of exposure to disease transmission. As already described, the shifting transmission due to changes in peak biting time and place is attributed to behavioural adaptation by mosquitoes in response to insecticidal interventions used indoors. This increased the risks of malaria transmission when people are outdoors, before they go to bed, posing a challenge to malaria control programmes (Killeen et al., 2006). Interventions like bed nets and aerosol sprays were originally designed for indoor use, and are not suitable for outdoor conditions (Killeen, 2014). People do not permanently sleep outdoors, although they may do so occasionally. However, in most cases, the outdoor environment does not include structures that could be used to suspend bed nets or curtains. Aerosols are diluted when used outdoors, before reaching the knockdown effect. Thus, human behaviour should be given greater attention .

The presence of mosquitoes where people are present indicates that human behaviour and practices need to be evaluated before outdoor malaria transmission can be addressed. There is a clear need for further studies to understand the contribution of human behaviour to remaining transmission in areas where there is full coverage of frontline interventions such as LLIN and/ or IRS, with active ingredients to which local vectors are fully susceptible (Killeen, 2014).

1.8 Study objectives

1.8.1 Overall Research Aim

The main aim of this study was to assess the role of routine and sporadic outdoor human activities on persistent malaria transmission in rural Tanzanian communities where LLINs are already widely used.

1.8.2 Specific Objectives

I. To identify common everyday human outdoor activities that expose people to mosquito bites that contribute to malaria transmission risks, and to identity the reasons why people conduct particular activities outside their houses at times when such risk is heightened.

II. To identify supplementary seasonal and ceremonial activities which involve outdoor activities with risks of exposure to mosquitoes.

III. To estimate the proportion of exposure and biting risks as contributed by human outdoor activities.

IV. To describe and analyze peoples' views, opinions, knowledge, and experiences on mosquito biting and malaria transmission and the difference between indoor and outdoor transmission.

V. To identify available intervention tools and patterns of use, and to explore peoples' perceptions of these on exposure to bites and malaria transmission prevention.

CHAPTER 2: METHODS

2.0 Introduction

This PhD study used a mixed method approach to identify mosquito and human activities and practices that result in risks of outdoor malaria transmission. The combination of these methods helps to provide a greater understanding from both the quantitative side, which is complemented by the richness of data collected from the qualitative methods to describe the complexities of human behaviour. Such data cannot be obtained from the use of quantitative methods alone.

This section describes the methodology used in this study. The first section (2.1) provides the reasons for choosing the study area, and its geographical location, so placing the study in context. This is followed by a description of the study design, including the various study components and sampling procedures in section 2.2. The different types of research instruments used in this study during fieldwork are described in section 2.3, while sections 2.4 and 2.5 describe data collection, processing, management, and quality assurance procedures for both quantitative and qualitative methods used in this study, and for the entomological study as well as the human research. The last section describes the limitations to the study and the means used to address them.

2.1 Study area

The study was conducted in Kilombero Valley in Morogoro Region in Tanzania, in both urban and rural areas (see Figure 7, below) between 2014 and 2016. The valley was selected because of the experience of frequent episodes of malaria by people in this setting, an observed increase in outdoor biting, logistic considerations, and the geographical proximity from IHI to the study villages. During the rainy season, a large part of this valley is covered by flood water, which provides an ample area for growing rice, but also provides a conducive environment for mosquito breeding. This leads to a considerable increase in mosquito density in the rainy season, as compared to the dry season. Malaria transmission in this area was documented to be higher than 300

infectious bites per person per year in 1990s, and malaria was noted to be the main cause of infant mortality (Smith et al., 1993b).

The Kilombero Valley is among the most important wetland areas in Tanzania and is the major freshwater fishing area. It contributes to about two-thirds of the water to Rufiji River, and is a crucial source of nutrients and sediments to the large mangrove stands, mud flats and sea grass beds in the delta (RIS, 2002, Dinesen, 2016) . The floodplains of Kilombero Valley have a rich flora and fauna as well as other plants, birds and frog species (Hood L et al., 2002). The villages in this valley lie at approximately 300 meters above sea level. The area has two rainy seasons: the short rainy season normally starts in October and ends in January, and the longer rainy season commences in mid-February and ends in May. Annual rainfall ranges from 1200-1800 mm and annual mean temperatures between 20°C and 32.6°C, with an annual temperature range from 16^0 to 32^0C. According to the 2012 Tanzania National Census Report, the population in this valley was estimated to be 55,695 people (Tanzania Bureau of Statistic Ministry of Finance, 2013), but according to Ifakara HDSS data, it is now estimated to have reached 171,828 people for both urban and rural (Geubbels et al., 2015). The area includes both Christian and Muslim communities, and their economic activities include agriculture, fishing and small businesses.

Due to the presence of the wetlands, the valley is an important rice producer in the country, including for both export and domestic use. In addition, due to its fertile soil, farmers engage in maize production, sugarcane farming and cocoa growing.

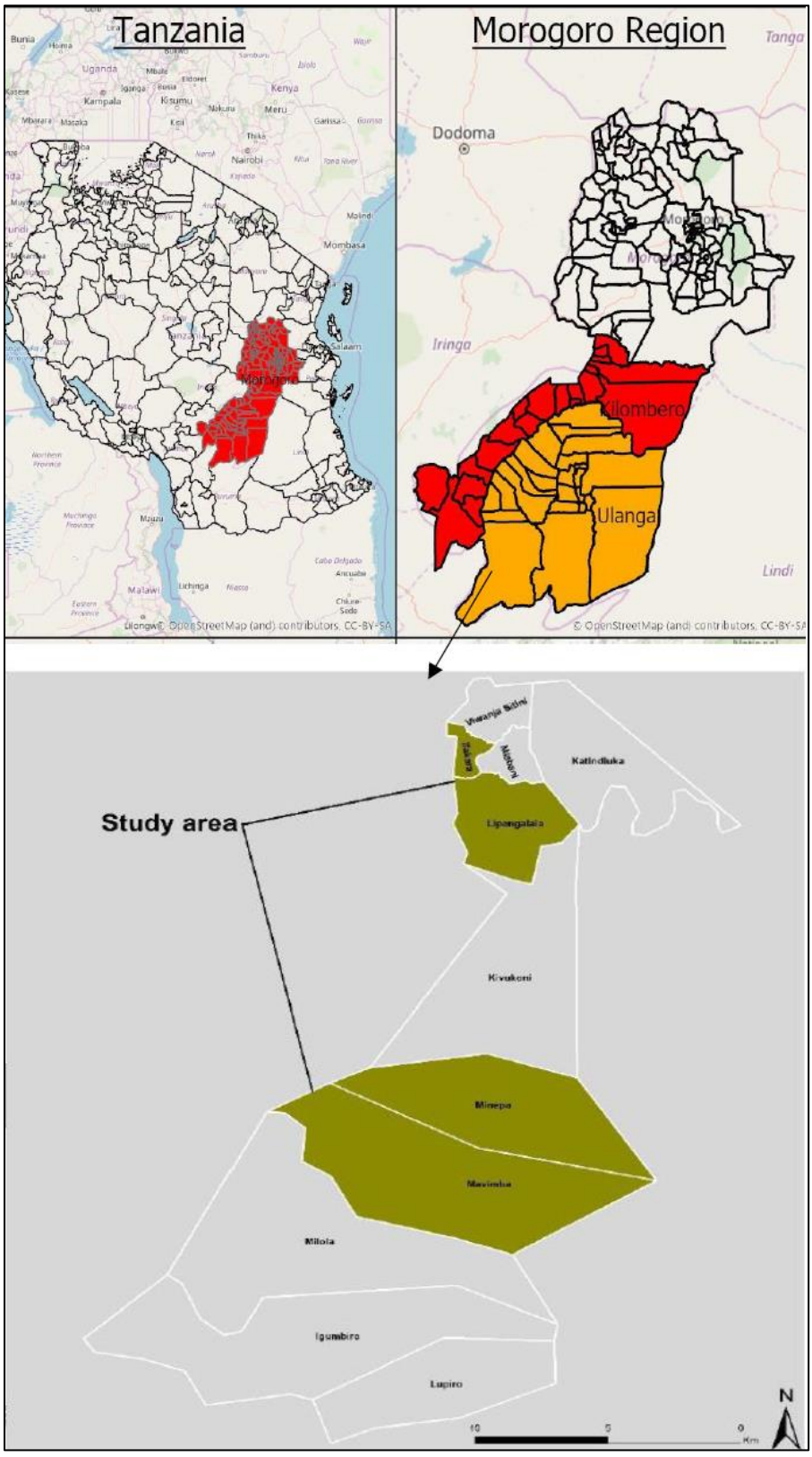


Figure 1.0**:** Map of Kilombero Valley indicating study villages

2.2 Study design

In this study, an explanatory sequential design (Creswell, 2013) was used. This type of design uses a mixed method research approach, whereby both qualitative and quantitative data were collected separately in different phases of the research process. A longitudinal study design was used for the quantitative data, which comprised of various quantitative methods (structured observations of people's way of living and activities performed outdoors). These data informed the qualitative data collected. A cross-sectional study design was used for assessments of qualitative aspects, which included knowledge, views, and peoples' perceptions on outdoor malaria transmission, what activities and practices are conducted outdoors, the reasons for conducting them, the identification of available interventions, and their use (or not) to prevent mosquito bites outdoors. This study was complemented by a longitudinal entomological study where field experiments were conducted using entomological techniques. Analysis of data was conducted separately for different data sets, with subsequent joint interpretation of the findings.

2.2.1 Longitudinal study on outdoor human activities

This study design aimed at identifying human outdoor activities that exposed people to outdoor biting and malaria transmission. The study was conducted in two villages from each of the two districts in the Kilombero Valley, making a total of four villages for the whole study. Convenience sampling was used to select houses from densely populated areas and houses from more lightly populated areas. This was used to identify any difference between outdoor activities performed and the level of exposure between the two, and to remove variation biases. The sample size calculated was 174, but I added two households to make a total of 176 households with an equal number of households in each study village, i.e., 44 households from each selected village. In this case, the household was defined as a house and its occupants were regarded as a unit. The observations in all households, in all four villages, used a structured observation tool/sheet. Two villages represented peri-urban areas, and the other two represented rural areas. The structured observation data were collected for six days in every village during collection weeks, to capture a range of peri-domestic activities for both seasons (wet and dry). These observational data of peri-domestic activities were complemented by observational data from non-peri-domestic areas, e.g. at funerals and during various

celebrations conducted within the communities. The study also involved observations of the human activities at household and community level, and interviews to obtain people's views regarding outdoor malaria transmission, outdoor biting, and intervention use. The seasonal data collected helped to identify variations of outdoor activities and time spent outdoors during the evening (from 6 p.m to 7 a.m)

2.2.2 Cross-sectional study

The aim of using this design was to understand people's knowledge, views, and perspectives on outdoor malaria transmission. To reach the intended goal, purposive sampling of households was used. The inclusion criterium were, a household with at least one child not more than ten years of age, to be able to capture all information required for both adults and children. Therefore, in this study, 40 in-depth interviews were conducted which included ten households in each study village. The interviews were complemented by eight focus group discussions to gain group perspectives, with each group constituted of eight to twelve participants. These data were also complemented by eight key informant in-depth interviews. The respondents for the key informant interviews were recruited from the village leadership, and were respected people from the study communities who were considered to be opinion leaders. Due to the flexible nature of qualitative methods, the sampling for focus groups and key informants were subjected to reduction or increase to get the required depth and to reach saturation point where no more new information was gathered.

2.3 Data collection methods

Below is the description of the activities, data collection methods and procedures used in this study to obtain the required data for each objective;

2.3.1 Identification of outdoor human activities during evenings

This method was used to identify common outdoor activities that predisposed people to mosquito bites, resulting in malaria transmission risks in natural settings around peoples' households. These observations were undertaken by six selected and trained researchers in each study village, who conducted these observations over a period of six days in each village; this allowed us to capture variations in activities on different

days of the week. The observers were selected from their own villages to minimize the risks of mistrust as might have occurred had the observers been selected from different villages. The use of this small team in each village was helpful, and not only saved time and ensured the collection of high quality data but was also cost effective. A structured observation sheet was used which showed all possible pre-determined activities that reflected community livelihood activities at different times of night, and these were used to document any observed activities, with extra space to mark other activities which were not listed (Appendix 5). Field observation notes were taken to help the researcher reflect back during the analysis process.

2.3.2 Observations of ceremonies and gatherings

This study was undertaken to identify ceremonies and gatherings that are conducted outdoors within the study communities away from peri-domestic areas, which exposed people to mosquito bites, and to identify the range of interventions used by people to protect themselves from mosquito bites while attending and participating in these ceremonies and gatherings. These ceremonies and gatherings included funerals conducted throughout the year, and other ceremonies that are conducted primarily during the post-harvesting periods. These latter activities included weddings, baptisms, Holy Communion, Mawlid (the birth of Muhammad, celebrated by Muslims), birthdays, and ceremonies to commemorate children's entry to adulthood (after circumcision for boys, both Christians and Muslim, and first menstruation for girls). Through regular contacts with village leaders, key and influential people from each study village, we obtained information of the ceremonies conducted within those villages, and two to three observers were allocated to observe and note all observed practices consistent with the research questions.

2.3.3 In-depth interviews

The in-depth interviews (IDIs) were conducted in ten households per village. Thus, a total of 40 in-depth interviews (Interview guide Appendix 2) were conducted for the all study. The interviews focused on exploring the views, opinions, and experiences of outdoor mosquito bites, malaria transmission risks, and interventions that people use outdoors for protection from mosquito bites. During the interviews, we were also able to obtain information of the range of activities which are conducted outdoors on a daily basis, the reasons why these activities were conducted in particular places, and people's

understandings of the relation of such activities to outdoor malaria transmission risks due to exposure to mosquito bites.

2.3.4 Key Informant Interviews (KII)

This method was used to explore and gather information on the types and meaning of the ceremonies and gatherings conducted within the study communities, the meanings attached to them, reasons for conducting them and their importance. A total of 8 KIIs were conducted by using Key Informant Interview Guide (Appendix 3) were conducted with village leaders/tribe leaders, natives or elders of the community who have lived within the community for more than 10 years.

2.3.5 Focus Group Discussions

This method was used to explore shared views and contradictions in opinions and experiences regarding outdoor malaria transmission. I also gathered information regarding the ceremonies and gatherings conducted within the study communities, the reasons for conducting them, and their importance. The focus groups helped to identify patterns of individual and group meanings and drew out existing contradictions and diverse opinions on the subject matter. Adult men and women, who were household heads, or the spouse of the household head, or the caregiver to children under the age of ten years, were recruited and invited to participate. Each focus group discussion (FGD) comprised of around 8 to 12 participants. The focus group interview guide (Appendix 4) was developed by considering opinions on risks factors such as knowledge, activities and practices which were informed by the KII which are associated with outdoor mosquito biting

2.3.6 Collection of Qualitative data

During the data collection, information on demographic variables was collected from respondents who were involved in the study for IDIs, KIIs and FGDs were collected. Collection of qualitative data was conducted differently as IDIs were conducted between June and July 2014 while FGDs and KIIs were conducted between February and March 2016.

Sampling techniques for selection of participant were different between IDIs, KII, FGDs. Purposive sampling was used to select households in all study villages. Two

inclusion criteria were used, namely 1) households near the main road and at the edges of the villages for logistic purposes, (2) the household should have at least one child aged 0–5 years. During the selection, 40 households were selected, 10 from each of the four study villages and one member from these households (above 18 years of age who was a parent/guardian) were involved in the study. Also, the same sampling technique was used for selection of participants for KIIs, whose selection criteria was that he/she should be a key person or leader in the community who has lived in there for more than 10 years.

However, 8 FGDs were conducted to complement the interviews and gather group understanding and opinion on outdoor malaria transmission, prevention, meaning identify social and cultural gathers that are conducted outdoors during the evening and meaning attached to them. Selection for FGD participants was assisted by village leaders and each FGD had 10 to 12 participants.

For the IDs, the interviews were conducted at participants' households, KIIs at village leaders' offices while FGDs were conducted at the village offices or vacant classrooms at nearby schools. Selection of venues for all interviews considered two criteria which includes accessibility and convenient for study participants. During the interviews and discussion, Swahili language was used as a medium of communication and all the interviews were tape-recorded for a complete record and for quality assurance. Note-taking was conducted during the interviews and discussions, which then complemented the recordings. Voluntary informed consent to participate in the study and for audio recording were obtained from all the study participants prior to data collection.

For the FGDs, before commencing data collection, two research assistants were selected, while for IDIs one research assistant was selected, and all of them were trained for five days. The training focused on research ethics, qualitative data collections methods and familiarization with the data collection tools, as well as editing ambiguous or unclear questions. However, pilot studies were conducted before the actual data collection for all interviews to analyze if the questions in the interview guides were understood, to identify missing aspects and un-important aspects. Preliminary analysis of all collected data was conducted from the beginning of data collection to be able to iterate and evaluate if the collected data were of good quality or if there was an aspect that was missing so that they could be included in the ongoing interviews. Probing was

also used in all interviews and discussion in order to capture and gather more information from participants and data collection ceased when saturation for all interviews were reached and no new information was obtained.

