Awareness and acceptance of alternative interventions for malaria control among stakeholders in Tanzania: a community engagement process

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Candidate declaration

I, **Marceline Francis Finda**, declare that this thesis is my own work and has not been submitted for any other degree or at any other university. All materials adopted from previously published work have been appropriately cited in this thesis.

1st October 2021

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Marceline Francis Finda **Date**

Dedication

This work is dedicated with love and gratitude to my beloved mama Joan Finda and babu Oliver Wilgress

I will forever be grateful for your love and support. May your gentle souls rest in eternal peace

Abstract

Background: Despite great progress made over the past decade, malaria continues to be a significant threat to human health globally, where more than three billion people are at risk of malaria. Current malaria vector control tools have contributed to significant declines in malaria burden over the recent decades, but these interventions are rapidly reaching their limits due to challenges with resistance to public health insecticides and antimalarial drugs, changes in mosquito behaviours and sub-optimal access and compliance to malaria control interventions. It is increasingly recognized that alternative interventions are needed to supplement the current interventions to speed up malaria control and elimination efforts. In order to ensure that new or alternative interventions are appropriate and effective, it is crucial that all key stakeholders are appropriately and adequately engaged. However, currently there is limited information on how alternative interventions may be perceived by the stakeholders, and limited information on the best strategies to engage the stakeholders in research and implementation of the interventions . My PhD aimed to explore and assess awareness and acceptance of alternative interventions for malaria control and elimination among key stakeholders in Tanzania, as a first step towards developing a stakeholder engagement model towards effective malaria control and elimination in Tanzania.

Aims: The overall aim of the PhD was to assess awareness and perceptions of the alternative interventions for malaria control and elimination among key stakeholders in Tanzania, and to explore opportunities for improving malaria control and elimination efforts through stakeholder engagement. It had the following specific objectives: To explore opinions of stakeholders on the need and potential of alternative interventions for malaria control in Tanzania; 2. To investigate community perceptions regarding genetically-modified mosquitoes (GMMs) and their potential for malaria control in Tanzanian villages; 3. To investigate key obstacles and opportunities relevant for effective rollout of larviciding for malaria control in southern Tanzania; and 4. To explore perceptions and recommendations for housing improvement for malaria control among in malaria endemic settings in southern Tanzania.

Methodology: An exploratory sequential mixed-methods approach was used, incorporating focus group discussions (FGD), key informant interviews (KII) and survey questionnaires. A series of FGDs were done with representatives of key stakeholder groups in the country to explore their views and opinions regarding the alternative technologies for malaria control. Preliminary findings from the FGD were used to develop a questionnaire to assess the baseline awareness and acceptance of the alternative among the stakeholders. Key informant interviews (KII) were conducted with district malaria control officials to explore their awareness, experiences and perceptions of larviciding as an alternative malaria control intervention in Morogoro region.

Key findings: The following key findings were observed in this study: (i) There was an overall agreement among stakeholders that the Tanzanian government has made great efforts in malaria control over the past couple of decades. There was also an overall agreement that the current interventions were not sufficient to help achieve malaria elimination by 2030. (ii) Larviciding was the most preferred alternative intervention to invest in by all stakeholder groups. However, its implementation was shadowed by a number of limitations including insufficient knowledge among the district and local implementers as well as inadequate funding, brought on by lack involvement of local organization in the implementation. (iii) Mosquito modification technology generated mixed views between the stakeholder groups. While community members, policy makers and regulators indicated varying degrees of support for this technology, research scientists expressed skepticism, question whether the country is ready for such an advanced technology. The concept of genetic modification was not new among the community members; they were able to draw similarities with their practices of cross-breeding domestic animals and using hybrid crop seeds. (iv) Housing improvement was the most understood and the most preferred alternative intervention among community members, who viewed it as the most sustainable intervention in eliminating malaria and many other infectious diseases. However, this intervention drew skepticism among policy makers, regulators and research scientists who questions its sustainability. (v) Effective stakeholder engagement was recommended as the most crucial determinant of success in malaria control and elimination efforts in Tanzania.

Conclusions: Different stakeholders preferred different interventions; however larviciding was overall the most accepted intervention. While implementation of larviciding has already commenced across the country, further research into this intervention revealed a number of gaps, which will need to be responded to for its success. Stakeholder engagement was recommended to be a crucial aspect in determining the success of the malaria control efforts in Tanzania. Effective stakeholder engagement is therefore an essential component in determining and implementing malaria control interventions. Stakeholders in this study propose engagement methods that build equal partnership with all key actors of malaria control including local public and private organizations, and not only improve knowledge of malaria transmission and its control among the key players, but also take into account the needs and preferences of the targeted communities. Further research is needed to determine stakeholder engagement models that can be effective in different malaria endemic settings. Likewise, additional research is needed to thoroughly explore the potential of the other preferred interventions, i.e. housing improvement and mosquito modification technology in malaria control and elimination in Tanzania.

Key words: Malaria control and elimination, alternative interventions, stakeholder engagement, housing improvement, larviciding, mosquito modification technologies.

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Original papers

The thesis is based on the following articles:

1. **Finda MF,** Christofides N, Lezaun J, Tarimo B, Chaki P, Kelly AH, Kapologwe N, Kazyoba P, Emidi B, Okumu FO. Opinions of key stakeholders on alternative interventions for malaria control and elimination in Tanzania. Malar J. 2020;1–13.

2. **Finda MF**, Okumu FO, Minja E, Njalambaha R, Mponzi W, Tarimo B, Chaki P, Lezaun J, Kelly AH, Christofides, N. Hybrid mosquitoes ? Evidence from rural Tanzania on how local communities conceptualize and respond to modi ed mosquitoes as a tool for malaria control. Malar J. BioMed Central; 2021; 20:1–20.

3. Mapua SA*, **Finda MF***, Nambunga IH, Msugupakulya BJ, Ukio Kusirye, Chaki PP, Tripet F, Kelly AH, Christofides N, Lezaun J, Okumu, FO. 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. Malar J. BioMed Central; 2021;20: 1–14.

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* These authors contributed equally to this work.

Conference proceedings

1. **Finda MF** et al. Awareness and perceptions of key stakeholder on alternative interventions for malaria control and elimination in Tanzania. June 2019. Anti-Vec; 2nd Annual meeting, London – UK:

2. **Finda MF** et al. Awareness and perceptions of key stakeholder on alternative interventions for malaria control and elimination in Tanzania. September 2019, Pan African Mosquito Control Association, Yaounde - Cameroon:

3. **Finda MF** et al. Opinions of key stakeholders on alternative interventions for malaria control and elimination in Tanzania. American Society for Tropical Medicine & Hygiene. November 2019, Maryland – USA

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List of abbreviation

ACT	Artemisinin Combination Therapy
CARTA	Consortium for Advanced Research Training in Africa
CDC	Centers for Disease Control
CHW	Community health workers
CI	Confidence Interval
DDT	Dichloro-diphenyl-trichloroethane
DNA	Deoxyribonucleic Acid
DSS	Demographic Surveillance System
FGD	Focus Group Discussions
GMM	Genetically modified mosquitoes
HDSS	Human Demographic Surveillance System
HLC	Human Landing Catch
IDI	In-depth interview
IHI	Ifakara Health Institute
IPTp	Intermittent Preventative Treatment in Pregnancy
IRB	Ifakara Review Board
IRS	Indoor Residual Spraying
ITNs	Insecticide treated nets
LLINs	Long Lasting Insecticide Treated Nets
LSM	Larval Source Management
MalERA	Malaria Eradication Research Agenda
MDA	Mass drug administration
MFP	Malaria focal persons
mRDT	Malaria rapid diagnostic test
NIMR	National Institute for Medical Research
NA	Not applicable
NGO	Non-governmental organizations
NMCP	National Malaria Control Program
ODK	Open Data Kit
OR	Odds ratio
PAMCA	Pan-African Mosquito Control Association
PCR	Polymerase Chain Reaction
RBM	Roll Back Malaria
RR	Relative Rates
SSA	Sub Saharan Africa
TMIS	Tanzania Malaria Indicators Survey
VSO	Vector surveillance officer
WHO	World Health Organization
WITS	University of the Witwatersrand

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Organization of the thesis

This doctoral thesis is submitted in a block format based on publications. It is organized into 9 chapters. Chapter 1 introduces the thesis by outlining the background information, existing gap and rationale for conducting this study. The general aim of the study is also presented in this chapter. Chapter 2 reviews the magnitude of malaria burden in sub Saharan Africa and Tanzania, and challenges that have made it difficult to achieve effective control and elimination. The chapter also reviews the alternative interventions that are explored in this study, and the necessity for stakeholder engagement in ensuring effective malaria control and elimination. The chapter also paints a picture of the key stakeholders selected, and presents conceptual framework used to guide this study.

In Chapter 3, the methods chapter, methodological approaches that were used to conduct each of the sub-studies as well as the measurement of different variable constructs are presented. Over-arching data analysis strategies used to meet each of the study objectives are also outlined. Chapters 4, 5, 6 and 7 are "results chapters". Each chapter follows a format of a journal article and provides background of the work, presentation of methods, findings and concluded by a discussion of findings. These articles were written with supervisors playing the role of co-authors, therefore in each paper, the contribution of all individuals is acknowledged. Papers presented in chapters 4-6 are published and the manuscript presented in chapter 7 is in a publishable format but has not been submitted to a journal yet. Chapter 8 is a discussion and conclusion chapter, which discusses overall picture emerging from the thesis, integrating results from all results chapters as well as conceptual framework. Key messages from the entire study as well as limitations are also summarized in this chapter. This chapter also concludes the thesis and offers recommendations for future studies. Finally, chapter 9 provides a list of all the references used in the entire thesis.

Author contributions

Author	**Contribution**	**Chapters**
Marceline Francis Finda	Study design, proposal writing, data collection, analyses, manuscript writing, thesis writing	All
Nicola Christofides	Study design & overall supervision	All
Javier Lezaun	Study design & overall supervision	All
Ann H. Kelly	Study design & supervision	All
Winnfrida Mponzi	Data collection & manuscript review	5
Elihaika Minja	Data collection & manuscript review	5
Rukiyah Njalambaha	Data collection & manuscript review	5
Brian Tarimo	Data collection & manuscript review	4 & 5
Prosper Chaki	Data collection & manuscript review	4, 5 & 6
Paul Kazyoba	Data collection & manuscript review	4
Ntuli Kapologwe	Data collection & manuscript review	4
Basiliana Emidi	Data collection & manuscript review	4
Salum Abdallah Mapua	Data collection, manuscript writing	6
Ismail H. Nambunga	Data collection & manuscript review	6
Betwel J. Msugupakulya	Data collection & manuscript review	6
Ukio Kusirye	Data collection & manuscript review	6
Frederic Tripet	Data collection & manuscript review	6

Chapter 1: Introduction

Despite great progress made over the past decade, malaria continues to be a significant threat to human health globally, where more than three billion people are at risk of malaria (1). In 2019 alone, there were 229 million malaria cases and 409, 000 deaths globally, 94% of which were in sub-Saharan Africa (SSA) (1). Current malaria vector control tools, mainly insecticide-treated nets (ITNs) and indoor residual spraying (IRS) have massively contributed to the recent reductions in malaria burden (1,2). However, these interventions are rapidly reaching their limits. Challenges such as insecticide resistance to the pyrethroids commonly used for vector control, as well as behavioral resistance observed in mosquitoes are increasingly defying the progress that has been made thus far (3–7). Other challenges include emergence of resistance to antimalarial drugs (8–10), inadequate access to malaria control services for most at-risk and hard to reach populations such as mobile and migratory populations (11,12) and suboptimal compliance to malaria control interventions (13,14).

Malaria control efforts in Tanzania reduced malaria incidence by nearly 50% between 2008 and 2017 (15,16). Major contributors to this decline included mass coverage with ITNs IRS (17–21), improved malaria diagnosis and case management (22), intermittent preventive treatment for pregnant women (23) and overall improvements in livelihoods. However, malaria is still one of the leading causes of morbidity and mortality in Tanzania. In 2019 there were more than 6 million estimated malaria cases and more than 20 thousand deaths in Tanzania, more than two thirds being children under 5 years (1). Like in most other malaria endemic settings in the world, malaria control efforts are becoming increasingly compromised by widespread mosquito resistance to insecticides (3,24), changes in mosquito behaviors (25,26), high cost of malaria control interventions and low compliance among users (27) among other challenges.

In 2018, Tanzania's National Malaria Control Program (NMCP) set a goal to reduce the country's malaria prevalence to below 1% by 2030 (28). To achieve this ambitious goal the country set a strategy to ensure universal coverage of vector control interventions, further improvements in malaria diagnosis and case management, and a roll-out of novel complementary interventions for malaria vector control (28). Several complementary interventions are being considered to speed up malaria control efforts. In this study six complementary interventions were considered including larval source management (29,30), insecticide-spraying of mosquito swarms (31–33), genetically-modified mosquitoes (GMMs) (34–36), housing improvement (37–39), spatial repellents (40,41) and mass drug administration (MDA) with endectocides such as ivermectin (42,43). Many of these interventions are not new in disease-vector control, but for others, there is inadequate evidence of effectiveness, costs, regulatory requirements and level of acceptance by key stakeholders. To ensure that they meet user needs and are sustainable, it is crucial to consider the views and opinions of the key stakeholders at local, regional and national levels.

Early-on and effective stakeholder engagement is one of the most crucial determinants of success of novel malaria control interventions as it paves the way for smooth acceptance and implementation of the interventions within the targeted settings (44,45). Early stakeholder engagements provides the researchers with an opportunity to not only educate stakeholders about prospectives of the interventions, but also to take into account recommendations on how the interventions could best serve the needs of the targeted communities (46–48). However, stakeholder engagement needs to be preceded by an assessment of the knowledge gap and preformed perceptions in order to share quality information, to provide the stakeholders with adequate and appropriate information (44,47).

Chapter 2: Literature review

2.1: Burden of malaria in sub-Saharan Africa

Africa carries the vast majority of the global malaria burden. In 2019 alone there were 215 million malaria cases and 384 thousand deaths in SSA, accounting for 94% of the global malaria cases and deaths (1). Children under 5 years of age accounted for two thirds of the cases and deaths (1). But effects of malaria in SSA go far beyond the measures of morbidity and mortality; malaria is closely associated with poverty both at the individual and country level (1,49–51). More than 90% of malaria transmission is concentrated in some of the world's poorest countries (1,51), and within those the majority of the burden is shouldered by the poorest communities, those least able to afford preventive measures or medical treatment (38,50,52). Estimated cost of malaria control and treatment is significantly higher than the malaria endemic countries can afford, leaving them dependable to international aid (1). In 2019 a total of US$3.0 billion was used for malaria control and elimination globally. Nearly 70% of this funding came from international funders, with local governments contributing just 30% of the cost (1). The economic burden of malaria is also taking a toll on governments and families. In 2016 alone more than 2.6 billion USD was spent on malaria control and treatment in SSA (53). SSA governments contributed to 26.3% of the total cost, while households and families contributed 18.1% of the cost, and foreign aid gave 53.1% of the overall cost (53).

2.2: Burden of malaria in Tanzania

Tanzania is also one of top 10 countries with the highest burden of malaria globally (1), with more than 90% of the country's population living in malaria endemic zones (16). In 2016 alone, malaria was estimated to have consumed 193.6 million USD; 64.2% of this was obtained through international aid, 28.2% was borne by the Tanzanian government and 7.1% by households and families (53). Malaria transmission has been historically transmitted by members from the *Anopheles gambiae* complex, mainly *Anopheles gambiae s.s.* and *Anopheles arabiensis*, but recent studies are showing an increasing significance of *Anopheles funestus* in transmitting malaria infections in some parts of the country (26,52,54).

The past decade has seen a great overall success in the management of malaria (Figure 2.1). Malaria prevalence among children below 6 years has gone down by more than 50% over the past decade, from 14% in 2008 to 7.3% in 2017 (16,55). The country has attempted a great deal of efforts to control malaria over the past two decades. In the early 2000s the government started with interventions such as social marketing of ITNs, intermittent preventive treatment in pregnancy (IPTp), and a national voucher scheme to provide all pregnant women and young children with bed nets (22). These efforts lowered malaria prevalence from 18% in 2004 to 14% in 2008 (15,22). In late 2000s distribution of bed nets was expanded to cover all households in high transmission settings and IRS was implemented in some regions (22). Additionally, malaria rapid diagnostic tests (mRDTs) and Artemisinin-based combination therapy (ACT) were introduced as more affordable and effective diagnosis and treatment methods (22). These efforts further lowered malaria prevalence to 9% in 2012 (55). Signs of mosquitoes' resistance to insecticides used in ITNs and IRS and changes in mosquito behaviours started to emerge in early 2010s (22,25), causing an upsurge of malaria prevalence to 14% in 2016 (56). However, a separate survey in 2018 did show malaria prevalence to have dropped down to 7.3% in 2017 (16).

Following recommendations in the WHO's Global Technical Strategy for Malaria, to reduce malaria incidence and mortality by 90% worldwide by 2030 (57), Tanzania's national malaria control program (NMCP) put together a strategic plan to further reduce malaria prevalence to below 1% in the country (28). To achieve this ambitious goal the country set a strategy to improve coverage and effectiveness of current vector control interventions, improve malaria diagnosis and case management, and roll-out of novel complementary interventions where there is sufficient local evidence for impact (28).

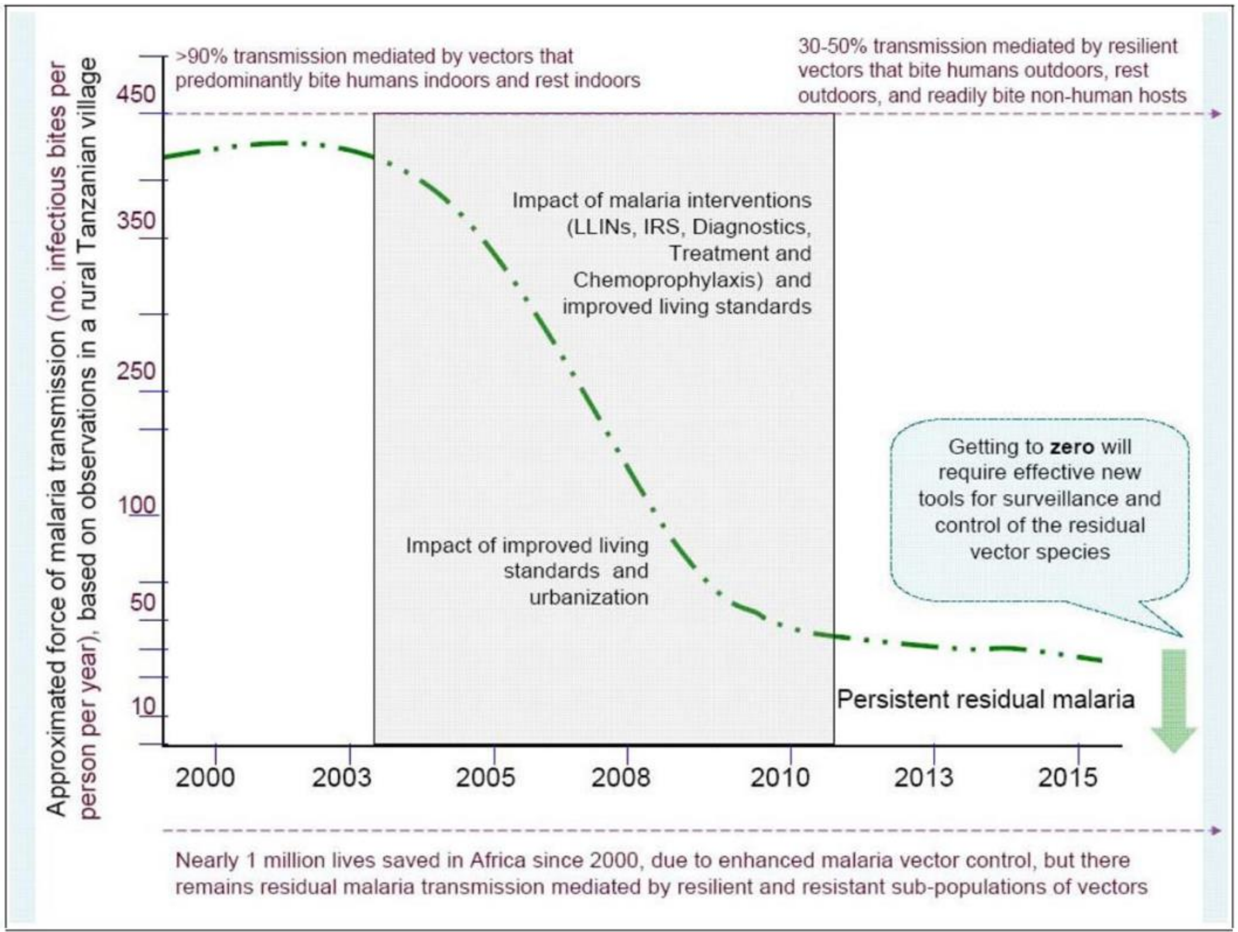

Figure 2.1: Diagrammatic representation of progress made against malaria over the past decade. Approximate values are based on observations in the Kilombero Valley

2.3: Need for alternative interventions for malaria vector control

In line with the NMCP's strategies, several novel alternative interventions have proven to have a potential for consideration to help with malaria control and elimination efforts in Tanzania. The main one is larval source management (LSM) (29,30). However, there are also several new technologies being evaluated by scientists, which could play a part in future control strategies in Tanzania and beyond. These may include: insecticide-spraying of mosquito swarms (31–33), mosquito modification technologies (34–36), housing improvement (37–39), spatial repellents (40,41) and novel pharmaceutical interventions, including mass drug administration with endectocides (e.g. ivermectin) (42,43). Many of these interventions have proven effective in control of disease vectors in different settings across the world, but many lack adequate evidence of effectiveness, sustainability and suitability for malaria control in SSA and more specifically, in Tanzania.

