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The needs and opportunities for housing improvement for malaria control in Southern Tanzania

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NM-AIST

THE NEEDS AND OPPORTUNITIES FOR HOUSING IMPROVEMENT FOR MALARIA CONTROL IN SOUTHERN TANZANIA

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A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Public Health Research of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

There is evidence that mosquito-proofed houses can reduce malaria risk. However, housing improvement is rarely included in malaria control toolboxes. This study assessed the need, magnitude, and opportunities for housing improvement to control malaria in Tanzania. The exploratory mixed-methods study was conducted in 19 villages across four councils in southern Tanzania. A structured survey was administered to 1292 community members to assess need, perceptions, and opportunities for housing improvement. Direct observations of 802 houses and surrounding environments were done to identify the needs, opportunities, and to validate the survey findings. A market survey was done to assess availability, cost of resources and services necessary for mosquito-proofing homes. Focus group discussions were conducted with key stakeholders to explore insights on the potential and challenges of housing improvement. Of the 735 respondents who needed housing improvements, a majority needed window screening (91.1%), repairs of holes in walls (79.4%), door covers (41.6%), closing eave spaces (31.2%) and bettering roofs (19.0%). Community members invested significant efforts to improve their homes against malaria and other dangers, but these efforts were delayed due to high costs and limited incomes. Study participants suggested several mechanisms of support to improve their homes, including loans and subsidies. Addressing the need for housing improvement is a critical component of malaria control. A majority of the community members needed modest modifications and had plans to work on it. Thus, it is crucial to bring together key players across sectors to reduce barriers and making housing improvement accessible and affordable to residents.

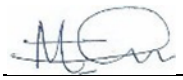
Key words: Housing improvement; need; magnitude; opportunities; malaria control, Mosquito-proofed houses

DECLARATION

I, Ramadhani Mohamedi Bofu hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation titled "*Need and opportunities for housing improvement for malaria control in southern Tanzania*" is my original work and that it has not been submitted for consideration of similar degree award in any institutions.

Ramadhani Mohamedi Bofu Date

The declaration is confirmed by:



Dr. Marceline (Lina) Francis Finda Date

Dr. Fredros O. Okumu Date

[redacted]

Date

Dr. Joseph Swilla Date

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance for the dissertation entitled *"Need and opportunities for housing improvement for malaria control in*

southern Tanzania" In Partial Fulfilment of the Award of Master of Science in Public Health Research of the Nelson Mandela African Institution of Science and Technology.

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DEDICATION

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LIST OF ABBREVIATIONS AND SYMBOLS

CHW	Community Health Workers
CIs	Confidence Intervals
d^2	Marginal error
DPs	Development Partners
FGDs	Focused Group Discussions
HI	Housing Improvement(s)
IDIs	Idepth Informant Interview
IHI	Ifakara Health Institute
IHI-IRB	Ifakara Health Institute Institutional Review Board
IRS	Indoor Residual Spray
ITNs	Insecticides Treated Nets
LLINs	Long Lasting Insecticides Nets
LSM	Larva Source Management
MDA-IVM	Mass Drug Administration with Ivermectin
MoHCDGEC	Ministry of Health, Community Development, Gender, Elderly and Children
NBS	National Bureau of Statistics
NGOs	Non-Governmental Organization
NIMR	National Institute for Medical Research
NM-AIST	Nelson Mandela African Institution of Science and Technology
NMCP	National Malaria Control Program
OR	Odd Ratio
SDGs	Sustainable Development Goals
SMS	Swarms Management Spray
SR	Spatial repellent
SSA	Sub Saharan Africa
UNOPS	United Nations Office for Project Services
WHO	World Health Organization
Z	Level of significance

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Malaria is often recognized as a disease of poverty (Gallup & Sachs, 2001; Sachs & Malaney, 2002), and continues to affect millions lives globally. More than 90% of malaria cases and deaths are concentrated in the world's poorest countries (WHO, 2022). At more local levels, malaria is mostly concentrated in rural and poorer regions (Finda *et al.,* 2018, 2019a), where poor housing is a common factor. Despite the changing behavior of malaria transmitting mosquitoes that include early evening and outdoor biting (Mathania *et al.*, 2016; Russell *et al*., 2011), still more than 80% of malaria transmission in sub-Saharan Africa occurs indoors (Huho *et al.*, 2013), making house quality one of the key factors associated with malaria risk. Housing Improvement (HI) such as screening windows and doors is one of the oldest reported malaria control interventions in the world, dating back to the 19th and 20th century in Italy, Europe and the Americas (Celli, 1900; Lindsay *et al.,* 2002), and is linked to malaria elimination in those contexts (Boyd, 1926; Lindsay *et al.,* 2002). However, interest in HI for malaria control declined following the discovery of insecticidal methods for killing mosquitoes, which were considered simpler, more affordable, and highly effective (Lindsay *et al.*, 2002; Pampana, 1969; Wilson *et al.,* 2020).

The common insecticidal methods include long-lasting insecticide-treated net (LLINs) and indoor residual spray (IRS) as well as effective case management (WHO, 2021b). However, these interventions are rapidly reaching their limit as there has been a slowdown in malaria reduction over the past decade (WHO, 2021b), in fact, malaria cases and deaths have been resurging over the past year (WHO, 2022). These malaria control interventions face multiple challenges including inadequate physical lifespan of LLINs bed nets (Lorenz *et al*., 2020), insecticide resistance (WHO, 2016), changes in mosquitoes' behaviors (Matiya *et al.,* 2019), and anti-malaria drug resistance (Greenwood, 2017). These challenges appeal for integrating additional alternative vector control methods to supplement the current interventions to maintain the progress that has been made so far. Some of these alternative interventions include housing improvement, larval source management, genetic control technologies and malaria vaccines (Hemingway *et al.,* 2016; Tizifa *et al.,* 2018).

1.2 Statement of the Problem

Recent studies across sub-Saharan Africa have associated modest improvement in housing quality with decreased mosquito density and malaria incidence (Bradley *et al.,* 2013; Snyman *et al.,* 2015;

Tusting *et al.,* 2016, 2017a). It has been noted, for example, that children living in improved houses made with brick walls, metal roofs, and closed eave space had 9% to 14% lower odds of being infected with malaria compared to those living in unimproved houses made with mud walls and thatched roofs across sub-Saharan Africa (Bradley *et al.,* 2013; Snyman *et al.,* 2015; Tusting *et al.,* 2017a). Other studies have also indicated higher densities of malaria vectors in unimproved houses compared to improved houses (Finda *et al.,* 2018; Jones *et al.,* 2022; Kirby *et al.,* 2008; Lwetoijera *et al.,* 2013; Tizifa *et al.,* 2022).

Despite the evidence that housing structures influence malaria risk (Tusting *et al.*, 2015, 2017b), this intervention is rarely considered in the malaria control toolbox. This is likely because there is a poor understanding among and across stakeholders of the need, magnitude, and opportunities for housing improvement as a malaria control tool. This current study, therefore aimed to understand the perspectives of community leaders and other stakeholders regarding the need, magnitude, and opportunities for housing improvement for malaria control.

1.3 Rationale of the Study

Housing improvement is of utmost importance for malaria control and elimination. However, resources required to support them partly provide barrier to the investment of housing improvement programs. Therefore, this study added on provision of a list of housing stakeholders "Communities definition of malaria-proof house(s)", proportion of houses with various improvement needs, available resources and costs for housing improvement as a malaria control tool**.**

1.4 Research Objectives

1.4.1 General Objective

The aim of this study was to explore and assess the need, magnitude, and opportunities for housing improvement for malaria control in malaria endemic communities in southern Tanzania.

1.4.2 Specific Objectives

(i) To map the key stakeholders of housing improvement for malaria control in southern Tanzania.

(ii) To explore communities' definitions of mosquito-proof house and values attached to those meanings in southern Tanzania.

(iii) To assess the need and magnitude of housing improvement for malaria control and elimination in southern Tanzania.

(iv) To explore opportunities for responding to the existing gaps in housing improvement for malaria control in southern Tanzania.

1.5 Research Questions

(i) Who are the key stakeholders of housing improvement in malaria endemic settings?

(ii) How do malaria endemic communities define a mosquito-proof house?

(iii) What is the need and magnitude of housing improvement for malaria control in southern Tanzania?

(iv) What are current gaps in housing improvement for malaria control in southern Tanzania, and what opportunities exist to fill the gaps?

1.6 Significance of the Study

This study provided critical information to various stakeholders including communities, government, and private sectors in the planning, designing and implementing housing improvement programs for malaria control. The results also provided benchmark data to Ministries on the development of health housing policies and guidelines in the control of vector borne diseases including malaria.

1.7 Delineation of the Study

Earlier studies have investigated the impact of improved house (screening windows, eaves, doors, cover holes in the walls, and install ceiling) to prevent mosquitoes' entry and lowering malaria risks. But, often, these interventions have not taken into consideration the actual needs and preferences of the communities in the endemic settings, and opportunities that are locally available to them. This dissertation assessed the community's housing improvement needs, perceived challenges and opportunities to support them to control malaria in rural Tanzania.

The major limitation of this study is that it was conducted in a community that is relatively homogeneous in southern Tanzania. Therefore, these findings may not be generalizable to the whole country or to other malaria endemic settings in Africa. Still, these findings offer a baseline from which further studies can be developed in other malaria endemic settings, to explore the need and potential of housing improvement to help speed up malaria control and elimination efforts.

Another limitation of this study was that, while it has been increasingly reported that houses with brick walls are more protective compared to mud-walled houses, however, the actual risk that different house types or conditions pose was not assessed in this study. Moreover, community leaders also described an ideal malaria-proof house to have enough space for people to be able to spend more time indoors. However, in this study did not dive deep in defining what 'big space' meant in the context of these communities. While this study laid the essential groundwork for developing housing improvement as a malaria prevention tool, further studies are needed to investigate this concept as it may have implications on the overall cost of housing improvement.

CHAPTER TWO

LITERATURE REVIEW

2.1 Ecological Model in the Context of Housing Improvement

Ecological model offers a valuable lens to assess the need and opportunities for housing improvement. This model recognizes the complex interactions between individuals, their environments and broader social systems (Hardcastle *et al.,* 1981; Mcleroy *et al.,* 1988), emphasizing how factors at each level significantly affect housing improvement (Fig. 1). This study identified community's needs, knowledge, and perceptions about mosquito-proof houses. The study focused on individual levels such as perceptions of the needs and limitations, interpersonal levels such as relationships among the community members and their leaders at different levels, community levels such as availability of resources, and societal levels such as values attached to improved houses (Fig. 1). These factors were assessed against the observed and reported need and opportunities for housing improvement in the communities we investigated.

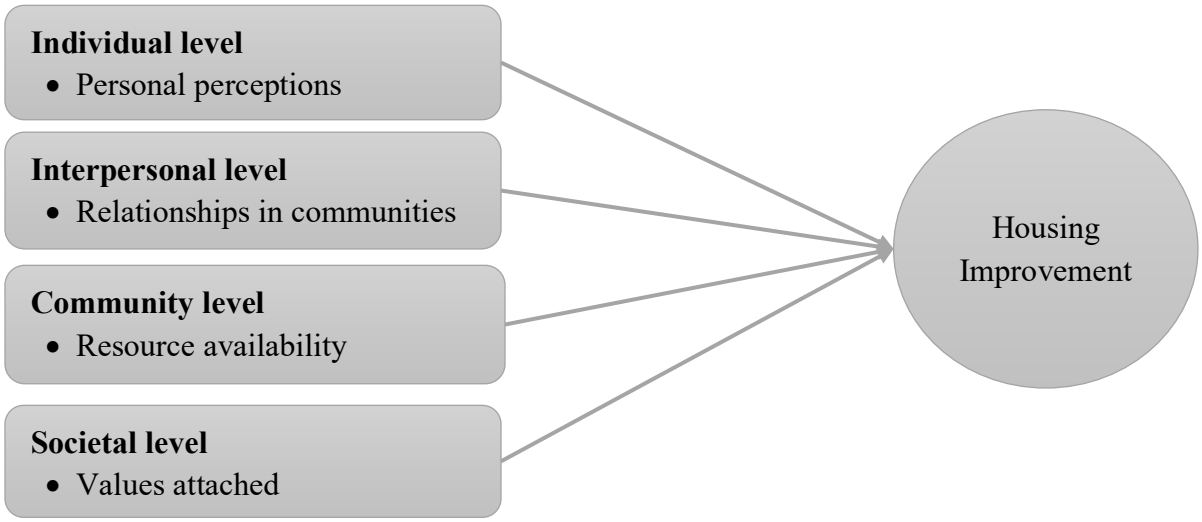

Figure 1: Factors influencing housing improvement

2.2 Malaria Vector

Anopheles mosquito is the responsible vector genus for malaria transmission (WHO-Factsheet, 2020). There are more than 400 different species of *Anopheles* mosquito; nearly 40 *Anopheles* species are malaria vectors of public health importance which bite between sunset and sunrise (WHO, 2019). However, species usually vary depending on several factors which has the potential to influence malaria control, including resistance to insecticides, biting and resting locations, host preference and their geographical distribution (Wiebe *et al.,* 2017). Therefore, it is crucial to consider the species responsible for the disease and other factors to design an impactful intervention for malaria control.

The main African malaria vectors belong to two species complexes: *Anopheles gambiae* and *Anopheles funestus* (Coetzee, 2020). In Tanzania, *Anopheles funestus* is now leading malaria transmission due to strong resistance to pyrethroids and carbamates and most of malaria transmission still occur indoor and before bed time (Okumu & Finda, 2021). Thus, complementing the core vector control strategies with housing improvement for preventing indoor malaria is highly important.

2.3 Vector Control Strategy in Malaria Elimination

Long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS) are widely used vector control strategies that are responsible for the highest malaria burden reductions achieved in sub Saharan Africa (SSH) (WHO, 2019). However, growing resistance to the existing insecticides, operational constraints, growing expenses on interventions, and lack of compliance are the common reported challenges which makes these interventions insufficient to eliminate malaria (Killeen *et al.,* 2017). Furthermore, incomplete indoor residual spray which leave other surfaces unsprayed like roofs and ceilings where a significant proportions of mosquito rest on contributing to residual malaria transmissions (Msugupakulya *et al.*, 2020). In high income countries, mosquito control has been primarily achieved through a combination of mosquito-proofing houses and environmental management, supplemented with frequent, large-scale insecticide applications to larval habitats and outdoor spaces, to kill off mosquito population (Killeen *et al.,* 2017). Importantly, vector control strategies in SSA can be achieved through integration of vector control strategies including housing improvement.

In Tanzania, malaria control efforts have reduced malaria incidence by nearly 50% over the past decade (NBS, 2018). However, malaria continues to be among the leading causes of morbidity and mortality in the country (Mboera *et al.,* 2018). Tanzania's National Malaria Control Program (NMCP) set an ambitious goal to achieve malaria elimination across the country by 2030 (MoHCDGEC, 2018). Some of the strategies put in place to achieve this goal are ensuring universal coverage of vector control interventions and rollout of alternative malaria control interventions to complement the current interventions (MoHCDGEC, 2018). Several alternative interventions are either under consideration or have been implemented in the country. These include larval source management, housing improvement and genetically modified mosquitoes (Finda *et al.,* 2020).

Another line of research has been to assess whether community members living in malaria endemic settings understand the associations between housing structure and malaria transmission. In rural Tanzania, Kaindoa *et al.* (2018) found that, while community members living in malaria endemic

settings were aware of the risk of living in poorly constructed houses on malaria transmission, low-income levels and competing household priorities prevented them from improving their houses (Kaindoa *et al.*, 2018). A different study by Ogoma *et al*. (2009), in urban Tanzania, found that a majority of community members associated housing improvement with lower risk of malaria transmission (Ogoma *et al.,* 2009). On the contrary, a survey done in western Kenya to assess community knowledge and perceptions on malaria prevention and house screening reported low awareness of the impact of housing screening for malaria control (Nganga *et al.*, 2019).

2.4 Housing and Health

Housing is a basic need for human health despite the little attention it has received in global health (Tusting *et al.,* 2020). Healthy housing is an integral part of SDGs 3 through many linked health outcomes including prevention against respiratory diseases, soil transmitted helminths, diarrhea and vector borne diseases like malaria (Tusting *et al.,* 2019). The population of malaria-endemic countries is expected to double in the next 30 years, and the demand for housing will rise alongside it (UNOPS, 2021). But, housing in Africa has been improving rapidly together with economic development (Tusting *et al.,* 2020). In SSA, between 2000 and 2015 improved housing with improved water and sanitation, adequate inhabitable areas, and permanent construction increased from 11% to 23% respectively (Tusting *et al.*, 2019). Therefore, progress of these improvement must include important attributes that keeping out vector of public health concern.