2.3.7 Assessment of household environment

All the selected households for the study were characterized according to their surroundings and house features. The assessment based on the materials used for house construction including walls, roofs as well as conditions of the windows and doors. However, the other aspects considered were availability of nets, usage, items owned by the households, access to social services such as water, electricity as well as energy. The observation was done using direct observation and closed ended questionnaire (Appendix 5).

2.3.8 Assessment of mosquito biting patterns and *Plasmodium* infection rates

This study used Centres for Disease Control (CDC) light trap to estimate human biting rates and was supplemented by mosquito collections by using miniaturized double net trap (DN-Min) due to the minimal efficiency of CDC light traps for indoor-outdoor biting risks comparison. Training over 5 days was conducted as a refresher course on the mosquito collection even for volunteers who were involved in Human Landing Catches (HLC). The training was essential for all volunteers who were involved in mosquito collection by using double net as this was a new collection method designed to replace HLC. However, training of volunteers has been an important step for preparation of mosquito collection within the institute in order to ensure only qualified volunteers are involved in data collection to minimize errors during collection and mosquito sampling.

However, volunteers were given chemoprophylaxis to prevent the development of malaria following any possible inoculation. We collected mosquitoes by using a CDC light trap to determine the biting pattern of mosquitoes both indoors and outdoors in the same study villages. The modified CDC-light trap with a bag was made to hold the trapped mosquitoes (see Figures 2.1a and 2.1b, below). Mosquito collection was done on an hourly basis both indoors and outdoors from 18:00 pm to 07:00 am. Indoors, the modified CDC light trap was placed next to an occupied bed net, while outdoors

volunteers were required to sit inside a bed net for 45 minutes and change the collection bags of trapped mosquitoes on the remaining 15 minutes of each hour from 1800 hours to 0700 hours. During the 15-minute, the volunteers were required to exchange the indoors and outdoors trap-bags (one bag for each hour), and to record the number of people inside or outside the house. One adult male member of the family (or a relative in the case of a household that did not have a willing adult male) was recruited to assist with mosquito sampling as a volunteer. All volunteers were provided with five days training on how to sample mosquitoes indoors and outdoors. The collection was conducted in five selected households among the 10 selected for observation activities on the study villages. The collection was done for 3 days in a month with a gap between collection days (the free days in between allowed the collectors to rest so that the collection can be done well as required. All the collections were supervised and sport checking was conducted by supervisors to ensure the work is done properly as per the guidelines.

However, mosquito collection by using CDC-light traps were identified to be not effective for indoor-outdoor comparison of biting risks since the data could not match *Anopheles* behavior within the valley. So, the data was complemented by using miniaturized double net trap (DN-Mini). This double net trap whose structure help to protect collectors from mosquito bites was initially used to assess outdoor biting densities in houses that had spatial repellents (Tangena et al., 2015). (More description of the trap is explained in the published paper 3, ie Finda *et* al., 2019)

During mosquito collection with the use of miniaturized double net, volunteers (collectors) used mouth aspirators to capture all mosquitoes caught between the double layers and store them in paper cups labeled according to time, on an hourly basis from 1800 hours to 0700 hours the following day. The collection of mosquitoes using this method was conducted for three days per week for three months, in both dry and wet seasons. Thus, the total occasions for the collections for CDC light traps were 1620 trap nights while for the DN-Mini trap was 320 trap nights (as indicated in tale 3.1).

Morphological identification of all collected mosquitoes was conducted each morning using dichotomous keys (Gillies and Coetzee, 1987), whereby all collected mosquitoes

were identified by qualified individuals who had undergone training on mosquito identification. As a standard procedure to maintain accuracy and accountability, the qualified volunteers signed delivery papers every day upon delivery of mosquitoes. Then, they prepared mosquitoes for sampling (i.e., the mosquitoes were suffocated by using ethanol until death in an airtight container), then all species were identified. All malaria vectors identified were stored in Eppendorf® microcentrifuge tubes, containing silica gel and cotton wool to protect them from further decay. All tubes were labeled and stored in different boxes according to their respective dates of collection. All sampled malaria vectors were transported to Ifakara Health Institute Laboratory where identification of sibling species was conducted through polymerase chain reaction (PCR) (Koekemoer et al., 2002). However, further molecular identification and enzyme-linked immunosorbent assay (ELISA), was performed to determine *Plasmodium falciparum* sporozoite infection rates of all the collected sampled mosquitoes (Wirtz et al., 2007). The laboratory work was performed by two qualified laboratory scientists at Ifakara Health Institute.

Figure 2.1a**:** Modified CDC light trap hung indoors: Figure 2.1b: Illustration of volunteer during the outdoor mosquito catch by using CDC light trap hung aside.

Figure 2.1: A miniaturized double-net trap (DN-Mini) that was used for comparison of indoor and outdoor host seeking mosquito densities.

2.4 Data analysis

2.4.1Analysis of qualitative data

All interviews and focus groups were conducted in Kiswahili. All IDIs, KIIs and FGDs were tape-recorded with signed permission, and all recorded sessions were transcribed, and field notes were reviewed. The interviews were transcribed precisely word for word in Swahili and field notes were reviewed. Non-verbal cues which could only be captured from the field notes were added. All transcripts were translated from Kiswahili to English by the researcher and double-checked to maintain consistency. All word transcripts, field notes, and visual files were imported into Nvivo software, specialized software in managing qualitative data, for analysis. The data were organized into manageable units and synthesized to reveal patterns based on themes, using Nvivo software to identify them. The data were then analyzed through thematic content analysis (Burnard et al., 2008, Pope et al., 2000), first by reading the texts multiple times before developing codes and themes. The themes identified were then agreed among the researchers involved in the study, who also identified sub-themes within the transcripts. Then all researchers went through the transcripts to check if the identified

themes matched the content of the transcript. After themes were identified during the analysis, we conducted a discussion on the important themes and subthemes to be included according to the findings.

2.4.2 Analysis of quantitative data

The analysis of these data was undertaken using R statistical software (R: Development CoreTeam, 2014). Frequencies of identified human activities and numbers of mosquitoes caught were entered and processed in Microsoft Excel spreadsheets 2013 text files, and then exported for further processing, graphing and analysis in R statistical software. For quality assurance, all data were checked for consistency before data entry. Mosquito biting rates (only from collected/caught *Anopheles* species which transmit malaria) were analyzed, and logistic regressions (LR) were performed separately for each *Anopheles* species to determine the rate of exposure to the risk of malaria transmission as per identified activities. Then, graphing and analysis in R statistical software, mosquito biting rates were determined by using generalized linear mixed-effects models (GLMM) separately for each species, accounting for both fixed and random factors, with log-linked Poisson error distribution, using the *lme4* package in R. The biting rates were modeled as a function of different outdoor human activities, location, and month of data collection as fixed factors, while the date and household identification codes were used as random factors (A detailed analysis of the mosquito data is provided on page 7 of the published paper- Finda *et* al, 2019).

2.4.3 Ethical clearance and protection of human research participants

All participants in the study voluntarily agreed to participate in the study and provided their consent before the actual data collection. I took full responsibility by explaining the objectives and all risks associated with their participation in the study, before activities. Regarding security, the study area was safe, since people from these communities have long been involved in research activities, and we had no reported incidents of researchers being physically injured. In the event of any reported cases of illness among people who were living in the household selected for the study, a member of the research team assisted them by transporting them to a health facility. Informed

consent was obtained not only from all individuals in the selected households for study, but also from all volunteers who were involved in the mosquito-catching process/collection and observation.

Ethics approval for this study was obtained from the Institutional Ethics Review Board of Ifakara Health Institute, where this research was conducted; the approval number is REF IHI/IRB/NO: 24-2013 (dated 26th July 2013) and IHI/IRB/NO: 34-2014. Ethics approval was also obtained from the Medical Research Coordinating Council at the National Institute for Medical Research in Tanzania (MRCC-NIMR) with the approval no NIMRlHQlR.8alVol. IXll761 and NIMRlHQlR.8alVol. IX/1903. Ethics approval was also obtained from the Human Research Ethics Committee (Medical) at the University of the Witwatersrand (approval certificate No: M151012). I also undertook two human research ethics courses with certificate numbers *1127469* for NIH and research ethics course from Collaborative Institutional Training Initiative (CITI) reference number *10805508). (*Appendix 6 & 7)

CHAPTER 3: SUMMARY OF KEY FINDINGS

3.0 Introduction

This chapter summarizes the key findings of this study, drawing on the two studies conducted. The detailed results are presented in the three papers that follow. Paper 1 (*Community Perceptions on Outdoor Malaria Transmission in Kilombero Valley, Southern Tanzania*) presents people's knowledge, perception and experience on malaria transmission and outdoor malaria and interventions use. Paper 2 (*Outdoor malaria transmission risks and social life: A qualitative study in south-eastern Tanzania*) describes and analyses the social and cultural gatherings which are conducted outdoors, their importance, and their implications for outdoor malaria transmission. Paper 3 (*Linking human behaviours and malaria vector biting risk in south-eastern Tanzania*) presents the data on activities that are conducted outdoors and entomological data that shows the active host-seeking mosquitoes, and the associated risk of exposure to malaria infection on a daily basis.

3.1 Nature of knowledge on outdoor malaria transmission

The results indicate that there is minimal knowledge within the community on outdoor malaria transmission, and that this has an impact on risk behaviour and the use of interventions both indoors and outdoors. Peoples' existing knowledge on malaria transmission is based on behavior change communication messages distributed to people on transmission risks and interventions to be used, with a focus on indoor interventions, primarily bed nets (PMI, 2017, Hetzel et al., 2007). The use of a behaviour change communication strategy in Tanzania was minimal during the 1990s and early 2000s, due to understaffing in the Ministry of Health and required capacity, thus the BCC activities tended to be partial. In 2007, President Malaria Initiatives (PMI), which was among the major funders for malaria interventions, supported an integrated approach including ITN, case management, use of ACTs for malaria treatment, and IPTp use, and started the first BCC known as "Communication and Malaria Initiative in Tanzania" (NMCP, 2010, 2014, PMI, 2017). Contemporary knowledge within the community assumes still the occurrence of transmission indoors from midnight to early morning, even though there is also an increasingly high level of experience of outdoor biting. The main intervention to prevent transmission is through

the use of bed nets, promoted from the 1990s and used by the majority of people in the study area. A community education and engagement programme was conducted in 1997, and examined social and cultural aspects of the distribution, delivery, acquisition and use of ITNs by focusing on local knowledge, practice and household dynamics (Schellenberg et al., 1999). Minja and colleagues have argued that individual knowledge is not a product of one factor, but rather a number of factors, including the interactions that exist within the community within which they live. Household power dynamics also affect the access and use of interventions such as bed nets at household level . However, the continued (to date, i.e. 2019) broadcasting and advertisements on the use of bed nets for malaria prevention focuses on risks during sleeping hours, with bed nets presented as the sole (or primary) means to prevent such risks. This existing knowledge is disseminated through the use of different slogans to increase the use of interventions *Malaria Haikubaliki, Tumia Chandarua* (Malaria is unacceptable, use bednets) and *Kabla ya kulala, weka/shusha chandarua* (Put on the bednet before sleeping) (Figure 3.1 and 3.2). This type of knowledge influences peoples' perceptions on the use of interventions for malaria prevention, and suggests too that knowledge makes a significant contribution to behaviour. While these slogans were highly appropriate when introduced in the 1990s, with the increasing risk of outdoor transmission, they need to be changed to reflect the growing prevalence of both indoor and outdoor malaria transmission.

Several studies have indicated the existence and risks of outdoor malaria transmission in malaria endemic areas within the country (Govella and Ferguson, 2012, Matowo et al., 2013, Okumu et al., 2013, Russell et al., 2011). These studies have indicated that malaria vectors such as *An. gambiae s.s.* were observed to bite outdoors with a high proportion of outdoor biting among *An. funestus,* thus indicating the need for interventions that could target malaria vectors that feed outdoors (Kaindoa et al., 2017, Killeen, 2014, Matowo et al., 2013). Communities and different stakeholders such as researchers, donors and manufacturers of interventions that deal with malaria prevention within communities, need to be informed of the existing risk of outdoor malaria transmission, and low-cost measures need to be developed and promoted to prevent or minimize such risks. Approaches that will take into account both indoor and outdoor transmission risks by allocating vector control measures are important to reduce malaria.

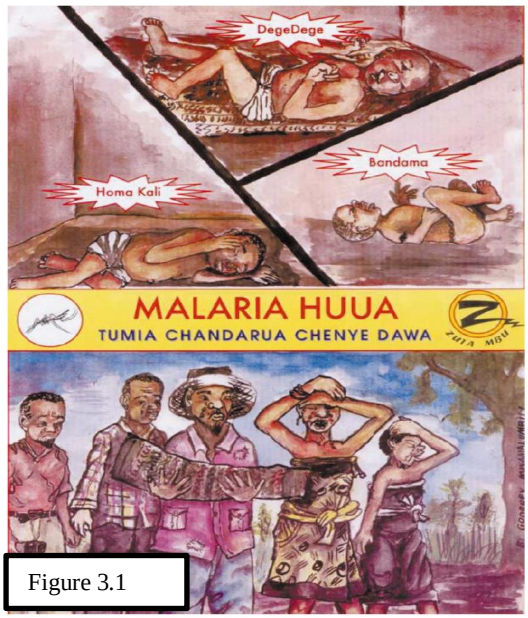


Figure 3.1

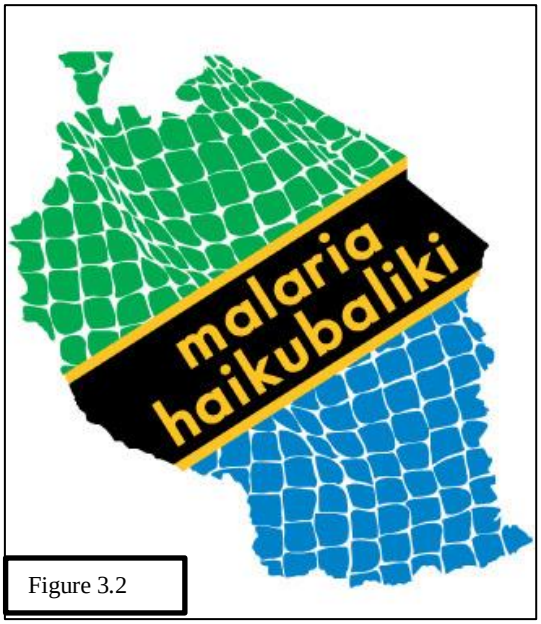


Figure 3.2

Source: Figure 3.1 (Minja et al., 2001) and Figure 3.2: Rob and Koenker.

Figure 3.1 and Figure 3.2: Pictures described the slogans that were used for BCC and other communication channels to improve understanding on malaria and intervention use particularly bed nets.

The use of BCC should be a continuous approach and needs to keep pace with changes in disease, population and ecology. Environment and ecology have considerable impact on the behaviour of the vector and pathogens, and if those changes and patterns are determined, it is important for this to be communicated. The importance of considering changes in disease transmission is reflected in Paper 1, where participants offered contradictory responses in relation to the transmission of malaria:

> *Malaria is transmitted from midnight while indoors sleeping (female, low-subsistence farmer, IDI)*

> *We are bitten by mosquitoes more when outdoors than indoors (male, middle-subsistence farmer, FGD)*

> *I slap myself when outside, while outside. Inside, I only use mosquito bed nets (male, middle-subsistence farmer, IDI).*

3.2 Nature of exposure to the risk of outdoor malaria transmission at the household level

Basing on both modified CDC light trap collection and miniaturized trap

A total of 165,028 mosquitoes were collected from both CDC light traps and DN-Mini trap. In total, 94.8% were sampled from CDC-light traps and remaining 5.2% from DN-Mini traps. From all the sampled mosquitoes, 13,822 were *Anopheles* of which 90.6% were *An. gambiae s.l, An. funestus* 3.7% and the remaining 5.7% were other *Anopheles* species. However, recent studies conducted in the Valley have demonstrated that, majority of An. *funestus* comprised of 95% *An. funestus s.s* and the remaining 5% comprised of other siblings such as *An. rivulorum* and *An. leesoni* while for *An. gambiae s.l* consist entirely of *An. Arabiensis* thus among other factors, existing malaria transmission may also be likely mediated by *An. funestus* (Kaindoa et al., 2017, Ngowo et al., 2017). (More details are provided on published paper 3, Finda *et* al., 2019).