2.3.1: Larval Source Management

Larval source management includes the use of larvicides as well as environmental management to destroy mosquitoes' larval habitats (29,58,59). While strong evidence on effectiveness of this intervention for malaria control is lacking, some field trials have demonstrated significant reduction in malaria burden and entomological indicators (58). Mathematical modelers have also predicted that, when appropriately and continuously used, LSM can significantly reduce both indoor and outdoor mosquito density and can possibly lead to elimination of malaria vectors (60). A large scale coverage of larviciding resulted in Dar es Salaam resulted in 21% reduction in malaria prevalence between 2006 and 2008 (61). In efforts to speed up the malaria elimination agenda, since 2017, the Tanzanian government has invested in a large scale manufacturing and distribution of biolarvicides *Bacillus thuringiensis var. israelensis* (Bti) and *Bacillus sphaericus* (Bs) in rural and urban settings across the country (28,62).

2.3.2: Insecticide-spraying of mosquito swarms

Space spraying is the process of dispersing liquid droplets of insecticides into an area, either on the ground or in the air (63,64). While in the past it has been considered rather expensive, recent advances in the understanding of mosquito mating behaviours has resulted in more efficient targeting of flying mosquitoes. Recent studies in Burkina Faso and Tanzania have indicated that, with adequate training, mosquito swarms can be located and targeted by community members (31–33). These swarms were observed to occur at approximately the same time, usually at sunset, the same locations and same length of time throughout the year (31–33). These studies have shown that community-based targeting of *Anopheles* mosquito swarms may provide an effective, affordable and environmentally friendly intervention for the control of mosquitoes outdoors (31–33).

2.3.3. Mosquito modification technologies

Mosquito modification technologies involve alteration of mosquito genes or physiology to reduce their competencies in diseases transmission (34–36). The modified mosquitoes are released in the environment so that they can mate with wild mosquitoes, and either limit their reproductive capacity or disseminate traits that make local vectors refractory to pathogen transmission (34–36). Technologies such as Sterile Insect-technic (SIT) (65), the

Release of Insects carrying a Dominant Lethal gene (RIDL) (66), gene-drive technologies (34,35,67–69) and mosquitoes infected with *Wolbachia* bacteria and other endosymbionts (70–72) are getting increased public interest as novel complementary tools for malaria control and elimination, particularly in SSA (73–76). These technologies are not all new, but research into their potential for malaria control and elimination has significantly increased in the recent decades (35,77).

2.3.3.1. Sterile Insect Technique

Sterile Insect Technique is a mosquito modification technology that involves sterilization of male mosquitoes, either by radiation or using chemosterilants (78–80). The sterilized mosquitoes are released repeatedly to increase their chances of mating with wild female mosquitoes, resulting in unviable eggs (78–80). This method of vector control is species specific, and provides an environmentally friendly alternative to insecticides but is rather expensive, especially for the low income countries like Tanzania. Since each release of modified mosquitoes ends up with viable offspring, this technology does require multiple releases before its potential is observed (79,80).

2.3.3.2. Release of Insects carrying a Dominant Lethal Gene

This technique involves inserting a self-limiting gene into mosquitoes' DNA, preventing them from surviving into adulthood (81–83). In the laboratory mosquitoes are reared in environment that protects them against the lethal genetic system (such as under environments containing specific antibiotics), but when released in the wild to mate with wild mosquitoes, modified mosquitoes pass on the lethal gene to their offspring, preventing them from surviving into adulthood (65). Like SIT, RIDL is species-specific. This technology has been successfully used in countries like Brazil, Malaysia and Cayman islands to suppress population of *Aedes aegypti* (84), and its efficacy in controlling malaria-transmitting *Anopheles* mosquitoes is currently being investigated.

2.3.3.3. Gene drives

Gene drive is another genetic modification technique that enhances likelihood of the modified genes to be inherited, ensuring their quick spread through the population (35,77,81). This novel technology is self-sustaining and can be relatively sustainable compared to other mosquito modification technologies. Gene drive technology takes two main approaches for disease-vector control, which are population suppression approach and population replacement approach (35,77,81). Population suppression approach involves introduction of a gene that interferes with the vector's reproduction system by either distorting sex chromosome and influence the sex of the chromosome, for example so that all offspring are males, or by distorting female fertility genes such that they are infertile (35,77,81). Both of these options can result in suppression of the wild mosquito population over several generations (35,85). Population replacement approach involves introducing gene constructs to reduce vector's ability to transmit pathogens, for example modifying mosquitoes so that they are unable to carry the malaria parasite. These gene forms can spread in the wild population and transforming it into harmless mosquitoes (35,85).

2.3.3.4. Wolbachia-carrying mosquitoes

Wolbachia is a gram-negative bacterium that is naturally present in up to 60% of insects (86,87). It is vertically transmitted; *Wolbachia*-carrying females can successfully mate with infected or uninfected males and have healthy but *Wolbachia*-carrying offspring. On the other hand, when uninfected female mates with an infected male, the resultant offspring do not hatch (88,89). This mechanism therefore allows for a spread of the bacteria in the population through *Wolbachia*-carrying females (90). Various *Wolbachia* strains have been found to protect mosquitoes from viral infections; naturally occurring protect *Aedes albopictus* against Dengue virus (91). Artificially infected *Aedes aegypti* have also displayed a greatly reduced DENV transmission (70), and this technology has been used to successfully transform populations of disease-transmitting *Ae. aegypti* in Australia (92–94), Brazil (95,96) and Indonesia (97). In malaria control, recent reports have indicated natural Wolbachia infections in *Anopheles gambiae* s.l., one of the leading malaria vectors across SSA (98–102), and have been associated with reduced *Plasmodium falciparum* infection in the mosquitoes (90,98,103). These remarkable findings open up possibilities for the application of *Wolbachia* in malaria control. However, most *Wolbachia*-based techniques are mostly for *Aedes*, and that we do not currently have any viable *Wolbachia* based approach for malaria mosquitoes.

2.3.4. Housing improvement

Housing improvement such as screening windows and doors is one of the oldest reported malaria control interventions in world, and is linked to malaria elimination in different parts of Europe and America (104,105). In SSA, recent studies have indicated that modest improvements in house quality are associated with decreased mosquito density and decreased malaria incidence (38,50,106,107). Children living in improved houses made with brick walls, metal roof and closed eave space had lower odds of being infected with malaria compared to those living in unimproved houses made with mud walls and thatched roof across SSA (38,106,107). Other studies have also indicated lower densities of malaria vectors in improved houses compared to unimproved houses (52,108,109). Acceptance of several housing improvement interventions have also shown to be high in Tanzania, Ethiopia and The Gambia (85).

2.3.5. Spatial repellents

Spatial repellents (SP) are chemicals that work in vapor phase to prevent biting by blood-seeking insects, such as mosquitoes (40). They work by preventing host-seeking mosquitoes from entering targeted areas, limiting contact between humans and mosquitoes (40). Common active ingredients in spatial repellents include citronella, transfluthrin and metofluthrin (40,110,111). Some of these actives, such as transfluthrin also have significant toxicity to mosquitoes, thus result in high levels of mosquito mortality (112). They can be delivered in different formats, such as mosquito coils, repellent-treated clothing, oil lamps and eave ribbons (40,41,112,113). This technology is especially useful in providing protection against outdoor-biting mosquitoes (114) and among migratory communities (115).

2.3.6. Mass drug administration with endectocides

Endectocides such as ivermectin are drugs with endoparasitocidal as well as ectoparasitocidal effects (42); they are commonly used to control nematodes in humans and other vertebrates. Ivermectin, for example, has been extensively used in mass campaigns for elimination of neglected tropical diseases such as lymphatic filariasis and onchocerciasis in Tanzania (116,117). Over the recent years ivermectin has been increasing in popularity as a malaria control tool; it has been found to be toxic to mosquitoes when they take blood meal from hosts that have recently received these drugs (43,118,119). *Anopheles* species in particular have been found to be highly susceptible to ivermectin (43,120–122). Additionally, sub-lethal concentration of ivermectin in blood has also been found to reduce female mosquitoes' fecundity and survival of their larvae(43,121,122). MDA with ivermectin offers a novel and relatively easy means of targeting host seeking mosquitoes. Since ivermectin is routinely given to both humans and livestock as an antihelminthic drug, it is a novel way of targeting both anthrophagic and zoophagic mosquitoes. A large trial funded by UNITAID is currently ongoing in Tanzania and Mozambique to assess the epidemiological, entomological and economic impact of mass distribution of ivermectin to humans and animals (123).

2.4. The need to engage stakeholders

The need to involve community members and engage stakeholders has historically been a constant in malaria control and elimination efforts (69,124,125). This is the foundational principle that drives and justifies social scientific research within malaria control programs. Malaria transmission is dynamic across different settings, hence the social factors driving transmission and morbidity, and the needs and experiences of the affected communities vary greatly across local contexts. To ensure that potential alternative interventions for malaria control meet user needs and are sustainable, it is crucial to consider, early on in their development, the views and opinions of the key stakeholders (124). Stakeholder engagement is also necessary in ensuring a country or community buy-in of the novel interventions for malaria control (124,126).

Stakeholder engagement is much more than just providing education or raising awareness; it is an iterative process, focusing on a series of communications, deliberation and reflection, aiming to build relationships and empower the stakeholders (69,76,127). According to Scheufele (2013), stakeholder engagement needs to go beyond merely explaining scientific technologies to lay audiences (46), as different people may interpret the information differently based on their culture, values, experiences and interests (46,48). Stakeholder engagement also needs to go beyond just informing or consulting with the stakeholders; it needs build partnership between researchers and the community in order to occupy the attention or efforts of the community (44,46,48). WHO recommends that stakeholder engagement be conducted throughout the development, research and implementation of a project (69,75).

There are recent examples of such stakeholder engagement in malaria control across the world, such as the use of community knowledge to target areas with high densities of malaria vectors in Tanzania (128), the use of community volunteers to identify and spray *Anopheles* swarms with insecticides in Tanzania and Burkina Faso (31,129), community-based LSM in Tanzania and Malawi (130,131) and the involvement of communities in the release and monitoring the progress of Wolbachia-infected mosquitoes in Brazil (132).

While the need for effective stakeholder engagement in disease-vector control is clear, there is an urgent need of guidance on what proper stakeholder engagement is, or guidance on how to achieve adequate engagement with regards to novel technologies for malaria control, particularly in SSA settings (47,133,134). Several reports of outcomes of inadequate stakeholder engagements in malaria control are available, including initial failure of bed net distribution in Kenya (135), resistance towards releases of genetically modified mosquitoes in Key Wes Florida (136), and failures in releases of genetically modified mosquitoes in Cayman islands (44). Recent studies have recommended that stakeholder engagement needs to begin at the onset of a project and continue throughout the lifetime of a project on an ongoing and incremental basis, focusing on different areas of technology at different stages along the project timeline (47). The source of the information and manner of communication with stakeholders are also critical, especially for interventions that are relatively newer to the stakeholder (45). This stresses the need for scientists to work with community and communication experts to formulate and deliver not only accurate but also culture-sensitive and understandable engagement messages to the public (45).

2.5. Rationale of the study

Currently, there is limited evidence on the awareness, and attitude of stakeholders regarding the alternative technologies for malaria control and elimination in SSA, and particularly in Tanzania. There is limited literature that provides information on how these technologies are perceived by stakeholders in malaria endemic settings. There is also limited information on the best strategies to engage stakeholders in the development and implementation of these alternative technologies. Furthermore, there is a lack of clear guidelines on policies, regulations and ethical considerations necessary for implementing these technologies.

This study therefore explored and assessed awareness and perceptions of alternative novel interventions for malaria control among key stakeholders in Tanzania, as a first step towards developing a stakeholder engagement model towards effective malaria control and elimination in Tanzania. For some of the technologies such as genetically modified mosquitoes, which have not previously been tested locally, this study aimed to explore how local communities in malaria endemic settings would respond to these technologies when rolled out for testing or use. This study will help advance the methodological tool-kit for the social science of malaria control, and help in future development of guidelines for effective stakeholder engagement in malaria control and elimination in SSA. This study looked across a number of proposed alternative interventions for malaria control, and looked across several stakeholder groups. This provides an opportunity to weigh-in perceived benefits and risks of various interventions across the stakeholder groups, and provides an opportunity for developing adequate and appropriate stakeholder engagement models.

2.6. Conceptual Framework: Diffusion of innovation theory

Everet Rogers' diffusion of innovation theory (137) was used to guide this study. This theory explains how new innovations are adopted among the intended audience. The theory elaborates that there are five attributes that can determine the adoption of an innovation including relative advantage, observability, compatibility, complexity and triability (Figure 2.2) (137). Rogers explains relative advantage as the degree to which an innovation is perceived to be more beneficial than the situation it supersedes (137,138). In this study we compared the relative advantage of the alternative interventions for malaria control to the currently available tools. Compatibility is defined as the degree to which an innovation fits within needs, values and experiences of the target audience (137,138). In this study we took into account the stakeholders' experiences with burden and severity of malaria transmission when assessing their perceptions of the alternative interventions. Rogers refers to c*omplexity* as the degree to which an innovation is perceived as difficult to understand and use, proposing that the simpler the innovation is perceived the better the chances of adoption (137,138). We assessed the stakeholders' perceptions of the feasibility and availability of the alternative interventions. Triability is defined as the degree to which an innovation can be experimented with on a limited basis (137,138). This refers to the perceived ability of the target audience to have an input in the innovation, and in this study, we explored and assessed the stakeholders' perceptions of their involvement in the research and implementation of the alternative interventions for malaria control and elimination. Last but not least, *observability* is the degree to which the results of an innovation are visible to the target audience (137,138). In this study we explored and assessed stakeholders' perceptions on how efficacy and effectiveness of the alternative interventions should be determined.

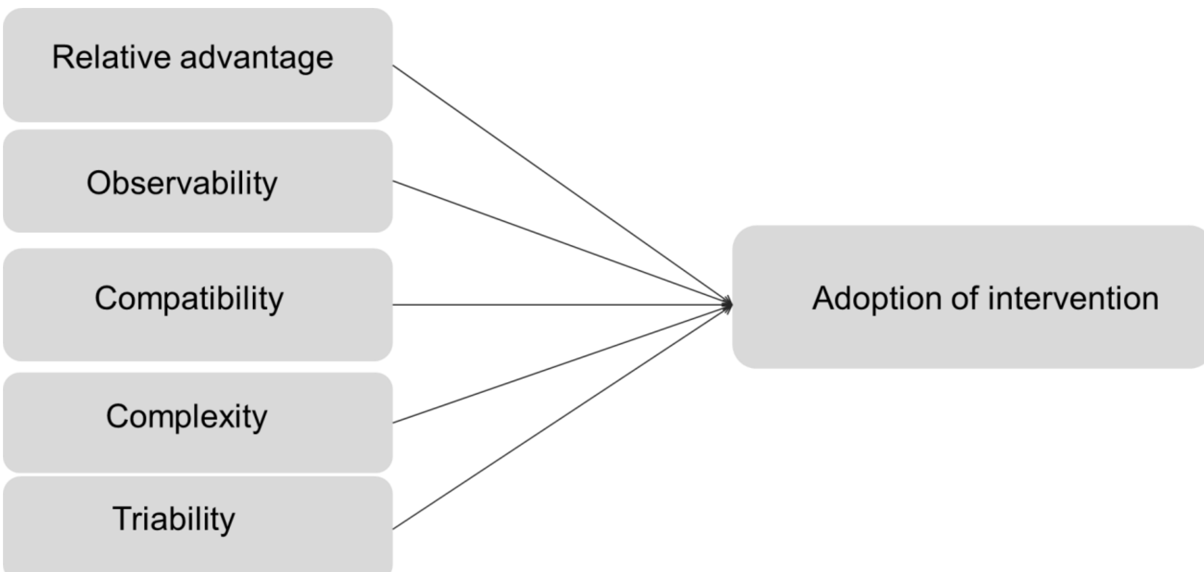

Figure 2.2: Factors influencing adoption of an innovation according to Evert Rogers (137)

2.7. Exploratory sequential mixed methods approach

Mixed methods study approach is increasingly being recognized as essential in conducting public health research (139,140). This study used exploratory sequential mixed methods study approach (141,142) as recommended by Cresswell to explore and assess awareness and perceptions of alternative interventions for malaria control and elimination in Tanzania. This study design is recommended when the variables under investigation are unknown, or when there is no guiding framework for the study (143), as was the case for our study; a majority of the alternative interventions for malaria control and elimination were novel, and some while not new altogether, had not yet been implemented in the country or in the communities in the study area. Cresswell proposes that the qualitative component be conducted first to explore the phenomena under investigation, and the information obtained is then used to develop the quantitative questions (141–143). Detailed description of how this approach was used is provided in chapter 3.

2.8. Aim and objectives

2.8.1. Aim

The overall aim of my PhD was to assess awareness and perceptions of the alternative interventions for malaria control and elimination among key stakeholders in Tanzania, and to explore opportunities for improving malaria control and elimination efforts through stakeholder engagement.

2.8.2. Specific objectives

Specific objectives of this study included:

1. To explore opinions of stakeholders on the need and potential of alternative interventions for malaria control in Tanzania
2. To investigate community perceptions regarding genetically-modified mosquitoes (GMMs) and their potential for malaria control in Tanzanian villages
3. To investigate key obstacles and opportunities relevant for effective rollout of larviciding for malaria control in southern Tanzania.
4. To explore perceptions and recommendations for housing improvement for malaria control among community members in malaria endemic settings in southern Tanzania.

Chapter 3. Methodology

3.1: Study site and participants

This study was done in Tanzania. Key stakeholder groups selected included policy makers, regulators, research scientists, district malaria control officials and community members. These stakeholders are spread across the country, except for community members, who were sampled from ten randomly selected villages in two districts (Ulanga and Kilombero) in the Kilombero Valley in south-eastern Tanzania. Ulanga and Kilombero districts were purposively selected due to their malaria endemicity and proximity to Ifakara Health Institute. District malaria control officials were selected from nine districts in Morogoro region in southern Tanzania (Figure 3.1). Detailed description of the study participants is provided in section 3.3.1.

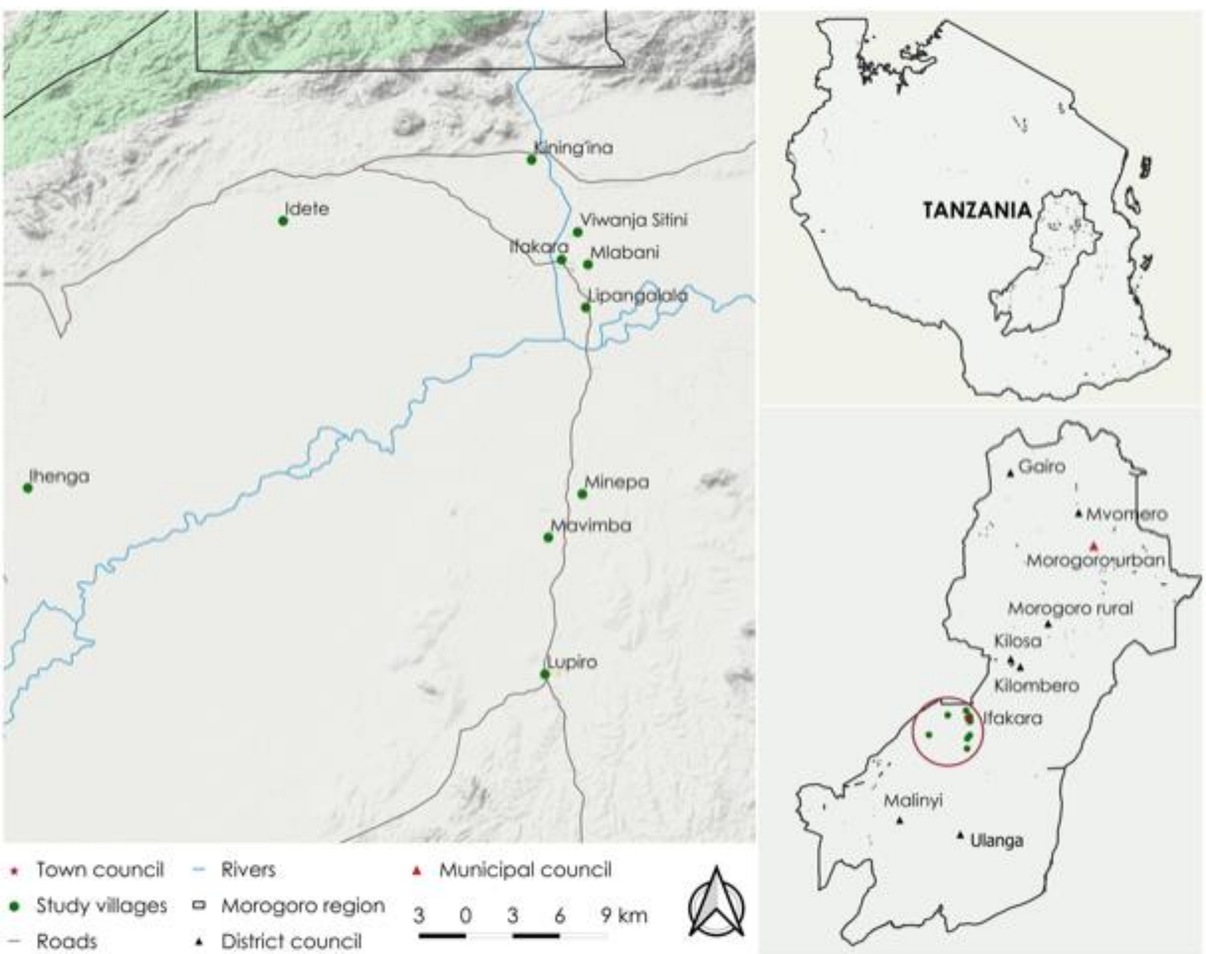

Figure 3.1: Map of Morogoro Region, Tanzania, showing the districts, wards and villages where the study was conducted. Map prepared by Najat Kahamba.