Housing condition is an important determinant of risk of malaria transmission, burden and severity (Tusting *et al.,* 2017b). Evidence revealed a simple act of screening windows, doors, eaves, plastering walls and metal roofs are associated with the lowering malaria incidences and severity in sub-Saharan Africa (Kirby *et al.,* 2008; Tusting *et al.,* 2015). Moreover, housing designs which prevent mosquitoes entry and provide comfort to live are necessary in hot climates regions (Jatta *et al.*, 2018). For example, a well-designed house may have strong association with bed nets use to inhabitants (Von Seidlein *et al.,* 2019), through increased ventilation which reduced indoor temperature, weakening CO_2 plumes emanating from houses and lowering density malaria mosquito from entering inside house (Jatta *et al.,* 2021; Von Seidlein *et al.*, 2019) and hence lowering risk for malaria transmissions. In line with this, a regression analysis from the data pooled in eight countries revealed that housing improvement may lead to approximately 25% reduction in the number of malaria cases among under five children (Nabassaga *et al.,* 2019). However, low income households with poor housing conditions are the most affected people with the malaria infections (Degarege *et al.,* 2019; Tusting *et al.,* 2016). In Tanzania significant proportions of households in rural areas live in houses with open eaves, unscreened windows and gaps on doors (Kaindoa *et al.,* 2018), increasing the chance of indoor biting and malaria

transmission irrespective of high coverage of ITNs (Steven *et al.,* 2021). Thus, improving houses mark as the crucial alternative interventions against the spread of malaria infections in the community.

2.5 Primary Stakeholders on Housing Improvement

In the recent era, the housing improvement has regained its importance from the edge of ITNS and IRS in vector control (Kirby *et al.,* 2010). In Tanzania, recent study explored perceptions of key stakeholders on the potential of housing improvement for malaria control. The study documented that community members in endemic settings highly preferred housing improvement compared to other alternative interventions, policy makers, regulators and research scientists expressed their skepticism over perceived high cost and lack of sustainability (Finda *et al.*, 2020). Studies have indicated the progress that has been witnessed on housing improvement in Africa largely depends on the communities themselves (Tusting *et al.,* 2019). It was noted that the observed improvement in house design in the communities occurs spontaneously because of socioeconomic improvements over time (Tusting *et al.,* 2015). But the government has the duty to formulate a practical policies, laws, regulations and guidelines as important tools for promoting and monitoring the quality of houses for disease control (WHO, 2021). However, limited understanding on the potential of community engagement, inadequate investment on infrastructure and resources to support sustainable community participation deter the implementation of the intervention in malaria endemic areas (Atkinson *et al.,* 2011). Therefore, community centered approaches with the support from other stakeholders can help to accelerate housing improvement in malaria endemic-settings.

2.6 Multisector Collaboration on Housing Improvement

Housing is the major entry point for inter-sectoral collaboration on public health programs and primary prevention of diseases (WHO, 2018). For instance, development of housing programs that are designed to reduce number of mosquitoes in and around homes, requires collaborative effort from stakeholders including individuals, ministries, disciplines and institutions (WHO, 2020). Yet stakeholders are working independently which partly slow down the speed and coverage of improve housing in rural communities (WHO, 2021). Evidence have shown that integration of stakeholders efforts could help to optimize housing improvement coverage in low income households (Mccann *et al.,* 2021), this may include; promotion and education on how to improve housing conditions to prevent malaria transmission risk (Tizifa *et al.,* 2022), provision of funding, inclusive policies, and regulations (Liu & Ong, 2021; Nugroho, 2020; Sururi *et al.*, 2022), presence of affordable building materials and construction expertise (Jatta *et al.,* 2018; Nepal, 2007), effective coordination of stakeholders efforts, and supporting poorest households (Mccann *et al.*,

2021). Thus, bringing together key players across the sector may provide sustainable solutions and enhance wide coverage of improved houses for malaria control.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted in nineteen villages within the Mlimba, Malinyi and Ulanga district councils and the Ifakara town council, all in the Kilombero valley, southern Tanzania (Fig. 2). In Mlimba district, this study was done in Merera, Mofu, Njage and Namwawala villages. In Malinyi district, the study was conducted in Itete, Kalengakelo, Mtimbira and Sofi mission villages. From Ulanga district Igumbiro, Iragua mission, Lupiro, Ebuyu and Mzelezi villages were recruited and in Ifakara Town council Mlabani, Kibaoni, Ifakara mjini, Sululu, Mang'ula B, and Mkamba villages participated in this study. The councils have a diversity of settlements including urban, peri-urban and rural. A vast majority of the residents in rural and peri-urban settings are primarily farmers, but some also supplement that with other activities such as small businesses, fishing and livestock keeping. In the urban settings, many residents do various forms of entrepreneurship, supplementing it with farming. A majority of the houses in the area are made of brick walls and metal roof, and only a few have mud walls and thatched roofs (Finda *et al*., 2018; Kaindoa *et al.,* 2018*;* Msugupakulya *et al.,* 2020).

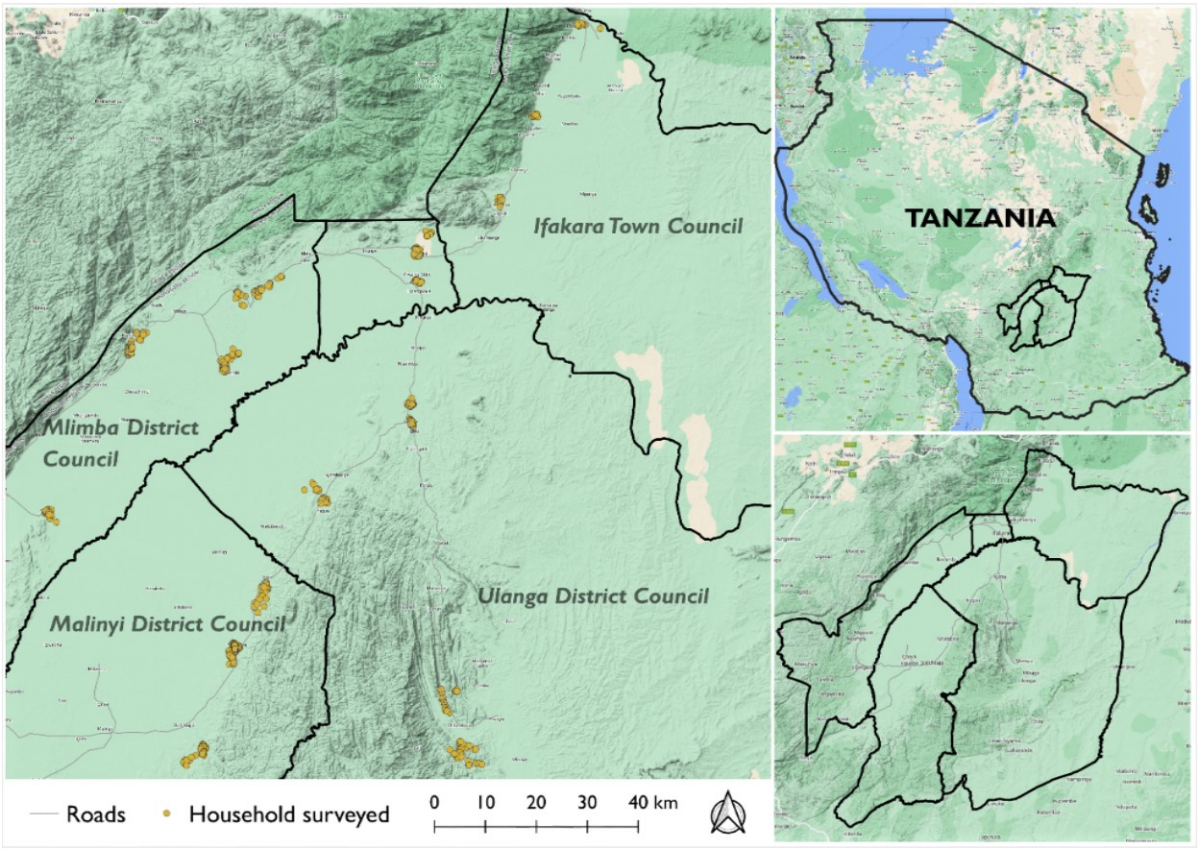

Figure 2: Map of study areas in the Kilombero valley, Tanzania

3.2 Sample Size Determination

The suitable sample size was calculated using Cochran's sampling equation considering prevalence of malaria in Kilombero valley of 14% (Harchut *et al*., 2013) marginal error 5%, and 95% confidence level.

$N=\frac{Z^2*P*(1-P)}{d^2}$ ----------equation (1)

$N=\frac{1.96^2*0.14*(1-0.14)}{0.05^2} \approx 185$ -----equation (2)

Where;

N= 185

N Desired sample size of households

Z Level of significance

P Proportion of the population

d^2 Marginal error

However, a total of 802 households was included in this study for the second round survey, which is around to 200 households per council as adapted in Kaindoa *et al.* (2018)

3.3 Inclusion Criteria

The participants aged 18 years old and above who capable to provide necessary information on the house structure, and malaria prevention measures were included in the survey of this study. Policy makers, regulators, scientists and community leaders were recruited to participate in focus group discussions, and building materials vendors, carpenters, masons and metal-workers were involved in in-depth discussions for market analysis.

3.4 Study Design and Procedure

This study adapted exploratory mixed method design (Fetters *et al.*, 2013; Joseph, 2003) to explore and assess preferences, need, perceptions and opportunities for housing improvement as a malaria control intervention in southern Tanzania. In this study, qualitative was done followed by the quantitative phase. The qualitative component involved a series of focus group discussions (FGDs) with the key stakeholders about their perceptions on the potential of alternative strategies for malaria control and elimination in Tanzania. Housing improvement was one of the alternative strategies explored. Preliminary findings from this component were used to develop the first and the second rounds of quantitative surveys as indicated on Fig. 3. Quantitative component included two cross-sectional surveys, direct observations of houses and surrounding environments and market analysis for availability and cost of building materials. The exploratory qualitative component included focus group discussions (FGDs) with community leaders to explore their insights on the potential and challenges of housing improvement as malaria control interventions,

as well as a market survey in form of in-depth interviews with hardware store owners and builders to explore available resources and services for housing improvement. The choice to involve various levels of stakeholders was guided by the ecological model to gain perspectives across all levels (household, community, science, and policy) needed to consider housing improvement for malaria prevention. Each level of stakeholder has a unique influence for population health and interventions (Mcleroy *et al*., 1988). A literature review was done to investigate potential stakeholders for housing improvement for malaria control and their levels of influence.

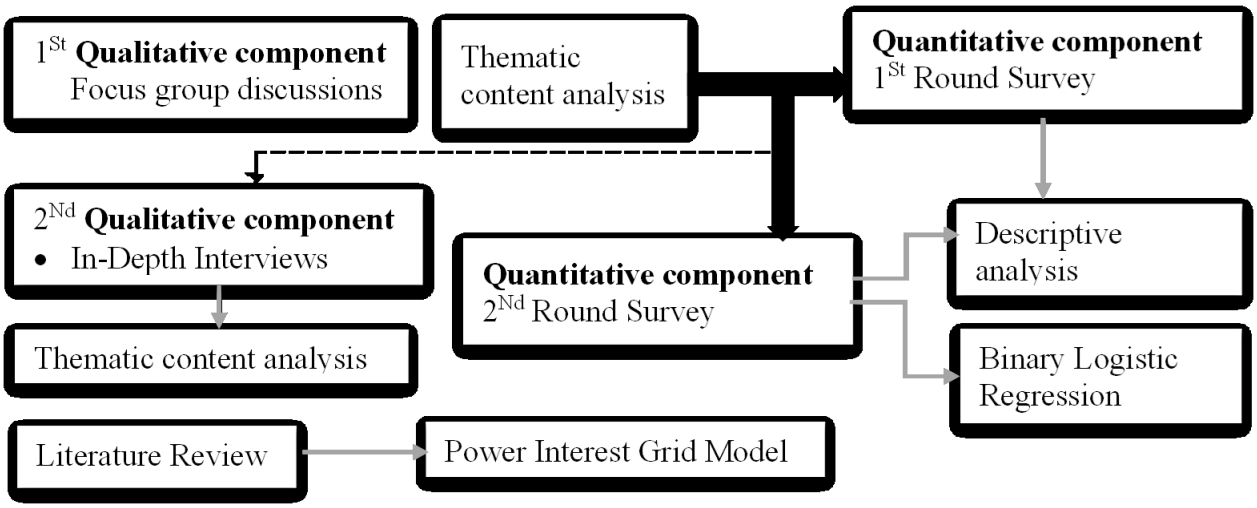

Figure 3: Exploratory Mixed Method Framework

Table 1: Summary table for participants and methods used

Participants	Number of participants (n)	Method
Policy makers	14	Focus Group Discussion
Regulators	14	
Scientists and	16	
Community leaders	16	
Community Members	490	Round one survey
Community Members	802	Round two Survey and Observation
Store owners and Builders	10	Market Survey in the form of In-depth Interview

3.5 Literature Review for Mapping Key Stakeholders for Housing Improvement

For academic literatures a systematic search was conducted using PubMed, Google scholar, and ProQuest electronic databases. The key terms used in the bibliographical search include: "Malaria", "Housing improvement", "actors", "roles" and "stakeholders". Bibliographical scans

of the included references were also used to add literatures. Hand search technique was involved to retrieve legislations and other documents from the websites. The primary outcome for this review is a list of stakeholders and their potential roles related to housing improvement.

3.5.1 Initial Selection Criteria

All literatures described potential stakeholders and their roles for housing improvement were included. The review was not restricted to year of study or the country the study was conducted. Only studies published in peer review journals, Legal and official documents, and authorized websites written in English were considered. Unpublished articles, or unendorsed documents, and other studies that reported irrelevant information were excluded from this review.

3.5.2 Quality Assessment

The fundamental questions for quality assurance of literatures that met the criteria included: Was the study purpose stated clearly? Was the study relevant to topic? Was the method clearly described? Was conclusion fitting the study design and results?

One author recorded the list of studies conducted from 2006 to October 2022. Titles and abstracts were reviewed to examine if the studies met the initial inclusion criteria; all eligible studies were included for a full review. A Microsoft Excel was used to record potential stakeholders, roles, type of literature, and method used. Additionally, in-person inquiry was conducted with local builders, to get more insight on people involved and how do they take part in the housing improvement.

3.6 Focus Group Discussions

Secondary data from eight FGDs with key stakeholders to discuss their insights on the potential of housing improvement as a malaria control intervention were analyzed. Potential of housing improvement was discussed relative to other alternative tools for malaria control and elimination as previously described by Finda *et al*. (2020). The FGDs were done between December 2018 and December 2019. The key stakeholders were recruited from four groups that are all directly or indirectly involved with malaria control in Tanzania. These included policy makers, regulators, research scientists from two leading research institutions in the country, and community leaders from the villages where the surveys were conducted. The group of policy makers included senior officials from the government ministries who direct or indirect influence malaria control strategies, and regulators included regulatory authorities (Finda *et al.*, 2020*)*. Two FGD sessions were had per stakeholder group, each including between six and ten participants. For the community leaders, men and women were separated to maximize participation by women (Nyumba *et al.*, 2018), but

this separation was not done among the other stakeholder groups as it was deemed unnecessary. A semi-structured discussion guide was used to facilitate the discussions. The sessions were audio-recorded and detailed notes were taken.

3.7 Questionnaire Survey

Two rounds of surveys were done in two different times; secondary data were taken from the first-round survey which was done between November and December 2019, reaching 490 community members in ten villages. This survey assessed community members' awareness, knowledge, and preferences for alternative strategies to supplement current interventions for malaria control. The community members were provided with a list of six alternative strategies for malaria control and elimination including: (a) larval source management (LSM), (b) spatial repellents (SR), (c) targeted spraying of mosquito swarms (SMS), (d) mass drug administration with ivermectin (MDA IVM) to reduce vector densities, (e) release of modified mosquitoes (MM), including genetically modified strains, and (f) housing improvement (HI).

The second round of survey was administered between March and June 2022 to 802 community members in 19 villages. This survey aimed to assess community perceptions, awareness, and available opportunities for housing improvement as a malaria control intervention. The villages in the second survey included the 10 villages in the first survey, but individuals surveyed were not necessarily the same. In both surveys, the households were randomly selected with guidance from household lists from the Ifakara Health and Demographic Surveillance System (Geubbels *et al.*, 2015), village sanitation registers and community leaders from the respective villages. Lists of households were identified in each sub-village, and a simple random formula was generated in excel. In case a household on the list no longer existed, the closest neighbor-household was visited and recruited to participate in the study. The surveys were administered to one adult household representative only after they had given written consent to participate. The survey was administered using Kobotoolbox^{TM} software (Harvard Humanitarian Initiative, 2005) on electronic tablets.