The study findings indicated that household activities conducted on a daily basis contribute to the risks of malaria infection/transmission outdoors. These activities are conducted at the household level and they include cooking, resting, storytelling, playing cards, eating, and selling commodities outdoors. At the same time as these activities take place, the host-seeking mosquitoes such as *An. funestus* and *An. gambiae s.l.* were observed to be active around human dwellings. Human outdoor activities and host-seeking mosquito activities occurred at the same time. Human activities are conducted from the early hours of the evening on a daily basis. During the dry season, the highest biting peak was observed among *An. gambiae s.l.* at 20:00 pm, while among *An. funestus* the highest peak was observed at 21:00. During the wet season, the highest peak biting rate among *An. gambiae s.l.* was observed at 22:00 but started to peak at 19:00 pm. For *An. funestus*, the biting rate was low throughout the night, with a slight peak between 22:00 and midnight. The highest peak biting patterns of both vectors were observed at times when there was moderate or low frequency of activities, but even with the low biting rates, during times when there was high frequency of activities, the risks of transmission are still present. This is due to the fact that malaria transmission

is not restricted to the highest number of mosquitoes and high biting rates. It should also be noted that there was a difference between these two seasons among *An. gambiae s.l.*, where the highest peak was observed at 20:00 during the dry season but at 22:00 during the wet season (Figures 3.3 and 3.4).

When comparing biting patterns between indoor and outdoor areas, the study found that the indoor biting rates among *An. gambiae* during the dry season started to peak at 19:00 with the highest peak at 21:00, while for *An. funestus* there was a steady biting pattern and a slight increase between 2:00 and 3:00 am. During the wet season, the indoor biting rate among *An. gambiae s.l.* started to peak at 19:00, with the highest peak at 22:00 hours when there was very low frequency of activities indoors, while among *An. funestus* the biting rates were still low with a slight increase between 22:00 hours to midight where there was very low frequency of activities indoors as indicated in Figures 3.5 and 3.6. People within the communities added that they were more often bitten by mosquitoes while outdoors than when they were indoors.

The findings of this study are consistent with findings of other studies that showed that the biting pattern of *An.funestus* was not affected by season (Kaindoa et al., 2017, Lwetoijera et al., 2014), while biting patterns for *An.gambiae s.l* start to peak very early in the evening in the dry season and occurred slightly later at night during the wet season (Reddy et al., 2011, Russell et al., 2011, Wanji et al., 2003). This indicates that both seasons have risks of transmission, but the greatest risks were observed to be in the evening during the dry season due to high numbers of host seeking mosquitoes at times when more people were outdoors undertaking various household activities without protection against mosquito bites. So, conducting activities during the evening outdoors every day, in the presence of host seeking mosquitoes, exposes people to frequent mosquito bites and the risk of malaria transmission and infection. However, the hourly exposure to host-seeking mosquitos indicates higher exposure indoors when not using bednets outdoors, as shown in Figure 3.7. Despite low exposure outdoor but the risks of transmission is still there due to existence of mosquito bites. So, more studies should be conducted to quantify the risks of transmission while outdoors to reduce existing disease burden.

This suggests that, even though there is risk of transmission outdoors, the higher risks of transmission continue to be indoors, so interventions for both indoors and outdoors

are needed. However, the estimated EIR for outdoor catches for the six months of collections was 8.34 infectious bites per person per year (ib/p/yr) where, according to species, the EIR was much higher among *An. funestus* -- 6.64 ib/p/yr compared to *An. arabiensis* which had EIR of 1.64 ib/p/yr. These results indicate that *An. funestus* primarily mediates transmission in this area.

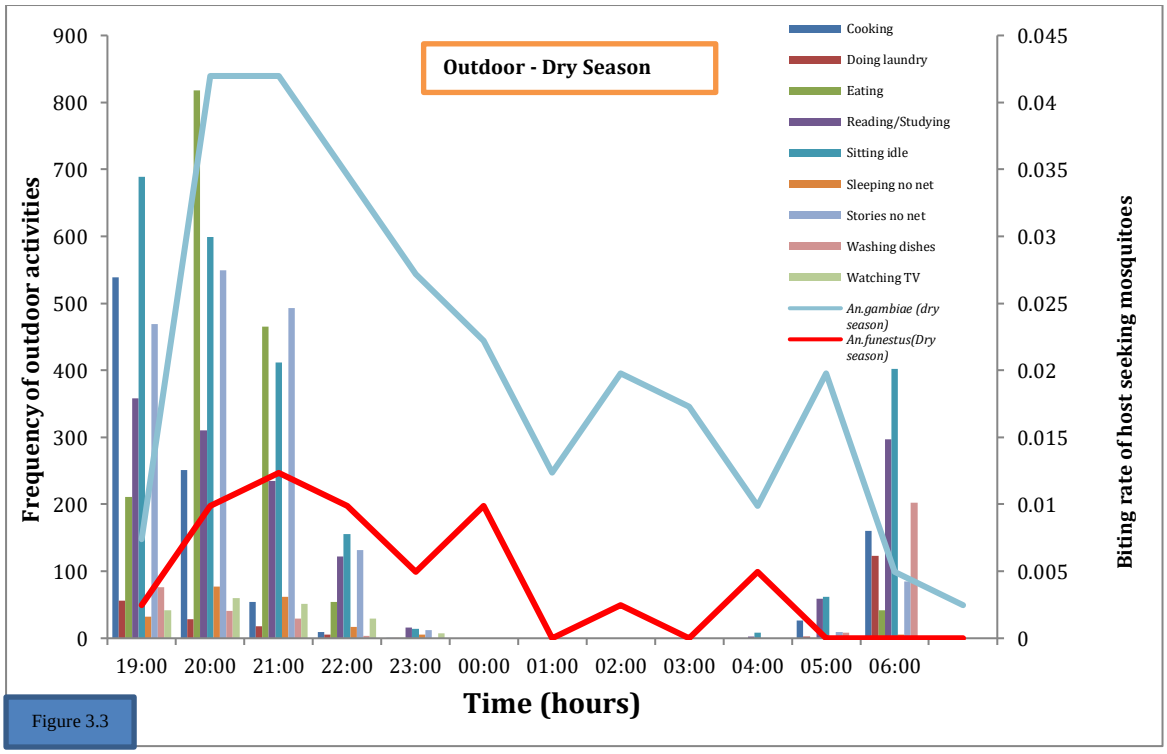


Figure 3.3

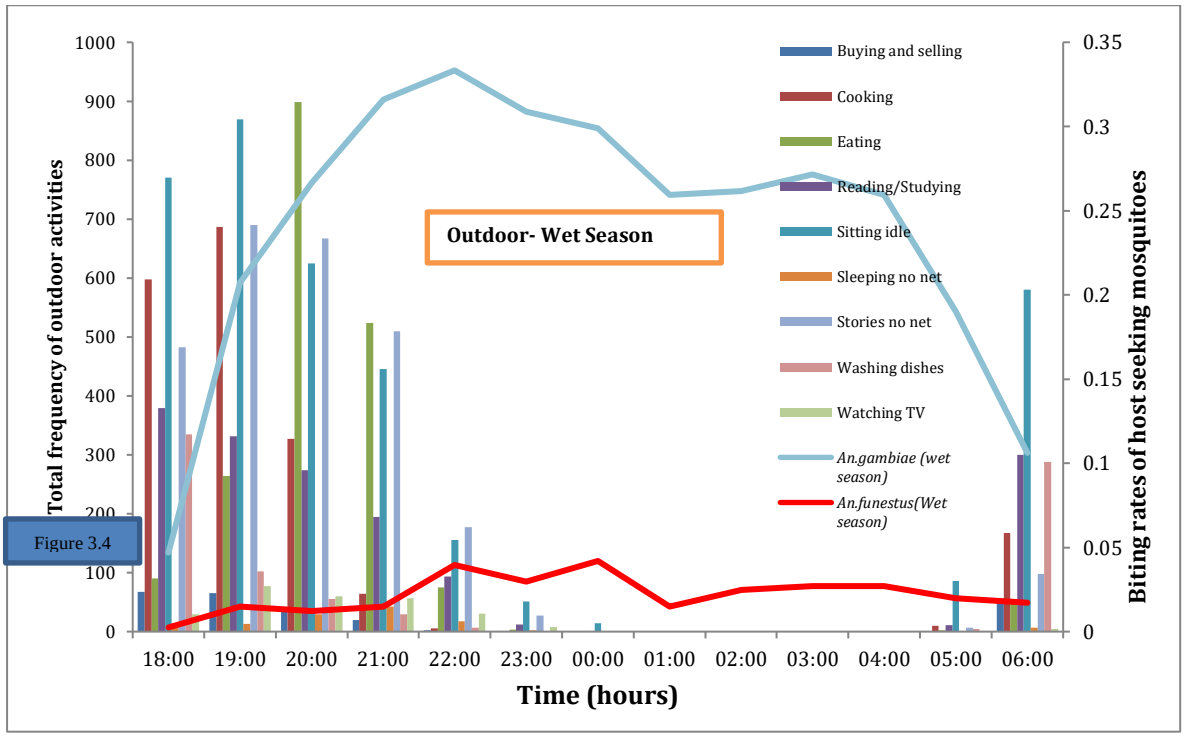


Figure 3.4

Figure 3.3 and Figure 3.4: Correlation of human activities conducted outdoors during the evenings and biting rates of host-seeking mosquitoes outdoors.

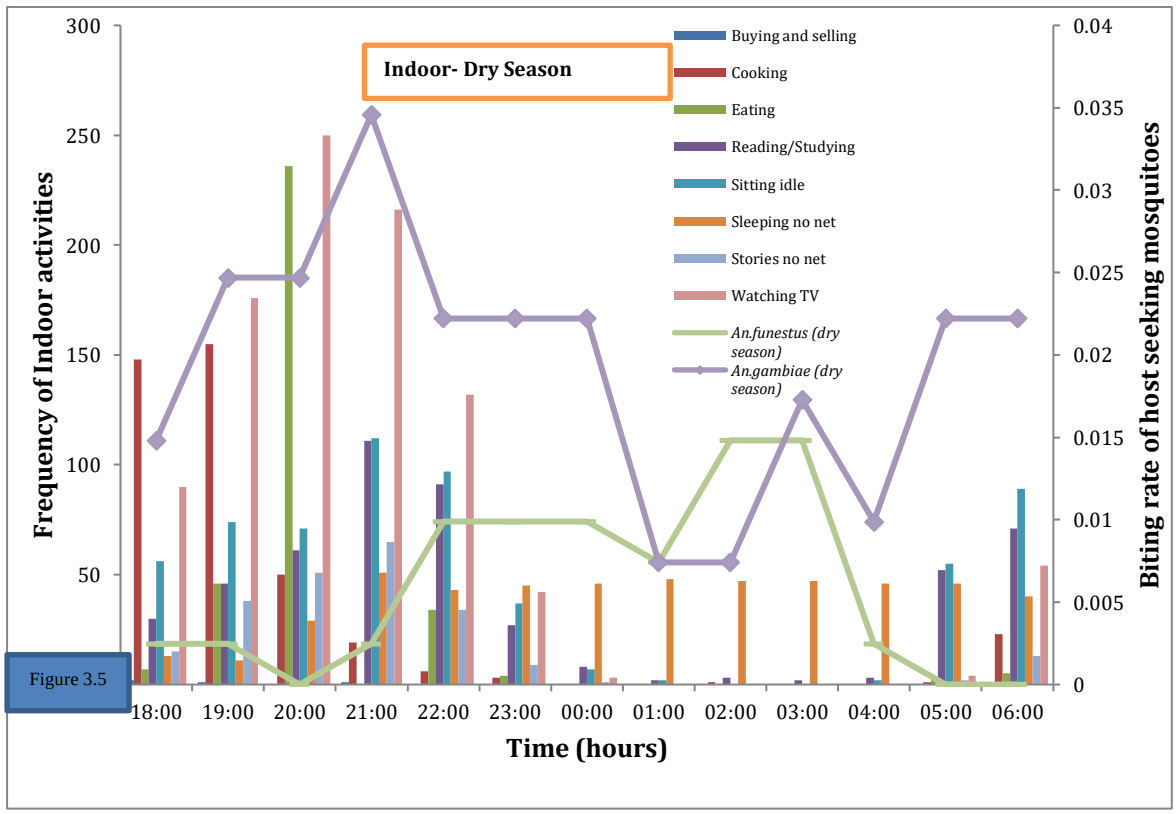


Figure 3.5

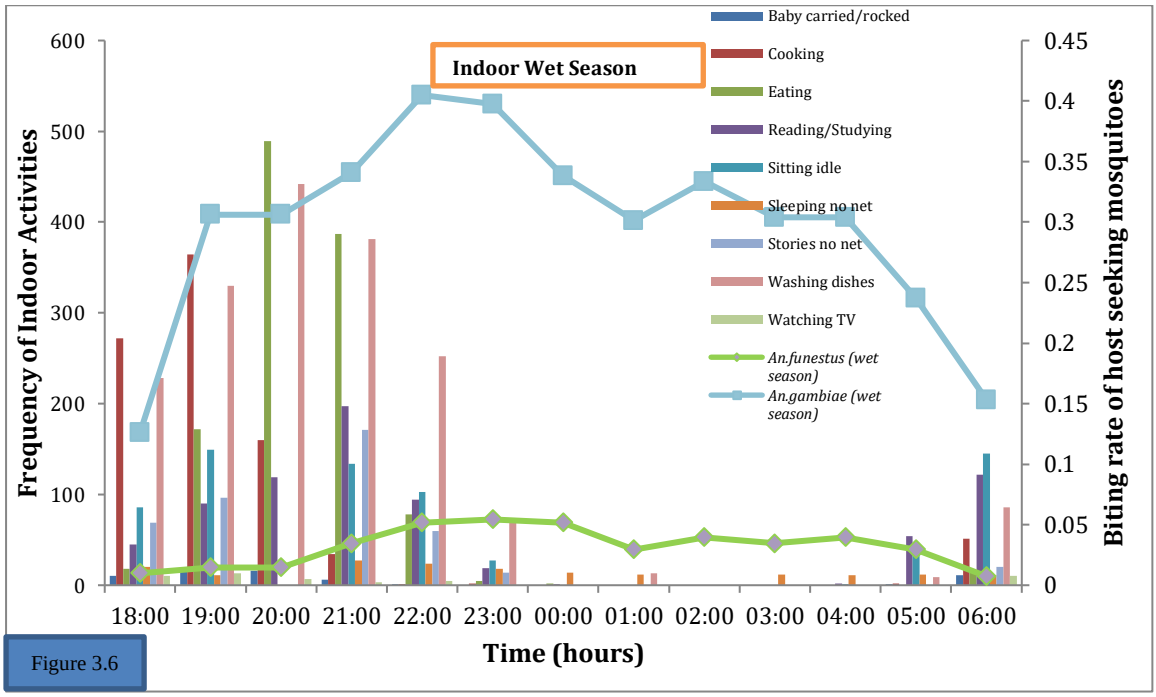


Figure 3.6

Figure 3.5 and Figure 3.6: Correlation of human activities conducted indoors during the evenings and biting rates of host-seeking mosquitoes indoors.

A total of 165,028 mosquitoes were collected from the study villages of which 94.8 % (156,456) were sampled by CDC-light traps and 5.2% (8572) were sampled y DN-Mini trap. The species composition of all the catches were: 88.3% were *Culex species*, 8.4% *Anopheles*, 2.5% *Mansonia*, and 0.8% for other species. Of the anopheles (n = 13,822) were An. gambiae s.l which composed 90.6%, *An. funestus* 3.7 % and other species, 5.7%. However, recent studies conducted in the Valley have demonstrated that, majority of An. *funestus* comprised of 95% *An. funestus s.s* and the remaining 5% comprised of other siblings such as *An. rivulorum* and *An. leesoni* while for *An. gambiae s.l* consist entirely of *An. arabiensis.* More visualization of data including the differences in catch according to traps is presented on the table below and published paper 3.

Table 3.1: Number of different mosquito species collected indoors and outdoors using CDC-light traps or miniaturized double net traps (DN-Mini) in the study area.

Trap type	**No. of trap nights**	**No. houses**	**Mosquito species**	**No. mosquitoes indoors (%)**	**No. mosquitoes outdoors (%)**	**Total**
CDC light trap	1,620	90	Anopheles arabiensis	7,766 (64.2%)	4,330 (35.8%)	12,096
			Anopheles funestus	238 (56.7%)	182 (43.3%)	420
			Other Anopheles species	69 (7.1%)	698 (92.9%)	767
			Mansonia spp	1,182 (31.4%)	2,578 (68.6%)	3,760
			Culex spp	92,005 (66.6%)	46,039 (33.4%)	138,044
			Other mosquito species	422 (30.3%)	947 (69.7%)	1,369
DN-Mini trap	320	8	Anopheles arabiensis	125 (29.1%)	304 (70.9%)	429
			Anopheles funestus	58 (62.4%)	35 (37.6%)	93
			Other Anopheles species	4 (28.1%)	13 (71.9%)	17
			Mansonia spp	13 (4.4%)	282 (95.6%)	295
			Culex spp	4,744 (61.4%)	2,983 (38.6%)	7,727
			Other mosquito species	3 (26.7%)	8 (73.3%)	11

However, there is a considerable high protection indoor when people are under treated bed net. However, there was noted that the protective efficacy of treated bed nets from indoor exposure was only 73% thus, there is a considerable proportion of people who were still exposed to mosquito bites even when they are under bed nets. Figure 3.7 indicate the amount of exposure indoor and the proportion to which ITNs protects an individual from mosquito bites.