3.2: Study design and methods

An exploratory sequential mixed-methods approach (144) was used, incorporating focus group discussions (FGD), key informant interviews (KII) and survey questionnaires (Figure 3.2). This method was deemed suitable for this study due to the complexity of the study; exploring perceptions of different stakeholders on different interventions for malaria control. Following the mapping and selection of stakeholders, a qualitative component of the study proceeded, including: 1) a series of FGDs with representatives of key stakeholder groups in the country to explore their views and opinions regarding the alternative technologies for malaria control, and 2) a series of key informant interviews (KII) with district malaria control officials to explore their awareness, experiences and perceptions of larviciding as an alternative malaria control intervention in Morogoro region. Preliminary findings from the FGD, were used to develop a questionnaire to assess the baseline awareness and acceptance of the alternative among the stakeholders. Findings from the two components were then presented back to representatives of the stakeholder groups and an intervention for building stakeholder engagement model was selected.

3.3: Study procedures

3.3.1: Activity 1: Mapping key stakeholders of malaria control and elimination in Tanzania

Stakeholder mapping was done to obtain the key players in the malaria control and elimination efforts at the community, regional and national level in Tanzania. Five major institutions were identified as the key direct and indirect influencers of malaria control interventions in the country. These were policy makers, regulators, research scientists, district malaria control officials and community members. The selection was further narrowed to institutions within the stakeholder groups that have direct or indirect influence on malaria control activities in the country. Once the specific institutions were identified, letters were sent to heads of the institutions to request their assistance in identifying individuals that work in malaria-related activities within the institutions. These individuals were contacted to request their participation in the study. With regards to the community members, these were randomly selected from ten villages in the two districts of Ulanga and Kilombero in the malaria-endemic Kilombero valley in southern Tanzania (26,52,54,145).

3.3.1.1: Policy makers

Policy-makers included senior officials from government ministries, all located in Dodoma, Tanzania's administrative capital. They were selected from seven government ministries with direct or indirect influence on malaria control activities. These included a) Ministry of Agriculture, b) Ministry of Education and Vocational Training, c) Ministry of Health, Community Development, Gender, Elderly and Children, d) Ministry of Housing and Infrastructure, e) Ministry of Livestock and Fisheries Development, f) Ministry of Water and Irrigation and g) President's Office-Regional Administration and Local Government. Two officials were recruited in each of the seven ministries to participate in this study.

3.3.1.2: Research Scientists

Participants in this group were selected from two leading research institutions in Tanzania; Ifakara Health Institute (IHI) and National Institute for Medical Research (NIMR). IHI is a leading research organization in Africa, with a strong track record in developing, testing and validating innovations for health. Driven by a core strategic mandate for research, training and services, the institute's work now spans a wide spectrum, covering biomedical and ecological sciences, intervention studies, health-systems research and policy translation (146). Eight IHI research scientists participated in the study. NIMR, on the other hand, is the largest public health research institution in Tanzania, whose mission is to conduct, regulate, coordinate, and promote health research that is responsive to the needs and wellbeing of Tanzanians. The institute works under the Ministry of Health, Community Development, Gender, Elderly, and Children (147). Eight NIMR research scientists participated in the FGDs. In both institutions, the participants included persons working on malaria control strategies in the country, including entomologists, economists, health systems and policy researchers, molecular biologists and ethicists. These were based in Dar es Salaam, Kibaha and Morogoro regions, although their work spans across the country.

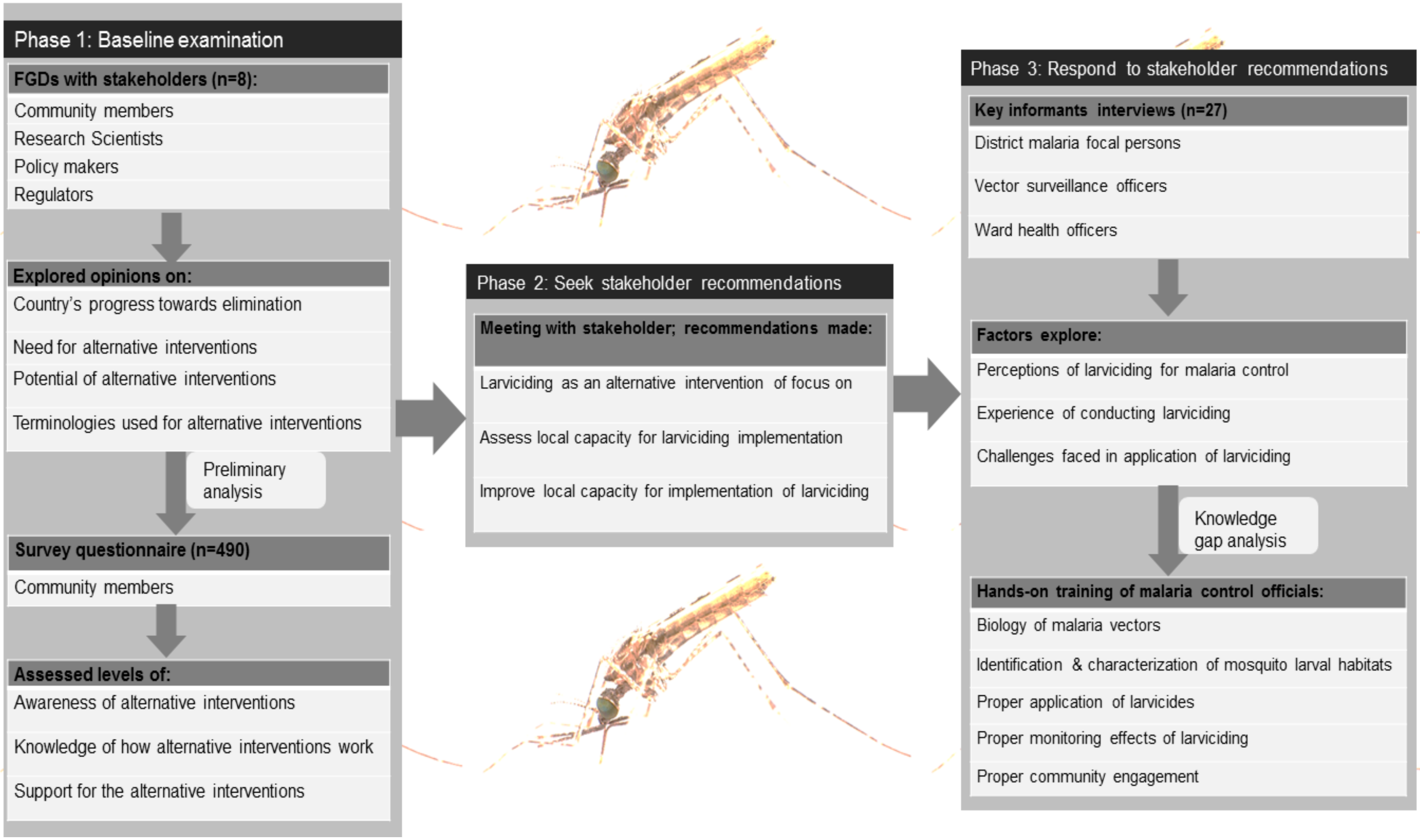

Figure 3.2: Illustration of the exploratory sequential mixed-methods approach used in this study.

3.3.1.3: Regulators

Participants in this group included officials from regulatory agencies in the country, including officials from the Tanzania Medicines & Medical Devices Authority, Tanzania Commission for Science and Technology, and National Environmental Management Committee. These were based in Dar es Salaam and Dodoma, the business and administrative capitals of the country. Altogether 15 regulators participated in the study.

3.3.1.4: District malaria control officials

District malaria control officials selected included malaria focal persons (MFPs), vector surveillance officers (VSOs) and ward health officers, all from the nine districts and councils of the Morogoro region in southern Tanzania (Figure 3.1). Malaria focal persons are medical doctors or environmental health specialists responsible for all aspects of malaria control in the district, including monitoring the trend of malaria cases, deaths and control. One malaria focal person from each of the 9 council in the region was recruited to participate in key informant interviews (KII). Vector surveillance officers are environmental health specialists with a special training in disease-vector control, and are responsible for organizing, supervising and executing disease-vector control programmes at the district level. One VSO was recruited from each of the 9 district to participate in the KIIs. Ward health officers are also environmental health specialists, and are responsible for all health-related issues at the ward level, including planning, supervising, monitoring and evaluating overall health services at the ward level. Like with MFPs and VSOs, one ward health officer was recruited to participate in the KIIs.

3.3.1.5: Community members

Lastly, community members were comprised of local residents and community leaders from villages in Ulanga and Kilombero districts in the Kilombero valley in south-eastern Tanzania. Ten villages were randomly selected from the two districts using excel RAND function. Randomization was done by MFF. The selected villages were Idete (8.09°S, 36.51°E), Ihenga (8.28°S, 36.34°E) and Kining'ina (8.11°S, 36.67°E) were selected from rural Kilombero district; Ifakara (8.38°S, 36.67°E), Lipangalala (8.15°S, 36.68°E), Mlabani (8.21°S, 36.68°E) and Viwanja Sitini (8.13°S, 36.67°E) were selected from urban Kilombero district, and Lupiro (8.01°S, 36.63°E), Mavimba (8.31°S, 36.67°E) and Minepa (8.27°S, 36.67°E) were selected from Ulanga district, which is mostly rural (Figure 3.1). The residents are mostly subsistence farmers, pastoralists or small business owners (26,54,145). Malaria transmission is highly heterogeneous in the area, ranging from <1infectious bites per person per year (ib/p/yr) to about 16ib/p/yr (52,129). Likewise, malaria prevalence ranges from <1% in the urban and peri-urban sites to >40% in rural settings (148), (Swai *et al, unpublished*). Assuming a population of 11,000 households in the study area, with 95% confidence interval and a power of 80% (based on experience with the area), a sample size of 463 households was calculated, and was equally divided between ten wards in the two districts. This number was later on rounded up to 500 households. One consenting adult household member was surveyed.

Community leaders participating in focus group discussions were selected from the ten villages as the community members. The leaders are government officials elected by the community members every two years, and represent their communities in meetings and decision making.

3.3.2: Activity 2: Exploring opinions of stakeholders on the need and potential of alternative interventions for malaria control in Tanzania

This activity answers specific objective two. Focus Group Discussions (FGDs) (Appendix 10) were conducted with representatives of four stakeholder groups to explore their opinions on the potential of alternative interventions for malaria control and elimination in Tanzania. A total of eight FGD sessions were conducted; two per stakeholder group. Stakeholder groups that participated in this component were policy makers, research scientists, regulators and community leaders representing community members. Each FGD session had between 6 and 8 participants. Participants from each group were purposively selected based on their experience working in malaria control and availability. A semi-structured discussion guide was used to guide discussions on participants' opinions on the country's progress towards malaria elimination, effectiveness of current malaria control interventions, and the need and potential of alternative interventions for malaria control. Since a number of the alternative interventions are new in the country or not well known among the FGD participants, the facilitators presented a brief overview of the alternative interventions for malaria control and elimination, and the presentation was followed by discussions of the interventions. The FGD sessions were conducted between December 2018 and May 2019.

3.3.3: Activity 3: Assessing baseline awareness and acceptance of alternative interventions for malaria control among stakeholders in Tanzania

This activity answers specific objectives three and four. A structured questionnaire (Appendix 12) was developed based on preliminary analysis of the FGDs. The survey, conducted in Swahili language, aimed to assess awareness and perceptions of alternative interventions for malaria control and elimination in the country. KobotoolboxTM software (149) was used to administer the surveys via electronic tablets, and the survey was done between November and December 2019. The survey questionnaire contained ten sections; the first and second sections gathered identifying information and socio-demographic information respectively. The third section gathered information on awareness and perception of risk of malaria transmission and burden, and sections four through ten assessed awareness and perceptions of the different alternative interventions.

The individual-level perception of community members towards the alternative interventions were assessed by measuring levels of agreement towards positive statements towards alternative interventions for malaria control and elimination. A 5-point Likert-scale was used, ranging from strongly agree (1) to strongly disagree (5). The statements were the same for all the interventions assessed and were as follows: i) [*intervention*] will be effective for malaria control, ii) [*intervention*] will fill gaps left by other interventions, iii) [*intervention*] is safe for humans, animals and the environment, iv) [*intervention*] will be easy to perform, v) [*intervention*] supplies and equipment will be easily accessible, vi) [*intervention*] will be affordable to community members and vii) [*intervention*] will be acceptable in the community. The final perception level was determined by comparing individual perception scores against the median score (see data analysis section).

3.3.4: Activity 4: Identifying and responding to challenges in implementation of alternative interventions for malaria control among stakeholders in Tanzania

This activity answers specific objective three. Preliminary findings from the FGD and baseline survey were presented back to representatives of the stakeholder groups and further discussions were conducted on what intervention should be used as a case study for developing stakeholder engagement model. Larviciding was selected as an intervention to build public engagement intervention on. The main reason was that the Tanzanian government had recently invested in a large scale production and distribution of biolarvicides through Tanzania Biotech Products Limited (TBPL) (150). There had also been a presidential pronouncement encouraging larviciding in all administrative councils across the country. TBPL manufactures two types of biolarvicides; *Bacillus thuringiensis var. israelensis* (*Bti*) and *Bacillus sphaericus* (*Bs*) (150), which are procured by district councils across the country, and distributed to all administrative wards for application in mosquito larval habitat.

To assess the capacity of the council to conduct large scale implementation of larviciding at the district level, key informant interviews (KII) (Appendix 11) were conducted with district malaria control officials, including malaria focal persons, vector surveillance officers and ward health officers. The interviews aimed to explore knowledge, awareness and perceptions of larviciding among the district malaria control officials, and their experience of conducting larviciding in their districts. The KIIs were done between February and March of 2020 at the respective district offices. Semi-structured interview guides were used, and their interviews were audio-recorded following the written consent of the participants.

A stakeholder-informed training program (appendix 1) was developed based on preliminary findings of the KIIs with district malaria control officials, which indicated inadequate technical knowledge of conducting larviciding and conducting community engagement as some of the major challenges to implement larviciding within the districts.

3.4: Data processing and analysis

3.4.1: Qualitative component

Audio recordings of the focus group discussions and key informant interviews were transcribed and translated from Swahili to English. The written transcripts were reviewed and imported to NVIVO 12 Plus software (151) for further processing and analysis. Analyses were conducted separately for different interventions. The objective of the study, FGD guide, KII guide and Diffusion of Innovation theory were used to develop deductive or topic codes. Inductive codes were derived from detailed studying of the FGD and KII transcripts. A coding framework with definitions was applied to all the transcripts and field notes. Memos were used during the coding to process to note all analytic questions for further exploration. Once the coding was completed, codes were grouped, and emerging patterns were used to identify themes. The coding framework was discussed with supervisors and co-investigators.

3.4.2: Quantitative component

The survey data was exported to Excel, cleaned and analyzed using R statistical software version 4.0.0 (152). Descriptive analyses were used to assess socio-demographic characteristics of the survey respondents, and to summarize their knowledge and awareness of the alternative interventions for malaria control and elimination. Shapiro test was used to test for normality of the data (152). Continuous variables were expressed as means and categorical variables expressed as percentages.

Perception of community members towards the alternative interventions was assessed by measuring the level of agreement towards seven positive statements about the alternative interventions using a 5-point Likert-scale, ranging from strongly agree (1), agree (2), neutral (3), disagree (4) and strongly disagree (5). To assess this, the sum of scores of the seven statements was calculated for each survey respondent for each alternative intervention. A median of these scores calculated, and perception level was determined by comparing individual perception scores against the median perception score; scores above the median were considered negative perception and scores at or below the median score were considered positive. Cronbach alpha-test was used to assess internal consistency of the Likert scale items (153). Univariate and multivariate analyses were used to assess influence of respondents' socio-demographic characteristics (independent variables) on their perceptions of and support for alternative interventions for malaria control and elimination (outcome variables). Odds ratio was calculated at 95% confidence intervals (CIs).

3.4.3: Integration of qualitative and quantitative components

Integration of the quantitative and qualitative data was done at the interpretation and reporting level (142), and was reported differently for the different published works. Detailed description is provided under each article.

3.5: Researcher positionality

My own role as a researcher differed depending on the stakeholder group I was interacting with. Having worked in malaria research over the past five years, I personally knew many of the community members and research scientists that participated in this study, so my positionality with these stakeholders was that of an "insider". A majority of research scientists were either my colleagues or we had interacted in conferences or collaborated in some research over the past few years. A lot of my previous research had focused in malaria-endemic settings in southern Tanzania, so I had also occasionally interacted with the community members as well as malaria control officials to some extent. My position with regards to policy makers and regulators was that of an "outsider". I had never before interacted with participants in these groups. Despite the familiarity (or lack thereof) with the stakeholders, I maintained a neutral position with regards to the prospects of concerns over the alternative interventions for malaria control and elimination. I was accompanied with at least one research assistants when facilitating the discussions or interviews. Different research assistants also transcribed and translated recordings of the discussions or interviews, and the analysis was reviewed and crosschecked by the supervisors.

3.6: Ethical considerations

Ethical approvals for this study were obtained from Ifakara Health Institute's Institutional Review Board (Protocol ID: IHI/IRB/EXT/No: 015 – 2018) (Appendix 8), the Medical Research Coordinating Committee (MRCC) at the National Institute for Medical Research (Protocol ID: NIMR/HQ/R.8a/Vol.IX/2697) (Appendix 9), in Tanzania, and from University of the Witwatersrand (UW) in South Africa (Clearance certificate No. M180820) (Appendix 7). Meetings were held with leaders of each stakeholder groups to request their consent to conduct this study and to recommend participants from their institutes or communities. Upon consent, formal letters were sent to each of the recommended participants to invite them to the discussions. Written consents were also sought from all participants of this study, after they had understood the purpose and procedure of the discussions.

Chapter 4: Opinions of key stakeholders on alternative interventions for malaria control and elimination in Tanzania

4.1: Abstract

Malaria control in Tanzania currently relies primarily on long-lasting insecticidal nets and indoor residual spraying, alongside effective case management and behaviour change communication. This study explored opinions of key stakeholders on suitability and potential of six alternative vector control interventions for supplementing ongoing malaria control and elimination efforts in Tanzania.

Focus group discussions were held with policy-makers, regulators, research scientists and community members, each group having 6-10 participants. Alternative interventions discussed included: a) improved housing, b) larval source management, c) mass drug administration (MDA) with ivermectin to reduce vector densities, d) modified mosquitoes including genetically-modified or irradiated mosquitoes, e) targeted spraying of mosquito swarms, and f) spatial repellents. Discussions focused on stakeholder opinions on comparative value of these interventions for supplementing efforts towards the 2030 malaria elimination target.

Larval source management and spatial repellents were widely supported across all stakeholder groups, while insecticide-spraying of mosquito swarms was least preferred. Support for MDA with ivermectin was high among policy makers, regulators and research scientists, but encountered opposition among community members due to perceptions that it requires significant efforts and compliance. Community members expressed strong desire and support for programmes to improve housing for poor people in high transmission areas, while policy makers challenged sustainability of this strategy given its high costs. Techniques of mosquito modification, specifically those involving gene drives, were viewed positively by community members, policy makers and regulators, but encountered high degrees of scepticism among scientists. Overall, policy-makers, regulators and community members trusted scientists to provide appropriate advice for decision making.