3.8 Direct Observations

Direct observations were done in each of the 802 households in the second survey to assess various houses and surrounding environmental conditions. Information on house characteristics included conditions of walls, roofs, floors, windows, and doors. Information about the surrounding environment was recorded up to 10-meter radius surrounding the candidate house, and included presence of toilets, sources of domestic water sources, trash and potential breeding habitats for

mosquitoes. The observation guide was incorporated in the survey that was administered to the household representatives and was done by a researcher conducting the main survey.

3.9 Market Survey

A market survey was conducted between September and November 2022 in one town in each of the four councils to investigate availability of building materials and services to respond to the identified needs for housing improvement. Altogether, 37 stores were identified, unevenly distributed between the four councils (Table 1). The stores were visited in-person where possible, and in other cases, phone numbers of store owners were obtained, and interviews were conducted through phone. The store owners were asked to provide general information about building products they sold, such as different product brands, their prices and popularity, and general information about their customers, such as where they come from and purchasing behaviors. Only stores that specialize in selling building materials such as wire mesh, insect screens, cement, metal sheets, ceiling boards, woods and nails were surveyed. In addition to the assessment of hardware stores, in-depth discussions were also conducted with various vendors including store owners, carpenters, ironsmiths as well as masons to investigate cost for various house improvements services, varying from minor improvements such as window screening to major changes such as whole house constructions. Cost of the materials and services was determined.

Table 2: Availability of vendors of building materials in the Kilombero Valley

Council	Town	Number hardware stores
Ifakara Town Council	Ifakara	25
Mlimba District Council	Chita	5
Malinyi District Council	Mtimbira	4
Ulanga District Council	Lupiro	3

3.10 Data Analysis

3.10.1 Review Data

Review data was analyzed using Power Interest Grid Model to classify stakeholders into key and minor stakeholders based on their roles in housing improvement (Bronwen, 2005). Power Interest Grid Model is a powerful tool for categorizing key stakeholders, identifying their relationships, anticipate potential conflict of interests and maximize support of the intervention (Freeman, 2015). Key stakeholders refers to those who can significantly influence or are powerful for the implementation of the housing improvement for malaria control (WHO, 2005). In this review, a list of stakeholders and their roles for housing improvement were scrutinized, and appropriately allocated in respective quadrant of the grid based on the position and influence in housing

improvement as a malaria control stratergy (Fig. 4) (Freeman, 2015), those who placed in high interest, high power quadrant or both were termed as key stakeholders (WHO, 2005). The guiding definitions for each quadrant are; a high-power stakeholder has an influence on either supporting or disregarding the implementation of housing improvement. A low-power stakeholder who has some influence, however, can not stop the implementation of housing improvement. A high-interest stakeholder has a direct impact on the implementation of housing improvement. A Low-interest stakeholder has less or indirect impacts on the implementation of housing improvement (WHO, 2005).

3.10.2 Quantitative Data

was analyzed using R statistical software version 4.2.1 (R Development Core Team, 2011). Descriptive analysis was used to assess socio-demographic characteristics of the survey respondents, and summarize the characteristics of the houses, needed improvement and awareness of housing improvement as a malaria control intervention, and presence and cost of building materials and services. Binary logistic regression was used to examine the associations between the independent variables (wall type, roof type, window covers, door covers, social economic status, and location) and outcome variables (need and plan for improvement); odds ratio was calculated at 95% confidence intervals (CIs). The cost of house improvement needs per house was computed based on the market price of building materials, where the highest price of the item during a survey was taken as a market price, workmanship charges and local constructors' experiences using bill of quantities (BoQ) for improving or building a standard house with an average of three sleeping rooms, four windows, and two doors. All cost were provided in TZS and converted into USD.

3.10.3 Qualitative Data

For qualitative data, audio recordings from the FGDs were transcribed immediately following the discussions and translated from Swahili to English. The written transcripts were reviewed and analyzed using NVIVO 12 Plus software (NVIVO, 2015). Objectives of the study and discussion guides were used to develop deductive codes, and inductive codes were generated through thorough reviews of the transcripts. Similar codes were grouped, and emergent patterns used to identify themes and concepts. Weaving approach (Fetters *et al.,* 2013) was used to present both quantitative and qualitative findings together. Perceptions of community members about housing improvement from the questionnaire were integrated with perceptions and the opinions of community leaders on the potential of housing improvement as a malaria control intervention.

Where relevant, direct quotations from participants were used to support the claims. For the in-depth discussions with materials vendors their information were noted and translated into English.

3.11 Ethical Consideration

Ethical approvals for this project was obtained from Ifakara Health Institute's Institutional Review Board (Protocol ID: IHI/IRB/EXT/No: 015 - 2018) and the Medical Research Coordinating Committee (MRCC) at the National Institute for Medical Research (Protocol ID: NIMR/HQ/R.8a/Vol.IX/2697), in Tanzania, as well as University of the Witwatersrand (UW) in South Africa (Clearance certificate No. M180820). Written consent was obtained from all participants of this study, after they had been informed of the purpose and procedure of the discussions using a local language (*Swahili*).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Characteristics of the Reviewed Literatures

A total of 344 articles were retrieved from electronic databases, and authentic websites, of those: 31 articles were eligible for review (Fig. 4); A majority (64.5%, n=20) of the studies were original articles, 16.1% (n=5) review papers, 6.5% (n=2) case study, 6.5% (n=2) government reports, and 6.5% (n=2) legislation and perspective papers.

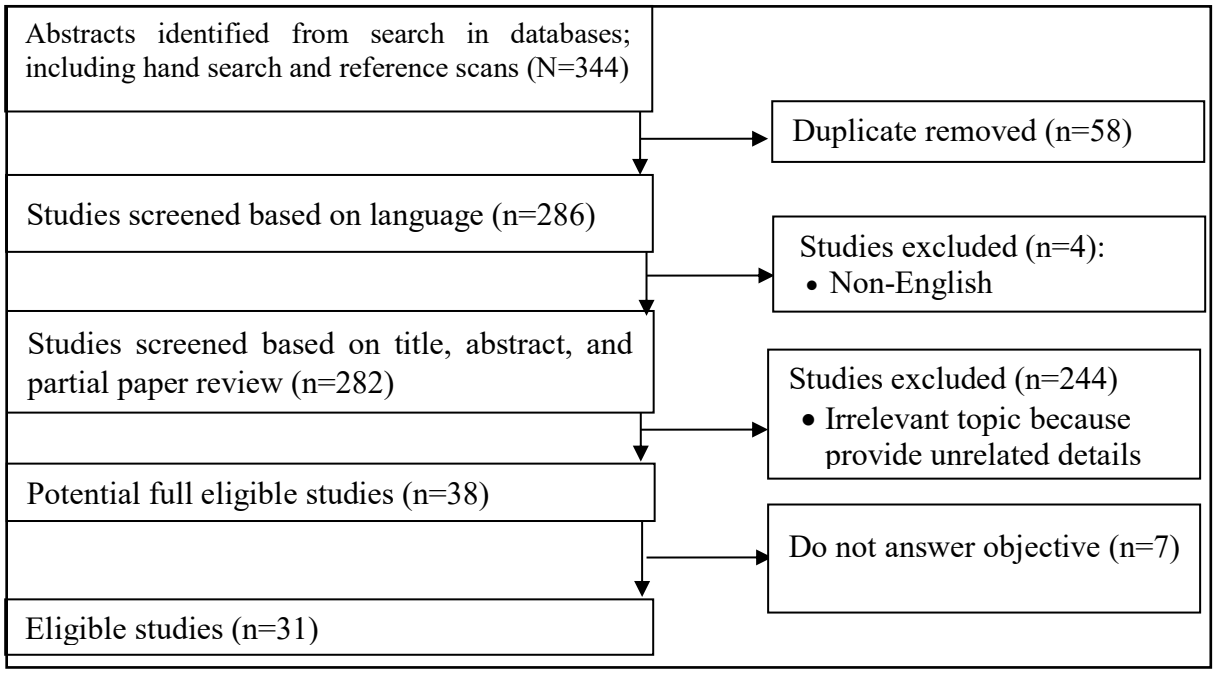

Figure 4: Literature Review Flow chart

4.1.2 Plotted Stakeholders for Housing Improvement

Stakeholders were plotted on a grid (Fig. 5) based on their relative positions and the potential implications for housing improvement programs. Stakeholders with high power and less interest are located in the top left quadrant of the grid (A). Those with high-level decision-making authority and influence in the national wide implementation. They are evidence oriented to provide directives and guidance on the action. These stakeholders need to be satisfied with the right information for the success of the house improvement program. Stakeholders with both high power and high interest are located in the top right quadrant of the grid (B). They are directly involved in the implementation of housing improvement strategy. These stakeholders are likely to have the most influence and impact on the house improvement programs for malaria control, and

may need to be engaged and consulted closely throughout the planning and implementation process. Stakeholders with low power and low interest, on the other hand, would be located in the bottom left quadrant of the grid (C). These stakeholders have less influence and power and may less or not be involved in the housing improvement interventions. Stakeholders with high interest and less power are located in the bottom right quadrant of the grid (D). These stakeholders have impact in the implementation of housing improvement, often demonstrate the readiness to support once they adequately informed.

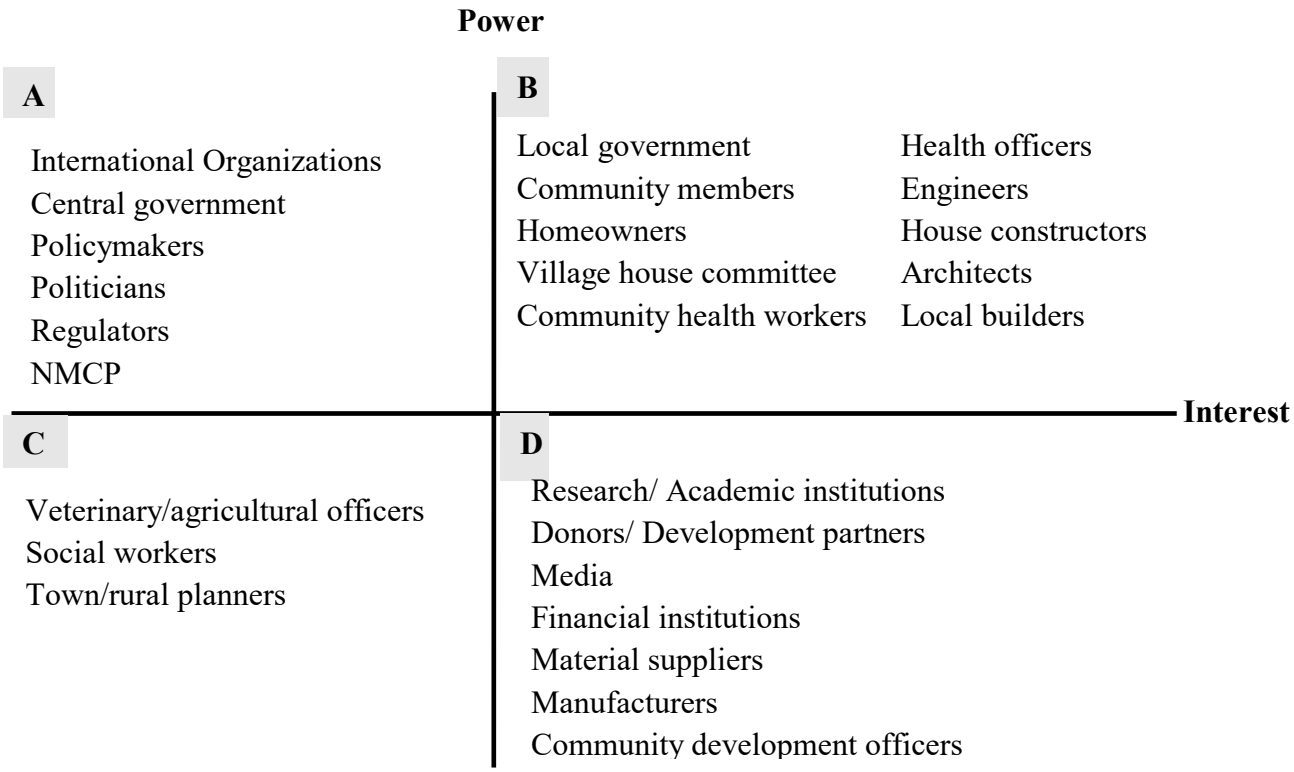

Figure 5: Power Interest Grid Model

4.1.3 Stakeholders Engagement for Housing Improvement Program

Different stakeholders may be engaged in different ways as indicated on Appendix 1, for example; homeowners are the primary stakeholders as they are the ones who will be directly impacted by the improvements. They may be motivated to improve their home to protect against malaria transmission and to improve the overall health and well-being of their family (Mukiibi & Machyo, 2021; Palacios *et al.,* 2021). Community member may provide valuable insights into the local context and may be involved in implementing and maintaining the housing improvements, and the community in which the housing is located may also be impacted by the improvements, as changes to the physical appearance of the neighborhood or increased property values can affect the overall quality of life (Berg *et al.*, 2018; Castro-arroyave *et al.,* 2020; Tizifa *et al.,* 2022).

Local government, including city council members and health departments, may have an interest in the improvements as they can affect the overall health and well-being of the community (Herrera- *et al.*, 2021; Mukiibi & Machyo, 2021). The contractors and other service providers who will be responsible for completing the improvements. They will be impacted by the budget, timeline, and scope of the project (Jatta *et al.*, 2018; Jawara *et al.,* 2018; Mburu *et al.*, 2018; Okeyo, 2022; Tizifa *et al.*, 2022; Waleckx *et al.,* 2018). Funding agencies or government programs, may also providing financial assistance for the improvements (Berg *et al.,* 2018; Nepal, 2007; Satterthwaite *et al.,* 2020).

International organizations or local health departments, may provide guidance on the most effective methods for preventing malaria transmission and may be able to assist with technical, funding or resources (RollBack-malaria, 2016). Private sector may bring expertise and resources to the design and implementation of program (Nepal, 2007; RollBack-malaria, 2016). Researchers and academic institutions may provide evidence-based recommendations and evaluations to ensure the effectiveness of the HIs (Finda *et al.,* 2020; Musiime *et al.,* 2022; Shenton *et al.*, 2022; Wilson *et al.,* 2019). A more in-depth summary of a list of potential stakeholders and their roles for HI is attached in Appendix 1.

4.1.4 Socio-Demographic Characteristics of the Participants

A total of 1352 people participated in this study, including 490 community members in the first round of community-based survey, 802 in the second round of survey and 60 people participated in the FGDs. A detailed description of the community members who participated in the first round of survey and the FGDs is provided elsewhere (Finda *et al.,* 2020, 2021; Mapua *et al.,* 2021). For the second-round survey the description of study participants is summarized in Table 3.

Table 3: Socio demographic characteristics of the participants

Characteristics	Category	n (%)
Average Household size (Range)		4.3 (1 to 27) people
average age (Range) in years		45 (18 to 89) years
Average Monthly income in TZS *		222 300.00 ≈ $ 95.34
Sex	Women	486 (60.6%)
	Men	316 (39.4%)
Highest education level	No formal educatior	118 (14.7%)
	Primary education	579 (72.2%)
	≥ Secondary educati	105 (13.1%)
Income Generating activities**	Farming	732 (91.3%)
	Business	130 (16.2%)
	Pastoralist	60 (7.5%)
	Formal employment	14 (1.7%)
Monthly income (Shillings)***	Below 495, 628	749 (93.4%)
	≥ 495, 628	53 (6.6%)

*$1 was converted to TZS 2332.43 **Percentage adds up to above 100 because of multiple selection ***Categories based on 2022 Rural Tanzania Living Income Reference Value of 495,628 Tanzanian Shillings (Anker report, 2023).

Generally, houses with brick walls and metal roofs were the most common type, comprising more than three-quarters of all surveyed houses (Fig. 6). Interestingly, most of these houses were found in urban areas (93.5%, n=188) compared to rural areas (67.0%, n=260). About half (50.1%, n=402) of the households had flush toilets located outside of the main living area. Solar lamps were the main source of light in 40.1% (n=322) of the households. Nearly a third (30.5%, n=245) of the respondents used pump water from community centers, and about two thirds (69.3%, n=556) used firewood for cooking.