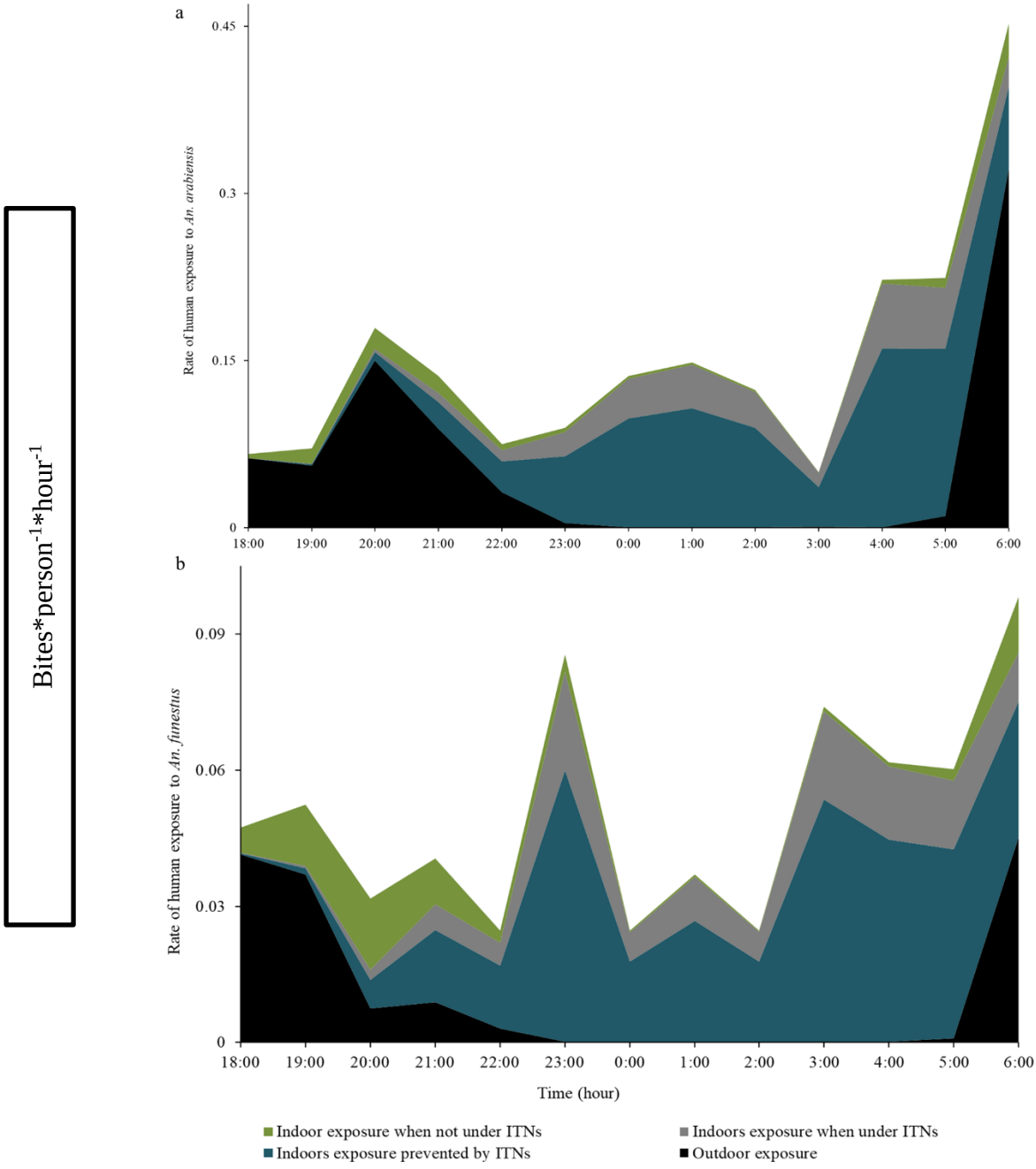


Figure 3.7: Estimation of hourly exposure to indoor and outdoor mosquito bites and proportions preventable using bed nets: (a) *An. arabiensis*; (b) *An. funestus*

Houses in the study communities are characteristically poorly ventilated, and during the dry season when the mean temperature is high, houses become particularly hot, and at times unbearable, due to the absence of ceiling boards. As a result, people spend more time outdoors than indoors. Most houses are characterized by small unscreened windows, open eaves and unscreened doors, which contribute to the easy access of mosquitos and so the continued risk of exposure to mosquito bites (Table 3.1). In

addition, most houses have two bedrooms only, and are typically characterised by minimal or no amenities like kitchens, bathrooms and living rooms, further encouraging people to spend more time outdoors,conducting every day living activities outside of the house. Most people use charcoal and firewood for cooking which cannot be accomodated in their small houses, thus cooking is mostly undertaken outdoors as indicated in the sources of energy for cooking in Table 3.2.

Table 3.2**:** Description of house structure and house amenities in study area.

Variables	**Frequency**	**Percentage**
House wall types		
Grass	2	1.1
Baked bricks	143	82.7
Cement bricks	5	2.8
Poles & mud plastered	21(1.1)	12.1
Wood/timber	2	1.1
Roof types		
Iron sheets	128	72.7
Grass/Thatch	45	25.5
Asbestos	2	1.1
Others	1	0.6
House screening		
Windows: No screens	84	47.7
Some screens	53	30.1
Every window	39	22.2
Door: No screens	148	84.6
Some screens	16	9.1
Every door	11	6.3
Types of toilets		
Traditional latrines	13	7.4
Pit Latrine	148	84.1
Flush toilets	15	8.5
Cooking Energy		
Electricity	7	4.0
Kerosene	10	5.6
Firewood	54	30.7
Charcoal	102	58
Cooking grass	3	1.7

3.3 Nature of social and cultural gatherings: Maintenance of social cohesion

The social and cultural study revealed the existence of different practices that maintain peace, unity and sustain reciprocity within the community. These gatherings and ceremonies are also mostly conducted outdoors at times when host-seeking mosquitoes are active. During these activities/gatherings there is minimal use of interventions that

might prevent mosquito bites; in the absence of prevention, people were at risk of malaria. These activities take place in adherence with religious or cultural beliefs and personal interests, and include circumcision, worshipping and pleasing the gods/ancestors. Even though most gatherings are conducted during the dry season when there are fewer mosquitoes, gatherings associated with mourning and funerals are conducted in both dry and wet seasons, and their occurrence does not vary according to season and climate. During these times, the bereaved family mourns for their loved ones while receiving support from other family members and community members. In the study setting, mourning involves several days of spending time outdoors day and night, although people are most likely to participate in mourning in the evening after the long working day/hours. Such attendance is of great importance and symbolizes support provided to the bereaved family, which is known as *Kumsitiri mwenzetu* in Swahili *(*to console) and to cooperate with community members. Attending such events and providing support to kin and neighbors guarantees that individuals will receive the same support when faced with similar problems, and/or when they are in need of social support. The society operates on the basis of reciprocity, so helping to maintain unity and cooperation among people and to facilitate social cohesion. On these occasions, there is minimal use of interventions to prevent bites, and sometimes the use of interventions is seen as going against social norms. In order to show respect and maintain the values of the communities, for example, people tend not to carry and use interventions during such gatherings. Additionally, there is also minimal access to interventions that can be used outdoors such as topical repellents or treated clothes, due to their cost. The following quotes provide a sense of these circumstances and associated attitudes:

> *In this community, we have celebrations like Holy Communion, baptism, weddings where we celebrate a lot. There are other celebrations like mawlid which other people do and celebrate (middle-income subsistence farmer, FGD).*

> *These gatherings have great importance, even in the holy books (referring to the Bible or Quran), and they bring people together. Failure to cooperate with (each) other has several impacts but most important is isolation (middle-income subsistence farmer, KII)*

Mosquitoes bite people when they are in gatherings like in places of worship, like mosques and churches, because they bite people when they are settled and not on the move like dancing or the like. They also bite people who are mourning because when people get there, they mostly sit down and sleep without protection, hence providing the best opportunity for mosquitoes to bite (high-income subsistence farmer, FGD).

You cannot come with a net into the house when people are mourning. It suggests that you think you are better than the rest of the people who are there. (middle income subsistence farmer, FGD).

Thus, these three main themes for this study identify important factors such as knowledge and perception of the people, biting pattern of host-seeking mosquitoes (malaria vectors) during the early evening as well as the daily activities and seasonal social and cultural practices that contribute to the risks of outdoor malaria transmission. This study explains the need to understand that societies exist and operate under adherence to social norms and beliefs that not only maintain them, but also ensure respect, peace, harmony and cooperation.

There is a need to understand that certain situations in communities, such as risk of malaria transmission, may change positively or negatively, based on the responses that people have on the use of interventions. Over time, the use of front-line interventions to prevent malaria transmission indoors has contributed to the increasing of outdoor interventions. Since the introduction of these interventions, the population has changed, as well as the climate, and increasing population and human activities are held to help community members to meet their basic needs. The study helps to illustrate that the changing ecology in the Kilombero Valley as well as behaviour change in indoor intervention use have impacted changes in vector behaviour. This needs to be communicated to the society to prevent health problems and maintain the successes of malaria reduction.

CHAPTER 4: DISCUSSION AND CONCLUSION.

4.1 Discussion and Conclusion

Outdoor malaria transmission is a growing concern that currently threatens the success of malaria control programmes in driving down transmission in Tanzania and in other malaria endemic countries. Insecticide and drug resistance (N'Guessan et al., 2007, Nkya et al., 2014, WHO, 2010), unresponsive health systems, poor surveillance and insufficient funds to cover interventions, vector surveillance and diagnosis and treatment, and poor political and financial commitment from governments of different malaria endemic countries, all undermine success in control (WHO, 2015a, 2017). While more funds are directed to diseases such as HIV/AIDS, malaria and tuberculosis, and for vaccines to prevent diseases among children, accessing required interventions and the implementation of strategies on prevention, diagnosis and cure is becoming increasingly problematic for economic, financial and political reasons. The challenges that affect the health system in Tanzania include poor funding, lack of priority to the health sector such as allocation of unqualified and inefficient allocation of personnel, and insufficient funds for drugs and other medical supplies that contribute to poor health care services, which then lead to high disease burden. Other challenges include unstable political commitment and political interference, which continuously challenge health systems in many low-income countries, so affecting the implementation of health programmes and resulting in the untimely disbursement of funds from the central government, impacting the health sector tremendously. Further, the lack of community participation in planning, poor quality of services and weak referral systems (Jenkins et al., 2011, HRHSP_MHSW, 2014, Frumence et al., 2013) contribute to poor health and deaths that could easy be avoided.

Recent research studies in Africa have confirmed the existence of and increased outdoor feeding by malaria vectors, such as *An. gambiae* and *An. funestus,* which are believed to be attributed to different factors including the increasing use of LLINs and IRS (Reddy et al., 2011, Russell et al., 2011). Mosquitoes have developed physical and behavioural resistance to these interventions and bite people while they are outdoors, as well as indoors before they retire to bed under bednets. Malaria vector mosquitoes such as *An. gambiae* and *An. funestus* are behaviourally resistant to existing control measures and thus contribute to persistent and existing residual malaria transmission in

Kilombero Valley and other malaria endemic areas (Bayoh et al., 2010, Bugoro et al., 2011, Killeen and Moore, 2012, Yohannes and Boelee, 2012, Govella and Ferguson, 2012, Killeen, 2014, Moiroux et al., 2012). Even with minimal numbers, *An. funestus* is the primary vector that mediates malaria transmission in the valley, so interventions to reduce such risks are urgently required to prevent the risks of transmission (Kaindoa et al., 2017). Other factors include climate change as a result of human activities, which has lead to increases in temperature that favour mosquito survival,. Although climate change is a global and planetary issue, at a local level, clearing trees and changes of land use for cultivation have contributed to the increase in mosquito vectors (Lindblade et al., 2000, Patz et al., 2005). Warm and hot climatic conditions are more favorable for the development of mosquito larvae, whereas areas with temperatures below 18^0C and more than 40^0C are less favorable for mosquitoes and in most cases as a result these areas have less malaria transmission. The three aspects of climatic conditions that influence or directly affect malaria transmission are humidity, temperature and rainfall. So, the increases of temperature, but below 40^0C, contribute significantly to larvae development and mosquito survival. However, in the study area, insecticide resistance is one of the major contributing factors for change in malaria vector host-seeking behaviour from midnight to early evening and later at night (Matowo et al., 2017). Also, people experience frequent malaria infections despite high use of bednets indoors .

The current study found that people's behaviour and practices contribute to exposure to outdoor biting, placing people at risk of malaria infection. Although people have always conducted activities outdoors, the increasing incidence of vectors outdoors increases the risk of infection. The different activities in which people are engaged on a daily basis, seasonal religious and cultural gatherings, and life events that occur throughout the year, all contribute significantly to exposure to mosquito bites. Spending time outdoors, particularly during the dry season when it is very warm, as documented in Ghana (Monroe et al., 2015), indicates the extent to which human behaviour puts people at risk of malaria transmission. In Bioko, Equatorial Guinea, activities such as eating and drinking outdoors were also observed to occur at the peak time of feeding of host-seeking mosquitoes (Reddy et al., 2011). The current study indicated that children who are vulnerable to malaria accompany their parents outdoors, so they are exposed to mosquito bites as they play while their mothers are preparing the evening meal, while they eat, and before they go to bed. The interventions that are currently distributed that

target children under the age of 5 years, such as bednets, are not conducive for use outdoors to prevent children from mosquito bites. Thus, this vulnerable group continues to be at high risk of infection. The daily exposure of people to mosquitoes put people at risk of mosquito-borne diseases such as malaria, Zika, dengue, Rift Valley fever, yellow fever and chikungunya, so the prevention of mosquito bites prevents transmission of a range of mosquito-borne diseases. Since malaria transmission occurs during blood feeding when the protozoa from the mosquito salivary glands are injected into the skin of a human being, this indicates the need to reduce the frequency of mosquito-human contact. Thus, prevention of mosquito bites on a daily basis is very important.

As described in the thesis and in the published articles, house structures also contribute to why people spend time outdoors, because most household activities cannot be accommodated. As noted most houses are small, with minimal ventilation and amenities inside, which both enable mosquito entry contributing to indoor transmission risks, and outdoor malaria transmission (Ogoma et al., 2010, Lindsay et al., 2003a, Matowo et al., 2013), (Moshi et al., 2017, Finda et al., 2019). Studies have indicated that poorly-ventilated households are among the factors that contribute to risks of malaria transmission at the household level (Ghebreyesus et al., 2000, Lwetoijera et al., 2013), which was also observed in this valley. Home improvement may be particularly helpful in curbing such risks, because it will accommodate all the required amenities such as kitchen, living and bedrooms, toilets inside and with screens (doors, windows and eaves), could prevent and reduce mosquito entry (Lindsay et al., 2002, Lindsay et al., 2003b). However, these interventions are expensive, and this is not feasible in this very poor area. Despite the significant contribution of improved houses in disease reduction, such changes might also have a negative impact on social interactions outdoors if time spent outdoors and social interactions were considerably reduced. Given the negative impact of such interventions, the use of environmental and culturally compelling-approaches to reduce malaria transmission risks and intervention use, with minimal effect on people's life and social interactions, is of great importance.

Knowledge on malaria prevention and control is the cornerstone for reducing malaria transmission (Adongo et al., 2005, Govere et al., 2000, Mazigo et al., 2010), if paired with access to interventions. The findings of this study indicate good knowledge of

indoor malaria transmission, but minimal awareness of people on outdoor malaria transmission, and this affects the way people protect themselves while outdoors. The current means for mosquito protection in these communities while outdoors includes wearing long-sleeved clothing and long trousers or skirts, slapping and fanning oneself to disperse mosquitoes, and, for a few people, the use of repellents. These interventions do not provide adequate protection, so there is a need for other interventions such as treated clothes and increasing access to and use of affordable repellents. Existing measures such as the use of topical repellents, treated clothes and larviciding in highly-populated areas are encouraged by WHO, so that they can be used together with existing interventions that target prevention of indoor transmission (WHO, 2015a). The successful use of these and other interventions require an integrated health approach for malaria prevention and control. This needs to include behaviour change communication on outdoor malaria transmission risks to improve community knowledge on the current risks which involves vector and human behaviours, and access to and use of interventions which may enhance intervention use and malaria control efforts.