Stakeholder opinions regarding alternative malaria interventions were divergent, except for larval source management and spatial repellents for which there was universal support. MDA with ivermectin, house improvement and modified mosquitoes were also widely

supported though each faced concerns from at least one stakeholder group. While policy-makers, regulators and community members all noted their dependence on scientists to make informed decisions, their reasoning on benefits and drawbacks of specific interventions included factors beyond technical efficiency. This study suggests the need to encourage and strengthen dialogue between scientists, policy makers, regulators and communities regarding new interventions.

Finda, Marceline F, Nicola Christofides, Javier Lezaun, Brian Tarimo, Prosper Chaki, Ann H Kelly, Ntuli Kapologwe, Paul Kazyoba, Basiliana Emidi, and Fredros O Okumu. 2020. “Opinions of Key Stakeholders on Alternative Interventions for Malaria Control and Elimination in Tanzania.” Malaria Journal, 1–13. https://doi.org/10.1186/s12936-020-03239-z.

See Appendix 3.

4.2: Background

The World Health Organization's Global Technical Strategy for Malaria was aimed at reducing malaria incidence and mortality by 90% worldwide by 2030, and to eliminate malaria in 35 countries by the same year (57). Tanzania is one of the countries currently pursuing malaria elimination by 2030, and has witnessed significant gains since 2000 (28). To achieve this ambitious goal, the National Malaria Control Programme (NMCP) has a strategy to ensure adequate coverage of vector control interventions, primarily the use of long-lasting insecticide-treated nets (LLINs) and indoor residual spraying (IRS) (28). The strategy also includes improved malaria diagnosis and case management, as well as roll-out of new complementary interventions where there is sufficient local evidence for impact (28). This strategy however faces multiple challenges, including widespread mosquito resistance to insecticides (3,24), tendency of some vector populations to bite people outdoors or earlier in the evenings (25,26), high costs and sub-optimal compliance among users (27).

Several complementary vector control interventions have been proposed as possible candidates to accelerate the malaria elimination efforts (2). Examples include: a) larval source management (LSM) (29,30), b) topical repellents for personal protection (154,155), c) mass drug administration with endectocides such as ivermectin (42,43), d) use of genetically-modified mosquitoes, currently under development (34–36), e) outdoor targeting of malaria mosquitoes e.g. through insecticide-spraying of mosquito swarms (31–33), f) housing improvement measures such as window screening and improved house designs (37–39), g) spatial repellents, which protect multiple people over wide areas (40,41), h) attractive toxic sugar baits, which target sugar-seeking mosquitoes (156,157) and i) mosquito-killing fungal spores and toxins(158,159).

Unfortunately, most of these interventions still do not have adequate evidence to support deployment at a larger scale. Instead, significant investments, as well as strong multi-sectoral collaborations are still needed to complete their development and evaluation. Moreover, to ensure that these potential alternative interventions meet user needs and are sustainable, it is crucial to consider, early on in their development, the views and opinions of the key stakeholders. This study therefore explored opinions of key stakeholders regarding suitability and potential of six alternative vector control interventions, which could be used to supplement malaria elimination efforts in Tanzania.

4.3: Methods

4.3.1: Study site and stakeholder selection

This study was done in Tanzania between December 2018 and May 2019, and involved four groups of stakeholders, namely: a) policy-makers, b) regulators, c) research scientists and d) community members. The stakeholders were all involved either directly or indirectly in malaria control in Tanzania.

Research scientists were selected from two leading research institutes in the country: Ifakara Health Institute (IHI) and National Institute for Medical Research (NIMR), and included persons working on malaria control strategies in Tanzania. The group included entomologists, economists, health systems and policy researchers, molecular biologists and ethicists. Policy-makers on the other hand included senior officials from government ministries located in Dodoma, Tanzania's administrative capital. Participants in this group were selected from seven government ministries with direct or indirect influence on malaria control activities. These included a) Ministry of Health, Community Development, Gender, Elderly and Children, b) Ministry of Education and Vocational Training, c) Ministry of Agriculture, d) Ministry of Livestock and Fisheries Development, e) Ministry of Water and Irrigation, f) Ministry of Housing and Infrastructure and g) President's Office-Regional Administration and Local Government. Regulators on the other hand included officials from the Tanzania Medicines & Medical Devices Authority, Tanzania Commission for Science and Technology, and National Environmental Management Committee.

Lastly, community members were comprised of local community leaders drawn from ten wards in Ulanga and Kilombero districts in the Kilombero valley, in south-eastern Tanzania, where residents are mostly subsistence farmers, pastoralists or small business owners. Malaria prevalence in these areas is highly heterogeneous ranging from <1% in the urban and peri-urban sites to >40% in some of the villages (Swai et al unpublished) and transmission intensities also varying from <1 to ~20 infectious bites per person per year (54,160).

4.3.2: Study procedures and interventions evaluated

In this qualitative study, Focus Group Discussions (FGDs) were used to explore opinions of the stakeholders on suitability and potential of alternative interventions that are either available or are currently being evaluated for malaria elimination in Tanzania. The alternatives assessed included: a) improved housing, b) larval source management, c) mass drug administration (MDA) with ivermectin to reduce vector densities, d) modified mosquitoes, including genetically-modified such as those with gene drives or irradiated mosquitoes, e) targeted spraying of mosquito swarms, and f) spatial repellents. All of these have previously been proposed as potential complementary interventions towards malaria control and elimination in different settings. Table 4.1 shows basic summaries on these interventions, including evidence on potential for each.

A total of eight FGD sessions, two per stakeholder group, were conducted, each with 6-10 participants. During the FGDs done with community members, men and women were separated to maximize participation of women, based on previous experiences (161). This separation was considered unnecessary for the other stakeholder groups. To avoid framing the discussions narrowly, a semi-structured discussion guide was used. Participants were first asked open-ended questions about their opinions on the country's progress towards malaria elimination, their views on the effectiveness of current malaria control interventions, and the need for alternative interventions for malaria control. The facilitator then presented a brief overview of the alternative interventions for malaria elimination, by way of PowerPoint slides. The presentation was followed by participants' discussions of the interventions.

The discussions were done in Swahili (the main language spoken in Tanzania). The sessions lasted 120 - 150 minutes each and were audio-recorded with consent from participants. Additionally, detailed notes were taken during the discussions

Table 4.1: Descriptions of alternative interventions to complement ongoing malaria control and elimination efforts, as discussed with key stakeholders in Tanzania.

Intervention	**Description**
Improved housing	House improvement as malaria control intervention involves mosquito-proofing houses to limit mosquito entrance into the house (38,162). General housing improvement was used as supplementary components in the malaria elimination strategies in developed countries (163). In developing countries, simple modifications like screening windows and doors and closing eave spaces have resulted in a 50% decline in entomological inoculation rates (164). In Tanzania for example, housing improvement was linked to significant historical declines of Malaria in Dar es Salaam (165), and was likely a major factor in more than 99% decline in Malaria in Ifakara town (52).
Larval source management	Larval source management (LSM) refers to environmental manipulations to target mosquito larval habitats (29). LSM can include the use of larvicides as well as environmental management methods (29,30,166). In Tanzania, a large scale coverage of larviciding resulted in 21% reduction in malaria prevalence in Dar es Salaam between 2006 and 2008 (61). The Tanzanian government is currently conducting targeted larviciding in urban and rural settings as a means to speed up the malaria elimination agenda (62).
Mass drug administration of ivermectin	Ivermectin is an anti-helminthic drug commonly used to control parasitic nematodes in humans and animals (119). It has been extensively used in mass campaigns for elimination of lymphatic filariasis and onchocerciasis in Tanzania (116,117). Ivermectin has been increasing in popularity as a malaria control tool; it significantly reduces female mosquito fecundity and survival when mosquitoes blood-feed on hosts that have taken ivermectin (43,118,119).
Targeted spraying of mosquito swarms	Male mosquitoes aggregate in swarms as they compete for attention of female mosquitoes searching for mating partners (167). Swarms usually occur at approximately the same time, usually at sunset, and repeatedly at same locations throughout the year (167). Studies done in Burkina Faso and Tanzania have shown that *Anopheles* mosquito swarms can be easily identified and targeted, and are effective for reducing overall mosquito density (31,32,129).
Modified mosquitoes	This intervention involves alterations of mosquito genes or physiology for the purpose of reducing their competence in diseases transmission. The modified mosquitoes are released in the environments so that they can interbreed with the wild mosquitoes and either transform them from disease-vectors into harmless mosquitoes, or to eliminate their population. Interventions currently under study include Sterile Insect-technique (SIT), which relies on irradiation of mosquitoes to make them sterile (168), genetic sterilization of mosquitoes (169) and use of gene drive systems, which spread traits of lethality or refractoriness in mosquito population (i.e. population suppression or replacement) (34,170,171). While there are currently no field studies or historical evidence of effectiveness of this technology, laboratory studies and mathematical models indicate promising results (172).
Spatial repellents	Spatial repellents (SP) prevent host-seeking mosquitoes from entering areas with the treatment, usually in form of vapor-phased active ingredients, limiting contact between humans and mosquitoes (40). SP include botanical and pyrethroid compounds such as citronella, transfluthrin and metofluthrin (40,110,111). They can be delivered in different formats, such as mosquito coils, repellent-treated clothing, repellent sandals (Finda et al unpublished), kerosene lamps (113) and eave ribbons (40,41,112). Compared to widely available topical repellents, SP can provide long-lasting repellency, requiring minimal participation from the users.

4.3.3: Data processing and analysis

Audio recordings of the FGDs were transcribed immediately following the discussions, then translated from Swahili to English language. Field notes were incorporated in the written transcripts as additional data. The final transcripts were reviewed in detail then imported to Nvivo 12 Plus software (151) for further processing and analysis. Deductive analysis was used to categorize codes based on the FGD guide, which explored participants' opinions on: a) the country progress towards malaria elimination, b) potential and limits of current interventions for malaria elimination, c) need for alternative approaches and techniques to support elimination efforts, d) merits and limitations of the alternative interventions, and e) their potential applications as complementary interventions in the efforts towards the 2030 malaria elimination target. Guiding quotes from participants were used to support the themes.

4.4: Results

4.4.1: Opinions on progress towards malaria elimination in Tanzania

Research scientists, regulators and policy makers discussed the progress made by Tanzania towards malaria elimination in terms of declining malaria prevalence as observed during the past decade. On the other hand, community members discussed the progress in terms of their daily life experiences.

Two major arguments emerged within this theme. On the one hand, it was agreed that the country had made good progress and was on the right track. On the other hand, it was also noted that the progress was slow and inadequate for elimination by 2030 as planned. Participants who emphasized that the country was on track referred to the significant reduction in malaria prevalence over the past decade, particularly noting that malaria has reduced by more than 50% since 2000. For example, one policy maker stated, "*Of course we have come far from when prevalence was as high as 20% in the whole country. Back then when you look at the map it was all red, all red I tell you. There was malaria everywhere. But now you can see quite a lot of places that have prevalence of less than 1%, so when I see that I know that we are doing well.*" (Female, Policy maker).

For community members, their idea of progress was informed mostly by their lived experiences. For example, they noted that the frequency and severity of malaria has greatly declined over the years, noting that unlike in the past when malaria infections were very frequent, several months could now go by without their children getting sick. Even when they did get sick, it was more likely not to be malaria. As one participant said, "*Ten years back there was a lot of malaria. During that time, every time you did not feel well and went to the hospital you would be told that you have malaria. Kids were getting sick very often. But now we can go for even six months without our children getting sick or needing to go to the hospital. And when we do go we hear about other diseases like urinary tract infections or typhoid. So then I know that malaria is not a big disease like it used to be."* (Female, Community member).

There was also a group of participants who argued more cautiously that while there has been some progress, it is too slow, and does not reflect the amount of effort that the country has put in place. They also noted that the decline in malaria prevalence is not uniform across the country. As one policy maker reported, *"I think we are doing well, but not as well as I would like. As a country we have put a great deal of efforts to finish off this disease, but I am sad to see that there are areas in the country where prevalence is as high as 40%. We should not be in a situation like this."* (Male, Policy maker).

4.4.2: Opinions on potential of current interventions in leading the country towards malaria elimination

Two main viewpoints were expressed regarding the potential of current interventions in leading the country through elimination by 2030. One viewpoint, expressed by a majority of the participants, was that current interventions would not be sufficient to achieve elimination even if they were utilized fully and effectively. One reason given was that the current interventions do not address challenges such as insecticide resistance and changes in mosquito biting behaviours. As one community leader explained, *"I really do not think that the insecticide-sprays or the bed nets are enough, because if they were enough we would not have malaria anymore. I sleep under a bed net every night, but mosquitoes still bite me when I am outside cooking or chatting with my family and friends. Sometimes I also spray my house with insecticides, but when I go inside to sleep, I see there are mosquitoes still. So then I know that these sprays are useless."* (Female, Community member).

An opposite viewpoint was that the currently available interventions would be enough to lead the country through elimination if they were utilized to their maximum potential. As pointed out by one research scientist, *"We already have what it takes to achieve elimination. If bed nets were properly made, properly distributed and properly used, why would we not eliminate the disease? If they killed mosquitoes as they are supposed to, if the universal distribution was actually universal, and if people actually slept under bed nets, I do not think we would need anything else…"* (Female, Scientist).

Other participants pointed out that the current interventions are passive rather than active. That is, they only target mosquitoes coming to human dwellings rather than actively targeting them in their larval habitats and hiding places. As one policy maker stated, *"We need means to target and eliminate all the mosquitoes, not just the ones that get inside the house. If we decide to kill mosquitoes, then we should really kill all of them. We should target them at larval stage and adult stage to make sure that we are not leaving any windows for escape."* (Male, Policy maker).

4.4.3: Opinions on the need for alternative interventions for malaria elimination in Tanzania

There were diverse inputs from participants on the need for complementary interventions for malaria elimination in Tanzania, although the majority of participants agreed that it would be unavoidable to have some of the alternative approaches used to complement current ones. Insights that emerged most clearly included: a) the importance of learning from similar countries that have achieved elimination, b) importance of knowing more about current interventions, including where or why they have failed or succeeded, and c) the need to consider combinations of interventions as a more holistic approach to achieve malaria elimination.

Those participants who emphasized the value of learning from other successful countries argued that there was no need to develop interventions from scratch, and that the country should follow in the footsteps of those who had been successful in eliminating malaria. Other participant noted that, since malaria prevalence was not homogeneous across the country, it would be essential to employ different interventions in different settings based on the specific conditions. For example, one participant stated, *"Malaria prevalence is not* *the same in all the country. There are parts of the country that are near elimination, and there are parts that have prevalence in double digits. This should tell you that one single method is not enough for the whole country. You need to look at different places and figure out what can work where."* (Female, Regulator).

Participants who recommended combinations of interventions argued that we now have greater knowledge of mosquito behaviours than in the past, and that this knowledge can be used to target them from multiple angles to accelerate elimination. In one of the FGDs, one participant noted that *"In order to really eliminate mosquitoes we need a combination of different strategies…We need to target all the water bodies to get rid of the larval stages, then all the hiding places like long grass and bushes, and then in the houses where they go to look for people to bite. If we do all of this, can you tell me how we can still have malaria in our country?"* (Male, Policy maker).

There were also participants who suggested that it was not wise to rush to new interventions without learning from limitations of current interventions, and possibly addressing those first. In one session, there was an elaborate pronouncement by one policy maker, who noted that, *"Why aren't the bed nets killing mosquitoes? Why are the indoor insecticide sprays not killing mosquitoes? We have heard a lot about mosquitoes being resistant to the insecticides, but I still think we have not answered the question of where the resistance is coming from; what causes it and how it can be prevented or corrected. And also, do people know that the insecticides no longer kill mosquitoes? And if this is already a common knowledge, why are we still using these insecticides? I am sure that it costs a great deal of money to treat all the bed nets in the country with insecticides; but if these insecticides no longer work as insecticides, then why are we still using them?"* (Male, Policy maker).

4.4.4: Opinions on the potential of the selected alternative interventions for malaria elimination in Tanzania

Discussions on alternative interventions for malaria elimination were based on participants' opinions about their effectiveness, sustainability, safety, as well as about Tanzania's readiness to adapt the interventions. There was a wide variation in levels of preference for different intervention options as described below:

Improved housing: All stakeholder groups associated improved housing conditions with reduced malaria risk. However, there were disagreements on need for the government to support transition towards better living conditions in malaria endemic communities. While community members were strongly supportive of this idea, policy makers were hesitant, pointing out issues of sustainability, affordability and competing government priorities.

The community members, in support of improved housing, argued that no intervention would be fully effective without adequate housing. Specifically, they noted that none of the other interventions under discussion would be particularly useful, if people continued to live in poorly-constructed houses with gaps on walls, roofs, doors and eave spaces. They further stressed that the government could indeed afford housing for the poorest community members living in areas with high malaria burden. The community members proposed several ways that the government could assist these communities, such as by providing loans for people to build improved houses, subsidizing prices for building materials or building and renting houses to the poorest at a reduced price. As one community member said, *"If the government could listen, I would advise them to assist people, especially the poor people, to build improved houses. They can maybe build the houses, and people can repay the government slowly, everyone can pay according to what they can afford."* (Female, Community member).

Policy makers also agreed that improved houses provide extra protection against malaria-transmitting mosquitoes. However, they were against the idea of the government building or modifying houses for poor people living in areas of high malaria transmission. They noted that it is not the responsibility of the government to build houses for citizens, and that given the required magnitude, the program would be expensive and unsustainable. As one policy maker said: *"You know our country is still poor, which means that a lot more people live in poverty than not. If you say that we start building or improving houses for all* *the poor people, then we will not have money for any of the other important things like health care and education."* (Female, Policy maker). Additionally, policy makers also indicated that building better houses alone would not be enough to eliminate malaria; a lot more effort would still be needed to ensure that mosquitoes are controlled in their larval habitats and hiding places.

Research scientists and regulators also agreed that it would be advantageous if poor people in malaria endemic areas had access to better housing. Nonetheless, they too noted that it would not be sustainable for the government to support this initiative, or even to get funding to investigate its potential. As one researcher noted: *"For house improvement, no one denies that this works. The only problem is cost implications; that could be one of the reasons that this has not been taken up. Also, the way our research is organized and funded does not help in things like house improvement. It is difficult to get funding for this"* (Male, Scientist).

Larval source management: Two strategies were discussed regarding this intervention: environmental management and larviciding (Table 3.1). However, most of the interest was directed towards larviciding. One major issue voiced by all stakeholder groups was lack of clear regulations or enforcement on environmental management regulations, especially in relation to settlement planning and waste water management. Community members complained about lack of regulations on where people build, cultivate crops or manufacture bricks for construction, which often results in the accumulation of standing water near settlements, increasing the risk of malaria and other mosquito-borne diseases. In the words of a community member, "*The town is rapidly growing now. There were parts of the town that people were allowed to make bricks in the past; no one lived there at the time. But now many people live there, and it is not safe because there are so many brick-pits, hence so many mosquito breeding places…It would be important if there were requirements,* [for example] *that the brick makers move to other unoccupied places, or* [that] *they should be required to fill in the pits"* (Female, Community member).

The use of larvicides for malaria control was highly preferred across the stakeholder groups, but with some caveats. Policy makers strongly supported the use of bio-larvicides, stating that the government had invested on creation of a bio-larvicide plant as part of the national strategy towards malaria elimination, but that use of this bio-larvicide remained low. *“The biolarvicides we are producing are designed to only affect mosquitoes, so they are relatively safe on the environment. We expected a high uptake from community and civil organizations, but I am sad to say that we are getting more customers from outside the country than within the country….”* (Female, Policy maker). Research scientists were also supportive of larviciding for malaria elimination, but they noted that the efficacy of the locally produced bio-larvicides should be evaluated since any perception of low efficacy might cause low uptake.

While a majority of the community members were in favour of larviciding for malaria control, a few members expressed concerns that there were so many water pools in their villages, particularly in the rainy season, that it would be difficult to treat all of them with larvicides without harming the environment, particularly the fish. One person stated: *“I would also like to stress that I do not trust this idea of putting chemicals in water. We all know that all of this water makes its way into the river where we get our fish. If we treat all the pools then that means a lot of chemicals will be going to the river. Now, are you telling me that it will not harm the fish? Most of us are fishermen here and our fish is part of who we are. Anything that can harm the fish will not be welcomed here. Maybe if you want to put these chemicals, you can do it during the dry season, but then there are no many mosquitoes during this time, so it will just be a waste”* (Male, Community member).

MDA using the endectocide, ivermectin: MDA with ivermectin is currently undergoing trials as a potential vector control tool, but there are already several completed trials demonstrating impact on mosquito populations and malaria burden (43,173). When given to humans and/or cattle, it kills malaria vectors that bite these hosts. The drug was widely known among all stakeholder groups as it is already widely distributed for control of lymphatic filariasis in humans (116,117) and several cattle diseases (174).

Community members referred to it as *Usubi*, and spoke of ‘health workers’ going from house to house every year to distribute the drug and encourage people to take it for control of *Matende* (elephantiasis) and *Mabusha* (hydrocele), conditions commonly associated with lymphatic filariasis. Despite the high awareness of this drug, there were mixed views among the stakeholder groups on its use for malaria control. Regulators, policy-makers and research scientists were hopeful and supportive of the approach, given its safety and effectiveness for control and treatment of lymphatic filariasis in Tanzania. They argued that deploying it for control of malaria-carrying mosquitoes would represent an important advantage at relatively low cost. They also stressed the need to spend time and resources to educate and raise awareness of the alternative use of ivermectin among target communities.