Figure 6: **Common house type in the study sites: a) brick walls with metal roof, b) brick walls with thatched roof, c) mud walls with metal roof, d) mud walls with thatched roof**

4.1.5 Common House Characteristics

The surveyed houses had an average of 3 rooms, 4 windows, and 2 doors. Majority had brick walls (83.9%, n=673), metal roof (80.7%, n=647), and 95.8% (n=768) of houses had windows. Common window covers included wire mesh (50.9%, n=391), insect screen (45.6%, n=350), and bricks (39.3%, n=302), and common door covers were wood (76.2%, n=611). While holes were observed in (74.1%, n=569) of the windows, 60.3% (n=484) of the doors and 51.9% (n=416%) of the houses had open eaves with an average width size of 15 cm, ranging from 2 cm to 60 cm (Table 4).

Table 4: Characteristic of the surveyed houses

Variables	Category	All n (%)	Urban n (%)	Peri-urban n (%)	Rural n (%)
All houses		802 (100%)	201 (25.1%)	213 (26.6%)	388 (48.4%)
Major house type	Bricks wall & Metal roof	626 (78.1%)	188 (93.5%)	178 (83.6%)	260 (67.0%)
	Mud wall & Thatched roof	108 (13.5%)	6 (3.0%)	14 (6.6%)	88 (22.7%)
	Bricks wall & Thatched roof	47 (5.9%)	2 (1.0%)	15 (7.0%)	30 (7.7%)
	Mud wall & Metal roof	21 (2.6%)	5 (2.5%)	6 (2.8%)	10 (2.6%)
Wall type	Plastered bricks	246 (30.7%)	105 (52.2%)	67 (31.5%)	74 (19.1%)
	Unplastered bricks	427 (53.2%)	85 (42.3%)	126 (59.2%)	216 (55.7%)
	Mud	129 (16.1%)	11 (5.5%)	20 (9.4%)	98 (25.3%)
Condition of walls	No holes	474 (59.1%)	125 (62.2%)	133 (62.4%)	216 (55.7%)
	Holes	328 (40.9%)	76 (37.8%)	80 (37.6%)	172 (44.3%)
Roof type	Metal sheet	647 (80.7%)	193 (96.0%)	184 (86.4%)	270 (69.6%)
	Thatched	155 (19.3%)	8 (4.0%)	29 (13.6%)	118 (30.4%)
Condition of the roof	No holes	579 (72.2%)	123 (61.2%)	171 (80.3%)	285 (73.5%)
	Holes	223 (27.8%)	78 (38.8%)	42 (19.7%)	103 (26.5%)
Windows cover*	Wire mesh	391 (50.9%)	134 (66.7%)	118 (57.6%)	139 (38.4%)
	Insect screens	350 (45.6%)	117 (58.2%)	103 (50.2%)	130 (35.9%)
	Bricks	302 (39.3%)	60 (29.9%)	86 (42.0%)	156 (43.1%)
	Uncovered	85 (11.1%)	25 (12.4%)	22 (10.7%)	38 (10.5%)
	Curtains/clothes	80 (10.4%)	18 (9.0%)	21 (10.2%)	41 (11.3%)
	Wood/ bamboo	75 (9.8%)	17 (8.5%)	18 (8.8%)	40 (11.0%)
	Others	36 (4.7%)	18 (9.0%)	9 (4.4%)	9 (2.5%)
Condition of the Windows cover	No holes	199 (25.9%)	70 (34.8%)	57 (27.8%)	72 (19.9%)
	Holes	569 (74.1%)	131 (65.2%)	148 (72.2%)	290 (80.1%)
	Wood/bamboo	611 (76.2%)	161 (80.1%)	154 (72.3%)	296 (76.3%)

Variables	Category	All n (%)	Urban n (%)	Peri-urban n (%)	Rural n (%)
Entry door cover*	Metal sheet	194 (24.2%)	35 (17.4%)	58 (27.2%)	101 (26.0%)
	Grill	67 (8.4%)	38 (18.9%)	17 (8.0%)	12 (3.1%)
	Uncovered	35 (4.4%)	6 (3.0%)	11 (5.2%)	18 (4.6%)
	Bricks	16 (2.0%)	3 (1.5%)	5 (2.3%)	8 (2.1%)
Condition of the doors cover	No holes	318 (39.7%)	92 (45.8%)	78 (36.6%)	148 (38.1%)
	Holes	484 (60.3%)	109 (54.2%)	135 (63.4%)	240 (61.9%)
Eaves space	Open Eaves	416 (51.9%)	83 (41.3%)	103 (48.6%)	230 (59.3%)
	Closed eaves	385 (48.1%)	118 (58.7%)	109 (51.4%)	158 (40.7%)
	Average open eave width	15 (2-60) cm	8 (2- 40) cm	14 (3-60) cm	15 (2-60) cm
Ceiling	Not present	727 (90.6%)	164 (81.6%)	200 (93.9%)	363 (93.6%)
	Present	75 (9.4%)	37 (18.4%)	13 (6.1%)	25 (6.4%)
Ceiling type	Gypsum	38 (50.7%)	24 (64.9%)	11 (84.6%)	3 (12.0%)
	Wood	26 (34.7%)	10 (27.0%)	0 (0.0%)	16 (64.0%)
	Nylon	11 (14.6%)	3 (8.1%)	2 (15.4%)	6 (24.0%)
Condition of ceiling	No holes	59 (78.7%)	32 (86.5%)	13 (100%)	14 (56.0%)
	Holes	16 (21.3%)	5 (13.5%)	0 (0.0%)	11 (44.0%)
Floor-type	Mud	449 (56.0%)	60 (29.9%)	115 (54.0%)	274 (70.6%)
	Cement	324 (40.4%)	125 (62.2%)	89 (41.8%)	110 (28.4%)
	Tiled	29 (3.6%)	16 (8.0%)	9 (4.2%)	4 (1.0%)

*Percentages add to more than 100% because of multiple selections

4.1.6 Definition of a Mosquito-Proof House

Community leaders associated 'modern' houses with being mosquito-proof. When asked to define what a mosquito-proof house meant to them, the leaders termed it as a modern house (*Nyumba ya kisasa)*, and listed many features including large house size, large windows, screened doors and windows, brick walls, metal roof and electricity. The leaders explained that well-ventilated lighted and uncluttered indoor environment would be unsuitable for mosquitoes, as expressed by these two leaders:

> *Three main important things are brick walls and metal roofs and big windows. Those are the basic, other things can be added with time. You also need to put netting on the doors and windows, and then another big addition is also to put electricity. Mosquitoes do not like electricity. Then if you have electricity, you can also have a fan, and a fan chases mosquitoes away, they do not like a fan. I tell you, if a house is well lit with big windows, mosquitoes can never have a chance* [Male community leader].

> *For me, a modern house is a brick house that has big enough windows that can allow air and light in. It has enough space to sit and cook. It has a bathroom and a sitting room. It is a house that people can feel comfortable to stay in and cook, eat, and relax. That is what I think is a modern house* [Female community leader].

When asked whether or not their current houses provided protection against malaria vectors, a majority (88.4%, n=709) of the survey respondents said no, and only (11.6%, n=93) believed that their houses provided protection. Of those that said their houses did not provide protection, they described their houses as having a lot of holes in the walls and roofs through which mosquitoes get inside. The houses were also dark and cluttered hence providing a lot of hiding places for mosquitoes. One community leader said:

> *I tell you that these traditional houses have a lot of hiding places for mosquitoes. Also, you see people normally put very small windows, or they do not put any windows at all, or sometimes they have small windows, but they completely cover them with clothes or bricks, as a result, it is always dark inside, and we all know that mosquitoes like the dark* [Male community leader].

The community leaders further explained that their houses are generally very small, forcing people to conduct household chores outdoors, exposing them to the risk of outdoor malaria transmission.

It was in some cases difficult to use currently available mosquito control interventions such as bed nets or insecticide-sprays due to the small size and structures of the houses, or the holes in the houses through which mosquitoes can enter freely. One community leader explained the difficulty using insecticide spraying as follows:

> *It is quite difficult to kill mosquitoes in these houses as however many times you spray the insecticides, mosquitoes keep coming back because these houses have a lot of holes, so new mosquitoes can keep coming in* [Male community leader].

4.1.7 Perceptions of Housing Improvement for Malaria Control

When presented with several alternative strategies for mosquito control, a majority (91.6%, n=449) of the community members that participated in the first survey reported awareness of the potential of HI in controlling malaria vectors. Additionally, 70.0% (n=343) of the community members had correct knowledge of how housing improvements works in malaria control, and 89.0% (n=436) preferred housing improvement compared to the other alternative tools (Fig. 7). Preference for HI was also widely expressed during the FGDs with the key stakeholders, where most of the community leaders discussed that all other strategies would not be fully effective in controlling or eliminating malaria if people continue to live in poor houses that do not offer any protection against mosquitoes. The leaders further explained that the potential of HI made the most sense to them compared to the other strategies, as it provides protection against not only mosquitoes but also other diseases and dangers. Two leaders elaborate these concerns here:

> *For me to live well and feel safe I need to be in a nice house, made with bricks and metal roof, with big space and big windows with net. I like that it will protect me from not just mosquitoes, but also many other diseases and other dangers like snakes and flooding* [Male community leader].

> *I like improving or building houses for people so that they are safe from mosquitoes. All these other solutions are really good, but if people do not have houses that protect them then I do not think that anything will work 100%. So, I would advise that we put people in protective houses and then add other solutions* [Female community leader].

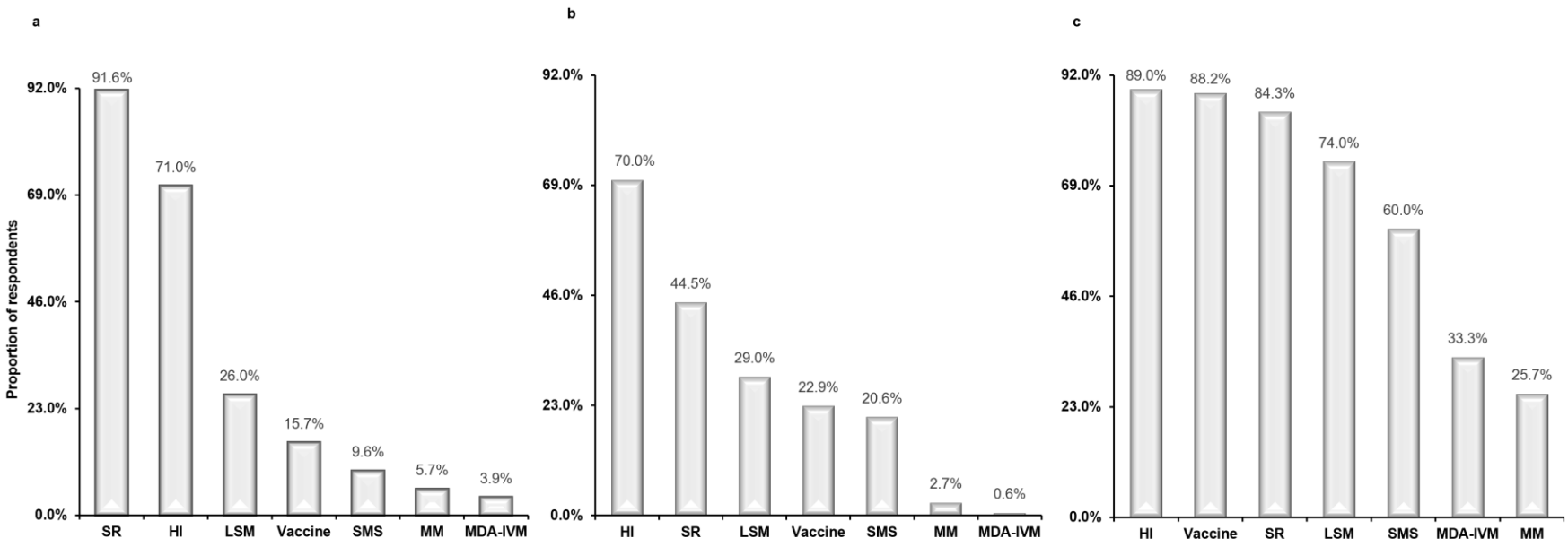

Figure 7: **Awareness, knowledge and preference of alternative tools for malaria control and elimination among community members in southern Tanzania: (a) awareness of housing improvement for mosquito control, (b) knowledge of how housing improvement works in mosquito control, (c) preference for housing improvement for malaria control**

The high preference for housing improvement for malaria control, however, was not reflected among other stakeholder groups, who feared that it would not be affordable or sustainable for a low-income country like Tanzania. Additionally, housing improvement was seen as insufficient in effectively controlling malaria as policy makers believed that the risk of malaria transmission was not confined inside houses as this policy maker explained:

> *I do not at all agree with the technology of improving houses for people because I do not think that malaria is only transmitted in the house; people can get malaria anywhere mosquitoes are, so I do not see the point of focusing on just houses. I think we should focus on getting rid of mosquitoes, not just keeping them outside the house* [Male Policy maker].

There were stakeholders that proposed focusing on environmental improvements rather than just the house noting that malaria transmission will still persist if the surrounding environment is mosquito-friendly as this regulator said:

> *In Dar-es Salaam there is a lot of waste that can facilitate mosquito reproduction. It does not matter how nice your house is, if the environment is suitable for mosquito reproduction, they will always be there. I would advise to focus on improving the environment and the sewage system, to destroy all the places mosquitoes can breed or hide* [Male regulator].

Furthermore, were participants, particularly scientists who explained that the potential of housing improvement for malaria control has not thoroughly investigated, hence inadequate evidence for it. These stakeholders discussed that it would not be advisable for the government to be directly involved in housing improvement for malaria control as this scientist said:

> *I do not think that this is an intervention that the government can invest in directly, maybe more indirectly. House improvement is a part of development, it happens naturally… But the problem is that we have not been documenting the impact of these changes in terms of malaria control, so we cannot really say for sure how this has contributed in malaria control* [Male scientist].

In the second community-based survey however, 69.6% (n=558) of the community members were aware that improved housing protects against malaria, a majority knowing from their daily experiences, learning from family and relatives as well as hearing about it in television and radio. For those that disagreed that improved housing provides protection against malaria, the main reasons given were that it was that improved houses alone would not provide complete protection against malaria, as mosquitoes could still get in through open doors or windows, and due to the traditions, people would still spend time outdoors.

4.1.8 Housing Improvement Needs among Community Members

Most (91.6 %, n=735) of the surveyed community members expressed the need for some improvement to make their houses mosquito-proof. Most of the improvements needed were on adding or repairing window screens (67.2%, n=494), repairing walls (43.0%, n=316), adding or repairing doors (36.7%, n=270), and changing or repairing roof (32.2%, n=237). Only 17.0% (n=125) of the surveyed respondents needed their whole houses reconstructed to provide any protection from mosquitoes (Table 5). When asked whether they had plans to make the needed improvements, 87.6% (n= 644) reported planning to do so in a period of between one and five years. Nearly three quarters (73.3%, n=588) of the community members listed affordability as the main reason for the delays in making the needed house improvements.

The issue of affordability also dominated the FGDs with community leaders, who explained that everyone wishes to live in an improved house, but the cost is too high. Some of the costliest materials were said to be doors, windows, and metal roofs. For example, one community leader elaborated that when people build modern houses, they normally put a lot of big windows and multiple doors to ventilate their houses. But since windows are expensive, people often temporarily cover the window openings with bricks until they can afford to install proper windows or doors as this community leader elaborated:

> *If people cannot afford to screen their windows, then they normally cover them with bricks. You know our biggest challenge is poverty. I know people like to live in nice houses with big windows that can allow ventilation, we like that very much. But if you have very little money, then you just have to deal with what you have, and that is why you see a lot of doors and windows that are not screened. We know that screening would provide protection against mosquitoes, we just cannot afford it* [Male community leader].

Table 5: Community-reported need for housing improvement

Improvement needs	Category	n (%)
Windows (n=494, 67.2%)	Adding or repairing screen	450 (91.1%)
	Adding wood or metal protection	57 (11.5%)
	Adding glass cover	40 (8.1%)
	Increasing windows size	32 (6.5%)
	Other window improvement	16 (3.2%)
Walls (n=316, 43.0%)	Plastering or repairing walls	251 (79.4%)
	Closing eave space	99 (31.2%)
	Painting walls	41 (13.0%)
	Other wall improvement	5 (1.6%)
Door (n=270, 36.7%)	Adding wood or metal cover	112 (41.6%)
	Adding or repairing screen	99 (36.7%)
	Adding wood or metal frame	49 (18.2%)
	Increasing door size	22 (8.2%)
	Other door improvement	18 (6.7%)
Roof (n=237, 32.2%)	Adding ceiling	120 (50.6%)
	Repairing roof	90 (38.0%)
	Bettering roof	45 (19.0%)
	Other roof improvement	13 (5.5%)
Whole house (n=125, 17.0%)	Rebuilding the whole house	109 (87.2%)
	Other house improvement	16 (12.8%)

4.1.9 Availability and Cost of Building Materials

Altogether a total of 37 stores were identified and contacted in four towns in the four councils in the Kilombero valley in southern Tanzania. Ifakara town, the most urban of the four councils, had the highest number of stores. Many of the Ifakara town stores sold both wholesale and retail, and their customers came from across the Kilombero valley, including store owners in the more rural councils. The stores in the more rural towns were smaller in size and sold just retail. Their customers were reported to be from within their surrounding communities.