In addition to daily tasks such as cooking, eating, bathing and clothes washing, seasonal social and cultural gatherings are conducted outdoors and are socially significant to people in these communities, and they expose people to mosquito bites. Although many of these gatherings are conducted during the dry season when mosquito density is relatively low (Figure 3.3), other studies have indicated that existing transmission in this particular valley may be mediated by the low numbers of *An. funestus* (Kaindoa et al., 2017). During the early dry season, soon after the wet season ends, vector densities start to decline, but such decline is not uniform for *An. funestus*, and its decline is very slow compared to *An. gambiae* (Smith et al., 1995). In the early dry season, there was high density of *An. funestus* in the valley. The presence of *An. funestus* outdoors, together with *An. gambiae*, indicates a greater risk of malaria infection outdoors because the available indoor interventions are inappropriate and ineffective for outdoor use.

This doctoral study applied different approaches to explain existing situations and to quantify the activities, timing, and extent of biting rates of host-seeking mosquitoes which contribute to malaria transmission. It provides new knowledge regarding the

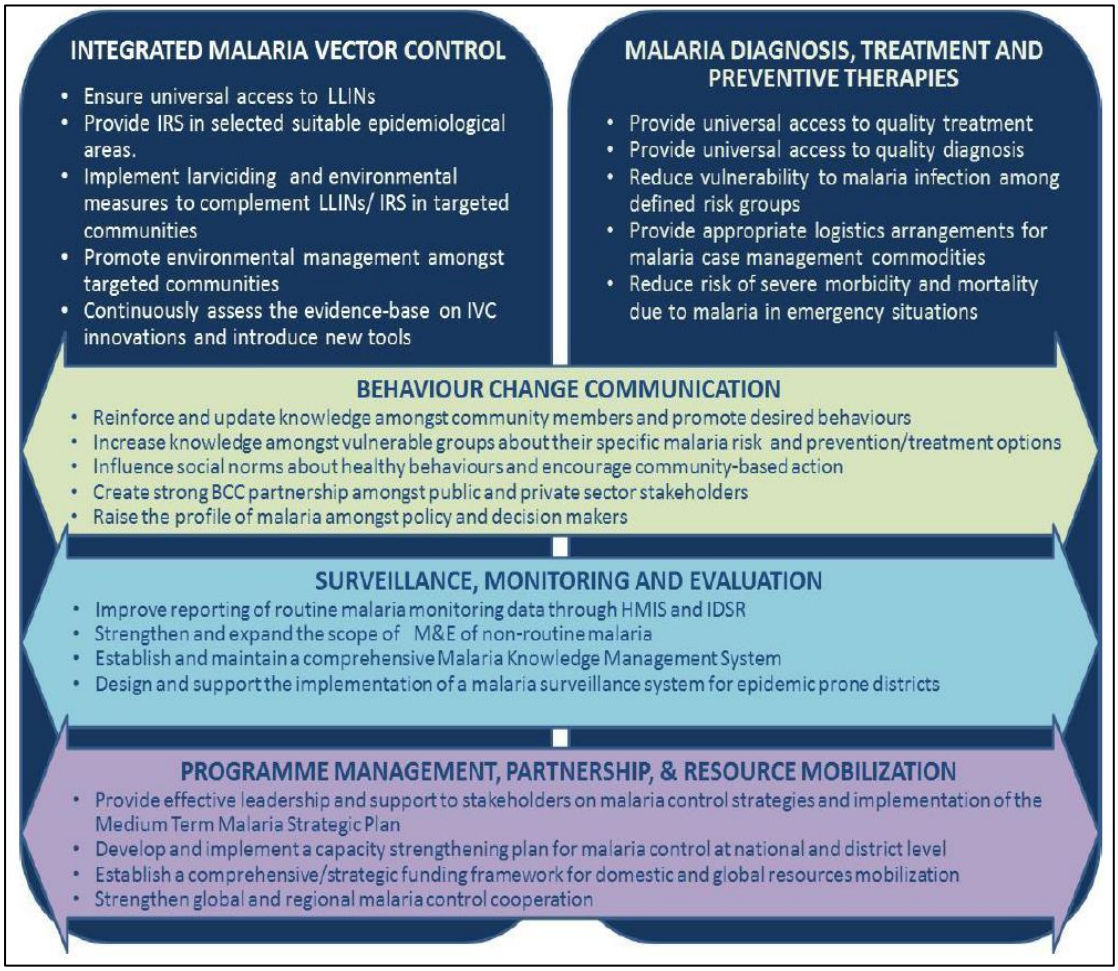
complex ways in which changes in mosquito biting, access to information on malaria transmission, overdependency on a single intervention, minimal access to other interventions, and social and cultural practices, combine to contribute significantly to malaria transmission risks. The collection of human activities data together with mosquito data provides information which helps to formulate a clear correlation between outdoor activities and biting pattern of host-seeking mosquitoes and the risks of exposure to malaria infection. However, poorly ventilated and small house structures lead to a range of activities conducted outdoors, and so play a significant role in exposure to mosquito bites and malaria transmission. Poverty plays a significant role in individual decision making on the purchase and use of interventions (Moshi et al., 2018, Moshi et al., 2017). The decision to buy interventions for malaria prevention cannot take precedence over family basic needs. In addition, findings of this study have shown that there is minimal knowledge among community members on the role of social structures, culture, beliefs and social capital which impact social interactions. The appended papers discuss the research findings in greater detail.

4.2 Implications of the research findings

4.2.1 Implications and lessons for integrated policy and practice

Malaria prevention and control strategies are well integrated in the National Malaria Control Programmes (NMCPs), which are geared toward reduction in malaria transmission and control of malaria through provision of and increasing access to interventions, prompt diagnostics and treatment. However, the approach for the prevention of identified outdoor malaria transmission risks is not explicitly indicated in the current strategic plan as compared to the indicated strategies to prevent indoor transmission such as increasing access to LLINs and IRS. The current strategic plan, introduced in 2012, aimed to reduce malaria prevalence from 10% in 2012 to 1% in 2020 by ensuring all citizens have access to quality, effective, safe and affordable malaria interventions through timely and sustainable collaborations with different stakeholders. In 2019, the prevalence is estimated to be 15% which is higher than the preceded year which was 9%, so the 2020 goal is clearly unachievable. The fifth integrated malaria vector control plan aims to assess the evidence-base on integrated vector control innovations and introduce new tools in malaria prevention and

surveillance to be able to monitor and evaluate malaria burden so to allocate required interventions. This plan aims to provide updated information on malaria to improve individual and community knowledge on malaria risks and prevention, as indicated in Figure 4.1. The strategy indicates future plans for malaria prevention and control in the country, and work geared towards malaria elimination and evaluation as well as reinforcing and updating knowledge on malaria transmission and prevention amongst community members. However, the use of interventions such as LLINs and IRS seem to be intensified through the use of non-pyrethroids due to existing insecticide resistance, so they will be using organophosphate and carbamates (NMCP, 2014). These strategies resemble those set for malaria prevention and control according to the President's Malaria Initiatives (PMI), which budgeted a total of $45 million for Tanzania alone over 4 years (NMCP, 2014). PMI is working on prevention, treatment and control, as well as strengthening health systems in the country, to adapt to best preventive and control measures and support proactive disease prevention. PMI has invested in and provided community education through different messages such as 'Not every Fever is Malaria' (*Sio kila Homa ni Malaria*) (PMI, 2017) as a means to increase awareness regarding malaria and the use of health care facilities for malaria diagnostics. Malaria prevention and control in Tanzania might have reached more than 70% donor funding, so even the operation plan from the NMCP cannot concentrate on other risks because donors focus on their own priorities, with these needing to be accommodated by the government in order to receive the required funds.



Source: National Malaria Strategic Plan

Figure 0.1: Overview of malaria strategies in Tanzania

The use of behaviour change communication (BCC) on the current strategic plan aims to improve communication among community members regarding malaria transmission and prevention through community leaders and health care providers. The aim of NMCP in increasing community knowledge is an important step that aims to engage communities, but the step-by-step process and the identification of people to do the tasks could have been better. However, within this strategy, NMCP aimed to influence social norms about health behaviour and encourage community-based action. So, the community involvement approach in determing the risk behaviour to malaria transmission and determining best practices for malaria prevention will contribute significantly to reduction in malaria transmission. However, the success of this approach depends particularly on strategic planning and implementation, which will

take into account social and cultural differences, practices and beliefs to be able to identify prevention ways and means, depending on the disease burden and best practices that are socially and culturally acceptable. This approach resembles the suggestions of the social ecological model, which proposes that social, political environmental and cultural factors of the societies be considered, and that these not be treated as a uniform entity.

Based on changes of existing transmission, this strategy should also take into account vulnerable groups such as people living with disabilities or otherwise vulnerable, and involvement of everyone countrywide, since more than 98% of the population is at risk of malaria infection. Nevertheless, the strategy has also indicated that the current BCC strategy developed by NMCP, informed by PMI, will build on pre-existing knowledge and reinforce understandings of desired behaviours through interpersonnel communication and malaria training programmes on the consistent use of bednets (LLINs), bednet care and repair, malaria testing/diagnostics and treatment. This is specified in the Social and Behaviour Change Communication (SBCC) under PMI (PMI, 2017). No content of communication on outdoor malaria is provided. Due to increased outdoor biting, communication strategies for prevention and control of outdoor malaria transmission needs to be well integrated and communicated to communities. Further, as Milali and colleagues have indicated, the risks of malaria transmission exist everywhere, regardless of time and place (Milali et al., 2017). The current study suggests the importance of the consideration of social and cultural factors that involve practices or behaviours that might increase the risks of malaria transmission and practices that might influence non-use or improper use of interventions outdoors (Moshi et al., 2018, Moshi et al., 2017) and indoors (Dunn et al., 2011). Thus, the allocation of interventions should consider not only environmental factors but also social and cultural factors. Even with changes in mosquito biting patterns (Russell et al., 2011), emphasis is still placed on the distribution and use of bednets only as the means to protect people from mosquito bites (NMCP, 2014).

Together with vector control tools, better health systems are important to the success of interventions, but it is not necessarily true that investment in this domain will result in better interventions use that can yield better results (Mills et al., 2006, Levine, 2004). To have sound impact on health outcomes from interventions, there is a need for top-

level political and financial commitment, the ability to deliver appropriate technologies, and innovations at the right price which can result in better health gains. The use of a socio-ecological approach for malaria prevention may be successful in this context, even in areas which are very poor and have weak health systems (Levine, 2004).

The current strategy has indicated the need to consider the ecology and physiological factors such as type of vectors, favourable breeding habitats, climatic conditions as well as the topography, in assigning prevention and control measures (NMCP, 2014). However, if this strategy does not consider the social aspects of the communities by treating them equally, the intended goal may not materialise. More attention needs to be given to factors that are missing in the current strategies for malaria prevention and control, such as risk of outdoor malaria transmission, human behaviour, changes in epidemiology, and social and cultural factors (Williams and Jones, 2004, Heggenhougen et al., 2003, Makundi et al., 2007). To attain better and promising results, based on the results of this study, I urge the consideration and use a socio-ecological model in the planning and implementation of strategies for malaria prevention and control, because the model provides the opportunity to not only involve people to identify the existing problem, but also to identify interventions and use compelling messages to mobilise people which will enhance acceptablity, uptake and use (Higginbotham et al., 2001). This approach will help to minimize two main aspects that lead to the failure of interventions: gaps between awareness of risks and action; and gaps between the intention to change behaviour and actual behaviour change. To ensure that people participate and take up interventions, there is a need to package health messages used for mobilization to ensure that they are culturally compelling.

However, there is also a need to formulate new interventions and strategies that are feasible and applicable, according to the risks and needs of particular environment that can contribute to reduction of mosquito bites and mosquito density. The committees that are dealing with malaria prevention and control at district levels need to pioneer prevention strategies for outdoor malaria transmission risks (based on evidence), increase access to and use of interventions to prevent such risks, and communicate changes of transmission and work with NGOs within their setting. There is a need to understand that people change in response to the environment around them, so disease interventions should take this into consideration while preparing for behaviour change communication strategies regarding malaria prevention.

Disease prevention and control require better management, with flexibility to change based on disease prevention needs that exist within the societies. The use of a top-down approach, even in disease prevention programmes, without taking into consideration changes in ecology and disease transmission risks at the district level, results in the blanket allocation of public health interventions as is the case when prevention strategies prioritize bed nets over all other strategies. At the same time, there is a need to consider allocating well-trained personnel for the management and surveillance of malaria trends at the district level. Currently, only a few districts have surveillance systems and most of these are not funded by the Ministry of Health or NMCP. The inclusion of surveillance systems and monitoring as per the new strategic plan and PMI focus area requires clear implementation plans, and well-trained personnel needs to be involved without political interference. Based on national prevalence rates, there has been a change from 9% in 2012 to 14% in 2016, and 7% in 2018 (Mbashine, 2018, TDHS-MIS, 2016, THMIS, 2013). This does not add up since the strategies that were used for prevention and control were the same. Improved surveillance will help to determine the changes in patterns of malaria transmission at district and regional level, and enable the allocation of appropriate interventions in all endemic areas countrywide.

Thus, a lesson for policy is that there is a need to cover the gaps in malaria transmission that cannot be targeted by existing malaria prevention and control strategies. Approaches for designing, implementing and evaluating interventions for malaria in Tanzania need to consider vector ecology (the epidemiology of disease and entomological data on vector species and their behaviour), environmental factors, social and political factors, additionally changes over time, also ought to be considered, so as to incorporate new information in BCC and intervention users. Updated malaria control strategies basing on research findings will help the allocation of new preventive approaches, depending on local epidemiology. The use of blanket public interventions will not yield promising results since transmission risks differ from place to place. The “one size fits all” approach in malaria prevention and control should be revisited, as indicated by Fishbein (2000).

4.2.2 Proposed actions to maximize malaria prevention

There is a need to integrate district level and national level malaria programmes to be able to determine the differences across districts regarding transmission risks, biting patterns, and vector ecology, to allocate interventions that are area specific. Such integration is important because the rate of outdoor transmission will differ regionally and locally because of different geographical and ecological characteristics, climatic conditions, social interaction and cultural practices, of which the latter helps to contribute to a cohesive society. Currently, only 62 out of 183 districts in Tanzania have vector surveillance systems, of which 28 are funded by the Global Fund and the remaining 34 districts surveillance systems are funded by the local governments (personal communication with entomologist). This indicates that most of the regional prevalence in different malaria indicator survey reports were estimated based on very limited data available at district levels. The district level malaria prevalence can only be obtained from donor-funded small projects that are not available in all districts within the country. In the district in which this study was conducted, the prevalence was approximately 14% as of 2014 (Harchut et al., 2013). This study also indicated the risks of over-reporting malaria parameters. However, a current study by Finda and colleagues (2018) have indicated a significance decrease in malaria transmission of more than 90% of the existed transmission risks from 2000s. Despite the decrease, with the increasing outdoor biting by malaria vectors, Kilombero and other malaria endemic regions in the country require surveillance and monitoring systems that will help to determine the actual prevalence without over- or underreporting, and this will also help to determine endemic areas and allocation of appropriate interventions. Even though the surveillance systems and monitoring systems are indicated in the NMCP Strategic Plan as indicated in the annual operation plan for financial year (FY 2017 (PMI, 2017), surveillance systems are not present in all malaria-endemic areas.

Based on the findings of this study, there is a need for updated behaviour change communication on malaria transmission risks and prevention, human activities, and social and cultural practices that expose people to risks of mosquito bites and interfere with intervention use while outdoors. The integration of outdoor malaria transmission risks and identification of the depth of the problem, identification of prevention methods and implementation strategies to curb the risks of malaria transmission will be of great significance if malaria is to be eliminated. It is important not to rely on a blanket

approach informed by country/regional rates, but rather to develop programmes based on the nature and extent of disease burden (malaria burden) from the wards, district and regional level and prepare integrated approach for malaria prevention and control both indoors and outdoors. Even though NMCP has great plans for malaria prevention and control, the implementation of other strategies becomes difficult to materialize since most interventions and control measures are donor funded (MoHSW, 2014). Funding for malaria prevention is allocated on interventions that target indoor malaria prevention (as per donor decisions), with no funds allocated for interventions that could target transmission risks outdoors. The existing risks of outdoor mosquito bites by malaria vectors call upon government, donors and other malaria stakeholders to understand the need to allocate funding for interventions that will target the regaining segment of malaria transmission that cannot be targeted by existing interventions. In Tanzania, main donors for malaria prevention and treatment programmes include the President's Malaria Initiative (PMI), Global Fund, World Bank and other donors (Mandike, 2011). Even though the government provides funds for malaria programmes, most is invested in personnel and not in interventions, and these cannot be quantified in annual budget for malaria (personal communication, NMCP stakeholder). Government financial commitment to finance interventions or strategies that are not covered by donor funds is of great significance in the fight against malaria to complement existing interventions. So, due to its overdependence on donor funding for malaria programmes, the current role of the NMCP has remained as the provider of strategic direction in policy development, provision of technical support and capacity building at district levels, and the coordination of all malaria prevention and control activities in the country. The decision on what interventions should be distributed, increased or introduced to supplement existing malaria prevention programmes have remained solely in the hands of the donors. NMCP does not fund any interventions, except for the current larvicide distribution that was accepted for implementation in 2018 but has not yet materialized due to insufficient funds (personal communication, NMCP Stakeholder, 2019).