Community members on the other hand had strong objections to this intervention, reporting negative experiences with previous mass drug administration (MDA) campaigns, particularly of Praziquantel, which is commonly used for treatment and control of schistosomiasis among school children. They reported that a number of children who received the drug suffered fainting spells in schools, and this resulted in negative sentiments among community members. They also noted that generally people did not like to take medicines. One participant stated: *"I really must tell you that these medicines that you have to swallow have a challenge. When they brought Usubi, even with all the education and the advocacy they had provided, people still did not take the medicines. Some people just picked it so as not to make the health workers feel bad, but after they* [health workers] *left people threw the medicine away."* (Male, Community member).

Targeted spraying of mosquito swarms: A great deal of scepticism was expressed by all stakeholder groups about sustainability and feasibility of targeted spraying of swarms of *Anopheles* mosquitoes. It was noted that the approach would require extensive community participation, and would be expensive. One participant stated: "*The setback with this is that you need a lot of people to do that, so it may also be expensive. But I agree maybe you use less insecticides, but if you are worrying about the cost of the insecticides, you will still be spending more in paying people to spray*" (Male, Policy maker). Community members also pointed out that it would be inconvenient to spray at the time of the day when mosquitoes swarm and in many of the locations where they do so: *"…it will be difficult to find someone at home during that time, people will still be at work, or they will be too tired to accept more work."* (Male, Community member).

Modified mosquitoes: This possibility of releasing modified mosquitoes generated a lot of discussions and resulted in polarized viewpoints among all stakeholder groups. Although groups were introduced to different technological approaches constituting mosquito modification (i.e., sterile insect technique, genetically modified-sterile mosquitoes and gene drive technology), most of the interest centered on implications of gene drive technologies, particularly those used for suppression of malaria vector populations.

Scientists were the most critical of gene drive technology. They questioned its safety and the country's readiness for such advancements. They also pointed out that there are still a lot of unknowns, and that long-term research would be needed to provide evidence on various aspects of the technology. They expressed concerns about possibility of mutations in either the *Plasmodium* parasite or the modified mosquitoes themselves. Specific concerns in this case were that the modified malaria vectors could become vectors for other diseases or the *Plasmodium* parasite could mutate and survive in other mosquito species. The fact that the technology would target a single malaria vector was also seen as a risk as this could possibly increase the prevalence or vectorial capacity of the other malaria vectors. Targeting one mosquito species was also seen as a drawback in securing community acceptance. One participant stated: "*For the people, no malaria means no mosquitoes. They still cannot distinguish between malaria-transmitting and non-malaria transmitting mosquitoes, so if you tell them that you are controlling malaria then they need to see mosquitoes gone."* (Female, Scientist). The scientists were also concerned that there were not many African and particularly Tanzanian scientists taking leading roles in this research. One scientist stated: *"There are more fears than certainty regarding this technology. It is mainly being driven by foreigners. I worry that there are not many African researchers participating in the detailed research of this technology"* (Female, Scientist).

Policy makers were divided in their views regarding gene drives. Some were in favor of it, pointing out that it was environmentally friendly and required little compliance from communities, yet others were skeptical, noting that there is currently a great deal of controversy over genetically-modified food products, thus it might be unwise to introduce another genetically-modified organism. One policy maker said; "*We are already struggling with acceptance of GM crops, adding yet something like this may bring havoc in the country. Let them [*other countries*] try it first, let us learn from our neighbours and go last in this."* (Female, Policy maker). The policy makers also recognized that the technology is not yet ready, and cannot be considered in the 2030 malaria elimination campaigns.

In contrast, and significantly, community members expressed a great deal of fascination with the technology. They were struck in particular by the fact that it will require little work or participation from residents, compared to traditional malaria interventions. They also expressed a preference for this technology since it was seen to pose the least harm to the environment, particularly to fish. One participant said: "*I like that it does not have any chemicals, so the environment and the fish are all safe, but the malaria-mosquitoes will be gone* (Male, Community member).

Regulators pointed out that, while the potential of gene drive technologies ought to be explored, there are currently no policies and regulations for their governance, and in order to put those in place, more research is needed to assure short- and long-term safety. One participant said: *"There are regulations for GMOs, but this technology you have is not GMO, rather GM edited organisms. Gene-edited is not the same as GMO. We do not have policies or regulations for that. I believe you can advise us on this; provide all the information needed and the evidence of its safety and we can add this into the regulations concerning GM organisms"* (Female, Regulator).

Spatial repellents: All stakeholder groups agreed that this technology would be appropriate as complementary (rather than primary) intervention for malaria control and elimination. Scientists however indicated that there was still insufficient evidence to indicate the best spatial repellents, and their availability, cost and feasibility of use.

Community members spoke positively about this technology, saying that it was most useful when people were outdoors in early night hours, when cooking, eating and relaxing with their family and friends before going indoors to sleep. They alleged that it would be best if the government could distribute bed nets together with spatial repellents as a package in order to tackle the problem of mosquitoes changing their behaviours. One participant stated: *"We have been told that mosquitoes are clever and have changed their biting times, so we have to be smart too and respond to that change using these repellents. If the government can provide these repellents to every household and teach them when, where and how to use them, I think we can make a very big progress in ending the malaria problem."* (Female, Community member).

4.5: Discussion

This study explored opinions of key stakeholders on Tanzania's progress towards malaria elimination, and their views on suitability and potential of six alternative interventions that might complement efforts to achieve that goal in the future. The stakeholders weighed alternative approaches to malaria control and elimination, rather than focusing the discussions on individual approaches.

Our findings reveal a considerable agreement across the stakeholder groups on the extent of progress achieved in the control of malaria in Tanzania over the last decade. It was also noted that policy makers, regulators and scientists pointed to statistical evidence of declining malaria prevalence, as reported in recent Tanzania's malaria indicator surveys (TMIS) (15,16). On the other hand, community members mostly pointed to their lived experiences of witnessing fewer episodes of malaria, and reduced severity of the disease. All participants commended the country's efforts in providing universal coverage with LLINs, reliable diagnosis and affordable treatment, all of which are also already demonstrated by various studies (26,27,175). There was also a general agreement that current interventions are not sufficient to achieve further reductions in malaria burden. Participants listed various challenges, such as insecticide resistance and outdoor biting exposure, which are also widely demonstrated in field studies (24,26).

While there was consensus that new, complementary interventions or technologies were needed to push the country further towards elimination, opinions differed on what technologies deserved prioritization and investment. The most preferred of the alternative interventions were larviciding and spatial repellents. During the discussions, the participants proposed that low-cost technologies e.g. spatial mosquito repellents could be used to provide temporary relief against early-evening and outdoor-biting mosquitoes, thereby complementing LLINs. Support for larviciding could be found in all stakeholders as well, and it was the most preferred option among policy makers, regulators and scientists. While community members had concerns regarding the environmental impact of larviciding, particularly on fish stocks, they did not have strong objections towards it. They rather offered their advice that it is done during the dry season when there is a lesser likelihood for the larvicides to get to the water. Current national policy already includes larviciding as a way to achieve further reductions in malaria incidence (28).

Insecticide-spraying of mosquito swarms was the least preferred by all stakeholder groups, due to perceived environmental harm, high cost and the assumed difficulty of area-wide implementation. This viewpoint was however not reflected in a survey previously done in the same settings as the community members, which showed that interventions targeting swarming mosquitoes were widely accepted in the community as swarming mosquitoes were considered dangerous (176). This difference in opinions is likely due to the fact that the community members involved in the FGDs had no real experience with the intervention compared to the community members assessed in the survey; hence they were unlikely to accept it.

One surprising outcome was the degree of skepticism that scientists expressed about prospects of mosquito modification technologies, particularly those based on gene drive constructs – and the comparatively more positive views expressed by, among others, community members. This is an important observation since any introduction of gene drive-based methods for malaria control in Tanzania will require strong support by local scientists, both because of operational reasons and because of the influence that scientists have on perceptions of all the other stakeholder groups (177). Some of the concerns discussed by researchers, such as their doubts about safety or undesirable mutations, can be addressed by producing more scientific evidence, but others, and in particular their complaint about inadequate involvement of African scientists in the development of the technology, require changes in the social and political organization of gene drive research approaches. Similar concerns have been observed in a recent study that explored perceptions of scientists in Nigeria on the potential release of genetically modified mosquitoes (178). In this study, policy makers and regulators repeatedly claimed that they needed further information from scientists to make informed decisions. This emphasizes the persuasive power of scientists, and stresses the need to not only expand involvement of local scientists on development of the technology, but also the need to encourage and strengthen collaboration between scientists, policy makers and regulators when developing or evaluating alternative technologies.

Community members, in contrast, expressed strong support for gene drive technology. They perceived it as being environmentally safer, and noted that it would require little work by communities. This was an unexpected finding, and contrasts with studies conducted elsewhere. A recent study from Mali, for instance, reveals that community members were reluctant to accept the release of genetically modified mosquitoes in their villages, arguing that they would prefer for this technology to be tried elsewhere first to show evidence of safety (179). A recent US study however demonstrated that nearly two thirds of people trusted universities and the department of agriculture (but not the private sector nor the department of defense) to research gene drives (180). This further stresses the need to earn approval of scientists, and to strengthen communication between scientists and communities in order to avoid delays in getting community acceptance of this technology.

Preference for house-improvement was highest among community members, who emphasized that it was a more sustainable approach to malaria prevention, and would have a similarly positive impact on control of many other vector-borne diseases. This point of view is supported by historical evidence that links successes against malaria with improved housing conditions in Europe and North America (181), and also recent findings of reduced malaria transmission following better housing or house screening (38,162). In contrast, scientists and policy makers were skeptical about investment on housing improvement as a malaria control technology, mostly because of the perceived high cost and lack of political feasibility.

MDA with ivermectin also generated polarized views among the stakeholder groups. Strong preference for the technology was observed among policy makers, regulators and scientists. It was on the other hand least preferred by the community members, who reported negative experiences with MDAs campaigns in primary schools for control of schistosomiasis. These reports echo studies conducted in Tanzania and Cameroon showing that adherence to ivermectin MDA was associated with previous experiences and perceptions towards MDAs, even when they concerned other drugs (182,183). Community members also pointed out that people generally did not like taking drugs, particularly when they did not suffer symptoms, an observation which could potentially limit scale-up of the approach.

This study had a number of limitations. Since a number of the approaches discussed in this study were new or not very well known among the participants, they were introduced and briefly described by the facilitator, which necessarily influences participants' perceptions. To minimize this effect, participants were first asked to list and discuss the approaches they were familiar with, and only after they had exhausted what they knew were they presented with additional approaches in generic format. Equal amount of time and information was given for each technology. Additionally, participants were very engaged with the discussion and asked a lot of questions before giving their opinion. To minimize the influence that the information provided by the facilitator might have had on participants' views, only generic responses were given, and the questions were often reverted back to the participants themselves to elucidate the reasons for their queries.

4.6: Conclusion

While it seems inevitable that new tools will be needed for Tanzania to achieve malaria elimination by 2030, it remains to be seen which particular combination of technologies will be adopted in the near future. Different stakeholders perceive differently the advantages and disadvantages of each individual approach to malaria control and elimination, and assess individual options in the context of existing methods and other potential alternatives. All stakeholder groups, however, claimed that they depend on the advice provided by scientists to make informed decisions. This shows the critical role scientists play as gate-keepers for new interventions, and suggests the importance of a robust dialogue and clear communication between scientists, policy makers, regulators and community members. The enthusiasm of community members to contribute to the knowledge and innovation towards malaria elimination stresses the need to actively involve citizens in the design, development and implementation of strategies to eliminate malaria in Tanzania. While scientists, regulators and policy-makers describe progress against malaria in terms of declining parasite prevalence, community members describe progress in terms of their daily life experiences. It is therefore vital to encourage and strengthen dialogue between scientists, policy makers, regulators and communities regarding any new interventions being considered or developed for malaria control and elimination. Lastly, the need for local scientists to engage in development and evaluation of new technologies such as gene drives is desirable to promote uptake, should such technologies prove effective.

Chapter 5: Hybrid mosquitoes? Evidence from rural Tanzania on how local communities conceptualize and respond to modified mosquitoes as a tool for malaria control

5.1: Abstract

Different forms of mosquito modification are being considered as potential high-impact and low-cost tools for future malaria control in Africa. Although still under evaluation, the eventual success of these technologies will require high-level public acceptance. Understanding prevailing community perceptions of mosquito modification is therefore crucial for effective design and implementation of these interventions. This study investigated community perceptions regarding genetically-modified mosquitoes (GMMs) and their potential for malaria control in Tanzanian villages where no research or campaign for such technologies has yet been undertaken.

A mixed-methods design was used, involving: i) focus group discussions (FGD) with community leaders to get insights on how they frame and would respond to GMMs, and ii) structured questionnaires administered to 490 community members to assess awareness, perceptions and support for GMMs for malaria control. Descriptive statistics were used to summarize the findings and thematic content analysis was used to identify key concepts and interpret the findings.

Nearly all survey respondents were unaware of mosquito modification technologies for malaria control (94.3%), and reported no knowledge of their specific characteristics (97.3%). However, community leaders participating in FGDs offered a set of distinctive interpretive frames to conceptualize interventions relying on GMMs for malaria control. The participants commonly referenced their experiences of cross-breeding for selecting preferred traits in domestic plants and animals. Preferred GMMs attributes included the expected reductions in insecticide use and human labour. Population suppression approaches, requiring as few releases as possible, were favoured. Common concerns included whether the GMMs would look or behave differently than wild mosquitoes, and how the technology would be integrated into current malaria control policies. The

participants emphasised the importance and the challenge of educating and engaging communities during the technology development.

Understanding how communities perceive and interpret novel technologies is crucial to the design and effective implementation of new vector control programs. This study offers vital clues on how communities with no prior experience of modified mosquitoes might conceptualize or respond to such technologies when deployed in the context of malaria control programs. Drawing upon existing interpretive frames and locally-resonant analogies when deploying such technologies may provide a basis for more durable public support in the future.

Adapted from Finda, Marceline F, Fredros F Okumu, Elihaika Minja, Rukiyah Njalambaha, Winfrida Mponzi, Brian Tarimo, Prosper Chaki, Javier Lezaun, Ann H Kelly, and Nicola Christofides. 2021. "Hybrid Mosquitoes ? Evidence from Rural Tanzania on How Local Communities Conceptualize and Respond to Modi Ed Mosquitoes as a Tool for Malaria Control." Malaria Journal, 1–20. https://doi.org/10.1186/s12936-021-03663-9.

See appendix 4

5.2: Background

Malaria is thought to have killed between 150 million and 300 million people worldwide during the 20th century (184). Although the situation has improved in the last two decades, malaria remains one of the leading causes of death and ill-health globally (1). In 2019 more than 200 million people were diagnosed with malaria and nearly half a million died, more than 90% of whom lived in sub-Saharan Africa (SSA) (1). Interventions such as insecticide-treated nets (ITN) and indoor residual spraying (IRS), combined with improved diagnosis and treatment account for most of the reductions in malaria burden (185). Yet these interventions appear to have reached the limit of their efficacy in many regions (3,25–27). Achieving further gains and not losing ground in the fight against the disease will require the development of novel and complementary interventions (2,73,186).

Mosquito modification technologies have garnered a great deal of public interest, particularly in SSA, where their impact is expected to be highest as a tool for malaria control and elimination (73–76). While experiments with some of these technologies, particularly the Sterile Insect Technique (SIT), go back several decades (65), significant progress has been made recently in the development and evaluation of novel approaches (35,77) such as the Release of Insects carrying a Dominant Lethal genes (RIDL) (66), gene-drive technologies (34,35,67–69), or the release of mosquitoes infected with *Wolbachia* bacteria and other endosymbionts (70–72).

These technologies are at different stages of development, and face specific questions from the perspective of communities considering their introduction. One important distinction is between interventions aiming to suppress the relevant mosquito species (population suppression), and those intended to permanently introduce a novel mosquito strain that will block or interfere with pathogen transmission (population replacement) (35). These differences suggest the need for distinct communication strategies, and imply a very different set of expectations on the coexistence between modified mosquitoes and the communities hosting the intervention (187).

Given the promise attributed to these technologies, their purported high-impact, and the numerous uncertainties that still surround their future deployment, extensive stakeholder engagement is essential in order to identify potential obstacles and concerns in malaria-endemic regions (35,44,188). Opposition to the release of genetically modified mosquitoes in south-east Asia and the Americas (126,189,190), and evidence of concerns among stakeholders in Mali (191), Nigeria (178) and Tanzania (134) suggest the importance of proceeding with caution (44,188). Robust social scientific research into how these novel technologies are perceived in areas where they might be deployed is a prerequisite for an effective public engagement strategy (192).

This study investigated community awareness and perceptions of genetically-modified mosquitoes (GMMs) and their potential for malaria control in south-eastern Tanzanian villages where no research or campaign for the introduction of such technologies is currently underway. To examine how a typical malaria-endemic community might respond to the introduction of GMMs technologies, the study explored the different conceptual frameworks and analogies that communities use to make sense of modified mosquitoes as a tool for malaria control.

5.3: Methods

This study was part of a larger public engagement process aiming to understand and improve public awareness and community evaluation of alternative interventions for malaria control and elimination. This particular study was carried out in ten randomly selected villages in two districts in south-eastern Tanzania between May and December 2019 (Figure 5.1). Detailed description of the wards is provided by Finda *et al* (26,52), Kaindoa *et al* (54) and Mmbando *et al* (193). Although this area has previously hosted numerous malaria research projects, there had not been any research on modified mosquitoes of any kind up to that point. Previous studies in the area have demonstrated high levels of knowledge about mechanisms and patterns of malaria transmission (26,176,194).

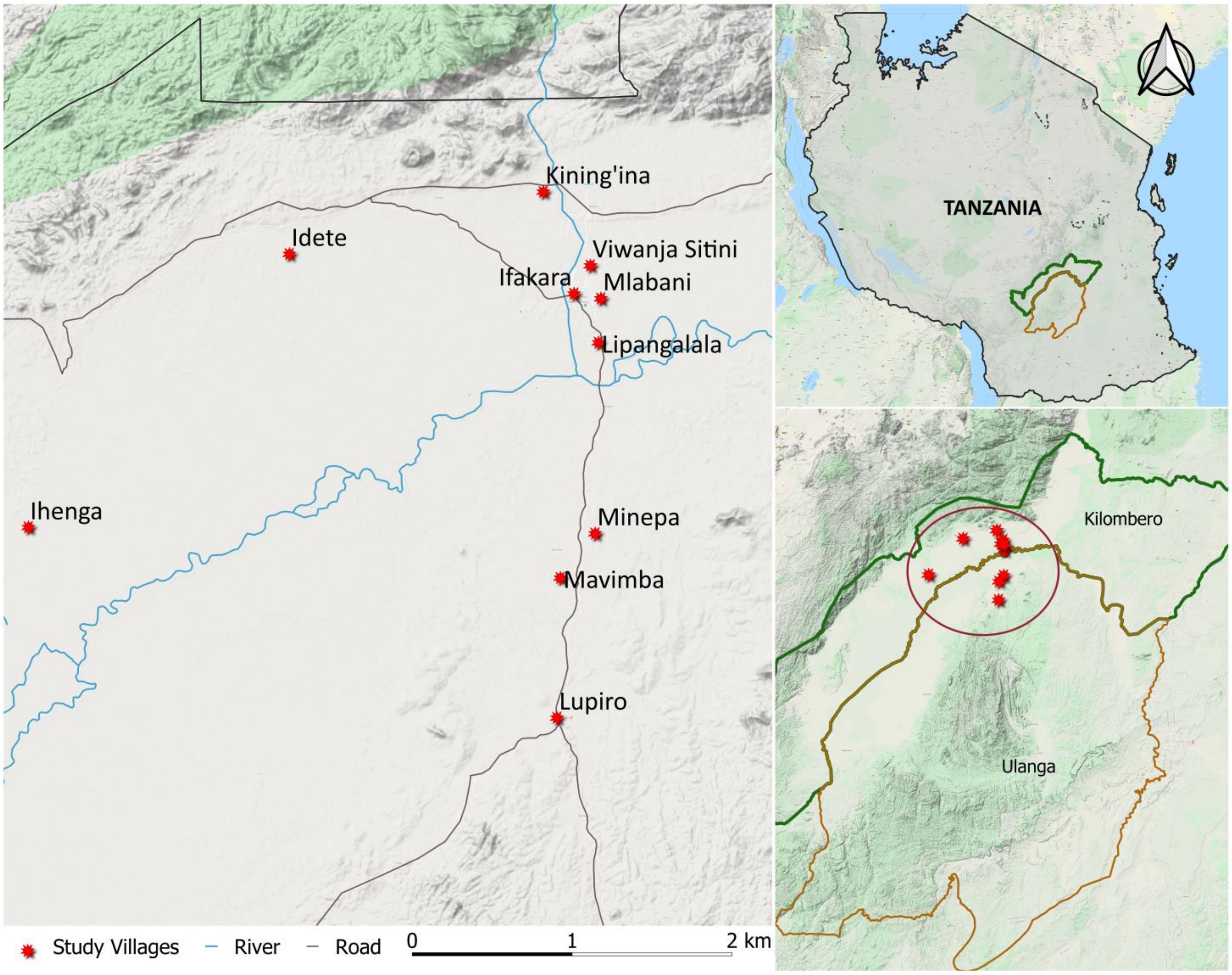

Figure 5.1: Map of the districts and villages where the study was conducted. Map prepared by Najat Kahamba.