The store owners explained that their highest selling season for building materials was immediately following the harvesting season. Most popular products were cement, metal sheet for roofing, and insect-screens for windows and doors. The interviews revealed that after selling their farm products, people would often start building bigger houses, but they would often not be able to complete these within the season, and would either complete parts of the houses or cover windows and doors with bricks and defer to the following harvesting season (Fig. 8). The store owners also reported that people would often purchase building materials at irregular intervals, depending on when they get funds. Due to this, building a single house could take years to complete. However,

it was common for people to move into unfinished house and keep on completing as they live in it (Fig. 8).

Figure 8: Examples of improved but incomplete houses that people were residing in: (a) un-roofed house, (b) bricks on windows with small gaps on top, (c) holes on the walls and open eaves and (d) no door or window covers installed

Like the store owners, builders and carpenters also explained that often people build their houses in steps, depending on when they can afford. They indicated that most people built the walls with bricks and mud, and later on plaster with cement and sand. This was said to be more affordable than building with bricks and cement. The builders said that the most expensive materials for people were cement, metal sheets, and door and window frames and covers. Bricks were said to be locally manufactured and affordable. They further indicated that sometimes it could take them years to complete a house construction depending on when the owners were able to secure building materials or afford to pay for the building services.

Estimated price for conducting various house improvements is provided on Table 6. This price is calculated for an average house in our sample, which has an average of three rooms, four windows,

two outlet doors, and 4 household members. The price presented is a combination of the price of materials in the stores as well as the cost of providing the services obtaining from discussions with the builders. Increase in complexity of improvement needs was directly associated with increase in cost for the planned. For example, minor improvements such as screening windows and doors, and closing eave gaps reported a modest cost ranging between $31.5 - 54.5. Medium improvements such as adding windows and door covers were estimated to cost between $166.9 - 463.3, and major improvements, in this case constructing a new house of the average size was estimated to cost between $4590.9 - 4967.0 (Table 6).

Table 6: Estimated cost for various house-improvements

Category	Estimated cost per average house (USD)
Adding or repairing window screens	31.5 - 34.4
Adding protective bars on windows	208.7 - 240.2
Adding window glass covers	394.7 - 463.3
Increasing window sizes	243.1 - 274.6
Plastering or repairing walls	351.8 - 386.1
Close eave gaps with bricks	42.2 - 47.8
Painting walls	540.1 - 557.7
Adding wood or metal door shutters	166.9 - 171.6
Adding or repairing door- screens	42.9 - 54.5
Adding door frames	103.0 - 128.7
Increasing door sizes	244.6 - 269.9
Adding ceiling	310.2 - 315.7
Repairing roofs	480.9 -750.4
Changing roofs	1491.2 - 1611.4
Constructing a whole house	4590.9 - 4967.0

4.1.10 Factors Associated with the Need for Housing Improvement for Malaria Control

A univariate analysis was done to understand how individual variable influence the outcome using binary regression analysis. Thus, in a univariate analysis, the need for housing improvement was significantly associated with the type of walls, window covers, door covers, and location of the houses (Table 7). Households with unplastered walls were more than five times more likely to demand housing improvement than those with plastered walls (OR = 5.71, *P*-value <0.001), and houses with mud walls were nearly four times more likely to need improvements compared to those with plastered walls (OR = 3.84, *P*-value = 0.002). In terms of windows, those that had been covered with bricks were more than six times more likely to need improvements compared to

screened windows (OR = 6.22, *P*-value <0.001). Doors that were covered with grill only or metal sheets only were also significantly more likely to need improvements compared to the traditional wood covers (Table 7). In terms of socio-economic status, survey respondents that we classified as poor were more than twice as likely to need housing improvement compared to those classified as less poor (OR = 2.58, *P*-value = 0.001). Finally, houses in rural settings were also more than twice as likely to need improvements compared to those in urban settings (Table 7).

Table 7: Factors associated with the need for housing improvement

Variable	Category	Univariate	
		OR (95% CI)	***P*- Value**
Wall type	Plastered bricks	Ref	-
	Unplastered bricks	5.71 (3.15-10.35)	<0.001
	Mud	3.84 (1.59- 9.31)	0.003
Roof type	Metal sheet	Ref	-
	Thatched	1.84 (0.86- 3.94)	0.116
Windows cover	Insect screen	Ref	-
	Wire mesh only	1.20(0.77- 1.87)	0.408
	Bricks only	6.22(2.77-13.99)	<0.001
	Wood only	0.65(0.34-1.26)	0.202
	Curtains only	2.43(0.85-6.99)	0.099
	Uncovered	1.60(0.70- 3.69)	0.266
Door cover	Wood	Ref	
	Grill only	0.26 (0.15-0.47)	<0.001
	Metal sheet only	5.27 (1.89-14.68)	0.001
	Uncovered	1.00 (0.23- 4.41)	0.998
Social Economic	Less poor	Ref	-
Status	Poor	2.58(1.44- 4.63)	0.001
	Poorest	2.20(1.09- 4.43)	0.027
Location	Urban	Ref	-
	Peri-urban	0.80(0.44-1.47)	0.480
	Rural	2.27(1.19-4.32)	0.013

OR = Odds Ratio; 95% CI = 95% Confidence Interval Ref = reference group

4.1.11 Options for Additional Support

Community leaders explained that people in the community were making great efforts in improving their homes, however, if left for people to do this on their own, the poorest in the communities would not afford to improve their houses fast enough to keep up with the government's efforts to eliminate malaria. The community leaders discussed various options that the government could consider helping its citizens. One of the popular options was for the

government to provide people with loans to build or improve houses. The participants elaborated that the government could work with community leaders to help identify the poorest people in the community and provide them with loans to build or improve houses, and people would slowly pay back; as this participant said:

> *I would advise the government to give house loans, especially to the very poor people so that they too can have houses that they can stay in and not be forced to spend half of the night outside. In the villages, most people are very poor and such help would be really good for them* [Female community leader].

There were participants who argued however, that it would not be easy for the government to single out the poorest people and help just those; these participants suggested that the government reduces the cost of building materials so that more people could afford to build better houses or improve their houses, explaining that if the building price is subsidized, then everyone could afford to improve their homes. The leaders took examples from various programs that the government has done to help its citizens achieve better homes. One example was Tanzania's Rural Energy Agency (REA) (Tanzania Ministry of Energy & Minerals, 2007), whose aim is to facilitate availability and access to affordable electricity in rural settings in Tanzania. The leaders explained that if the government has been able to subsidize electricity costs so that the poorest in the country can afford it, the government could use similar approach and subsidize building costs as these participants said:

> *It would be good if the government could help. You know, like they are helping with REA electricity, they look at people that are poor and they reduce the cost of installing electricity, so that everyone can afford. In the past only rich people could afford electricity, but now they have made it easy for us, so now we all have electricity. I think they can definitely do this with housing too. I am not saying that they should give us everything, but they should help make it easy for everyone to build a modern house* [Male community leader].

> *I think it would be very difficult for the government to help one person at a time. I think it would be easier for the government to just subsidize the costs of building materials, then everyone can afford to build. It is better than giving loans to individual people, which you don't even know that they will use them for building. Some people can use the money to buy food or send their kids to school, will you blame them* [Male community leader]?

Other participants suggested that the government should rather build standard houses and rent them to people at affordable prices or giving people an opportunity to refund. The participants

gave an example of "*Nyumba ni Choo"* (*A house is only as good as the toilet is*), a country-wide campaign to improve health status of the people by controlling water, sanitation and hygiene related diseases (Tanzania Ministry of Health Community Development Gender Elderly and Children, 2016); the government in collaboration with international partners had built proper latrines for the poorest people in the communities, and people paid back slowly. Similar approach was proposed for housing improvement, in which the community leaders proposed the government to identify the neediest in the communities and assist them in improving their houses, and then the community members would pay back slowly. One community leader explained this process below:

> *I know there was a time, a few years back when people came and gave us loans to build modern toilets. They built the toilets for the people; they brought their own builders and the materials, and then they asked people to pay them back slowly. Now most people in the villages have modern toilets but very poor houses... The government can maybe build the houses, and people can repay the government slowly, everyone can pay according to what they can afford* [Female Community leader].

4.2 Discussion

4.2.1 Ecological Model for Housing Improvement

In the context of malaria control and elimination, this study through a triangulation of various methods provided evidence that there are factors across all levels of the ecological model that can influence house improvement to control malaria in endemic settings (Mcleroy *et al.,* 1988). For example, community members' knowledge, awareness and perceptions about housing improvement for malaria control were directly linked to their need for such improvements. The wide need for the housing improvement services was also linked to the minimal availability of resources in the rural settings, making the community-level factors a crucial component to consider when making plans for housing improvement. Likewise, the cost of the available resources, while generally modest, was relatively high when compared to the average household annual income, further indicating the minimal opportunities at the community level. We recommend that robust scientific evidence be done to influence public policy formulations, laws, regulations and guidelines necessary to inform and speed up the improvement process.

4.2.2 Stakeholders for Housing Improvement

In the review objective of this dissertation, a list of key stakeholders and their roles for housing improvement were presented as an important step for wider stakeholders' engagement for the housing improvement intervention to control malaria. Indeed, some evidence reported limited

information about stakeholder engagement, stakeholders activities, and resources are among important barriers for long-term stakeholder participation to control malaria in endemic settings (Atkinson *et al.*, 2011), and certainly prevent an opportunities to integrate involvement of multiple stakeholders, effectiveness, scalability and sustainability of housing improvement efforts (Mccann *et al*., 2021). Given the importance of improved housing in malaria control, the necessity of malaria-proofing homes is inevitable, and thus mapping key stakeholders provide an opportunity for inclusive planning and implementation of housing improvement interventions for malaria control. Therefore, it is crucial to identify key stakeholders, roles and ways to engage relevant stakeholders for successfully and sustainable housing improvement programs.

4.2.3 Need for Housing Improvement for Malaria Control

This is the first study that has undertaken a thorough assessment of the magnitude, types of housing improvement needed for malaria control, and locally available and acceptable opportunities to respond to the need. This study indicates a majority of the surveyed households need relatively modest improvement to make their houses malaria proof. The most popular needs included adding window screens, installing better windows and doors, and covering holes on walls and roofs. Such improvements have been shown to vastly reduce the risk of malaria transmission in Tanzania (Kaindoa *et al.*, 2018), Equatorial Guinea (Bradley *et al*., 2013), Gambia (Jatta *et al*., 2018; Kirby *et al.*, 2008), and Uganda (Snyman *et al*., 2015), among other countries. Lower odds of malaria infection and fewer malaria cases have also been reported in people who live in improved houses (Tusting *et al*., 2015, 2017a). Of all the houses surveyed, only 17% needed to be reconstructed to be malaria-proof. This is a crucial finding, as this need for full-house construction is much lower than had been anticipated by policy makers, regulators and scientists. Additionally, the cost for reconstructing a full standard-size house was also estimated to be less than $5000, which is also relatively low cost, considering the potential benefit an improve house has, which spans far beyond malaria control (Jatta *et al*., 2021; Tusting *et al*., 2019; WHO, 2018). Additional cost-effectiveness studies are needed to demonstrate the overall health benefits of people living in improved houses.

4.2.4 Definition of Mosquito-Proof House

The definition of a mosquito-proof or modern house was uniform among the surveyed community members; it included houses that were built with brick walls, metal roofs, screened doors and windows, and closed eaves. Electricity was also listed as an essential. It was also evident in this study that community members are making incredible efforts to modify their houses to fit this ideal of an improved house, as more than three-quarters of the houses were what Tusting *et al*. (2019) referred to as modern houses, although a majority lived at or below the poverty line. Although this

drive to improve housing condition has been observed across the country (Hashemi *et al.,* 2016; Odufuwa *et al.*, 2020), when left to just the community members alone, the improvements take a long time to complete due to financial reasons, as community members reported that on average it could take them up to 5 years to malaria-proof their houses. Additional support to these community members could help improve and speed up malaria control and elimination efforts. Lindsay *et al* proposes that a range of facilitators, both in the public and private sectors need to be involved when discussing the prospects of housing improvement. These may include microfinance institutions, government ministries, town planners, architects, public health inspectors or environmental health practitioners, and community members among others, to ensure that citizens live in disease-free houses (Lindsay *et al*., 2021). Together these key players can come up with housing improvement solutions that are both affordable and sustainable for both the country and the affected communities.

4.2.5 Awareness and Values Attached to Improved House

Community members were aware of the value of an improved house in reducing the risk of malaria transmission; they linked small and unlit houses to increased risk of exposure to malaria vectors as they provide a suitable environment for mosquitoes to hide, and forced people to spend most of their evening and early night hours outdoors, exposing them to malaria vectors. This awareness of risk of outdoor malaria transmission is supported by a study done in the same settings which indicated that the highest risk of exposure to malaria transmission occurred during the early night hours when a majority of people were outdoors in peri domestic settings (Finda *et al.*, 2019b). Despite the existing awareness of the value attached to improved housing, the major concerns for the delay on the housing improvement were associated with low and or highly cyclical income; people are only able to afford building during the harvesting season when they can sell their farm products. Interestingly, a previous study by Kaindoa *et al*. (2018) in the same villages also indicated low income as the main factor associated with delays in housing improvement.

Even in the cases where considerable investments in housing improvements were made, it was observed that houses with brick walls or metal roofs failed to provide full protection against malaria vectors since many had holes on the walls, doors, windows, and roofs. Many houses were also found unfinished, albeit people lived in them due to high construction costs. For example, lack of proper window and door covers forced many households to build bricks to temporarily cover where windows and doors could have been in order to provide protection from other dangers such as animals and burglars. Smaller holes were then intentionally left on walls to let light and air in, and these also serve as potential mosquito entry points. The fact that many people live in somewhat improved houses may give misguided hope that they are in a malaria-protective

environment, but these houses may still expose to people to as much risk as if they lived in unimproved houses. In order to ensure rapid gains in malaria control and elimination efforts, governments and malaria control agencies must supplement the efforts that people make in malaria-endemic settings towards improving their houses.

4.2.6 Opportunities for Housing Improvement

Community leaders stressed that support from the government would be crucial in helping people to live in a safe and protective environment. They offered several recommendations for the government to help improve their houses more quickly. These included providing building loans, subsidizing the cost of building materials, or building standard houses and renting to the poor at an affordable price. However, policymakers were strongly opposed to the thought of the government assisting communities in improving their houses, claiming that it is neither affordable nor sustainable for the government, and that housing improvement alone would not be sufficient to eliminate malaria. However, this lack of support from the government officials is most likely due to lack of information on: (a) the actual magnitude of the need for housing improvement in malaria-endemic settings in the country, (b) the role that housing improvement has played in malaria elimination in other settings in the world (Boyd, 1926; Lindsay *et al*., 2002; Tusting *et al*., 2015), or (c) the evidence of how various housing improvement strategies have resulted in reduction in risk and severity of malaria (Tusting *et al.,* 2015). It is crucial to ensure that these decision makers at the government level are provided with adequate information on these aspects of housing improvement.

In a previous study with the same stakeholders, it was noted that decision-makers at the national and community level rely upon information from scientists to make informed decisions related to malaria control (Finda *et al*., 2020, 2021; Mapua *et al.,* 2021). It therefore, lies on the shoulders of the scientists to generate and adequately disseminate information on the potential of housing improvement for malaria control and opportunities for helping communities in endemic settings speed up the efforts they are already making in malaria-proofing their houses.