To achieve a greater degree of integration to support better health progress, there is a need to consider the realities of Tanzania's malaria control programmes, address challenges, and find suitable and practical solutions. The main goal of NMCP is to work

toward zero deaths from malaria and malaria elimination, and to achieve this, considerable rethinking is required.

4.2.3 Actions to achieve a greater degree of community protection against malaria

The data for malaria trends, community knowledge, and intervention use should be the cornerstone of national malaria prevention and control progress reports, to identify the progress made for malaria reduction, the actual burden of malaria, what is lacking and required within communities, patterns of intervention use, and existing gaps. Changes in outdoor feeding patterns by malaria vectors should be well communicated not only at the national level but also at the community level. In rural settings, appropriate communication messages on disease transmission, prevention and updates on current disease trends, and the availability of interventions (both preventive and control), will significantly contribute to great achievements of preventing disease transmission.

The success of malaria prevention and control programmes will be significantly enhanced by community involvement. Community members should be involved in identification of the disease and risks of transmission, and they need to be involved in prioritzation and prevention strategies. It is imperative to understand community perceptions and beliefs regarding the disease. The findings of this study have helped to document and provide insight into peoples' perceptions and beliefs regarding malaria and the risks of outdoor malaria transmission, which will help to determine the best ways to educate the community to improve awareness on risks and prevention means. Community understandings of the impact of the disease and people's ability to prevent the risks of such disease, will then increase the use of interventions. This is vital for future malaria prevention programmes; one cannot assume the risks and expect people to use interventions. It is ideal to use interventions that are affordable and available within the communities. such as repellent plants, treated clothes as well as treated chairs that protect people from mosquito bites (Paliga *et al*, 2019, *Unpublished*): this again requires further work.

4.3 Contribution to knowledge

This research contributes to the advancement of knowledge that provides an understanding of the relationship between human behaviour, mosquito behaviour, and outdoor malaria transmission risks. There are several research studies that provide an

understanding of ongoing outdoor malaria transmission basing on vector behaviour alone (Govella and Ferguson, 2012, Matowo et al., 2013, Okumu et al., 2013, Russell et al., 2011, Kaindoa et al., 2017, Lwetoijera et al., 2014, Moiroux et al., 2012). This thesis provides information about community social interactions and exposure to mosquito bites and risks of malaria infection in Tanzania. The current study is important because it further explains different factors including; social and cultural factors that influence particular behavior which impact community behavior toward malaria transmission risks and prevention for both indoor and outdoor, and the use of correlation between human activities and risks of outdoor biting which put people are risks of malaria and other mosquito borne diseases. This study also provides a better understanding on the need for refining and introducing complementary interventions based on the risk of transmission, characteristics of the particular areas, includingexisting vector species, human activities and social factors that facilitates transmission risks even though existing malaria interventions have worked so well in disease prevention and control, they need to be refined,. The use of socio-ecological approach on this study helps to understand different factors that facilitate disease transmission and prevention ut also, allocation of of interventions (and relevant resources) that are area specific and do not rely on a single technology to reduce and control disease. So, allocation of disease prevention and control strategies in the communities requires an understanding of social interactions, cultural beliefs, and practices, and to recognize the importance of these aspects in maintaining a cohesive society.

4.4 Methodological innovations

The most innovative aspect of this research was the application of both an entomological study and social science research in understanding the role of humans in malaria transmission risks, and their exposure to mosquito bites according to the coincidence of human activities and the biting patterns of the host-seeking mosquitoes. The data were analyzed separately, but the results were triangulated to provide a detailed single conclusion on how these factors interact and affect one another.

4.5 Limitations and challenges

The limitations and challenges of this research are discussed in the appended papers. The major challenge was the change of entomological data collection method from

HLC to the use of CDC-light trap, which also had an impact on the density of mosquitoes collected outdoors because this method is generally not suitable for outdoor mosquito collections. HLC is restricted for data collection due to the risks of malaria infections that collectors are exposed to, as well as for other security reasons. However, it was difficult to conclude, whether the higher indoor and lower outdoor malaria vectors densities were the result of mosquito behaviour or the sampling method.

Two questions emerge that highlight the limitations of this study: the representativeness of this study to Tanzania and the methodological approach in explaining the risks of mosquito bites in relation to human behaviour. The use of this methodological approach was time-consuming, labour intensive and costly for the entomology work. Moreover, it needed knowledgeable and experienced labour and constant supervision of the field work to minimize errors.

Another limitation was from the observational study and the likelihood of minimal accuracy of observation recordings due to the use of household members undertaking the recordings. Even though the collection was supervised through spot-checking, in the absence of the supervisors there was no way to know for sure whether observations were actually made at the specified times as required. If the CDC-light trap is to be used for mosquito sampling outdoors, it should be compared with another method to determine the accuracy as it was done in this study. Also, if the observation method is to be used elsewhere, the study team should ensure frequent supervision and spot-checking.

In addition, I did not interview implementers (from the NMCP) to determine the reasons for the continued focus on bed nets, nor the reasons for the lack of attention on strategies to address the risk of outdoor malaria transmission.

This research was conducted in two districts among the seven districts of Morogoro region and 169 districts in the country. The distinctive geographical area and climatic conditions mean that these district differ from others (as described in the methods section); this includes the presence of water bodies such as the river and swamps. Presence of water bodies facilitates presence of multiple breeding habitats, species distribution and mosquito density that help to maintain existence of malaria vectors and transmission. The two districts were not selected to represent the whole country,

but rather, they were selected to represent districts of similar characteristics to be used as case studies to provide data associating human activities and host-seeking mosquitoes in areas that experience similar outdoor malaria transmission risks. The experiences and social interactions observed in this study may be experienced elsewhere within the country, but this would need to be tested. The majority of studies on outdoor malaria transmission conducted in the country focus on the vector, and there are relatively few studies that integrate human behaviour and vector in Tanzania. Huho and colleagues , for example, determined the hours that residents spent indoors and outdoors at night, and established that there is considerable human-vector activity both indoors and outdoors. These expose people to mosquito bites which cannot be targeted by existing interventions such as ITNs and IRS. Similarly, a study conducted in Zambia found that human-vector activities were higher indoors than outdoors, with greater exposure among the non-users of LLINs (Seyoum et al., 2012a) .

The consideration and integration of behaviour change, behaviour and knowledge on malaria transmission has been the same for more than two decades, despite changes in biting patterns and increases in outdoor biting. The basic communication strategies are still based on the use of bed nets as distributed by KINET (Minja et al., 2001a, Schellenberg et al., 1999), and even with changes to mosquito vector behaviour and increasing outdoor feeding and feeding before sleeping under the bed nets, communication strategies are still based on bed net use, care and repair, pioneered by PMI (PMI, 2017). Studies in other countries have identified the relationship between human behaviour and practices to outdoor malaria transmission risks, including outdoor sleeping and overnight activities (Monroe et al., 2014). However, this thesis provided an explanation of the existing relationship of human outdoor activities on a daily basis, in the course of a range of social activities, and outdoor malaria transmission risks in Kilombero Valley which provide the basis for NMCP to plan the best interventions that could be used to reduce the risks of malaria transmission.

4.6 Conclusion

The innovative methodological approach used in this study and the triangulation of the results provide an understanding of the gaps in malaria prevention in areas that experience outdoor malaria transmission. The assessment of social data provided a clear understanding of peoples' knowledge on outdoor malaria transmission, daily activities

and seasonal practices which bring them into contact with mosquitoes. This study explains clearly that people have started to be aware of outdoor malaria transmission as they speculate that, since they sleep under the bed nets and are bitten more often outside than inside, then outdoor biting could be the cause of their sickness. However, they have minimal access to and the absence of affordable interventions for outdoor settings. In addition, cultural and social gatherings are connected to social norms that interfere with the use of interventions to prevent the risk of malaria infection outdoors. The study provided a detailed account of the social interactions and their contribution to the increasing rates of human-vector interactions that contribute to human exposure to mosquito bites. Human exposure to vectors outdoors in this study suggests the need for additional vector control measures that can complement LLINs and IRS by targeting the transmission segment that cannot be targeted by existing interventions, if malaria elimination is to be realized in Kilombero Valley (Killeen and Moore, 2012, Killeen, 2014, Takken and Knols, 2009). Outdoor malaria transmission is a great challenge to malaria control efforts, so well-integrated malaria control strategies (BCC included) are of great urgency. The consideration of outdoor malaria transmission risks in NMCP will give room for more research to be undertaken to determine these changes countrywide, identify and develop new interventions, and allocate appropriate intervention in specific areas according to existing vectors, biting patterns and risks of transmission. Existing interventions cannot be used to eliminate malaria, without complementing them due to changes in vector behaviour, environment and human behaviour.

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Appendices

Appendix 1

Summary data collection and analysis methods used for different study objectives in this study.

Objective	Data Collection	Data type	Data analysis	Expected title of papers
To identify common everyday human outdoor activities that expose people to mosquito bites, and so malaria transmission risks, and the reasons why they conduct particular activities outside their houses during early evening and early in the morning.	- Structured observation sheet (Appendix 7) - Interview guide - Focus Group guide (Appendix 5)	Number and frequency of human activities identified (quantitative data) -Qualitative data (Transcribed Interviews and Focus group discussion recorded sessions)	I will use R package – for analyzing quantitative data of human activities. - Thematic content analysis	Peri-domestic human activities performed outdoors at different times of night during both dry and wet seasons in rural Tanzania and their implications for malaria transmission
To identify supplementary seasonal and ceremonial activities that involves outdoor activities with risks of exposure to mosquitos.	- Structured observation sheet	Type of season, ceremonies and number of activities against time	I will use R package for analyzing quantitative data	Increasing risk of exposure to mosquito through seasonal and ceremonial activities in rural communities in southern Tanzania.
To estimate the proportion of exposure and biting risks as contributed by human outdoor activities	- Use of entomological tools	Number of mosquitoes caught in relation to time -Malaria incidence	Logistic regressions will be performed by using R-packages	Correlations of outdoor exposure and different peri-domestic human outdoor activities in Tanzania

To describe and analyze peoples' views, opinions, knowledge and experiences on mosquito biting and malaria transmission and the difference between indoor and outdoor transmission.	Interview guide - Focus group Guide (Appendix 5) - Interview guide - Focus group guide	Transcribed interviews and focus group discussion	Thematic content analysis (Burnard et al., 2008) with the help of ATLAS.ti software	Community views, knowledge and experiences towards outdoor mosquito bites and malaria transmission in rural Tanzania. Community
To identify available interventions tools and patterns of use, and to explore peoples' perceptions of these on exposure to bites and malaria transmission prevention.		Transcribed interviews and focus group discussion	Thematic content analysis	perception on the identified readily available, low cost and scalable intervention for malaria prevention and its' impact to the malaria control efforts in rural Tanzania.

Appendix 2

Data collection tools

Semi-structured Interview Guide

This guide will be used to explore community understandings, views, opinion and knowledge about malaria and outdoor malaria transmission. It is in a mixture of English and Swahili, but the medium to be used for data collection will only be Swahili.

Background: Mosquitos are a major problem in Tanzania, and people can get sick from mosquitoes bites (Anopheles). Knowledge of mosquito behaviour and peoples' response to control methods will help improve mosquito control and reduce disease transmission in a particular area. In this study we aim to explore people's knowledge and general understanding of mosquito bites and interventions which they use, before embarking on introducing other interventions. (***to avoid leading the respondents, they will only be informed about the aim of the study which is on the last two sentences***)

We will start with the informal discussion with the respondent in order to remove the tension and build rapport.

Facilitator: Thank you very much for agreeing to talk to me today. Our discussion will not take too long but it will all depend on your response. I would like you to know that the purpose of this discussion is not to verify your answers, rather to be able to know and learn from you about your understanding and experiences and general knowledge about malaria.

(***The questions below will only be used as a checklist for the discussion and will not be read verbatim during the interview***).

Section 1: General knowledge of mosquitos

❖ So, can you tell me what do you know about mosquitoes?

Where do you think mosquitos bite more and why?

- Probe on the timing that more bites occurs.
- Probe on the time of the day that people are mostly bitten by mosquitoes and why.

According to your experience, what time of the do you experience more mosquitoes?

- Probe on the places
- Probe on time of the year which they think there are more mosquitoes and why?

Section 2: Outdoor activities

❖ ***I would like to know about your daily routine here at home, and mostly during the evening. So how does you normal evening look like?***

- Probe on the usual timing and duration of time which they spend more outside.

- Why are you outside at that time? What exactly brings you outside at that particular time?
- What activities do you engage yourself in when outside?

- Probe: tell me more about the activities you conducted outdoors yesterday and time.

- What about the sleeping arrangement within this household? (indoor or outdoor and reasons)
- Do you sleep under a bednet? What condition is the bednet (*is it old, torned or new*)?
- What about the time thta you wake up? And kind of activities do you engage yourself in to?

  -Probe on activities that he/she engages him/herself, when they go outside in the morning?
- So when you are outdoors, who accompanies you?

- Probe for both morning and evening.
- Apart from what you had already mention, are there any other reasons that motivates you to stay outdoors?

Section 3: Protection from Mosquitoes

Thank you for all the above explanations and good answers. I would also like to know how do you and people within this community protect themselves from mosquitoes.

Please can describe the ways in which you protect yourself and your children from mosquitos when you are outdoors:

- What do you use as protective methods against mosquito?
  - Probe on methods used indoors.
  - Probe on methods used outdoors.
- Among that you have mentioned, which ones you will prefer as means of protection.
  - Do you know any other means or ways apart from the ones you have mentioned?
    Please mention them:
  - Do you know how they work? If YES, please elaborate.
  - Do you know any other method that is used to kill mosquitos outside peoples' houses?

Section 4: Knowledge on Malaria

I would like to ask you several questions regarding your knowledge on malaria.

- What is malaria, what do you know about malaria?
- What causes malaria? (probe more to get their understanding)

If participant mentions mosquitos, then ask the following:

- Would you mind telling me anything you know about them?

- Do they transmit disease? If he/she replies yes, then continue. If NO, skip and go to another section.
- Please list all the diseases that you know are transmitted by mosquitoes
- Have you ever heard about transmission that occurs outside people's houses? Where?
- Do you know the species responsible for such transmission? If yes, please mention them.

Now I would like to ask you about your health, and especially in relation to malaria.

- How many times in a year are you diagnosed with malaria?
  - What about your children and other members of the house? And how many times in a year?
- In this area, where do you go for diagnosis and treatment?
  - Probe on the time to be able to receive the treatment.
  - Kind of treatment which they receive.
- So, what do you do to avoid getting malaria?

Appendix 3

Focus Group Discussion Guide

This guide will be used to explore community understandings, views, opinion and knowledge about malaria and outdoor malaria transmission. It is in a mixture of English and Swahili, but the medium to be used for data collection will only be Swahili.

Background:

Mosquitos are a major problem in Tanzania, and people can get sick from mosquitoes bites. Knowledge of mosquito behaviour and peoples' response to control methods will help improve mosquito control and reduce disease transmission in a particular area. In this study we aim to explore people's knowledge and general understanding of mosquito bites and interventions which they use, before embarking on introducing other interventions.

Rationale:

We conduct Focus Group Discussions in order to gather group perspective on mosquitoes, disease transmitted by mosquitoes, activities that people mostly engage themselves into which expose them to mosquito bites and interventions that they use. However, to explore on the ceremonies and gatherings that are conducted outdoors that expose people to mosquito borne diseases and other diseases.

Inclusion criteria:

Participants will be men and women who are above 18 years old but not more than 60 years of age, and who have young children not more than 10 years old. The participant

must also be living in Kilombero Valley with at-least primary education level and a farmer.

Facilitator: *Thank you for your time and agree to come here and talk/have a discussion with me and other members from you community. The discussion will base on our general understanding, views and experiences in diseases, so we want you to be free to talk without any fear because we do not know what you know so we are here to learn from each other. Everyone is allowed to talk but let another person finish before you start talking in order to hear each other well and capture everything. You will be given numbers as your identities, so you will mention your number first and not your name. You are warmly welcome to our discussion.*
(*The questions below will only be used as a checklist for the discussion and will not be read verbatim during the interview*).