5.3.1: Study design and data collection

An exploratory sequential mixed-methods approach (142) was used. Focus group discussions (FGDs) were held with community leaders from each of the ten selected wards to explore in detail their perceptions of mosquito modification. Community leaders are government officials elected by the community members every two years, do not belong to any political party, and represent their respective villages in several district- and regional-level meetings. Their responsibilities include resolving conflicts, authorizing property sales, and monitoring migration in and out of their communities. Two community leaders, one male and the other female, were selected in each of the ten villages. Two separate FGD sessions were conducted, one with the female and another one with the male leaders, and were facilitated by MFF and a research assistant in Swahili language. The sessions were held in May 2019. Each session took around two hours. The discussions were structured to elicit vernacular modes of reasoning about mosquito modification, and the prospect of releasing modified mosquitoes to combat malaria. Specific attention was paid by the moderator to the analogies and examples that participants used to characterize GMMs.

Due to the low levels of awareness of mosquito modification technologies, FGD participants were provided with a brief PowerPoint presentation on mosquito modification to prompt and facilitate informed discussions. The presentation covered different approaches (i.e., sterile insect technique, male RIDL mosquitoes, and gene drive technology). The presentations also included basic information on how the mosquitoes are modified and released, and the current stage of development of each approach. These materials were designed to avoid any value judgment on the potential of any particular approach, so as to preempt, to the extent possible, any interpretive bias among participants. The discussions were guided to elicit participants' views on each of the mosquito modification technologies, including any perceived risks and benefits, and on the factors that might determine acceptance by the local community.

Following preliminary analysis of the FGD, a structured questionnaire was developed and administered to community members in the ten selected wards to assess their prior awareness, knowledge and perceptions of mosquito modification technologies for malaria control. According to data from the Ifakara Health and Demographic Survey System (195), the selected wards encompass a total of 11,000 households. Assuming a response rate of 80% and 95% confidence interval, we estimated that we would need a sample size of 463 household representatives. We rounded this number to 500 representatives to account for lack of consent. The 500 households were equally divided between the wards; in each of the ten wards, 50 households were randomly selected using Excel RAND function, and the selected households were visited by the study team accompanied by community leaders. One consenting adult in each household was interviewed. The survey was carried out between November and December 2019, and was administered using Kobotoolbox™ software (149) on electronic tablets. The study team asked the respondents questions and recorded their answers on the tablets.

5.3.2: Data processing and analysis

The proceedings of the FGDs were transcribed and analysed by MFF, EM, RN and WM. Verbatim transcriptions of the FGDs were translated from Swahili to English, and imported into NVIVO 12 Plus software (151) for coding. Both deductive and inductive coding were used. The FGD guide was used to develop deductive codes, but since the technologies under discussion were new to the participants most of the codes were generated inductively after extensive reviews and coding of the transcripts. Recurrent themes were extracted from the emergent patterns. Direct quotes from FGD participants are used below to illustrate some of the key themes.

R statistical software version 4.0.0 (152) was used to analyse the socio-demographic characteristics of the survey respondents, and to summarise their knowledge and awareness of GMMs. Since a vast majority of respondents lacked knowledge and awareness regarding the technology, no further analyses were necessary. Instead, lay presentations about the technologies were provided to prime further discussions in the FGDs.

5.4: Results

5.4.1: Characteristics of study respondents

A total of 506 people participated in this study; 16 community leaders who took part in the two FGD sessions; four leaders were unable to participate in the discussions due to various reasons. Three of the FGD participants had secondary school education (12 years of formal education), and the rest had primary school education (7 years of formal education).

A total of 490 community members responded to the survey. A detailed description of the survey respondents is provided in Table 5.1. The mean age was 42.5 years (range: 18-88), and were about equally divided between men and women. A majority of the respondents were married, had primary school education, and reported farming as their main income generating activity (Table 5.1). The reported average monthly household income was 132,155 Tanzanian shillings (~60 USD).

Table 5.1: Socio-demographic characteristics of the survey respondents (n=490)

Characteristics	**Category**	**n (%)**
Age (in years)	18 – 35	186 (37.9%)
	36 – 55	207 (42.3%)
	56 – 88	97 (19.8%)
Sex	Male	210 (42.9%)
	Female	280 (57.1%)
Marital status	Married	321 (65.5%)
	Not married	82 (16.7%)
	Divorced/separated	39 (8.0%)
	Widow/widower	48 (9.8%)
Highest educational level achieved	No formal education	43 (8.8%)
	Primary school	358 (73.0%)
	Secondary school	68 (13.9%)
	College/university	21 (4.3%)
Main income generating activities**	Farming	413 (84.3%)
	Entrepreneurship	174 (35.5%)
	Fishing	12 (2.4%)
	Animal husbandry	23 (4.7%)
	Formal employment	13 (2.7%)

** The totals add up to more than 100% because some participants chose to report more than one income generating activities.

5.4.2: Community awareness of malaria burden

Previous surveys in the study area have shown high levels of awareness among residents of these communities about malaria and its transmission by *Anopheles* mosquitoes (26,196,197). In this study, two thirds of the respondents (65.1%, n=319) believed that rural communities experienced higher burden of malaria, 63.9% (n=313) believed that poor communities experienced a higher burden of malaria, and 61.3% believed that transmission occurred mostly outdoors. However, when asked about specific details, only 15.3% (n=75) had a good estimate of current malaria prevalence in the country (as reported in the 2018 Malaria Indicator Survey report (16)). Approximately a half (51.6%, n=253) of all respondents believed that the country was making good progress in malaria control. 59.6%, (n=292) believed that it was possible to achieve elimination with the current interventions, but 86.1% (n=422) of respondents indicated that alternative interventions would be necessary to accelerate elimination efforts.

5.4.3: Community views on novel interventions for malaria control

All survey participants responded that any new technologies for malaria control should be effective, affordable, meet in-country regulations and community preferences, and be safe to people, animals and the environment. When asked about trusted sources of malaria-related information, health researchers and health care workers were ranked higher than government officials or politicians (Table 5.2).

Table 5.2: Community members' levels of trust for sources of information on malaria control interventions (N = 490)

Variables	Highly trusted	Somewhat trusted	Somewhat distrusted	Strongly distrusted
Health researchers	91.2%	7.6%	0.4%	0.8%
Health care workers	91.2%	8.2%	0.4%	0.2%
Government officials	84.9%	12.7%	1.6%	0.8%
Politicians	55.3%	26.1%	9.0%	9.6%

5.4.4: Awareness of mosquito modification technologies for malaria control

A vast majority of survey participants (94.3%, n=462) reported no prior awareness of mosquito modification technologies for malaria control. For the 13 respondents who were aware, the primary sources of information were Ifakara Health Institute staff, and radio or television. Likewise, nearly all participants (97.3% (n=477) reported no knowledge of how any of these technologies worked. When asked if they thought modified mosquitoes had ever been released in their communities, 83.5% (n=409) said they did not know and 16.5% (n=81) said they had not been released.

5.4.5: Community leaders' perceptions of mosquito modification

None of the community leaders who participated in the focus group discussions reported any prior knowledge of mosquito modification technology. They were able to discuss the subject at length and in detail, however, once they were provided with a brief presentation of issue. They often expressed a great deal of fascination over this approach to malaria control, preferring it over other malaria control interventions. Key attributes of the technology mentioned to justify this preference were the improvement of environmental safety (as a result of reducing the use of chemical insecticides), and the little effort the technology appeared to require from local residents (in contrast to other malaria control methods, such as larviciding or home improvements, deemed more labor intensive).

Although three distinct approaches of mosquito modification were presented to FGD participants, participants showed a clear preference for discussing gene drive technologies, and in particular the male-biased sex distorter gene drive that is currently being considered for deployment in several sub-Saharan countries (198). Gene drive technology was preferred because it was seen to require fewer releases of modified mosquitoes compared to the other two, a fact that participants thought would help reduce community skepticism towards the intervention.

> "*It is better if you do not release mosquitoes all the time. Even if people agree that you release mosquitoes, if you do it a lot they may start asking questions again, then you have to spend a lot of time convincing them. But I like this one that does*

not kill mosquitoes, but makes them have male babies. With this one you can do it just one time, then it is good." (Female).

As the above quote suggests, several participants were intrigued by the idea of eliminating mosquitoes by biasing the sex distribution of their offspring, rather than by killing them directly. This was in some cases considered a more humane way of eliminating the mosquitoes.

"I really like the idea of making them have just male babies, because, you see, males do not bite, and without females they cannot have babies. This way even your consciousness is clean, you have not killed them directly, you have just manipulated them and they will eventually die off. This is a very good and very advance technology" (Male).

5.4.6: Framings and analogies used to describe mosquito modification

Although FGD participants were unfamiliar with mosquito modification, they immediately grasped its public health logic by reference to their knowledge of cross-breeding and hybridisation. Several participants indicated that the best way to explain this technology to people in the community would be to describe it as a form of '*kupandikiza*', a term that can be literally translated as transplantation but is commonly used to describe hybrid plants. The term was used, without any prompt from the facilitator, in both FGD sessions. Participants used the example of the hybrid maize seeds that they buy in agricultural shops, which have a relatively higher yield and can better withstand drought than local maize varieties. FGD participants also referred to the technology as *'kubadilisha mbegu',* the practice of 'changing seeds.' The term is generally used to describe the introduction of desirable traits in crop seeds and domestic animals through cross-breeding. Several participants mentioned for example that they often borrow or pay for the use of their neighbours' male animals in order to get offspring with the desired traits.

"I do it often with my chickens. I don't have a strong rooster, but my neighbour has a very big one. So I ask my neighbour for her rooster to spend time with my chickens, then I can get its seeds. Everyone does that." (Female)

“It is very common with pigs. Sometimes there is one person in the village who has a very big boar, so then, if you want to get its seeds you pay that person money so that the boar can mate with your sows. Sometimes you pay money or sometimes you pay him with a litter. But we do that so that we can have the seed for big pigs.” (Male)

5.4.7: Will the modified mosquitoes look and behave differently?

Participants expressed curiosity and concern over the appearance and behaviour of the modified mosquitoes. They wondered, for example, whether or not the mosquitoes would look the same as ‘local’ mosquitoes. Participants drew again an analogy with their experience of selectively-bred animals or hybrid maize, and concluded that the modified mosquitoes would necessarily look different.

“Yes, they always look different. Even when we plant the hybrid maize, it does not look the same as our local maize, it has better yield, and you can tell just by looking that it is different kind of maize.” (Female)

Village leaders were also keen to know whether modified mosquitoes would still bite people, and whether or not current mosquito control tools could or should be applied to them.

I would like to know, if you want those traits to pass to their offspring, will we still need to kill these modified mosquitoes? Will they still bite people? If they bite, people will still want to kill them, and if they do, then it may not work.” (Male)

5.4.8: All mosquitoes are a nuisance; why not just eliminate all of them?

A majority of FGD participants suggested that technologies of mosquito modification should target all mosquitoes, and not just those transmitting malaria. This line of argument was particularly relevant for genetic modification approaches aimed at population replacement, and participants expressed the fear that modified mosquitoes, if they became a feature of the environment, would still be able to carry other pathogens. Additionally, participants stressed the fact that mosquitoes are always a nuisance, regardless of the species; their bites are itchy, painful and cause allergies, so it would be beneficial to just eliminate them altogether. Some participants drew a direct analogy with their experience of jiggers (*Tunga penetrans*) and lice, which were once prevalent in the region but have been eliminated altogether in their communities. They expected a similar sort of objective should be pursued in the case of mosquitoes.

> *"We should just eliminate all mosquitoes, the way jiggers were eliminated. In the past there were so many jiggers; as kids we had to go to the hospital to get them removed from our feet. But then something was done and they all disappeared. These days you never hear about them, and the children these days do not even know what jiggers are. I would like that to be the case with mosquitoes, all of them. I would be happy if the future generations do not know anything about mosquitoes, maybe they should only see them in the pictures."* (Male)

FGD participants drew a direct connection between the effectiveness of the intervention and a reduction in the overall density of mosquitoes. They argued that people would only have faith in the merits of the technology if they saw a substantial reduction in nuisance biting. They further noted that most people are unable to distinguish between malaria vector and non-vector mosquito species, and thus would fail to appreciate the impact of the intervention if it was limited to a single species.

> *"But why would you want the other mosquitoes to remain? For me that is a challenge, that there will still be mosquitoes. People may think that it is not working. The other technologies kill mosquitoes, so then you will know that mosquitoes are not as many. But with this technology there will still be mosquitoes – even if they do not spread malaria, but people will not know that."* (Female)

A few participants, however, did note that mosquitoes also have a place in the ecosystem, and thus supported the idea of eliminating only those responsible for malaria transmission. They pointed out that it would be impossible to eliminate all mosquitoes, because they had never been to or heard of a place where they are completely absent. They further expressed the view that it would be highly important to inform the community that not all mosquitoes would be eliminated, just the ones that spread malaria, so as to prevent mistrust of the technology.

> *"I do not think there is a need to eliminate all the others if they are not transmitting anything. Remember, there are other birds and other insects that feed on mosquitoes, so it is no use to kill something that is harmless. You know, even in countries that do not have malaria there are still mosquitoes. I know this. So then it is okay to have mosquitoes that do not have malaria. You just need to teach people to differentiate malaria mosquitoes from other mosquitoes so that they know the difference."* (Male)

5.4.9: Importance of engaging and educating community members

All FGD participants stressed the importance of educating and engaging the community in the development of these technologies. They emphasized that this should be done not just once but repeatedly until their level of awareness and knowledge was such that they could participate in any decision to bring the technology into the community.

> *"It is just very important to make sure that people are well aware of this technology. You have to educate them well. Tell people the benefits of this science, and the risks of continuing to have malaria mosquitoes. I think people should know what can happen if people agree to have these mosquitoes released, and what will happen if they do not. For example, you can talk to people maybe two or three times every month, and do it like that until it becomes a common thing that people talk about. That is when you can come with the modified mosquitoes. It is like that. If you do not do this then it may bring very big problem, and people may even attack you, chase you or embarrass you"* (Female)

FGD participants advised that, in order to win the trust of people, researchers would need to come up with means to show people the attributes of this technology, rather than just tell them. Village leaders explained that more efforts are still needed to educate people on different mosquito species, and on how to differentiate between malaria-transmitting and other mosquitoes. Without a degree of familiarity with these issues, it was noted that it would be impossible to convince people that the mosquitoes being released were harmless.

> *"When you go there with your mosquitoes and tell them that you want to release them, they will ask you if the mosquitoes can harm them, and you will say that these are harmless mosquitoes. They will then ask you to prove it. How will you do that? You will have to find a way of demonstrating to people that these mosquitoes are harmless. If you just tell people that any mosquitoes are harmless you are in for trouble. We all know that all mosquitoes spread diseases, and that all mosquitoes are bad."* (Male)

5.5: Discussion

Historically, the release of modified mosquitoes has received a mixed response from the communities hosting these interventions (199,200). Current field research projects on mosquito modification include extensive campaigns of public information and engagement (47,126,201). It has become abundantly clear that these campaigns must start well in advance of the deployment of the technology, and that they should be preceded by research into the concerns, expectations and interpretive frames that local residents bring to bear on the prospect of making disease control reliant on the introduction of altered mosquitoes into the environment (44,76,202).

This study attempted to explore perceptions of mosquito modification technologies in a region of southern Tanzania where no trials of modified mosquitoes have yet taken place, but where the epidemiology of malaria might in the near future recommend their use. This is a region, furthermore, where many other malaria control interventions have been piloted in the past, and where a significant proportion of the population is familiar with entomological research, thanks to the long-term presence of the Ifakara Health Institute

(26). Our study provides the first social scientific evidence on public perspectives on mosquito modification in Tanzania.

Nearly all community members that responded to the survey reported no knowledge or prior awareness of mosquito modification technologies for malaria control. This is understandable, since no releases have taken place in the country to date, and local and national media have offered very limited coverage of debates on this issue elsewhere in the region. Similar findings have been observed in Mali and Nigeria (178,179), for example, as well as in high-income countries such as United States of America, where a 2016 survey indicated that 46% of respondents reported no prior information about gene-edited mosquitoes (203). The generalized lack of knowledge and awareness made it difficult to assess in detail public perceptions of the technology, at least through a standardized survey questionnaire. FGDs were introduced to allow us to explore mosquito modification technologies in some detail with a select group of local residents, so as to study in depth the specific conceptual frames that might be used to make sense of the technology.

Although all FGD participants had never before heard about mosquito modification, they all expressed a great deal of fascination over this approach to malaria control once the discussions got underway. FGD participants associated the technology to several aspects of their lived experiences, specifically the practice of cross-breeding domestic animals to select for preferred traits, or the adoption of hybrid crop seeds that provide better yield and drought protection. The prospect that similar techniques could be used to eliminate malaria appeared therefore intuitively plausible, even before the specific principles of each form of mosquito modification were discussed.

The analogy with forms of biological modification familiar to local residents also shaped their initial consideration of risk, as it allowed them to balance any potential hazards the technology might carry with the promise of a direct benefit. Similar findings have been reported in the US, where support for genetic modification increased once the potential risks and benefits of the technology were communicated to the people (180). A study by

Widmar *et al* (2017), for example, indicated that genetic modification was most acceptable when used in human medicine and in disease control (204). In our case, participants were relatively supportive of the approach once mosquito modification was contrasted with other malaria control interventions, partly because it was seen as requiring less direct participation from the community, and because it was thought to reduce environmental risks they associated with other interventions (i.e. extensive use of chemicals in IRS, ITNs, or larviciding).

After being presented with several forms of modification, participants expressed the greatest interest in gene drive applications, particularly male-biased sex-distorting alterations. This was due to the low perception of risk associated with male mosquitoes and the high perception of risk associated with female mosquitoes. Previous research in the study site indicate near universal awareness in the community that malaria is transmitted by female *Anopheles* mosquitoes, and that male mosquitoes do not transmit any diseases (176,205). The participants also pointed out that the gene drive approach would require fewer and smaller releases compared to other mosquito modification technologies (34,35).

FGD participants contemplated the possibility that modified mosquitoes would look or behave differently than local mosquitoes, and sought further clarification on this particular point. These concerns, although expressed mildly in this case, have led to major controversies over the release of modified mosquitoes in the past. Examples include fears that mutations in the mosquito itself, or in the pathogen, could result in higher rates of disease transmission in the future, or that the modification introduced in the mosquito could be transmitted to humans through biting (45,134,178). It is crucial that these concerns are given careful consideration, and that researchers and sponsors of these technologies are in a position to allay these fears with adequate scientific evidence.

Participants in our FGDs also expressed the concern that eliminating just one mosquito species would not be enough, and would fail to garner sufficient public support for the intervention. This concern can be explained by the fact that people are generally unable to differentiate between malaria vectors and other mosquito species, and that the effectiveness of most other malaria vector control interventions is assessed against a reduction of overall mosquito density. It is estimated that malaria vectors in this region account for less than 10% of the overall mosquito population (26,160), and some key vector species, such as *Anopheles funestus*, represent a small proportion of anophelines. A technology targeting only a key vector species might be seen as not working if the community experiences little difference in their overall exposure to mosquito nuisance.

Addressing these perceptions and concerns will require a proactive strategy of public outreach. Community engagement in public health research needs to go beyond simply providing the community information or consulting users for their views. An effective program demands building durable partnerships between researchers and the community, eliciting and addressing concerns in terms that resonate locally, and through a process that is embedded within, rather than abstracted from, their everyday lives (44).

Participants in our study emphasized that it would not be enough to simply raise awareness about these technologies; people needed to be fully engaged in order to make sense of the technology in their specific context. They stressed the need to demonstrate, rather than tell, the safety and effectiveness of the intervention. Similar findings have been observed in studies carried out in Mali and Nigeria, where respondents asked that evidence of the technology's safety and effectiveness be provided before they could allow it in their settings (178,179). These discussions suggest that education is an iterative process, and that the provision of the facts of how the technology works is only a first step. To truly grasp the public health potential and significance of mosquito modification, communities would need to be able to contextualise these technologies within their everyday life, to translate abstract technical operations into practical concerns.

This study is not without limitations. Only two FGD sessions were conducted, which is a rather small sample size, and the community leaders that participated in the discussions represent a particular segment of the population. Additionally, the study was conducted among communities that have long been associated with public health and entomological research campaigns through Ifakara Health Institute, and therefore are knowledgeable about malaria transmission and prevention. These limitations to generalizability notwithstanding, the two groups still generated a wealth of qualitative data on the preferred interpretive frames and the most salient concerns that local residents in a rural, malaria-endemic region of Tanzania express in relation to the prospect of using modified mosquitoes as a public health tool. Further studies should be undertaken in communities that may be less familiar with malaria control practices, and to explore in greater depth responses to specific forms of mosquito modification. We believe that this study can serve as a baseline from which to develop more granular investigations of local concerns and perceptions, and upon which to build a robust and effective set of tools for public engagement.