4.2.7 Cost for Housing Improvement

In terms of cost of housing improvement, this study found the cost of screening windows and eave gaps for a standard house with an average of three rooms, four windows and two doors were stood up to approximately $35 and $48, respectively. When time is controlled, these costs are slightly lower compared to those reported on the randomized control trial study conducted in Gambia in 2009, considering four household size. The trial reported cost of full screening a house per person, for a window screening it cost $11.11 and ceiling $21.17, respectively (Kirby *et al.,* 2009). These

differences might be attributed by size of the houses and difference in the stability of national currency. I do recommend however, that future studies assess the cost-effectiveness strategy that will speed up housing improvement process and reducing malaria and other communicable diseases.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study found that housing improvement was a well-understood and supported intervention for malaria control among the rural communities in southern Tanzania. The majority of survey respondents who needed house improvements cited the need for window screening, repair of holes in walls, door covers, closing of eaves, and better roofs. Community members were willing to invest in improving their homes but were limited by financial constraints. Whereas most households surveyed needed only modest modifications, the high poverty levels meant that without additional support, it may take years for these households to obtain malaria-proof their homes. The study participants suggested government loans and subsidies as potential mechanisms of support to improve their homes against malaria.

Also, due to inadequate evidence on the needs and potential of housing improvement for malaria control, this strategy lacks support among the country's top decision makers. It is therefore highly necessary for scientists to generate and disseminate knowledge and evidence on what housing modifications can result in optimal success in providing protection against malaria and other infectious diseases. Finally, it is important to bring together all the key players in the housing sector to reduce barriers to malaria proofing housing in an endemic setting.

5.2 Recommendations

The need for HI for malaria control is urgent, and there are numerous opportunities to leverage existing resources and expertise to address this important public health issue. This study recommends: Involvement of all relevant stakeholders in the planning and implementation of HI for malaria control to ensure the success and sustainability of the program. Governments and other relevant agencies need to support low-income families through loans and subsidies to improve their homes against malaria. Key players have to come up with affordable and sustainable solutions for both the country and the affected communities. Scientists should generate and disseminate knowledge and evidence on what HI can result in optimal success in providing protection against malaria and other infectious diseases.

REFERENCES

Atkinson, J. A., Vallely, A., Fitzgerald, L., Whittaker, M., & Tanner, M. (2011). The architecture and effect of participation: A systematic review of community participation for communicable disease control and elimination. Implications for malaria elimination. *Malaria Journal*, *10*, 1–33.

Boyd, M. F. (1926). The Influence of Obstacles Unconsciously Erected Against Anophelines (Housing and Screening) Upon the Incidence of Malaria. *American Journal of Tropical Medicine*, 6, 157-60.

Bradley, J., Rehman, A. M., Schwabe, C., Vargas, D., Monti, F., Ela, C., Riloha, M. & Kleinschmidt, I. (2013). Reduced prevalence of malaria infection in children living in houses with window screening or closed eaves on Bioko Island, Equatorial Guinea. *PloS One*, 8(11), e80626.

Bronwen, G., & Gawler, M. (2005). *Cross-Cutting Tool-Stakeholder Analysis.* World Wildlife Fund. https://intranet. panda. org/

Castro-Arroyave, D., Monroy, M. C., & Irurita, M. I. (2020). Integrated vector control of Chagas disease in Guatemala: A case of social innovation in health. *Infectious Diseases of Poverty*, 9(1), 1-9.

Celli, A. (1900). The New Prophylaxis agaisnt Malaria*:* An account of experiments in Latium. *The Lancet,* 156(4031), 1603-1606.

Coetzee, M. (2020). Key to the females of Afrotropical Anopheles mosquitoes (Diptera: Culicidae). *Malaria Journal*, 2020, 1–20.

Degarege, A., Fennie, K., Degarege, D., Chennupati, S., & Madhivanan, P. (2019). Improving socioeconomic status may reduce the burden of malaria in sub Saharan Africa: A systematic review and meta-analysis. *PloS One,* 14(1), e0211205.

Eyre, M., Hashemi, A., Cruickshank, H., & Jordan, M. (2017). Transition in housing design and thermal comfort in rural Tanzania. In *5th International Conference on Zero Energy Mass Customised Housing-ZEMCH 2016* (pp. 79-98). ZEMCH Network.

Ferguson, A. C., & Yates, C. (2016). Federal Enactment of Healthy Homes Legislation in the United States to Improve Public Health. *Frontiers in Public Health*, 4, 48.

Fetters, M. D., Curry, L. A., & Creswell, J. W. (2013). Achieving integration in mixed methods designs - Principles and practices. *Health Services Research*, 48(6pt2), 2134-2156.

Finda, M. F., Christofides, N., Lezaun, J., Tarimo, B., Chaki, P., Kelly, A. H., Kapologwe, N., Kazyoba, P., Emidi, B., & Okumu, F. O. (2020). Opinions of key stakeholders on alternative interventions for malaria control and elimination in Tanzania. *Malaria Journal*, *19*(1), 1–13.

Finda, M. F., Limwagu, A. J., Ngowo, H. S., Matowo, N. S., Swai, J. K., Kaindoa, E., & Okumu, F. O. (2018). Dramatic decreases of malaria transmission intensities in Ifakara, south - eastern Tanzania since early 2000s. *Malaria Journal*, 17, 1–18.

Finda, M. F., Moshi, I. R., Monroe, A., Limwagu, A. J., Nyoni, P., Swai, J. K., Ngowo, H. S., Minja, E. G., Toe, L. P., Kaindoa, W., Coetzee, M., Manderson, L., & Okumu, F. O. (2019a). Linking human behaviours and malaria vector biting risk in south-eastern Tanzania. *PloS One*, *14*(6), 1–23.

Finda, M. F., Moshi, I. R., Monroe, A., Limwagu, A. J., Nyoni, P., Swai, J. K., Ngowo, H. S., Minja, E. G., Toe, L. P., Kaindoa, W., Coetzee, M., Manderson, L., & Okumu, F. O. (2019b). Linking human behaviours and malaria vector biting risk in south-eastern Tanzania. *PloS one*, *14*(6), 1–23.

Finda, M. F., Okumu, F. O., Minja, E., Njalambaha, R., Mponzi, W., Tarimo, B. B., Chaki, P., Lezaun, J., Kelly, A. H., & Christofides, N. (2021). Hybrid mosquitoes? Evidence from rural Tanzania on how local communities conceptualize and respond to modified mosquitoes as a tool for malaria control. *Malaria Journal*, *20*, 1–11.

Gallup, J. L., & Sachs, J. D. (2001). The economic burden of malaria. *American Journal of Tropical Medicine and Hygiene*, *64*(1-2 SUPPL.), 85–96.

Geubbels, E., Amri, S., Levira, F., Schellenberg, J., Masanja, H., & Nathan, R. (2015). Health & Demographic Surveillance System Profile: The Ifakara Rural and Urban Health and Demographic Surveillance System (Ifakara HDSS). *International Journal of Epidemiology*, *44*(3), 848–861.

Hardcastle, B., Byrnes, D., Bartlett, A., Denton, P., & Walsh, P. R. (1981). *The Ecology of Human Development: Experiments by Nature*

and Design by Urie Bronfenbrenner. Cambridge, Ma.: Harvard University Press, 1979. 330 pp. $16.50 . https://scholar.google.com/

Harvard Humanitarian Initiative. (2005). *KoBoToolbox*. https://hhi.harvard.edu/kobotoolbox

Huho, B., Briët, O., Seyoum, A., Sikaala, C., Bayoh, N., Gimnig, J., Okumu, F., Diallo, D., Abdulla, S., Smith, T., & Killeen, G. (2013). Consistently high estimates for the proportion of human exposure to malaria vector populations occurring indoors in rural Africa. *International Journal of Epidemiology*, *42*(1), 235–247.

Jatta, E., Carrasco-Tenezaca, M., Jawara, M., Bradley, J., Ceesay, S., D'Alessandro, U., Jeffries, D., Kandeh, B., Lee, D. S. H., Pinder, M., Wilson, A. L., Knudsen, J., & Lindsay, S. W. (2021). Impact of increased ventilation on indoor temperature and malaria mosquito density: An experimental study in the Gambia. *Journal of the Royal Society Interface, 18(178), 20201030.*

Jatta, E., Jawara, M., Bradley, J., Jeffries, D., Kandeh, B., Knudsen, J. B., Wilson, A. L., Pinder, M., & Alessandro, U. D. (2018). Articles How house design affects malaria mosquito density, temperature, and relative humidity: An experimental study in rural Gambia. *The Lancet Planetary Health*, *2*(11), e498–e508.

Jawara, M., Jatta, E., Bell, D., Burkot, T. R., Bradley, J., Hunt, V., Kandeh, B., Jones, C., Manjang, A. M., Pinder, M., Stone, S., D'Alessandro, U., Knudsen, J., & Lindsay, S. W. (2018). New prototype screened doors and windows for excluding mosquitoes from houses: A pilot study in rural Gambia. *American Journal of Tropical Medicine and Hygiene*, *99*(6), 1475–1484.

Jones, C., Matta, A., Pinder, M., D'Alessandro, U., Knudsen, J., & Lindsay, S. W. (2022). House screening for malaria control: Views and experiences of participants in the RooPfs trial. *Malaria Journal*, *21*(1), 1–16.

Kaindoa, E. W., Finda, M., Kiplagat, J., Mkandawile, G., Nyoni, A., Coetzee, M., & Okumu, F. O. (2018). Housing gaps, mosquitoes and public viewpoints: A mixed methods assessment of relationships between house characteristics, malaria vector biting risk and community perspectives in rural Tanzania. *Malaria Journal*, 17, 1–16.

Killeen, G. F., Tatarsky, A., Diabate, A., Chaccour, C. J., Marshall, J. M., Okumu, F. O., Brunner, S., Newby, G., Williams, Y. A., Malone, D., Tusting, L. S., & Gosling, R. D. (2017). Developing an expanded vector control toolbox for malaria elimination. *BMJ Global Health*, *2*(2), 1–8.

Kirby, M. J., Ameh, D., Bottomley, C., Green, C., Jawara, M., Milligan, P. J., Snell, P. C., Conway, D. J., & Lindsay, S. W. (2009). Effect of two different house screening interventions on exposure to malaria vectors and on anaemia in children in The Gambia: A randomised controlled trial. *The Lancet*, *374*(9694), 998–1009.

Kirby, M. J., Bah, P., Jones, C. O. H., Kelly, A. H., Jasseh, M., & Lindsay, S. W. (2010). Social acceptability and durability of two different house screening interventions against exposure to malaria vectors, Plasmodium falciparum infection, and anemia in children in The Gambia, West Africa. *American Journal of Tropical Medicine and Hygiene*, *83*(5), 965–972.

Kirby, M. J., Green, C., Milligan, P. M., Sismanidis, C., Jasseh, M., Conway, D. J., & Lindsay, S. W. (2008). Risk factors for house-entry by malaria vectors in a rural town and satellite villages in the Gambia. *Malaria Journal*, *7*, 1–9.

Lindsay, S. W., Davies, M., Alabaster, G., Altamirano, H., Jatta, E., Jawara, M., Carrasco-Tenezaca, M., von Seidlein, L., Shenton, F. C., Tusting, L. S., Wilson, A. L., & Knudsen, J. (2021). Recommendations for building out mosquito-transmitted diseases in sub-Saharan Africa: The DELIVER mnemonic. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *376*(1818), 20190814.

Lindsay, S. W., Emerson, P. M., & Charlwood, J. D. (2002). Reducing malaria by mosquito-proofing houses. *Trends in Parasitology*, *18*(11), 510–514.

Liu, J., & Ong, H. Y. (2021). Can Malaysia's national affordable housing policy guarantee housing affordability of low-income households? *Sustainability (Switzerland)*, *13*(16). 8841

Lwetoijera, D. W., Kiware, S. S., Mageni, Z. D., Dongus, S., Harris, C., Devine, G. J., & Majambere, S. (2013). A need for better housing to further reduce indoor malaria transmission in areas with high bed net coverage. *Parasites & Vectors,* 6, 1-9.

Makungu, C., Stephen, S., Kumburu, S., Govella, N. J., Dongus, S., Hildon, Z. J. L., Killeen, G. F., & Jones, C. (2017). Informing new or improved vector control tools for reducing the malaria burden in Tanzania: A qualitative exploration of perceptions of mosquitoes and methods for their control among the residents of Dar es Salaam. *Malaria Journal*, *16*(1), 1–18.

Manrique-Saide, P., Herrera-Bojórquez, J., Villegas-Chim, J., Puerta-Guardo, H., Ayora-Talavera, G., Parra-Cardeña, M., Medina-

Barreiro, A., Ramírez-Medina, M., Chi-Ku, A., Trujillo-Peña, E., & Méndez-Vales, R.E. (2021). Protective effect of house screening against indoor Aedes aegypti in Mérida, Mexico: A cluster randomised controlled trial. *Tropical Medicine & International Health*, 26(12), 1677-1688.

Mapua, S. A., Finda, M. F., Nambunga, I. H., Msugupakulya, B. J., & Ukio, K. (2021). Addressing key gaps in implementation of mosquito larviciding to accelerate malaria vector control in southern Tanzania: Results of a stakeholder engagement process in local district councils. *Malaria Journal*, 20, 1–14.

Mathania, M. M., Kimera, S. I., & Silayo, R. S. (2016). Knowledge and awareness of malaria and mosquito biting behaviour in selected sites within Morogoro and Dodoma regions Tanzania. *Malaria Journal*, *15*(1), 1–9.

Mboera, L. E. G., Rumisha, S. F., Lyimo, E. P., Chiduo, M. G., Mangu, C. D., Mremi, I. R., Kumalija, C. J., Joachim, C., Kishamawe, C., Massawe, I. S., Matemba, L. E., Kimario, E., Bwana, V. M., & Mkwashapi, D. M. (2018). Cause-specific mortality patterns among hospital deaths in Tanzania, 2006-2015. *PLoS One*, *13*(10), e0205833.

Mburu, M. M., Juurlink, M., Spitzen, J., Moraga, P., Hiscox, A., Mzilahowa, T., Takken, W., & McCann, R. S. (2018). Impact of partially and fully closed eaves on house entry rates by mosquitoes. *Parasites & Vectors*, *11*(1), 1–9.

Mccann, R. S., Kabaghe, A. N., Moraga, P., Gowelo, S., Mburu, M. M., Tizifa, T., Chipeta, M. G., Nkhono, W., Pasquale, A. Di, Maire, N., Taylor, L. M., Mzilahowa, T., Berg, H. Van Den, Diggle, P. J., Terlouw, D. J., Takken, W., Vugt, M. Van, & Phiri, K. S. (2021). The effect of community - driven larval source management and house improvement on malaria transmission when added to the standard malaria control strategies in Malawi: a cluster - randomized controlled trial. *Malaria Journal*, 20, 1–16.

Mcleroy, K. R., Bibeau, D., Steckler, A., & Glanz, K. (1988). An Ecological Perspective on Health Promotion Programs. *Health Education Quarterly*, *15*(4), 351–377.

MoHCDGEC. (2018). *Supplementary Malaria Midterm Strategic Plan (2018 – 2020).* https://www.moh.go.tz/

Msugupakulya, B. J., Kaindoa, E. W., Ngowo, H. S., Kihonda, J. M., Kahamba, N. F., Msaky, D. S., Muhia, D. M., Tungu, P. K., & Okumu, F. O. (2020). Preferred resting surfaces of dominant malaria vectors inside different house types in rural south - eastern

Tanzania. *Malaria Journal*, 19(1), 1–15.

Mukiibi, S., & Machyo, J. N. (2021). Housing Transformation in Kampala, Uganda: Causes and Opportunities. *East African Journal of Environment and Natural Resources*, *3*(1), 1–7.

Musiime, A. K., Krezanoski, P. J., Smith, D. L., Kilama, M., Conrad, M. D., Otto, G., Kyagamba, P., Asiimwe, J., Rek, J., Nankabirwa, J. I., Arinaitwe, E., Akol, A. M., Kamya, M. R., Staedke, S. G., Drakeley, C., Bousema, T., Lindsay, S. W., Dorsey, G., & Tusting, L. S. (2022). House design and risk of malaria, acute respiratory infection and gastrointestinal illness in Uganda: A cohort study. *PLOS Global Public Health*, *2*(3), e0000063.

Nabassaga, T., Bah, E. H., & Faye, I. (2019). *Working Paper 312- Quality Homes for Sustainable Malaria Prevention in Africa*. (No. 2438). https://scholar.google.com/

National Agency for Research on Better Homes and Building Material. (2022). *Who we Are*. https://www.nhbra.go.tz/

NBS. (2018). *Tanzania Malaria Indicator Survey (TMIS) 2017: Dar es Salaam, Tanzania.* https://www.nbs.go.tz/

Nepal, M. (2007). *Financing Shelter for the Urban Poor.* https://scholar.google.com/

Nieto-Sanchez, C., Bates, B. R., Guerrero, D., Jimenez, S., Baus, E. G., Grietens, K. P., & Grijalva, M. J. (2019). Home improvement and system-based health promotion for sustainable prevention of chagas disease: A qualitative study. *PLoS Neglected Tropical Diseases*, *13*(6), 1–24.