Section 1: General knowledge of mosquitos

- ❖ So, I would like to know your general knowledge about mosquitoes. What is mosquito?
- Probe on where are mosquitoes found
- Probe if they transmit diseases and what diseases are, they.
- How do they transmit the diseases and what time does such transmission occurs?

- ❖ If they mention bite, then ask the following:
  - Which places do you think mosquitos bite more?
  - What time does most biting occurs?
  -What time of the year do people in this community experience more biting?
  - What time of the year do people within this community experience more mosquitoes?

Section 2: Outdoor activities

In this section, I would like to know the kind of activities that you all engage yourselves in to and people within this community.

So, let's talk about what your day and evening look like.

- Probe on the activities that they engage themselves in to in the morning and where.
- Probe on the timing that they spend outdoors and their experience from the community.
- Why are they outside at that time? What exactly brings people outside at that particular time?
- What exactly do people do outdoors during those times?
- What about children within these communities?
- If they also spend time outdoors with their children, why do they do that?

❖ Could you think of any other reasons which will motivate people to stay outside during the evening?

Section 3: Protection from mosquito bites outdoors

In this section, we would like to know your views and experiences on how you protect yourselves or how well people can protect themselves from mosquito bite outdoors.

❖ How do you protect yourselves from mosquitoes?
  - Probe on the protection at community level. (adult and children)
  - Probe on methods used indoors.
  - Probe on methods used outdoors.

❖ What other means /ways that people use in these communities apart from the ones that you have mentioned and how accessible are they to the people. Please mention them.

❖ Can you tell me how they work? If YES, please elaborate.

❖ Are you aware of any methods that are used to kill mosquitos outside peoples' houses?

Section 4: Knowledge on Malaria

This section aims to understand the knowledge of people on malaria within the communities.

- What do you know about malaria?
- What time and where does transmission occur?
- What types of mosquito do transmit malaria and how does the transmission occur?
    - Do you know about outdoor malaria transmission?
    - How do people get malaria?
    - Which places do you think mosquitoes bite more? What time does most biting occur?

Section 5: Knowledge and meanings attached to outdoor activities, gatherings and ceremonies: (might be festivals after harvest, weddings, funerals, meetings, etc.)

This section intends to understand different outdoor activities such as types of gatherings and ceremonies which are conducted in this community as well as their meaning and importance. However, to understand if people are exposed to mosquitoes and if there are interventions used during those times.

❖ As members of this community, what are these different outdoor activities, ceremonies and gatherings that exist within their communities (**Probe as much as possible to get all the names and information of the gatherings, activities and ceremonies that are conducted outdoors. Let them mention as much as they can, do not limit the number**)

- Probe for time and season for each ceremony, and why that time (probe for all)
- What meanings do these activities, gatherings and ceremonies hold/ attach to them?
- What time do they spend outdoors?
    - Probe for time in a day and night
    - Probe for days they have to attend.

- Why that time? What is it that so important to be that particular period? If one do not spend that time what is going to happen?
- What advantage do they have if you attend or perform them according to that time?
- When you are outside during those gatherings, are you bitten by mosquitoes?
- If yes, what time are you bitten the most?
- What do you use to protect yourself from mosquito bites during that time? Probe on seasons as wet and dry, and timing from early evening to the time they leave the place.
- Do you think you can get malaria at that time?
- What would you like the situation to be? Probe what will they wish to happen to reduce exposure to mosquito bites? What will they want to change?
- What have you learned so far from these activities that have been conducted in this community?
- Do you think these activities, gatherings and ceremonies are important to continue to be conducted? Probe on the reasons for both (YES AND NO)

CLOSING REMARKS:

Thank you all for devoting your time and energy to participate in this session. Have a blessed day.

Appendix 4.

Key Informant Interview Guide

This guide will be used to explore community understandings, views, opinion and knowledge about malaria and outdoor malaria transmission. It will also be used to explore the meaning attached to the different ceremony celebrations within these communities. The guide is in English but it will be translated to Swahili, since medium to be used will be local Swahili language.

Background: Malaria is a major disease in Tanzania. It is transmitted through bites of female Anopheles mosquitoes. Knowledge on mosquito behaviour and peoples' response to control methods will help improve mosquito control for the area. In this study we aim to explore people's knowledge and general understanding of outdoor malaria transmission and the interventions they use, before embarking on introducing other interventions.

The Key Informant may be a traditional leader, or in his or her absence, another opinion leaders. It will be purposive sampling and village leaders from each study village will be asked to identify them. The selection criteria will be: Should be an elderly person who has stayed in the village for more than 20 years, has a leadership role in the village, respected and knowledgeable on the traditions of the people within their village. We will inform the village leader on the selection criteria in order to minimize selection of wrong participants.

Facilitator: Thank you very much for agreeing to talk to me today. Our discussion will not take too long but it will all depend on your response. I would like you to know that the purpose of this discussion is not to verify your answers, rather to be able to know and learn from you about your understanding and experiences and general knowledge about different practices within this community and your understanding about malaria.

(***The questions below will only be used as a checklist for the discussion and will not be read verbatim during the interview***).

Section 1: General knowledge on mosquitos: ***This section focuses on understand what people understand about mosquitoes in general.***

I would like to know what you know and your experience on mosquitoes

- Probe on biting time and place
- Probe on frequency of biting, time and their experience on outdoor biting.
- In a year, when do you experience more biting and why?
- What time of the year do you experience more mosquitoes and why?

Section 2: Knowledge and meanings attached to outdoor activities, gatherings and ceremonies: (might be festivals after harvest, weddings, funerals, meetings, etc)

This section intends to understand different outdoor activities such as types of gatherings and ceremonies which are conducted in this community as well as their meaning and importance. However, to understand if people are exposed to mosquitoes and if there are interventions used during those times.

- What are these different outdoor activities, ceremonies and gatherings that exist within their communities (**Probe as much as possible to get all the names and information of the gatherings, activities and ceremonies that are conducted outdoors. Let them mention as much as the can, do not limit the number**)
- Probe for time and season for each ceremony, and why that time (probe for all)
- What meanings do these activities, gatherings and ceremonies hold/ attach to them?
- What time do they spend outdoors?
    - Probe for time in a day and night
    - Probe for days they have to attend.
- Can you tell me about the importance of these ceremonies to be performed those times and impact of not performing them?

- What advantage do these gatherings and festivals have if one attend or perform them according to that time?
- From your experience, when people are outside during those gatherings, are you bitten by mosquitoes?
- What do you use to protect yourself from mosquito bites during that time? Probe on seasons as wet and dry, and timing from early evening to the time they leave the place.
- Do you think you can get malaria at that time?
- What would you like the situation to be? Probe what will they wish to happen to reduce exposure to mosquito bites? What will they want to change?
- What have you learned so far since you and the community have conducted these activities?
- Do you think these activities, gatherings and ceremonies are important to continue to be conducted? Probe on the reasons for both (YES AND NO)
- What do you think what can be done to reduce these gatherings, ceremonies and outdoor activities?
- What do you advise people to do to reduce exposure to mosquitoes
- Give your opinion regarding anything you think it is important within your society.

Appendix 5 – Observation Sheet - Separate attachment

Appendix 6:

Consent forms

Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania

Informed Consent Agreement –volunteers conducting Human Landing Catches

SERIAL NUMBER (Version 1_1C1) _____

Introduction: We welcome you to participate in our research study. I am a researcher from Ifakara Health Institute and a student from the University of the Witwatersrand in South Africa. Even though you have been selected but your participation is purely voluntary. We appreciate your time, and this work will take two to days in a week for three months during the wet season and dry season for 12 hours during the evening. We would like to give you time to read and understand the study according to the information provided in this sheet. Feel free to ask any questions at any stage which you need clarification. Below are the information regarding what the project is all about, the procedures and other research requirements before we start this work.

The study aims at understanding the contribution of outdoor human activities to outdoor malaria transmission as well as peoples' understanding on malaria transmission, prevention and control. The study is titled; **"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania"**

Background: Mosquitos are a major problem in Tanzania, and people can get sick from mosquitoes bites. Knowledge of mosquito behaviour and peoples' response to control methods will help improve mosquito control and reduce disease transmission in a particular area. In this study we aim to explore people's knowledge and general

understanding of mosquito bites and interventions which they use, before embarking on introducing other interventions.

Procedures: As a participant you will be asked to catch mosquitoes from your legs for six hours for fewer than five days each month for two months during dry season and two months during wet season. Therefore, you must wear a net jacket so mosquitoes can only approach your legs and you catch them using a siphon before they can bite you. A most required thing for every participant of this study is to take antimalarial drugs which will prevent you from getting malaria when bitten by mosquitoes. This drug must be taken once each week following the instructions of the doctor that will give you the drugs. These will be free to you for the time that you are working in the study. Catching mosquitoes from your legs may put you at risk of acquiring malaria parasites. You will therefore be provided with weekly screening for malaria parasites (the blood samples for screening will be taken by qualified technicians at the Molecular Laboratory at Ifakara Health Institute, Ifakara site) and offered free treatment if found to be infected. Such treatment will not be offered to you when you leave the study unless you leave the study while already infected. Infection with malaria parasites causes more severe disease in pregnant women and young persons. Therefore, we do not include women or people under the age of 18 years in studies for this reason. So, for those who will agree to participate in this study, we request you to sign this sheet to affirm your consent.

Potential Risks: The **risk** of taking part in this study is that you are catching mosquitoes from your legs so you are at a greater risk of malaria than if you slept at home under a treated bednet. However, you will be under constant medical supervision and will be provided with prompt access to appropriate diagnosis and treatment if you fall ill.

Potential Benefits: It is expected that the findings from this study will help to develop new ways of controlling disease transmitting mosquitoes, which will eventually contribute towards malaria elimination in your community and other communities across Africa. You will be given screening for malaria and treatment if you have parasites and you will be paid for overnight work.

Compensation: The participation will be voluntary, but the compensation rate will be agreed between the research team and the volunteer. Minimum amount will be 15,000 Tanzania shillings per day. Also, there will be immediate access to malaria diagnosis and treatment.

Withdrawal from participation: If you agree to take part in this study, you are free to end your participation at any time you want without having to give any reasons.

Further questions: In case you have any question or concern about this study please feel free to contact Dr . Mwifadhi Mrisho, representative of IHI institutional review board
(0788 766 676), Halfan Said Ngowo, Research Officer/PI at IHI (Tel: +255717519236), Fredros Okumu (Tel. No. +255 686 997 269), National Medical Reasearch Coordinating Commitee (Tel +255 22 2121400) and Irene R. Moshi (Tel. No. +255 712 498 879).

Informed consent record for the participant

I, ……. have read the study aims. I clearly understand the aims of the project and I agree to participate in the study. During my participation in these studies, I understand that field mosquitoes can infect me with malaria parasites. I also understand that working at night may expose me to increased risk of infection with malaria. I therefore undertake to submit to weekly screening for malaria parasites by microscopic examination of thick film blood smears. I also understand that I am entitled to free malaria prophylaxis and treatment for malaria if found to be infected with malaria parasites. I understand that I may revoke my consent and leave the study at any time.

Participant Name:

_____

Participant Signature: _____Date_____

Witness Name: _____

Witness signature: _____Date_____

Study team member's statement: I, the undersigned, have explained to the participant in a language that s/he understands: the procedures to be followed in the study, the risks and benefits involved, and the obligations of the study team

_____ _____ _____

Name Signature Date

Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania

Informed Consent Agreement – Heads of households in which outdoor activities will be Observed. SERIAL NUMBER (Version 1_IC2)_____

Introduction: We welcome you to participate in our research study. I am a researcher from Ifakara Health Institute and a student from the University of the Witwatersrand in South Africa. I would like to invite you to participate on our study. Even though your houses have been selected but your participation is purely voluntary. Below are the information regarding what the project is all about, the procedures and other research requirements before we start this work.

The study aims at understanding the contribution of outdoor human activities to outdoor malaria transmission as well as peoples' understanding on malaria transmission, prevention and control. The study is titled; **"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania"**

Background and purpose: Mosquitos are a major problem in Tanzania, and people can get sick from mosquitoes bites. Knowledge of mosquito behaviour and peoples' response to control methods will help improve mosquito control and reduce disease transmission in a particular area. In this study we aim to explore people's knowledge and general understanding of mosquito bites and interventions which they use, before embarking on introducing other interventions.

Later, we plan to develop an easy-to-implement strategy for locating and targeting mosquitoes that transmit diseases outside people's houses. But we first need to know the activities that people do outside, what people know about mosquito biting and the way they protect themselves. That way, we can be able to reduce, control and eliminate diseases as well as improving people's health and well being

Procedures: Your household has been selected as one among the houses which will be included in this study. We will focus on observing all the activities that are conducted by people living in this house. A volunteer selected for this work will be observing the activities that each household member is involved in, and he will record these activities on half hourly basis in a form that will be provided. The exercise will be conducted once every month for a period of three months.

Potential Risks: There are **no** health risks associated and participation in the observations research.

Potential benefits: It is expected that the findings from this study will help to develop new ways of preventing malaria transmission that occurs outside homes, and will eventually contribute towards malaria elimination in your community and other communities across Africa.

Compensation: Your participation is voluntary but we will compensate the head of household for agreeing observations to be conducted in their households. Minimum amount will be 5,000 Tanzania shillings for the work to be conducted there.

Withdrawal from participation: If you agree to take part you are free to end your participation in this study at any time you want without having to give reasons.

Additional Information: In case you have any question or concern about this study please feel free to contact Dr . Mwifadhi Mrisho, representative of IHI institutional review board (0788 766 676) , Halfan Said Ngowo, Research Officer/PI at IHI (Tel: +255717519236), Fredros Okumu (Tel. No. +255 686 997 269), and Irene R. Moshi (Tel. No. +255 712 498 879),

Informed consent record: Please read this statement carefully before you sign and if you agree on participating, please fill free to sign this form below to affirm your consent.

I, _____ clearly understand the aims of the project titled

"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania" which has been explained to me by the researcher. I have been given the chance to ask questions and I am satisfied with the answers to all of my questions and I agree to participate in the study. I understand that I may revoke my consent and leave the study at any stage, if I wish so, with no negative consequences.

Participant's name: _____

Participant's signature or thumbprint: _____ Date: _____

Witness Name (As appropriate): _____

Witness signature (As appropriate): _____ Date: _____

Study team member's statement: I, the undersigned, have explained to the participant in a language that s/he understands; the procedures to be followed in the study, the risks and benefits involved, and the obligations of the study team.

_____ _____ _____

Name Signature Date

Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania

Informed Consent Agreement – Observers of human outdoor activities within the households SERIAL NUMBER (Version 1_IC3)_____

Introduction: We welcome you to participate in our research study. I am a researcher from Ifakara Health Institute and a student from the University of the Witwatersrand in South Africa. I would like to invite you to participate on our study. Even though you have been selected but your participation is purely voluntary. You will be supposed to observe all the evening outdoor activities in the households which will be conducted in the selected households. Below are the information regarding what the project is all about, the procedures and other research requirements before we start this work.

The study aims at understanding the contribution of outdoor human activities to outdoor malaria transmission as well as peoples' understanding on malaria transmission, prevention and control. The study is titled; **"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania"**

Background and purpose: Mosquitos are a major problem in Tanzania, and people can get sick from mosquitoes bites. Knowledge of mosquito behaviour and peoples' response to control methods will help improve mosquito control and reduce disease transmission in a particular area. In this study we aim to explore people's knowledge and general understanding of mosquito bites and interventions which they use, before embarking on introducing other interventions.

Later, we plan to develop an easy-to-implement strategy for locating and targeting mosquitoes that transmit diseases outside people's houses. But we first need to know

the activities that people do outside, what people know about mosquito biting and the way they protect themselves. That way, we can be able to reduce, control and eliminate diseases as well as improving people's health and well being

Procedures: As a volunteer, you have been selected in this study to observe all the evening activities conducted in the selected households for this study. You will focus on observing all the activities that are conducted by people living in those houses. You will record all the activities that are conducted by each member of the household, and record these activities on half hourly basis in a form that will be provided. The exercise will be conducted once every month for a period of three months.

Potential Risks: There might be associated risks such as being bitten by mosquito and get sick but you will be treated if that will occur.

Potential benefits: It is expected that the findings from this study will help to develop new ways of preventing malaria transmission that occurs outside homes, and will eventually contribute towards malaria elimination in your community and other communities across Africa.

Compensation: Your participation is voluntary but we will compensate you for this work. Minimum amount will be 10,000 Tanzania shillings for participating in this work.

Withdrawal from participation: If you agree to take part you are free to end your participation in this study at any time you want without having to give reasons.

Additional Information: In case you have any question or concern about this study please feel free to contact Dr . Mwifadhi Mrisho, representative of IHI institutional review board (0788 766 676) , Halfan Said Ngowo, Research Officer/PI at IHI (Tel: +255717519236), Fredros Okumu (Tel. No. +255 686 997 269), and Irene R. Moshi (Tel. No. +255 712 498 879),

Informed consent record: Please read this statement carefully before you sign and if you agree on participating, please fill free to sign this form below to affirm your consent.