5.6: Conclusion

Understanding how communities perceive and interpret new public health technologies is crucial in generating durable support for these interventions. This study offers vital clues on how rural communities without prior awareness of mosquito modification technologies respond to the prospect of using genetically-modified mosquitoes as a tool for malaria control. Despite the lack of prior knowledge, FGD participants offered a set of distinctive interpretive frames to interpret mosquito modification technologies, referring in particular to their experiences selecting preferred traits in domestic plants and animals through cross-breeding. These interpretive frames and locally resonant analogies provide a basis for effective community engagement to address any specific concerns, support further social scientific research, and potentially aid in the future development and deployment of such technologies for malaria elimination. The findings of this study may find broader application in other settings where GMMs or similar approaches are being planned.

Chapter 6: Addressing key gaps in implementation of mosquito larviciding to accelerate malaria vector control in southern Tanzania: results of stakeholder engagement process in Morogoro region

6.1: Abstract

Larval source management was historically one of the most effective malaria control methods but is now widely deprioritized in favor of insecticide treated nets (ITNs) and indoor residual spraying (IRS). However, in Tanzania, following initial successes in urban Dar-es-Salaam starting early-2000s, the government now encourages larviciding in both rural and urban councils nationwide to complement other efforts, and a biolarvicide production-plant has been established outside the commercial capital. This study investigated key obstacles limiting effective rollout of larviciding in the meso-endemic region of Morogoro, southern Tanzania.

Key-informants were interviewed to assess awareness and perceptions of larviciding among designated malaria control officials (N = 27) in seven districts, this includes malaria focal persons, vector surveillance officers and ward health officers. Interviewer-administered questionnaires were used to assess awareness and perceptions of community members (N = 490) in selected areas regarding larviciding. Thematic content analysis was done and descriptive statistics were used to summarize the findings.

A majority of malaria control officials had been involved in implementation of larviciding at least once over the past three years. There was general support for larviciding in the districts, but also several challenges, notably: i) insufficient knowledge for identifying relevant aquatic habitats of malaria vectors and applying larvicides, ii) poor monitoring of program effectiveness, iii) limited financial resources and personal protective equipments. Although the key-informants reported sensitizing local communities, most community members were still unaware of larviciding. Nonetheless, support for larviciding for malaria control was high among all survey respondents.

The larviciding program was widely supported by both communities and malaria control officials, but there were gaps in technical knowledge, implementation and public engagement. To improve overall impact of the program, it is important to: i) intensify training efforts, particularly for identification of aquatic habitats for important vectors, ii)

adopt standard technical principles for application of larvicides, iii) improve financing for local implementation and iv) improve public engagement to boost community awareness and participation. These lessons could be valuable for other malaria endemic areas wishing to deploy larviciding for malaria control or elimination.

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*These authors had equal contribution to writing the manuscript

See appendix 5

6.2: Background

The world has witnessed a significant reduction in malaria burden since 2000 (206), mainly attributable to insecticide-treated bed nets (ITNs), indoor residual spraying (IRS), as well as effective case management (207,208). Yet, there were still more than 200 million cases, and 405,000 deaths globally in 2018, 90% of these in sub-Saharan Africa (206). Malaria control efforts are increasingly compromised by several factors, chief among them, parasite resistance to anti-malarial drugs (209,210), behavioral adaptation of mosquitoes to indoor methods of protection (25,211) and growing insecticide resistance in key malaria vector species (3,54). Anthropological factors continue to play a crucial role in mediating transmission, and people's behaviors, economic practices and perceptions of risk can increase dangers of infectious malaria vectors (26,212–214).

Malaria vector control in Tanzania is a major component of the fight against the disease, and has focused mainly on provision and use of ITNs and IRS (17,18,20,21,215). Vector control has been complemented with pharmaceutical interventions, such as increased access to reliable and affordable diagnostics and treatment (22), and universal distribution of prophylaxis for pregnant women (23). These efforts, combined with a general improvement in economic opportunity, have led to a tremendous decline in malaria transmission throughout the country (23,216).

Environmental management to eliminate mosquito aquatic habitats was among the first malaria control strategies attempted in the country, including improving drainage systems and the elimination of the permanent bodies of stagnant water near large human settlements (217). In recent times, the first major use of larviciding in Tanzania was in Dar-es-Salaam in early 2000s (130,218). These studies demonstrate that the application of biolarvicides by community-owned resources persons (CORPs) achieved as much benefit as ITNs (218).

The Tanzania National Malaria Strategic Plan, 2014-2020 recommended implementation of larviciding in selected urban settings (219), in line with World Health Organization guidance to conduct this type of intervention only in settings where malaria vectors breed in few, fixed and findable aquatic habitats (220). This policy initially was limited to the urban population, but in recent years the government has encouraged the extension of larviciding efforts to rural settings (221).

The nationwide expansion of larviciding followed the creation in 2014 of Tanzania Biotech Products Limited (TBPL), which is responsible for the production and distribution of biolarvicides (150). Since 2017, TBPL has been manufacturing two types of biolarvicides, *Bacillus thuringiensis var. israelensis* (*Bti*) and *Bacillus sphaericus* (*Bs*) (150). These products are procured by the district councils across the country, and distributed to all administrative wards. Councils often reserve budgets to compensate community-health workers (CHWs) and volunteers involved in community initiatives such as larviciding (222).

These recent developments by Tanzania to expand larviciding are excellent examples of the much-needed ownership for sustainable vector control, especially given the use of the domestic resources. If sustained, it could yield significant gains over what is currently accrued from the core interventions, and in the process generate important lessons for other countries. Unfortunately, given its extensive scale and novelty, there are still multiple challenges that must be addressed to achieve maximum impact. For example, major malaria vectors in the country use a wide variety of aquatic habitats, which in some cases are insufficiently characterized (223). Moreover, larviciding is also labor intensive requires active community involvement. These factors make targeted larviciding a significant challenge especially in rural areas.

This study therefore aimed to identify and characterize important gaps in the ongoing implementation of larviciding in Tanzania. Investigations were done on perceptions and experiences of key actors of larviciding in different district and municipal councils. Given the previously existing research engagements this study focused primarily on the mostly meso-endemic region of Morogoro, southeastern Tanzania.

6.3: Methods

6.3.1: Study area

The study was conducted in seven districts in the Morogoro region in southern Tanzania between October 2019 and March 2020. The area has a total population estimated at 2,218,492 people (224), and is currently classified as meso-endemic, with malaria prevalence estimated at 10% according to the most recent estimates (225). The study covered seven district councils, i.e. Gairo, Mvomero, Kilombero, Ulanga, Kilosa, Morogoro and Malinyi, and one municipal council (i.e. Morogoro municipal council) and Ifakara township council (Figure 3.1). The classification of the council into district, municipal and township is based mostly on population, size of the area and ability to generate revenue. For instance, a municipal council should have at least a population of 100,000, manufacturing industry, university, referral hospital and being able to run on its revenue by 70% (226,227). A township council should have a population of at least 30,000 people, and be able to run on its revenue by 50%. The community members surveyed were from Ulanga and Kilombero districts only.

6.3.2: Selection of stakeholders

Stakeholders selected for interviews included district health officials. These were malaria focal persons (MFPs), vector surveillance officers (VSOs) and ward health officers. Malaria focal persons are medical doctors or environmental health specialists in charge of all malaria related-matters at the district level. They have a degree in either medicine or environmental health science. In this study, all MFPs had been at their current position for at least two years. They are responsible for all aspects of malaria control in the district, including monitoring the trend of malaria cases, deaths and control.

Vector surveillance officers are environmental health specialists with a diploma in environmental health science and a special training in disease-vector control. VSOs are responsible for organizing, supervising and executing disease-vector control programmes at the district level. Ward health officers are also environmental health specialists and are responsible for all health-related issues at the ward level. They have a diploma or certificate in environmental health science, and their responsibilities include planning, supervising, monitoring and evaluating overall health services at the ward level. Each district has one MFP, one VSO and multiple ward health officers, although in some cases one ward health officer could serve multiple wards within the district.

Malaria focal persons and VSOs were recruited from all district, municipal and town councils within Morogoro region. Ward health officers were recruited from a randomly selected ward in each district, municipal or town council; each of seven districts involved in this study has between eight and thirty-eight wards. For the community survey, households were randomly selected from ten randomly selected wards in Ulanga and Kilombero districts in the region (Figure 3.1).

6.3.3: Study design and procedures

A concurrent triangulation mixed method study was used (141), incorporating key informant interviews (KII) and survey questionnaires. Key informant interviews were done with MFPs, VSOs and ward health officers. The interviews aimed to obtain information on the degree of awareness, experiences and perceptions of the MFPs, VSOs and ward health officers regarding larviciding. These interviews were conducted by the authors, SAM, MFF and IHN, between February and March of 2020 at the respective district offices. The interviews were audio-recorded following the consent of the participants; audio recordings were supplemented by hand-written notes. Each interview lasted between 15 and 60 minutes.

The surveys were conducted in Swahili language with community members from Ulanga and Kilombero district. These were used to gather data on awareness and perceptions of larviciding as a malaria control intervention. Kobotoolbox™ software (149) was used to administer the surveys via electronic tablets, between November and December 2019. The individual-level perception of community members towards larviciding was assessed by measuring the level of agreement towards positive statements on larviciding using a 5-point Likert-scale, ranging from strongly agree (1) to strongly disagree (5). The statements were as follows: i) larviciding will be effective for malaria control, ii) larviciding will fill gaps left by other interventions, iii) larviciding is safe for humans, animals and the environment, iv) larviciding will be easy to perform, v) larviciding supplies and equipment will be easily accessible, vi) larviciding will be affordable to community members and vii) larviciding will be acceptable in the community. The final perception level was determined by comparing individual perception scores against the median score (see data analysis section).

In addition, one joint stakeholder engagement meeting was conducted at the regional office, where all the MFPs and VSOs from the nine districts and councils participated, together with Ifakara Health Institute researchers. Discussions at this meeting involved options for improving larviciding operations in the respective councils, and what roles different stakeholders could play.

6.3.4: Data processing and analysis

Audio recordings of the key informant interviews were transcribed immediately following the discussions and translated from Swahili to English language. Field notes were added in the written transcripts. The written transcripts were analyzed using NVIVO 12 Plus software (151). Deductive and inductive coding were used to categorize the codes items. A KII guide was used to develop the deductive codes while the inductive codes were generated based on thorough reviews of the transcripts. Similar codes were grouped and emergent patterns used to identify themes. The extracted themes included: i) knowledge about larval habitats of malaria vectors, ii) awareness of larviciding as a malaria control intervention and iii) challenges facing the implementation of larviciding. Direct quotation from participants were used to support the themes. Information from the key informant interviews and survey were triangulated during the discussion of the findings (228).

The quantitative data on the other hand was analyzed using R statistical software version 4.0.0 (229). First, the sum of the scores of the seven statements was calculated for each survey respondent, and then a median of these scores calculated. Perception level was determined by comparing individual perception scores against the median perception score; scores above the median were considered negative perception and scores at or below the median score were considered positive. Internal validity of the scale was measured by calculating Cronbach's alpha (153). Univariate analyses were used to determine influence of the respondent sex, age group, education level and degree of previous awareness of larviciding on the main outcome variable, i.e. their perceptions of larviciding. Binary logistic regression was used to determine the association between the independent variables and the outcome variable; odds ratio was calculated at 95% confidence intervals (CIs).

6.4: Results

6.4.1: Characteristics of study respondents

A total of 517 people (43% (n=222) men and 57% (n=293) women) participated in this study; 27 as key informants in the in-depth interviews, and 490 community members responding to the administered questionnaires. Nineteen of the 27 KII participants were men, and all participants had a college or university degrees. The average age of participants in KII was 45 years, ranging from 33 to 60 years. Average duration of employment in their current position and at their current location was 7 years, ranging from six months to 35 years (Table 6.1).

Average age of the community members who participated on the survey was 42 years (range: 18 – 88 years) and approximately two thirds (65.5%, n=321) were married. About three quarters (73.1%, n=358) of the respondents had primary school education, 8.8% (n=43) had no formal education, 13.9% (n=68) had secondary education and 4.3% (n=21) had college-level education. A majority (84.3%, n=413) of the respondents reported small-scale farming as their main income-generating activity, but people also practiced small retail businesses, fishing, animal husbandry or had formal employment.

Table 6.1: Characteristics of Key Informant Interviewees

Key Informants	Mean age in years	Average years of service	Males	Females	Total
Malaria Focal Persons	40.1	4.5	6	3	9
Vector Surveillance Officers	47.9	7.4	6	3	9
Ward Health Officers	47.2	9.2	7	2	9
All Participants	**45.1**	**7.0**	**19**	**8**	**27**

6.4.2: Perception of the malaria burden

Nearly a half (48.2%, n=236) of the survey respondents reported not knowing the current malaria prevalence range in Tanzania. Only 15.3% (n=75) identified correct range of nation-wide prevalence (6-10% based on 2018 Malaria Indicator Survey (225)). Two thirds believed that rural communities or poor households suffer the heaviest burden. More than a half of respondents believed the country was progressing well towards elimination, and that it could achieve elimination with current interventions. However, a majority (86.1%, n=422) of the survey respondents noted that alternative interventions would be necessary to speed up these efforts (Table 6.2).

6.4.3: Awareness of larviciding as a malaria control intervention among community members

Approximately a quarter (26.1%, n=128) of survey respondents were aware of the government policy to include larviciding as a malaria intervention (Table 6.3), and more than a half (52.2%, n=255) did not know whether the intervention was ongoing in their districts. Three quarters (74.1%, n=363) also did not know the mode of action of larvicides despite knowing what the intervention itself is. Older respondents (46 - 55 years) were more aware of larviciding than those 25 years or younger.

6.4.4: Perception of larviciding among community members

Perception of community members towards larviciding was assessed based on levels of agreement towards positive statements on a 5-point Likert-scale, ranging from strongly agree to strongly disagree. The median score of the seven statements was 21. Reliability assessment of the perception scale yielded a Cronbach alpha score of 0.77, indicating an acceptable level of reliability of the scale and without any redundancy.

Of all survey participants, 40.4% (n=198) agreed that larviciding would be acceptable in their community as new intervention. However, a majority of the community members had neutral perceptions on whether larviciding would be effective, safe, feasible, accessible, affordable or acceptable for malaria elimination (Table 6.4). Community members who were previously aware of larviciding were more likely to welcome larviciding compared to respondents without previous knowledge prior to the survey (p = 0.029), Table 6.5). However, nearly three quarters (74.2%, n=364) of respondents said they would support larviciding if introduced to their communities.

6.4.5: Awareness, perceptions and experiences of district and ward-level health officials regarding larviciding for malaria control

Important aquatic habitats of malaria vectors: Generally, most KII participants reported that they knew the general characteristics of mosquito aquatic habitats, but not all were able to distinguish between habitats of key malaria vectors from other habitats. When asked to describe the aquatic habitats of important malaria vectors, respondents used terminologies such as fresh waters, standing waters, pit latrines, trash pits, septic pits, used tires, long grass and bushes.

Table 6.2: Perceptions of community members regarding malaria risk and burden (n = 490)

Questions asked	Variables	Percentage (n)
Which settings at highest risk of malaria?	Rural settings	65.1% (319)
	Urban settings	7.6% (37)
	Equal in rural and urban settings	23.7% (116)
	Do not know	3.7% (18)
Which communities are most affected by malaria?	Low-income communities	63.9% (313)
	All communities are equally affected	33.7% (165)
	Do not know	2.5% (12)
Where does most malaria transmission occur?	Outdoors	61.3% (300)
	Indoors	36.7% (180)
	Do not know	2.0% (10)
What is your opinion regarding country's progress towards malaria elimination	Very good	51.6% (253)
	Good but slow	43.9% (215)
	Very slow	4.5% (22)
Can malaria be eliminated	Possible	59.6% (292)
	Not possible	40.4% (198)
Do we need alternative interventions?	There is a need	86.1% (422)
	No need	13.9% (68)

Table 6.3: Knowledge and awareness of larviciding among community members (n = 490)

Variable assessed	Response	Percentage (n)
Awareness of larviciding (n=490)	Yes	26.1% (128)
	No	73.9% (362)
Sources of information (n=158)	Friends/family	48.1% (76)
	Radio/TV	21.5% (34)
	IHI scientists	10.8% (17)
	Community meetings	7.6% (12)
	Saw on a visit in Dar es Salaam	7.6% (12)
	Community health workers	4.4% (7)
Has larviciding been implemented in the community	Yes	4.5% (22)
	No	43.5% (213)
	Do not know	52.2% (255)
Larviciding works by killing mosquitoes in their juvenile stage	Agree	23.9% (117)
	Do not agree	2.0% (10)
	Do not know	74.1% (363)

Table 6.4: Perception of community members regarding effectiveness, feasibility, affordability and acceptability of larviciding for malaria prevention (n = 490).

Statement	Strongly agree (1)	Agree (2)	Neutral (3)	Disagree (4)	Strongly disagree(5)
Will be effective	29.8%	14.7%	54.5%	0.4%	0.2%
Will fill gaps left by ITNs	28.4%	13.1%	56.1%	1.2%	1.2%
Will be safe for humans, animals and environment	7.1%	8.4%	76.9%	3.9%	3.7%
Will be easy to use	19.6%	4.7%	72.5%	2.0%	1.2%
Will be easily accessible	2.6%	2.2%	84.1%	4.1%	6.9%
Will be affordable to residents	2.9%	1.4%	86.7%	1.6%	7.4%
Will be acceptable in community	34.3%	6.1%	56.7%	2.2%	0.6%

Table 6.5: Association between socio-demographic variables and perception towards larviciding.

Category	Variable	Odds ratio (95% CI)	p-value
Sex	Male	1.00	-
	Female	0.74 (0.32, 1.70)	0.470
Age category (in years)	18-25	1.00	-
	26-35	0.53 (0.14, 2.58)	0.382
	36-45	0.56 (1.34, 2.76)	0.428
	46-50	0.42 (0.07, 2.36)	0.300
	Above 50	0.60 (0.14, 3.04)	0.497
Education Level	No formal education	1.00	-
	Primary (7 years)	2.09 (0.41, 38.20)	0.478
	Secondary (12 years)	1.94 (0.24, 39.90)	0.752
	Tertiary (>12 years)	7.00 (0.83, 146.87)	0.102
Awareness of larviciding	Aware	1.00	-
	Not aware	0.40 (0.17, 0.93)	0.029*

When considered separately, most malaria focal persons and vector surveillance officers were able to distinguish between aquatic habitats of malaria vectors. They pointed out that *Anopheles* mosquitoes prefer fresh waters. A small number of MFPs however were unable to make this distinction, despite knowing that some mosquitoes preferred fresh water. They were unable to specify key characteristics of the actual malaria vectors vis a vis the habitats of non-vectors. On the other hand, a majority of the ward health officers were not aware of the differences in aquatic habitats between malaria and non-malaria vectors. This group only knew that mosquitoes breed in water, and characterized ponds, streams and river banks, septic tanks and pit latrines as possible aquatic habitats for all mosquitoes. They conceded that differentiating larval habitats was too technical a task for their capacities; their focus was on identifying places with standing water and treating them with larvicides.

> *"It is not too easy to differentiate the larval habitats, except if you see a place with a lot of water, then you just know that there will be mosquito larvae there, because we know mosquitoes like to lay their eggs in water. In my ward, for example, we have water ponds that last a whole year, so I know mosquitoes breed there. There are also communities where people still use pit latrines, but the holes are not covered and the toilets do not have doors or roofs. So I also know that mosquitoes can breed in those."* (Ward Health Officer, Male).

The term 'fresh water' generated great discussion among the key informants. Those who reported that malaria vectors preferred clean and fresh water also listed water storage buckets or pots and morning dew as potential habitats for malaria vectors.

> *"What I know is that there are different types of mosquitoes; I know there are* Anopheles, Culex *and* Aedes *mosquitoes. I know that Anopheles prefers to breed in clean and fresh water, so they can be found in buckets of clean water, in the clean morning dew.* Culex *on the other hand likes dirty water; they like to lay their eggs in septic pits and in other dirty places*." (Vector Surveillance Officer, Male).

*Knowledge of larviciding***:** All MFPs, VSOs and ward health officers knew that larviciding involved killing mosquitoes with chemicals during their larval stages. They also knew of two types of biolarvicides available for large-scale implementation in Tanzania, one used to treat fresh and clean water, and the other one used to treat dirty water. Many could however not name the biolarvicides, nor specify which types were applicable for malaria-vector control.

> *"Larviciding it is the killing of the second stage of mosquito's life cycle using chemicals called larvicides. In Tanzania we have biological larvicides, so they are called biolarvicides. I understand that these biolarvicides are some kind of bacteria;*

when they are put in water that contains mosquito larvae, the larvae feed on the bacteria, which kills them." (Malaria Focal Person, Male).