Nugroho, P., & Kismartini, K. (2020). Policy Implementation of Poverty Alleviation through Unfeasible House Improvement Reside Known as (RTLH) Program in Central Java Province. In *Proceedings of the 4th International Conference on Indonesian Social and Political Enquiries*, *ICISPE 2019, 21-22 October 2019, Semarang, Central Java, Indonesia*.

NVIVO 12 Plus. (2015). *Powerful analysis tools for qualitative and mixed-methods research*. https://scholar.google.com/

Nyasa DC. (2022). *Community developent, social welfare and youth*. https://nyasadc.go.tz/

Nyumba, T., Wilson, K., Derrick, C. J., & Mukherjee, N. (2018). The use of focus group discussion methodology: Insights from two decades of application in conservation. *Methods in Ecology and Evolution*, *9*(1), 20–32.

Odufuwa, O. G., Ross, A., Mlacha, Y. P., Juma, O., Mmbaga, S., Msellemu, D., & Moore, S. (2020). Household factors associated with access to insecticide-treated nets and house modification in Bagamoyo and Ulanga districts, Tanzania. *Malaria Journal*, *19*(1), 1–13.

Okeyo, H. B. (2022). *The role of the manufacturing sector in economic diversification, jobs creation and industrialization of Kenya: Opportunities and Challenges in Fostering Export-led Industrialization*. https://unctad.org/

Okumu, F., & Finda, M. (2021). Key Characteristics of Residual Malaria Transmission in Two Districts in South-Eastern Tanzania-Implications for Improved Control. *The Journal of Infectious Diseases*, *223*(2), S143–S154.

Palacios, J., Eichholtz, P., Kok, N., & Aydin, E. (2021). The impact of housing conditions on health outcomes. *Real Estate Economics*, *49*(4), 1172–1200.

Pampana, E. (1969). *A textbook of malaria eradication* (2nd Ed.). Oxford Medical Publications.

Pandi-Perumal, S. R., Akhter, S., Zizi, F., Jean-Louis, G., Ramasubramanian, C., Edward Freeman, R., & Narasimhan, M. (2015). Project Stakeholder Management in the Clinical Research environment: how to do it right. *Frontiers in Psychiatry*, 6, 71.

R Development Core Team. (2011). *A Language and Environment for Statistical Computing*. https://scholar.google.com/

RollBack Malaria. (2016). *Housing and Malaria Consensus Statement*. https://endmalaria.org/

Russell, T. L., Govella, N. J., Azizi, S., Drakeley, C. J., Kachur, S. P., & Killeen, G. F. (2011). Increased proportions of outdoor feeding among residual malaria vector populations following increased use of insecticide-treated nets in rural Tanzania. *Malaria Journal,* 10(1), 1-10.

Sachs, J., & Malaney, P. (2002). The economic and social burden of malaria. *Nature*, *415(6872)*, 680–685.

Satterthwaite, D., Archer, D., Colenbrander, S., Dodman, D., Hardoy, J., Mitlin, D., & Patel, S. (2020). Building Resilience to Climate Change in Informal Settlements. *One Earth*, *2*(2), 143–156.

Shenton, F. C., Addissie, A., Alabaster, G., Baziwe, D., Carrasco Tenezaca, M., Chinula, D., Jatta, E., Jawara, M., Jones, R., Knudsen, J., Krystosik, A. R., McCann, R., Murima, N., Mutuku, F., Nguela, R. L., Nieto Sanchez, C., Nix, E., Okumu, F., Ruel-Bergeron, S., … Lindsay, S. W. (2022). Research agenda for preventing mosquito-transmitted diseases through improving the built environment in sub-Saharan Africa. *Cities and Health*, *6*(1), 72–80.

Snyman, K., Mwangwa, F., Bigira, V., Kapisi, J., Clark, T. D., Osterbauer, B., Greenhouse, B., Sturrock, H., Gosling, R., Liu, J., & Dorsey, G. (2015). Poor housing construction associated with increased malaria incidence in a cohort of young Ugandan children. *American Journal of Tropical Medicine and Hygiene*, *92*(6), 1207–1213.

Sommerfeld, J., & Kroeger, A. (2015). Innovative community-based vector control interventions for improved dengue and Chagas disease prevention in Latin America: Introduction to the special issue. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *109*(2), 85–88.

Sururi, A., Rusli, B., Widianingsih, I., & Ismanto, S. U. (2022). Housing Policy for Low-Income Communities in Indonesia and Its Reforms: An Overview. *Public Policy and Administration*, *21*(1), 158–174.

Tanzania Ministry of Energy & Minerals. (2007). *Rural Energy Agency*. https://rea.go.tz/

Tanzania Ministry of Health Community Development Gender Elderly and Children. (2016). *Nyumba ni Choo*. https://nyumbanichoo.com/

Tashakkori, A., & Teddlie, C. (2003). Major issues and controversies in the use of mixed methods in the social and behavioral sciences. *Handbook of Mixed Methods in Social and Behaviral Research,* 2003, 3-50. https://tinyurl.com/487caa3u

Tizifa, T. A., Gowelo, S., Kabaghe, A. N., McCann, R. S., Malenga, T., Nkhata, R. M., Kadama, A., Chapeta, Y., Takken, W., Phiri, K. S., van Vugt, M., van den Berg, H., & Manda-Taylor, L. (2022). Community-based house improvement for malaria control in southern Malawi: Stakeholder perceptions, experiences, and acceptability. *PLOS Global Public Health*, *2*(7), e0000627.

Tusting, L. S., Bisanzio, D., Alabaster, G., Cameron, E., Cibulskis, R., Davies, M., Flaxman, S., Gibson, H. S., Knudsen, J., Mbogo, C., Okumu, F. O., von Seidlein, L., Weiss, D. J., Lindsay, S. W., Gething, P. W., & Bhatt, S. (2019). Mapping changes in housing in sub-Saharan Africa from 2000 to 2015. *Nature*, *568*(7752), 391–394.

Tusting, L. S., Bottomley, C., Gibson, H., Kleinschmidt, I., Tatem, A. J., Lindsay, S. W., & Gething, P. W. (2017). Housing Improvements and Malaria Risk in Sub-Saharan Africa: A Multi-Country Analysis of Survey Data. *PLoS Medicine*, *14*(2), 1–15.

Tusting, L. S., Gething, P. W., Gibsoni, H. S., Greenwoodi, B., Knudseni, J., Lindsayi, S. W., & Bhattid, S. (2020). Housing and child health in sub-Saharan Africa: A cross-sectional analysis. *PLoS Medicine*, *17*(3), 1–18.

Tusting, L. S., Ippolito, M. M., Willey, B. A., Kleinschmidt, I., Dorsey, G., Gosling, R. D., & Lindsay, S. W. (2015). The evidence for improving housing to reduce malaria: A systematic review and meta-analysis. *Malaria Journal*, *14*(1), 1-12.

Tusting, L. S., Rek, J., Arinaitwe, E., Staedke, S. G., Kamya, M. R., Cano, J., Bottomley, C., Johnston, D., Dorsey, G., Lindsay, S. W., & Lines, J. (2016). Why is malaria associated with poverty ? Findings from a cohort study in rural Uganda. *Infectious Diseases of Poverty*, 5(04), 45-55

UNOPS. (2021). *Multisectoral Action Guide to End Malaria*. https://endmalaria.org/

URT. (2009). *The Standard Act Number. 2 of 2009*. https://www.ecolex.org/

URT. (2012). *The Public Health (Sanitation and Hygiene Practices) Regulations of 2012*. https://nsmis.moh.go.tz/

URT.(2009). *The Public Health Act Number 1 of 2009*. http://www.ilo.org/

Von Seidlein, L., Wood, H., Brittain, O. S., Tusting, L., Bednarz, A., Mshamu, S., Kahabuka, C., Deen, J., Bell, D., Lindsay, S. W., & Knudsen, J. (2019). Knowledge gaps in the construction of rural healthy homes: A research agenda for improved low-cost housing in hot-humid Africa. *PLoS Medicine*, *16*(10), 1–11.

Waleckx, E., Camara-mejia, J., Ramirez-sierra, M. J., Cruz-chan, V., & Rosado-vallado, M. (2015). An innovative ecohealth intervention for Chagas disease vector control in Yucatan, Mexico. *Transactions of the Royal Society of Tropical Medicine and*

Hygiene, 109(2),143–149.

Waleckx, E., Pérez-Carrillo, S., Chávez-Lazo, S., Pasos-Alquicira, R., Cámara-Heredia, M., Acuña-Lizama, J., Collí-Balám, F., Cámara-Mejía, J., Ramírez-Sierra, M. J., Cruz-Chan, V., Rosado-Vallado, M., Vázquez-Narvaez, S., Najera-Vázquez, R., Gourbière, S., & Dumonteil, E. (2018). Non-randomized controlled trial of the long-term efficacy of an Ecohealth intervention against Chagas disease in Yucatan, Mexico. *PLoS Neglected Tropical Diseases*, *12*(7), 1–15.

WHO-Factsheet. (2020). *Vector-Borne Diseases*. https://www.who.int/

WHO. (2005). *Health Service Planning and Policy Making A toolkit for Nurses and Midwives*. http://www.wpro.who.int/

WHO. (2018). *WHO Housing and Health Guidelines*. http://www.who.int/.

WHO. (2019). *Guidelines for Malaria Vector Control.* https://apps.who.int/

WHO. (2020). *Multisectoral Approach to the Prevention and Control of Vector-Borne Diseases: A Conceptual Framework.* https://scholar.google.com

WHO. (2021). *Promoting Healthy Housing for all: Towards an Implementation Strategy for the WHO Housing and Health Guidelines, Summary Report of the Housing and Health Expert Consultation.* Geneva, Switzerland.

WHO. (2022). *World Malaria Report, 2022*. https://scholar.google.com/

Wiebe, A., Longbottom, J., Gleave, K., Shearer, F. M., Sinka, M. E., Massey, N. C., Cameron, E., Bhatt, S., Gething, P. W., Hemingway, J., Smith, D. L., Coleman, M., & Moyes, C. L. (2017). Geographical distributions of African malaria vector sibling species and evidence for insecticide resistance. *Malaria Journal*, 16(1), 1–10.

Wilson, A. L., Courtenay, O., Kelly-Hope, L. A., Scott, T. W., Takken, W., Torr, S. J., & Lindsay, S. W. (2020). The importance of vector control for the control and elimination of vector-borne diseases. *PLoS Neglected Tropical Diseases,* 14(1), e0007831.

Wilson, A. L., Davies, M., & Lindsay, S. W. (2019). Revisiting an old idea: Engineering against vector-borne diseases in the domestic

environment. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *113*(2), 53–55.

APPENDICES

Appendix 1: A List of Key stakeholders and their roles for HI as malaria intervention

Stakeholders	**Roles in housing improvement**	Ref*
International Organizations Such as WHO and UN	1) Provide funding and technical assistance for HI projects for malaria control 2) Provide housing framework that's allows malaria endemic state/country to adapt or benchmarking in their state environment 3) Provide evidence-based guidance in the appropriate HI for malaria control and elimination 4) Set global priority areas including HI for donors and funders to allocate resources for diseases control	(RollBack-malaria, 2016)
Central government (Such as Ministry of Health, and Ministry of Housing)	1) Develop legislations, housing policies, guidelines and strategy that provide enabling environment for low-income community to build and improving housing to protect malaria transmitting vectors 2) Develop sustainable financing mechanism that enable provision of adequate, affordable and mosquito-proof houses for the poorest of the poor 3) Initiate program and schemes that aims to overcome poverty through assisting people to improve their house into habitable and improve environmental health 4) Provide grant, loans with low interest and subsides for building materials such as corrugate iron sheet and insect screen 5) Fund and implement HI projects/program for malaria control	(Liu & Ong, 2021; Nugroho, 2020; Sururi *et al.,* 2022)
Local government (Such as City,	1) Engage inhabitants living in an informal/rural settlement on	(Herrera- *et al.,* 2021;

Stakeholders	Roles in housing improvement	Ref*
Municipal, Town and District Councils)	housing improvement 2) Oversee healthy housing development programs in their areas of jurisdiction 3) Regulate places to build houses, cultivate crops or manufacture bricks for constructions	Satterthwaite *et al.,* 2020)
Community members/ Residents/Homeowners	1) Support housing improvement initiatives including housing designs that lower mosquito densities and temperatures 2) Allocate funds for turning their houses mosquito proofed 3) Proper use and maintenance of house screening and ensuring door are closed most of time 4) Provide bricks, mud, wood, nails and tools for house improvement 5) Participate in community-based program such as improving structural house condition and environmental cleanliness surrounding their houses 6) Contribute their practical social and cultural knowledge that make their houses habitable and supports health living 7) Separate human houses and animals' sheds	(Berg *et al.,* 2018; Castro-arroyave *et al.,* 2020; Finda e*t al.,* 2020; Jones *et al.,* 2022; Kaindoa *et al.,* 2018; Makungu *et al.,* 2017; Nieto-Sanchez *et al.,* 2019; Palacios *et al.,* 2021; Tizifa *et al.,* 2022)
Private sectors organizations (e.g Manufacturers, Material suppliers and constructions companies)	1) Prioritize use of locally available material and develop already made and ready to install mosquito nets on door, eaves and windows 2) Supply materials for building or modification of houses for malaria residents' health 3) Involved in the design and implementation of housing improvement projects for malaria control	(Mani Ram Singh Mahat, 2007; RollBack-malaria, 2016; Tizifa *et al.,* 2022; Waleckx *et al.,* 2015)

Stakeholders	Roles in housing improvement	Ref*
Environmental health practitioners /Public health Inspectors	1) Scrutinize house drawings for approval 2) Conduct house to house inspection for assessing and recommending essential housing improvement for population health 3) Participate to monitor and evaluate effectiveness of the houses for public health 4) Enforce public health related laws for promoting healthy housing attributes such as malaria-proofing, adequate ventilation, lighting, thermal comfortability, improved toilets and environmental cleanliness	(MoH, 2012; PHA, 2009)
Engineers/architects	1) Design, draw and or certify house structure in urban settings 2) Demonstrate methods and technics for improving houses such as walls and floor 3) Involved in the design and supervisory work during house constructions 4) Empower community housing design to reflect the environment	(Castro-arroyave *et al.,* 2020; Mukiibi & Machyo, 2021)
Community Development Officers	1) Enhance community participation and involvement in development issues including improved housing	(Nyasa DC, 2022)
Local constructors (Masonry, carpenters, plumbers)	1) Build blocks or bricks for housing constructions using soils or cement and sand 2) Design and build the local house structure and install roof 3) Furnish the houses which include; plastering, install ceiling, windows, doors, screening eaves and painting 4) Carry out community houses maintenance through repair	(Jatta *et al.,* 2018; Jawara *et al.,* 2018; Nepal, 2007; Mburu *et al.,* 2018; Mukiibi & Machyo, 2021; Sommerfeld & Kroeger,

Stakeholders	Roles in housing improvement	Ref*
	window screens, doors, unblock sewage and cover up holes in various parts of the houses	2015; Waleckx *et al.,* 2018)
Researchers/ Scientists	1) Investigate the efficacy of the house designs for malaria 2) Engage and disseminate house designs that is potential for malaria proofing to policy and decision maker, regulator, implementors and the community	(Castro-arroyave *et al.,* 2020)
Regulators	1) Formulate standards, and ensure production of quality of building materials 2) Provide technical support on housing construction and promote low-cost building materials in the country 3) Prepare guidelines and strategy which guide manufacturers, buyers, and housing constructors	(Finda *et al.,* 2020; NHBRA, 2022; Parliament, 2009)
Policy makers	1) Prepare an inclusive and relevant policies for housing which breaks barriers for housing improvement among stakeholders 2) Develop, monitor, evaluate and review implementation of housing policies, legislations, standards, guidelines, strategies and programs; 3) Provide interlinkages between ministries to initiate policy processes to improve national and local housing standards.	(Finda *et al.,* 2020; Herrera- *et al.,* 2021)
Housing Improvement committee	1) Carry house improvement activities including storing the materials used for improving houses such as insect screens, hammers, and measuring tapes 2) Lobby for and coordinating community participation in improving their houses at the household and village level 3) Distribute and monitor the insect screens, wire mesh to the	(Berg *et al.,* 2018; Tizifa *et al.,* 2022)