I, _____ clearly understand the aims of the project titled **"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania"** which has been explained to me by the researcher. I have been given the chance to ask questions and I am satisfied with the answers to all of my questions and I agree to participate in the study. I understand that I may revoke my consent and leave the study at any stage, if I wish so, with no negative consequences.

Participant's name: _____

Participant's signature or thumbprint: _____ Date: _____

Witness Name (As appropriate): _____

Witness signature (As appropriate): _____ Date: _____

Study team member's statement: I, the undersigned, have explained to the participant in a language that s/he understands; the procedures to be followed in the study, the risks and benefits involved, and the obligations of the study team.

_____ _____ _____

Name Signature Date

Exploring Outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania

Informed Consent Agreement – In-depth Interview Participants, SERIAL NUMBER (Version 1_IC4)____

Introduction: We welcome you to participate in our research study. I am a researcher from Ifakara Health Institute and a student from the University of the Witwatersrand in South Africa. I would like to invite you to participate on our study. Even though you have been selected but your participation is purely voluntary. You are selected to participate in the interview which will take place in a place where you will be comfortable and the session will take 45 minutes to 1 hour during the day. During the session, it will only be you and the interviewer in order to maintain confidentiality. Below are the information regarding what the project is all about, the procedures and other research requirements before we start this work.

The study aims at understanding the contribution of outdoor human activities to outdoor malaria transmission as well as peoples' understanding on malaria transmission, prevention and control. The study is titled; **"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania"**

Background and purpose: Mosquitos are a major problem in Tanzania, and people can get sick from mosquitoes bites. Knowledge of mosquito behaviour and peoples' response to control methods will help improve mosquito control and reduce disease transmission in a particular area. In this study we aim to explore people's knowledge and general understanding of mosquito bites and interventions which they use.
Later on, we plan to develop an easy-to-implement strategy for locating and targeting the residual mosquito populations that perpetuate malaria in communities where most people already use insecticidal bednets, so as to better optimize and accelerate malaria

elimination efforts. My visit today is related to the assessment of what your views and opinions are regarding mosquito bite exposure and pathogen transmission in the communities.

Procedures: As you are a participant in this study, we would like to understand your views and opinion regarding mosquito bites, protection and transmission of mosquito-borne diseases.

This type of research method has increasingly been used in health research in order to understand people's views, opinions and knowledge which impact their behaviour. Apart from this method, this study is also using other methods such as participant observation, assessment of mosquito behaviour during the evening, key informant interviews and focus group discussions from selected individuals and households. We use all these information in order to get in-depth information from the target communities. During the interview, we would like you to switch off your phone or switch it to a silent mode to avoid any disturbances. We would like to tape-record the interview session so that we can make sure to capture the thoughts, opinions, and ideas we hear from you.

Confidentiality: Do not mention your name during the discussion. Additionally, no names will be attached to the statements and the tapes will be erased as soon as they are transcribed and the project is ended. However, when we write up the results, we will not use your name and we will write about places in ways that also do not identify where you live.

Potential risks: There are **no** health risks associated with the interviews. The only risks involved might be feeling distress which might be as a result of discussion about people's health or wellbeing. So, in this situation we would like you to rest for a while and decide if you will be ok to continue with the interview.

Potential benefits: It is expected that the findings from this study will help to develop new ways of preventing malaria transmission that occurs outside homes, and will eventually contribute toward disease control and improving people's health in your community and other communities across Africa.

Compensation: Compensation to the selected member of household for the interview will be a minimum amount will be 10,000 Tanzania shillings per day**.**

Withdrawal from participation: If you agree to take part you are free to end your participation in this study at any time you want without having to give reasons.

Additional Information: In case you have any question or concern about this study please feel free to contact Dr . Mwifadhi Mrisho, representative of IHI institutional review board (0788 766 676) , Halfan Said Ngowo, Research Officer/PI at IHI (Tel: +255717519236), Fredros Okumu (Tel. No. +255 686 997 269), and Irene R. Moshi (Tel. No. +255 712 498 879),

Informed consent record: Please read this statement carefully before you sign and if you agree on participating, please fill free to sign this form below to affirm your consent.

I, _____ clearly understand the aims of the project titled **"Outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania",** as it was explained to me by the facilitator. I have been given the chance to ask questions and I am satisfied with the answers to all of my questions and I agree to participate in the study. I understand that I may revoke my consent and leave the study at any stage, if I wish so, with no negative consequences.

Participant's name: _____

Participant's signature or thumbprint: _____ Date: _____

Witness Name (As appropriate): _____

Witness signature (As appropriate): _____ Date: _____

Study team member's statement: I, the undersigned, have explained to the participant in a language that s/he understands; the procedures to be followed in the study, the risks and benefits involved, and the obligations of the study team.

_____ _____ _____

Name Signature Date

Outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania

Informed Consent Agreement – Focus Group Discussion Participants

INFORMED CONSENT AGREEMENT SERIAL NUMBER (Version 1_IC5)___

Introduction: We welcome you to participate in our research study. I am a researcher from Ifakara Health Institute and a student from the University of the Witwatersrand in South Africa. With me are two researchers from Ifakara Health Institute who will introduce themselves later. I would like to invite you to participate in the group discussion for our study. Even though you have been selected but your participation is purely voluntary. You are selected to participate in the focus group discussion which will take place in a place where you will be comfortable and the session will take 1 to 2 hours. Below are the information regarding what the project is all about, the procedures and other research requirements before we start this work.

The study aims at understanding the contribution of outdoor human activities to outdoor malaria transmission as well as peoples' understanding on malaria transmission, prevention and control. The study is titled; **"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania"**

Background and purpose: Mosquitos are a major problem in Tanzania, and people can get sick from mosquitoes bites. Knowledge of mosquito behaviour and peoples' response to control methods will help improve mosquito control and reduce disease transmission in a particular area. In this study we aim to explore people's knowledge and general understanding of mosquito bites and interventions which they use, before embarking on introducing other interventions. This research study aim to develop an easy-to-implement strategy for locating and targeting the residual mosquito populations

that perpetuate malaria in communities where most people already use insecticidal bednets, so as to better optimize and accelerate malaria elimination efforts. My visit today is related to the assessment of what your views and opinions are regarding mosquito bite exposure and pathogen transmission in the communities.

Procedures: As participants for the Focus Group Discussion, we would like to understand your views and opinion regarding mosquito bites and outdoor malaria transmission as a group in this community. This type of research method has increasingly been used in health research in order to understand people's views, opinions and knowledge which impact their behaviour. Apart from this method, this study is also using other methods such as participant observation, entomological assessment, key informant interviews and semi structured interviews with one individual in every selected households. We use all these information in order to get in-depth information from the target communities.

The discussion will last from one hour to two hours with a break if necessary. I would like you to be free to move, feel free to excuse yourself and take as much time you need to think about the question with no hurry. During the response we would like people to speak one after the other in order to capture everyone's views. No other discussion should be conducted aside. During the discussion, we would like you to switch of your phone or switch it to a silent mode to avoid any disturbances. We would like to tape-record the interview session so that we can make sure to capture the thoughts, opinions, and ideas we hear from you.

Confidentiality: Confidentiality will not be guaranteed for this discussion. We request you not to mention names during the discussion. Additionally, no names will be attached to the statements and the tapes will be erased as soon as they are transcribed and the project is ended. When we write up the results, we will not use your name and we will write about places in ways that also do not identify where you live.

Potential risks: There are **no** health risks associated with the interviews. The only risks involved is taking too much of your time, but we would like to extend our sincere apologies about that. But we know discussion about people's health or wellbeing they

might feel distressed, in this situation we would like you to rest for a while and decide if you will be ok to continue with the interview

Potential benefits: It is expected that the findings from this study will help to develop new ways of preventing malaria transmission that occurs outside homes, and will eventually contribute toward disease control and improving people's health in your community and other communities across Africa.

Compensation: Any compensation to the selected member for the focus group discussion will be agreed between the research team and yourself. Minimum amount will be 10,000 Tanzania shillings per day**.**

Withdrawal from participation: If you agree to take part you are free to end your participation in this study at any time you want without having to give reasons.

Additional Information: In case you have any question or concern about this study please feel free to contact Dr . Mwifadhi Mrisho, representative of IHI institutional review board (0788 766 676) , Halfan Said Ngowo, Research Officer/PI at IHI (Tel: +255717519236), Fredros Okumu (Tel. No. +255 686 997 269), and Irene R. Moshi (Tel. No. +255 712 498 879),

Informed consent record: Please read this statement carefully before you sign and if you agree on participating, please fill free to sign this form below to affirm your consent.

I, _____ clearly understand the aims of the project titled **"Outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania",** as it was explained to me by the facilitator. I have been given the chance to ask questions and I am satisfied with the answers to all of my questions and I agree to participate in the study. I understand that I may revoke my consent and leave the study at any stage, if I wish so, with no negative consequences.

Participant's name:

_____

Participant's signature or thumbprint: _____ Date: _____

Witness Name (As appropriate): _____

Witness signature (As appropriate): _____ Date: _____

Study team member's statement: I, the undersigned, have explained to the participant in a language that s/he understands; the procedures to be followed in the study, the risks and benefits involved, and the obligations of the study team.

_____ _____ _____

Name Signature Date

Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania

Informed Consent Agreement – Key informant interview participants.

INFORMED CONSENT AGREEMENT SERIAL NUMBER (Version 1_IC6)___

Introduction: We welcome you to participate in our research study. I am a researcher from Ifakara Health Institute and a student from the University of the Witwatersrand in South Africa. I would like to invite you to participate on our study. Even though you have been selected but your participation is purely voluntary. You are selected to participate in the interview which will take place in a place where you will be comfortable and the session will take 45 minutes to 1 hour. During the session, it will only be you and the interviewer in order to maintain confidentiality. Below are the information regarding what the project is all about, the procedures and other research requirements before we start this work.

The study aims at understanding the contribution of outdoor human activities to outdoor malaria transmission as well as peoples' understanding on malaria transmission, prevention and control. The study is titled; **"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania"**

Background and purpose: Mosquitos are a major problem in Tanzania, and people can get sick from mosquitoes bites. Knowledge of mosquito behaviour and peoples' response to control methods will help improve mosquito control and reduce disease transmission in a particular area. In this study we aim to explore the way of people within this community, different practices and meaning attached to them. Also, to understand your general knowledge on your understanding on malaria transmission, prevention and control.

Later on we plan to develop an easy-to-implement strategy for locating and targeting mosquitoes that transmit diseases outside people's houses. But we first need to know the activities that people do outside, what people know about mosquito biting and the way they protect themselves. That way, we can be able to complement the existing strategies and reduce, control and eliminate diseases as well as improving people's health and wellbeing.

Procedures: You have been selected as a candidate for Key informant interview as an individual who has a leadership role in this community. Our aim is to be able to understand your views and opinion regarding mosquito bites, community practices, ceremonies and activities that expose people to outdoor disease transmission. This type of research method has increasingly been used in health research in order to understand people's views, opinions and knowledge which impact their behaviour. Apart from this, the study is also using other methods such as participant observation, assessment of mosquitoes, one to one interview and focus group discussions. We use all these methods/ways in order to get more understanding of what is going on within these communities

The interview will involve only two people and it will last for about thirty minutes to one hour. There will be a short break when you need to. I would like you to be free to move, feel free to say when you need a break. You are also allowed to take as much time you need to think about the question or ask when you do not understand anything. During the interview, we would like you to switch of your phone or switch it to a silent mode to avoid any interruption. We would like to tape-record the interview session so that we can make sure to capture the thoughts, opinions, and ideas we hear from you. No names will be included in any of the reports or anything that can identify you. The tapes will be erased/ discarded as soon as interviews have been transferred to words at the end of the project.

Confidentiality: No names will be attached to the statements and the tapes will be erased as soon as they are transcribed and the project is ended.

Potential risks: There are **no** health risks associated with the interviews. The only risks involved is taking too much of your time, but we would like to extend our sincere apologies about that.

Potential benefits: It is expected that the findings from this study will help to develop new ways of preventing malaria transmission that occurs outside homes, and will eventually contribute towards malaria elimination in your community and other communities across Africa.

Compensation: Compensation for your participation will be a minimum amount of 15, 000 Tanzania shillings per day.

Withdrawal from participation: If you agree to take part you are free to end your participation in this study at any time you want without having to give reasons.

Additional Information: In case you have any question or concern about this study please feel free to contact Dr . Mwifadhi Mrisho, representative of IHI institutional review board (0788 766 676) , Halfan Said Ngowo, Research Officer/PI at IHI (Tel: +255717519236), Fredros Okumu (Tel. No. +255 686 997 269), and Irene R. Moshi (Tel. No. +255 712 498 879),

Informed consent record: Please read this statement carefully before you sign and if you agree on participating, please fill free to sign this form below to affirm your consent.

I, _____ clearly understand the aims of the project titled **"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania"** which has been explained to me. I have been given the chance to ask questions and I am satisfied with the answers to all of my questions and I agree to participate in the study. I understand that I may revoke my consent and leave the study at any stage, if I wish so, with no negative consequences.

Participant's name:

_____

Participant's signature or thumbprint: _____ Date: _____

Witness Name (As appropriate):_____

Witness signature (As appropriate): _____ Date: _____

Study team member's statement: I, the undersigned, have explained to the participant in a
language that s/he understands; the procedures to be followed in the study, the risks and benefits involved, and the obligations of the study team.

_____ _____ _____

Name Signature Date

Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania

Informed Consent Agreement – Audio Recording

(For In-depth Interviews, Key informant interviews, and Focus Group Discussion Participants)

INFORMED CONSENT AGREEMENT SERIAL NUMBER (Version 1_IC7)_____

Type of Interview_____

Date of the Interview_____

Thank you for agreeing to participate in this study, which will be conducted in four villages of the Kilombero Valley in South-eastern Tanzania. This form details the purpose of this study, a description of the involvement required and your rights as a participant.

The study aims at understanding the contribution of outdoor human activities to outdoor malaria transmission as well as peoples' understanding on malaria transmission, prevention and control. The study is titled; **"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania"**

Background and purpose: Mosquitos are a major problem in Tanzania, and people can get sick from mosquito bites. Knowledge of mosquito behaviour and people's response to control methods will help improve mosquito control and reduce disease

transmission in a particular area. In this study we aim to explore the way of people within this community, different practices and meaning attached to them. Also, we want to understand your general knowledge on your understanding on malaria transmission, prevention and control.

Later, we plan to develop an easy-to-implement strategy for locating and targeting mosquitoes that transmit diseases outside people's houses. But we first need to know the activities that people do outside, what people know about mosquito biting and the way they protect themselves. That way, we can be able to complement the existing strategies and reduce, control and eliminate diseases as well as improving people's health and well-being.

The methods that will be used to meet this purpose include:

- One-on-one interviews
- Key Informant Interviews
- Focus Group Discussion groups of 8-12 participants

Our discussion will be audio taped to help me accurately capture your insights in your own words. The tapes will only be heard by me for the purpose of this study. If you feel uncomfortable with the recorder, you may ask that it be turned off at any time.
You also have the right to withdraw from the study at any time. In the event you choose to withdraw from the study all information you provide (including tapes) will be destroyed and omitted from the final report. Insight gathered from you and other participants will be used in writing a report for study purposes, planning further interventions and educating other communities of similar characteristics.

Though direct quotes from you may be used in the paper, your name and other identifying information will be kept anonymous.

Additional Information: In case you have any question or concern about this study please feel free to contact Dr. Mwifadhi Mrisho, representative of IHI institutional review board (0788 766 676), Halfan Said Ngowo, Research Officer/PI at IHI (Tel:

+255717519236), Fredros Okumu (Tel. No. +255 686 997 269), and Irene R. Moshi (Tel. No. +255 712 498 879),

Informed consent record: Please read this statement carefully before you sign and if you agree on participating, please fill free to sign this form below to affirm your consent.

By signing this consent form I certify that I, _____, agree to the
(Print full name here)

terms of this agreement to be recorded during the session in which I will participate in a study titled **"Exploring outdoor activities, mosquito biting and protection in Kilombero Valley, South Eastern Tanzania"** which has been explained to me. I have been given the chance to ask questions and I am satisfied with the answers to all of my questions and I agree to participate in the study. I understand that I may revoke my consent and leave the study at any stage, if I wish so, with no negative consequences.

_____ _____

(Signature) (Date)

Witness Name (As appropriate):_____

Witness signature (As appropriate): _____ Date: _____

Study team member's statement: I, the undersigned, have explained to the participant in a
language that s/he understands; the procedures to be followed in the study, the risks and benefits involved, and the obligations of the study team.

_____ _____ _____

Name Signature Date