Stakeholders	Roles in housing improvement	Ref*
	needing houses	
Village leaders	1) Organize villagers to participate in housing improvement intervention, meetings, and contributing their local knowledge 2) Assist in the selection of ideal community health workers with qualities like literacy skills, leadership potential and level of motivation 3) Promote health in their communities by overseeing the implementation of house improvement 4) Keep the record of houses with different features such as eaves, windows, doors, wall type and roof type	(Berg *et al.,* 2018; Mburu *et al.,* 2018; Tizifa *et al.,* 2022)
Research/ academic institutions	1) Set priority on innovating low-cost technology for housing improvement for malaria control 2) Teach the concept of health housing to public health/environmental health/ entomologist, architects and design students	(Nepal, 2007; Shenton *et al.,* 2022)
Housing coordinators	1) Monitor and supports implementation of house improvement 2) Coordinate and building capacity to community health workers, village and sub-village leaders	(Berg *et al.,* 2018)
NMCP	1) Build capacity of lower cadre practitioners on malaria prevention and control interventions including housing improvement 2) Train hand on activities to artisans on specific improvement for malaria control 3) Recommend house improvement interventions to the communities as the malaria control tool	(Herrera- *et al.,* 2021; Jatta *et al.,* 2018)

Stakeholders	Roles in housing improvement	Ref*
	4) Provide interlinkages with other ministries to initiate policy processes to establish national and local housing standards 5) Assist other sectors in ensuring that health housing objectives are incorporated into their policies and programs.	
NGOs/Donors	1) Donate insect screens for covering poorest household's house 2) Facilitate malaria-proof house training, promotions, transport, and provide incentives to community workers 3) Solicit funds for the housing improvement, basic infrastructure for poor, and empower communities	(Berg *et al.,* 2018; Nepal, 2007)
Financial institutions	1) Provide better ways to reduce upfront cost of house screening 2) Introduce cost saving strategy for housing improvement 3) Provide funding and financial services to enhance low-income households upgrade or build better housing 4) Provide soft loans to disadvantage groups for housing improvement 5) Disburse housing loans to promote house modifications	(Nepal, 2007; Satterthwaite *et al.,* 2020; Waleckx *et al.,* 2018)
Politicians	1) Assist promotion of malaria-proof houses to citizens 2) Enact and pass legislation and by laws that aims to improving houses to the community 3) Assist transportation of materials for house improvement for poorest households in the villages	(Castro-arroyave *et al.,* 2020; Ferguson & Yates, 2016)

*Ref = references

Appendix 2: Structured Housing Survey and Observation Guide

1. GENERAL INFORMATION

1 Identification Information

1.1 Council name

☐Ifakara TC ☐Ulanga DC ☐Malinyi DC ☐Mlimba DC

1.1.1 Village name Ifakara TC

☐Kibaoni ☐Sululu ☐Mlabani ☐Ifakara Mjini ☐Mkamba ☐Mang'ula B

1.1.2 Village name Ulanga DC

☐Ebuyu ☐Mzelezi ☐Lupiro ☐IraguaMission ☐Igumbiro

1.1.3 Village name Malinyi DC

☐Itete ☐Mtimbira ☐Sofi Mission ☐Kalonga kelo

1.1.4 Village name Mlimba DC

☐Njagi ☐Merera ☐Mofu ☐Namawala

1.2 Area

1.3 Household representative

☐Father ☐Mother ☐Other

1.4 Other household representative

1.5 Age_____

1.6 Sex

☐Male ☐Female

1.7 Marital status

☐Never married ☐Married ☐Divorced/separated ☐Widow/widower

1.8 Highest educational level achieved

☐No formal education ☐Primary school ☐Secondary school ☐College (certificate/diploma) ☐University

1.9 Highest university level achieved

☐BSc/BA ☐MSc/MA/MPH/MBA ☐PhD ☐Other

1.10 Describe other_____

2. SOCIO-DEMOGRAPHIC INFORMATION

2.1. Income generating activities

☐Farming ☐Business ☐Fishing ☐Pastoralist ☐Formal employment ☐Other

2.3.1 Please specify formal employment_____

2.3.2 Please specify other_____

2.2. What is your average monthly income in Shillings? _____

2.3. Is the main source of water for domestic use?

☐Tap water at home ☐Tap water away from home ☐Well at home ☐Pump water at home ☐ Pump water away from home ☐Well away from home ☐Other

2.3.1 Specify other_____

2.4. What type of toilet is used at the household?

☐Indoor flush toilet ☐Outdoors flush toilet ☐Pit latrine ☐Ventilated Improved Latrine (VIP)
☐Bushes ☐Other

2.4.1 Specify other_____

2.5. What do you use for cooking at home?

☐Fire wood ☐Charcoal ☐Gas ☐Electricity ☐Other

2.5.1 Specify other_____

2.6. What is the main source of light at home?

☐Electricity ☐Solar lamps ☐Oil lamps ☐Candles ☐Rechargeable lights
☐Other

2.6.1 Specify other_____

2.7. Number of household occupants_____

2.8. Male children of 5 years and under_____

2.9. Female children of 5 years and under_____

2.10. Male children of between 5 - 15 years_____

2.11. Female children of between 5 - 15 years_____

2.12. Males above 15 years_____

2.13. Females above 15 years_____

3. INFORMATION ABOUT THE MAIN HOUSE

3.1 Wall type

☐Plastered bricks - inside and outside ☐Plastered bricks - inside only ☐Plastered bricks - outside only
☐Unplastered bricks ☐Mud ☐Wood/timber ☐Wood/sticks ☐
Other

3.1.1 Describe other wall types_____

3.2 Condition of the wall

☐A lot of small holes ☐A few small holes ☐A lot of large holes ☐A few large holes ☐No holes or cracks ☐Other

3.2.1 Describe other_____

3.3 Roof type

☐Metal ☐Thatched ☐Other

3.3.1 Describe other_____

3.4 Condition of the roof

☐A lot of small holes ☐A few small holes ☐A lot of large holes ☐A few large holes ☐No holes ☐Difficult to observe

3.5 How many windows does the house have? _____

3.6 What are windows covered with?

☐Wire mesh ☐Fine netting ☐Glass ☐Wood ☐Curtains/clothes ☐ Metal sheets ☐Cardboard ☐Bricks ☐Uncovered ☐Other

3.6.1 List others_____

3.7 How many windows covered with wire mesh?_____

3.8 How many windows covered with fine netting?_____

3.9 How many windows covered with glass?_____

3.10 How many windows covered with wood? _____

3.11 How many windows covered with curtains/clothes? _____

3.12 How many windows covered with metal sheets? _____

3.13 How many windows covered with cardboard? _____

3.14 How many windows covered with bricks? _____

3.15 How many windows uncovered? _____

3.16 How many windows covered with other? _____

3.17 Condition of the window covers

☐A lot of small holes ☐A few small holes ☐A lot of large holes ☐A few large holes ☐No holes or openings

3.17.1 How many window(s) with a lot of small holes ? _____

3.17.2 How many window(s) with a few small holes ? _____

3.17.3 How many window(s) with a lot of large holes? _____

3.17.4 How many window(s) with a few large holes? _____

3.22. Number of entry doors_____

3.18 What are entry doors covered with?

☐Wood ☐Grill ☐Netting screen ☐Glass ☐Curtains/clothes ☐Metal sheets ☐Cardboard ☐Bricks ☐Uncovered ☐Other

3.18.1 How many doors covered with wood? _____

3.18.2 How many doors covered with grill? _____

3.18.3 How many doors covered with netting screen? _____

3.18.4 How many doors covered with glass? _____

3.18.5 How many doors covered with curtains/clothes? _____

3.18.6 How many doors covered with metal sheets? _____

3.18.7 How many doors covered with cardboard? _____

3.18.8 How many doors covered with bricks? _____

3.18.9 How many doors uncovered? _____

3.18.10How many doors covered with other? _____

3.18.10.1 List others _____

3.19 Condition of the entry doors

☐A lot of holes/big opening ☐A few holes ☐Unscreened fanlight ☐Gap between floor and the door ☐No holes or openings

3.20 Eave space

☐Open eaves ☐Screened eaves ☐Closed eaves ☐Others

3.20.1 Describe others_____

3.20.2 Width of the open eaves (in cm) _____

3.21 Size (circumference) of the open eaves

☐Large - around the whole house (all sides) ☐Small - one side ☐Medium - about half of the house (2 - 3 sides)

3.22 Does the house have a ceiling?

☐Yes ☐No ☐Other

3.22.1 If other, please describe_____

3.23 Type of ceiling

☐Card board ☐Wood/timber ☐Gypsum ☐Nylon ☐Other

3.23.1 Please describe other type of ceiling

3.24 Condition of the ceiling

☐All intact - no holes or tearing ☐Partly intact - a few holes or tearings ☐Poor - a lot of holes or tearings ☐Other

3.24.1 Please specify other ceiling condition_____

3.25 Condition of the floor

☐Mud ☐Bricks ☐Plastered with cement ☐Tiled ☐Other

3.25.1 Describe other_____

3.26 Number of rooms in the main house_____

3.27 Number of rooms used for sleeping_____

4. PERIDOMESTIC SURROUNDINGS

4.1 Please observe a 10-meter radius around the house being observed and select everything you see

☐Water source ☐Animal shed ☐Trash pit ☐Toilet ☐Fence ☐Cooking place ☐ Other buildings ☐Vegetations ☐Farm ☐Other

4.1.1 Please, specify others_____

4.2 Types of animals

☐Cattle ☐Goat/sheep ☐Chicken/Duck ☐Pigs ☐Dog ☐Others

4.2.1 List other domestic animals_____

4.3 Type of water source

☐Tap ☐Pump ☐Well ☐Other

4.3.1 Describe other water source near the house _____

4.4 Structure of the cooking place

☐Open - no walls or roof ☐Partly open ☐Enclosed ☐Other

4.4.1 Please describe other structures of cooking places _____

4.5 Crops in the farm

☐Maize ☐Rice ☐Beans/legumes ☐Cassava ☐Vegetables ☐Others

4.5.1 Describe other crops grown in the farm _____

4.6 Types of vegetations

☐Trees ☐Shrubs ☐Grass ☐Vegetable garden ☐Other

4.6.1 Please describe other types of vegetations around the house_____

4.7 Types of toilets

☐Flush toilet ☐Pit latrine ☐Improved Pit Latrine (VIP) ☐Other

4.7.1 Please describe other things seen around the peri domestic setting_____

5. PERCEPTIONS ABOUT HOUSING IMPROVEMENT FOR MALARIA CONTROL

5.1 Do you think a house can provide protection against disease-transmitting mosquitoes?

☐Yes ☐No ☐I don't know

5.2 If yes, what kind of protection?

☐Prevent mosquitoes from getting indoors ☐Prevent mosquitoes from approaching the house ☐I don't know

☐Other

5.2.1 Describe others _____

5.3 How well does YOUR house provide protection against disease-transmitting mosquitoes?

5.4 ☐A lot of protection ☐Some protection ☐A little bit of protection ☐No protection

☐I don't know

5.5 Do you think your house needs any improvement to provide protection against disease transmitting mosquitoes?

☐Yes ☐No ☐I don't know

6. HOUSING IMPROVEMENT NEEDS

6.1 If yes what type of improvement?

☐Windows ☐Doors ☐Walls ☐Roof ☐Floor ☐Whole house

☐Other

6.1.1 What type of window improvement

☐Increase size ☐Decrease size ☐Add screen ☐Remove bricks ☐Add grill or wood frame ☐Repair screen ☐Add wood cover ☐Other

6.1.1.1 Please describe other window improvement_____

6.2 What type of door improvement

☐Increase size ☐Decrease size ☐Add screen ☐Remove bricks ☐Add grill or wood frame

☐Repair screen ☐Add glass cover ☐Add wood cover ☐Other

6.2.1 Please describe other door improvement_____

6.3 What type of wall improvement

☐Brick walls ☐Plaster walls ☐Paint walls ☐Repair holes on the walls

☐Add windows on the walls ☐Close eave spaces ☐Screen eave spaces ☐Others

6.3.1 Please describe others _____

6.4 What type of roof improvement

☐Change to metal roof ☐Repair holes on roof ☐Raise up the roof ☐Add ceiling

☐Repair ceiling ☐Others

6.4.1 Please describe others_____

6.5 What type of floor improvement

☐Level off or repair floor ☐Install cement or tiled floor ☐Raise up floor ☐Other

6.5.1 Please describe other floor improvement_____

6.6 How would you like to improve the whole house? _____

6.6.1 Please describe other improvements to the whole house

☐Rebuild the whole house ☐Increase house size ☐Add rooms ☐Add indoor kitchen

☐Add indoor toilets ☐Other

6.6.1.1 Describe others_____

6.7 Are you planning on improving your house to provide more protection against mosquitoes?

☐Yes ☐No ☐I don't know

6.8 If yes when are you planning to do this?

☐1 - 6 months ☐6 - 12 months ☐1 - 5 years ☐More than 5 years ☐I don't know

6.9 Are you facing or have you faced any challenges in improving your house to provide more protection against mosquitoes?

☐Yes ☐No ☐I don't know

6.10 If yes, what challenges?

☐High cost ☐Resource/material availability ☐Education/understanding ☐Time ☐Temporary settlements ☐Other priorities

6.10.1 Describe others_____

Appendix 3: Summary List of Potential Stakeholders for Housing Improvement

Stakeholders	Potential role
House owner	• Provide funds to improve house and make it habitable to support health living (malaria-free house)
Environmental Health Officer/Public Health Inspector	• Inspect and scrutinize building plans to examine compliance to health housing standards • Approve building plan and provide certificate of occupancy
Architects	• Draw and Design building plan to reflect the environment or satisfy the design need of clients (house owner)
Engineer	• Demonstrate and supervise construction activities • Adhere to approved building plans
Local carpenters	• Build and install windows, door, roof and ceilings • Adhere to the client's needs/recommendation
Local builders	• Construction or modify the house structure • Adhere to the client's needs/recommendation
Financial institutions	• Provide low interest loans for house improvement • Secure the disbursed loans for housing improvement
Building material supplier	• Provide building material for housing modification • Satisfy clients with the needed building materials
Regulatory authority	• Regulating the quality of building material • Promote locally building materials
Ministry of health	• Provide leadership with other ministries linked to housing issues to develop and disseminate health housing guidelines • Build capacity to government officials on housing improvement
Central government	• Strengthen legal and institutional frame work for health housing • Develop an inclusive health housing policy
Manufacturers	• Produce low-cost building materials that meets the clients demands

NMCP	• Promote and recommends essential house improvements need for malaria control • Build capacity on malaria-proof housing
NGOs	• Promote and aids implementation of malaria-proof housing for poor • Solicit fund for housing improvement
Politicians	• Enact housing laws that supports population health
Health Volunteers (CHW)	• Advocate malaria-proof houses in the community • Disseminate housing improvement messages/ Information
International Organizations	• Provide improved house framework for countries to adapt or customize based on their resources • Guide and aspire nations to prioritize house improvement intervention
Research institutions	• Investigate and recommend appropriate improvement needs for malaria control • Provide evidence on housing intervention for appropriate decision making
Residents	• Notify the house owner on the house improvement need • Reports complaints to authority on the house improvement need
Media (eg. Radio)	• Disseminate house improvement message for malaria control in the community
Village leaders	• Organize and mobilize community meetings for house improvement
Donors	• Provide housing improvement supports to the communities for malaria control
Ward Development Committee	• Discuss, develop and oversee implementation of housing improvement for malaria control
Village house committee	• Monitor and promote housing improvement practice in the community • Participate in the development and enforcement house interventions
Housing coordinators	• Coordinate and supports house improvement activities
Local government	• Oversee implementation of house improvement activities in the council • Promote social innovations for health through community engagement
Policy maker	• Influence development of housing legislations, Strategy, Guidelines and Protocol
Decision makers	• Approval implementation of housing improvement as malaria control tool

Veterinarian	• Recommend appropriate allocation of animal sheds
Sociologist/Anthropologist	• Participate in house improvement initiatives
Planners	• Plan and allocate places for human settlement
Community development Officers	• Support housing association which provides affordable housing to local people • Sensitize and capacitate citizens to plan and implement development activities including environmental cleanliness and construction of improved housing
Housing construction companies	• Land acquisition, design, and mobilization of construction resources like building materials, capital, and labor for the construction of housing

RESEARCH OUTPUTS

(i) Scientific Publication

Bofu, R. M., Santos, E. M., Msugupakulya, B. J., Kahamba, N. F., Swilla, J. D., Njalambaha, R., Kelly, A. H., Lezaun, J., Christofides, N., Okumu, F. O., & Finda, M. F. (2023). The needs and opportunities for housing improvement for malaria control in southern Tanzania. *Malaria Journal*, *22*(69), 1-15.

(ii) Poster presentation