Supply and distribution of larvicides: MFPs reported having received two types of biolarvicides (totaling 720 litres per council) from the government to distribute to the wards within their districts through ward health officers. The first supply was delivered in 2018, and another supply delivered in 2019. Distribution of the biolarvicides was prioritized on wards with the highest reported malaria cases compared to others.

Implementation of larviciding: To support larviciding, the ward health officers recruited and trained community health workers (CHW), local residents who had previously participated in a community health training course. Where no CHWs were available, the ward health officers recruited volunteers, who were typically young male residents. The CHWs or volunteers were responsible for actual application of larvicides, with supervision from the ward health officers. The ward health officers would accompany the implementers to identify water bodies within their wards and during the first application. Unfortunately, a majority of the ward health officers had received no specific training on how to implement the larviciding. Moreover, in some districts one ward health officer was responsible for overseeing larviciding in up to four wards, thus they were unable to effectively supervise the CHWs.

> *"I supervised this work throughout. I recruited community health workers from different communities in my ward and gave them larvicides. This way I made sure that every community in my ward had larvicides."* (Ward Health Officer, Male).

> *"We were told to involve the community when we received the larvicides, so we spoke with village and community leaders, and with their help we found young men in the communities to help with this work. We then instructed the young men on how to apply the larvicides."* (Ward Health Officer, Male).

Training on application of bio-larvicides: Malaria focal persons reported that they had participated in at least one seminar on how to apply the larvicides, in 2018 and or 2019.

Some of the MFPs were not holding their current positions in 2018 and had therefore only received one training session. The training, provided jointly by the Muheza College of Health and Allied Sciences (230) at Muheza district and Kibaha Biotech Products Limited (TBPL) (150), was described as largely theoretical, providing information on the two types of biolarvicides and where to use them. There had been no practical training on identification of aquatic habitats, application of larvicides or monitoring of program effectiveness. Fortunately, all MFPs had been given written guidelines for biolarvicides application.

> *"I participated in this year's [2019] seminar. We were given a formula on how to calculate the amount of larvicides per liter, and they promised to share with us the template with the specific formula for the amount of diluted larvicides to apply in a aquatic habitat. It was a PowerPoint presentation; it was all theoretical."* (Malaria Focal Person, Male).

Unlike the MFPs, the VSOs and ward health officers reported not to have participated in the training programs, but had instead received information on dilution and application methods from the MFPs. Ward health officers then passed on the information to the CHWs and the community volunteers who were responsible for the hands-on implementation of the larviciding.

> *"I called the volunteers to my office and explained how to dilute the larvicides and how to apply them to the aquatic habitats. I did the training in my office. Then I provided them with the larvicides as well as masks to protect themselves."* (Ward Health Officer, Female).

Monitoring efficacy of the larvicides: There was no formal mechanism of monitoring effectiveness of the larviciding. Some ward health officers stated that they kept track of the number of malaria cases at the health centers, and assumed that reduced cases meant that the larviciding was working. Other ward health officers reported that they asked community members if they had experienced a reduction in mosquito annoyance. Others relied on their own experience living in the communities to detect a reduction in mosquito abundance. All respondents reported that they believed that larvicides were effective based on these factors.

Challenges during implementation of larviciding: Key challenges that district and ward health control officers faced during implementation of larviciding included insufficient technical knowledge on identifying habitats of malaria vectors and application of the larvicides, insufficient knowledge on safety of the larvicides, inadequate funding, inadequate supply of larvicides, some resistance from community members, late-involvement of VSOs and ward health officers and inadequate collaboration from non-governmental organizations in the districts or wards.

Table 6.6: Key challenges facing larviciding programs in Morogoro region, southern Tanzania. The table provides a brief description of each identified challenge, as well as examples of direct statements from the study respondents.

	Challenges	Description	Examples of respondent quotes
1	Insufficient technical knowledge on habitat identification and larviciding	Malaria Focal Persons, District Surveillance Officers and Ward Health Officers reported that they did not have adequate technical knowledge for assessing whether specific water bodies were likely to contain mosquito larvae, and whether those larvae were likely to belong to *Anopheles* species or other mosquitoes. As a result, ward health officers reported that they often treated all the water bodies they could find in their wards. The MFPs also reported that they did not have accurate information on the proper amount of larvicides to apply in specific water bodies. Instead, they often just guessed the amount, based on their perceived volumes of the habitats. There was also no uniformity on methods of monitoring efficacy of the larvicides. Some reported that they used number of malaria cases at the health centers as an indicator of efficacy and some used community testimonials on reduced mosquito nuisance bites.	*"it is not easy to differentiate mosquito breeding sites, however, there are areas that you can recognize as breeding sites upon seeing. For example, we have areas with ponds that last the whole year and a great example is an area close to the secondary school where brick laying created ponds which obvious attract mosquitoes as a breeding site."* (Ward Health Officer, Male). *"Like I said, we lack knowledge on this aspect. We do not even know how much larvicides to spray in a water pond for example. Even if you ask the VSO he will tell you the same. So then we do a lot of guess work, but we do not know for sure if we are putting too much or too little."* (Malaria Focal Person, Female). *"We do monitoring by asking community members, they are the ones who report sleeping comfortably."* (Ward Health Officer, Female). *"We look at the statistics, as to whether number of malaria patients increasing or decreasing."* (Ward Health Officer, Female).
2	Lack of knowledge regarding safety of the larvicides	There were also inconsistencies in knowledge about risks posed by the larvicides. MFPs and VSOs claimed that the larvicides did not pose any harm to people or their livestock, but were not sure whether the larvicides could cause harm to other aquatic organisms. In contrast, most ward health officers believed the larvicides could harm people or animals, since they smelled like poison and turned the color of the water.	*"I know that it is safe on humans, but I really do not know if they pose any harm on other insects in the water, on animals or on vegetation around the water. I only know that it does not have any harm on humans."* (Malaria Focal Person, Male). *"It has to have harm, I can just tell from the smell that comes when you apply it, the water also turns milky, so it just looks poisonous. So I advise people to not use the water immediately after the application, but if they wait after a while*

			the smell disappears and the color goes back to normal." (Ward Health Officer, Female).
3	Inadequate funding	All participants reported that lack of sufficient funding was a significant obstacle for successful implementation of larviciding. Funding was needed to provide compensations and wages to the CHWs or the volunteers, procure personal protective gear and application equipment and for transportation. In some cases the participants reported limiting larviciding activities due to limited financial support.	*"When you ask people in the community to help with this exercise, they expect to get a wage. But when we were implementing this there wasn't any money set aside for paying the volunteers or the CHWs. Sometimes I had to give them my own money, because I saw how hard they were working."* (Ward Health Officer, Male). *"In my district we had to stop before finishing because we just did not have any money to implement this project. We had the larvicides only, but nothing else. We requested money for protective gear, transportation, or for paying people that were doing the application but we did not receive it, so after some time we just had to stop."* (Vector Surveillance Officer, Female). *"For an example, my district has 31 wards, and it is not like the aquatic habitats are at the headquarters of the wards. You have to go deep into the villages. It is hard to walk with a can containing 20-liters of larvicide. There is only one car at the district, and even that is currently not functioning."* (Vector Surveillance Officer, Male).
4	Inadequate supply of larvicides:	Some of the ward health officers reported that the larvicides they received were not enough to treat all mosquito aquatic habitats in their area of jurisdiction. In particular, communities living in swampy areas, needed a lot more supplies than they received.	*"I will tell you that the larvicides were not enough. In all the aquatic habitats that I had surveyed, we could not cover all of them before running out of the larvicides. We needed more, but there was none."* (Ward Health Officer, Female). *"In 2018, I have received two cans of twenty liters which cannot be enough for my ward. In another round, I had received two cans of twenty liters per village which was not enough either, so we decided to prioritize the most significant settings."* (Ward Health Officer, Female).

5	Some resistance from members of the community	Key informants reported initially facing resistance from some community members who feared that the larvicides would be poisonous to chicken, livestock or fish. This was mostly due to the smell of the larvicides, and by the fact that the water turned milky immediately after application. This initial resistance was however reported to ease once the health officials spent time explaining the benefits and safety of the larvicides. Community sensitization was primarily done by ward health officers with assistance from CHWs.	*"The uptake was not very good in the beginning as people were not educated on what larvicides are, how they work or their safety. So they were always reluctant to let people spray near their homes."* (Vector Surveillance Officer, Female). *"Once people were sensitized, the uptake improved. People would even follow us and ask when we would be spraying again, or point me to aquatic habitats that I had missed."*(Ward Health Officer, Male).
6	Inadequate involvement of VSOs and Ward health officers in early stages	VSOs and ward health officers reported to not being involved in the initial planning of the larviciding programme at the district level, but rather receiving implementation plan from malaria focal person. This overshadows their significant inputs as they have spent more time in the settings on average compared to malaria focal persons.	*"I was not involved in the planning and these larvicides are new which requires training but we have only been given pamphlets. Only if we can be involved from the early stages, I think it will improve the practice."* (Vector Surveillance Officer, Female).
7	Insufficient collaboration with non-governmental organizations	Key informants reported inadequate involvement of the non-governmental organizations (NGOs) in the implementation of the larviciding programme. This has been attributed to larviciding not being priority among these NGOs.	*"Providing awareness to the community, maybe we could try but even Boresha Afya indicated disease prevention is not in their priorities but rather case management. SolidarMed priorities are in behavioral change, so we have no stakeholders in disease prevention."* (Malaria Focal Person, Male).

6.5: Discussion

Larviciding is considered as complementary to current major malaria control approaches, which include ITNs, IRS, affordable and accurate diagnosis and treatment (220). To accelerate malaria elimination efforts, the Tanzanian government has invested significantly in larviciding, including the establishment of a national production capacity and adoption of larviciding in both rural and urban settings (219). This study investigated some of the practical obstacles that limit the effective roll-out of this strategy across the country, with a particular focus on the perceptions and experiences of key stakeholders of malaria control in southern Tanzania.

Our key-informant interviews revealed the knowledge inadequacy among MFPs, VSOs and ward health officers towards implementation of the larviciding. For instance, all participants knew that mosquitoes have an aquatic habitat stage; but a majority could not easily differentiate the aquatic habitats typical of malaria vector species. Moreover, these health officials reported that malaria vectors do prefer “fresher” water compared to other mosquitoes, but what majority meant by fresh water was any water that looked clean such as water in clay pots or buckets. Ward health officers, who are closely anchored in the community and provide guidance to the community health workers and volunteers during the larviciding, could not differentiate between malaria and non-malaria vectors’ aquatic habitats and reported to use different methods to apply and monitor effectiveness of the larvicides. This lack of adequate knowledge and uniformity might be attributable to the lack of training on how, where and when to apply the larvicides as accorded by WHO guidelines (220). Some of these malaria control officials particularly MFPs and VSOs reported to have attended at least one theoretical training on larviciding. However, those training proved to be insufficient as acquiring necessary expertise would require practical, “on the job” training rather than a presentation of theoretical principles (231). No formal training to the actual implementers (i.e. ward health officers, CHWs and volunteers) was reported, this could undermine the overall impact of the programme.

Insufficient funding to assist with implementation of larviciding was among the practical obstacles reported by the MFPs, VSOs and ward health officers. Funding was needed to offer incentives, cover transportation and larvicides costs, and provide personal protective gears to the CHWs and volunteers who did the actual job of applying the larvicides. A successful large scale larviciding trial conducted in Dar-es-Salaam (218,232) by Urban Malaria Control Programme (UMCP), has demmonstrated the cost-effectiveness of the approach (233). However, larviciding is deemed operationally and financially infeasible in the rural settings (220). The recent study by Nambunga *et al* (223) has shed light on the possibility of minimizing the unnecessary costs, if larviciding could be species-specific. In Kilombero valley, *An. funestus* accounts for over 80% of the ongoing malaria transmission (54), its aquatic habitats have found to be few and highly distinctive (223). Thus, effective targeting of *An. funestus* aquatic habitats alone could potentially reduce malaria transmission by 80% in Kilombero valley. In this valley, *An. funestus* aquatic habitats adhere to WHO criteria (i.e. few, fixed and findable) for larviciding implementation (220). The application of larvicides for malaria control in Morogoro region is often directed towards all stagnant water bodies, thus undermining the intended amount of larvicides. Understanding ecology of the major malaria vectors in each district within Morogoro region could cut the unnecessary costs and provide effective larviciding approach. However, studies shows that control of Culicine mosquitoes that are responsible for enormous biting nuisance could maximize community acceptance and support towards malaria control programme (234,235).

This present study also revealed the need to strengthen the engagement of the community, despite efforts by district-level malaria control officials to inform and sensitize the residents. A majority of the community members surveyed were not aware of larviciding, did not know its function within malaria control efforts, and were not aware whether or not it had been implemented in their settings. This finding was in agreement with a previous study by Mboera *et al* (2014) in Mvomero district within Morogoro region, where only 17% of the survey respondents were aware of larviciding as a malaria control intervention (236). Both findings indicate inadequate community engagement methods during the implementation stage. However, community members in both studies showed willingness to support the implementation of larviciding in their communities. In our present study, age, sex and educational level of the survey respondents did not seem to influence their level of awareness and perception towards larviciding, but the contrary was observed in other studies (134,237). A majority of the districts in Morogoro region has at least one local radio station, thus dedicated campaign through these radio stations could further strengthen the community engagement.

Insufficient support from local stakeholders within Morogoro region might have been among the obstacles towards effective implementation of larviciding. Engagement of other stakeholders particularly non-government organizations (NGOs) have shown to yield fruitful impact in the malaria control. For instance, collaboration between Urban Malaria Control Programme (UMCP) and Ifakara Health institute (IHI) in Dar-es-Salaam during early 2000s towards malaria control through larval source management led to a significant impact (218). Thus, effective engagement of these NGOs such as IHI will somewhat ensure smooth implementation of larviciding through resources provision and/or capacity building.

Our study also revealed insufficient “early-on” involvement of VSOs and ward health officers during the budgeting and implementation planning. MFPs attend all council’s meeting that involve malaria control initiatives through district technical committee (238), and often instruct the VSOs and ward health officers on the way forward. This could lower the latters’ sense of ownership towards the larviciding programme. Adequate involvement of VSOs and ward health officers could strengthen the implementation of the programme, apart from VSOs holding a special training on disease-vectors control but also majority have spent significant number of years in the localities.

The study results should be interpreted in the light of several limitations. A response bias may have resulted partially inaccurate responses on the survey. Social desirability bias may have resulted in respondents saying ‘I don’t know’ to most of the statements that assessed their perceptions of larviciding as a majority had early-on indicated that they were not aware of this intervention. Demand characteristics may have also resulted from both the key informants who may have reported insufficient knowledge or lack of resources hoping that these would be provided to them. In addition, our present study did not include district medical officers (DMO) who also plays a crucial role in planning, coordinating and implementing the delivery of health services at the district level (222).

6.6: Conclusion

Both communities and district-level malaria control officials widely supported the larviciding programme, however, there were gaps in technical knowledge, implementation and stakeholders engagement. To maximize the overall impact of the programme, training efforts should be intensified, particularly for identification of aquatic habitats for important vectors and formal training should be given to the actual implementers (i.e. CHWs and volunteers) not just MFPs, VSOs and ward health officers. Standard technical principles for application of larvicides should strictly be adopted and improvement on financing at a district-level implementation. Furthermore, engagement of community members and other stakeholders such as NGOs should be improved to maximize awareness, participation and sustainability of the programme. These lessons learnt from Morogoro region shed the light for other malaria endemic areas on the possibility of deploying larviciding for malaria control or elimination.

Chapter 7: Perceptions and recommendations for housing improvement for malaria control in south-eastern Tanzania#

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See appendix 6

7.1. Abstract

Housing improvement has been associated with reduced risk of malaria transmission and lower odds of malaria infection in sub-Saharan Africa. However, there is limited information on how communities in malaria endemic settings perceive housing improvement as a malaria control intervention. This study aimed to explore perceptions and recommendations for housing improvement as a malaria control intervention among community members in malaria-endemic settings in southern Tanzania. A mixed-methods study design was used, involving 1) structured questionnaires administered to 490 community members to assess awareness and perceptions of housing improvement as a malaria control intervention, and 2) focus group discussions (FGD) with community leaders to get insights on the potential of housing improvement as a malaria control intervention. About two thirds of the survey respondents correctly indicated that rural and poor communities faced the highest burden of malaria transmission. Poorly constructed houses, i.e., small, with holes in the walls and roof and lacking windows were linked to increased risk of malaria transmission, as they forced people to spend time outdoors exposed to malaria-transmitting mosquitoes. High awareness (69.6%) and strong support (88.9%) for housing improvement for malaria control was observed among the survey respondents. However, high building costs slowed down house improvement initiatives. Community members proposed several options for the government to support housing improvement including providing building loans, subsidizing building costs, or building standard houses and renting to poorer community members. It is crucial to bring together all the key players in the housing sector to come up with solutions that can reduce barriers that communities living in malaria-endemic settings face in building mosquito-proof houses.

Keywords: Housing improvement; malaria transmission; community perceptions

7.2. Introduction

Malaria is often recognized as a disease of poverty (51,239). At a global level, more than 90% of malaria cases and deaths are concentrated in the world's poorest countries (240). At more local levels, malaria is concentrated in places that are more rural and poorer (26,52), where poor housing is a common factor. More than 80% malaria transmission in sub-Saharan Africa occurs indoors (241), making house quality one of the vital factors associated with malaria risk. Housing improvement such as screening windows and doors is one of the oldest reported malaria control interventions in world, dating back to the 19th and 20th century in Europe and America (105), and is linked to malaria elimination in different parts of Europe and America (104,105).

However, interest in housing improvement for malaria control declined following the discovery of insecticide methods for killing mosquitoes, which were considered simpler, more affordable and highly effective (105,242). Housing improvement for malaria control started regaining interest following the emergence and spread of insecticide resistance in malaria vectors; interventions not relying on insecticides were given consideration as one of the strategies to manage insecticide resistance (243).

More recent studies across sub Saharan Africa have associated modest improvement in housing quality with decreased mosquito density and decreased malaria incidence (38,50,106,107). Children living in improved houses made with brick walls, metal roof and closed eave space had lower odds of being infected with malaria compared to those living in unimproved houses made with mud walls and thatched roof across sub Saharan Africa (38,106,107). Other studies have also indicated higher densities of malaria vectors in unimproved houses compared to improved houses (52,108,109).

A few studies have been conducted to assess whether community members living in malaria endemic settings understand the association between housing structure and malaria transmission. In southern 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 (244). In a different survey done in western Kenya to assess community knowledge and perceptions on malaria prevention and house screening, Ng'anga *et al* (2019) reports low awareness of the impact of housing screening for malaria control among communities in malaria-endemic settings in western Kenya (245). In a similar study done in Tanzania, Ogoma et al (2009) report that a majority of community members were able to associate housing improvement with lower risk of malaria transmission (246).

While there is adequate information on the impact of housing improvement in malaria control, and on whether communities are able to associate housing structure to the risk of malaria transmission, there is fairly limited information on how communities in malaria-endemic settings define housing improvement, how they perceive its importance in malaria control and available opportunities for housing improvement in malaria-endemic settings. This study therefore aimed to explore how community members in a malaria-endemic setting in southern Tanzania define housing improvement, their perceptions about its impact in malaria control and their perceived opportunities for housing improvement in malaria endemic communities.

7.3. Methods

This study adapted an explanatory sequential mixed-methods approach (142) to explore and assess knowledge, awareness and perceptions of housing modification as a malaria control intervention in southern Tanzania. Field-work was conducted by the first author (MFF), EM, RN and WM, and the study was conducted in Swahili, the local language. The study was approved by Ifakara Health Institute's institutional review board and National Institute for Medical Research. The study was conducted in ten randomly selected wards in Ulanga and Kilombero districts in southern Tanzania. Detailed description of the study site and participants is provided by Finda et al (134,247).

For the qualitative component, two focus group discussions (FGD) were conducted with community leaders from the same wards, to further discuss their insights on the potential of housing improvement as a malaria-control intervention. Each FGD session included eight participants; men and women were separated to maximize participation by women. The two discussion sessions lasted for 110 minutes and 122 minutes. A semi-structured discussion guide was used to facilitate the discussions. The sessions were audio-recorded and detailed notes were taken.

For the quantitative component, 500 households were randomly selected from the ten wards, and the study team, accompanied by community leaders administered a survey questionnaire to one adult representative of each household. The survey was administered using Kobotoolbox™ software (149) on electronic tablets. Altogether 490 household heads agreed to participate in the survey. The survey was a structured questionnaire that aimed to assess their knowledge, awareness and perceptions of housing improvement as a malaria control intervention.

7.3.1. Data processing and analysis

For the qualitative data, audio recordings from the IDIs and FGDs were transcribed immediately following the discussions and translated from Swahili to English language. The written transcripts were reviewed and analyzed using NVivo 12 Plus software (151). Objectives of the study and discussion guides were used to develop deductive codes, and inductive codes were generated through reviews of the transcripts. Similar codes were grouped and emergent patterns used to identify themes and concepts.

Quantitative data was analyzed using R statistical software version 4.0.0 (229). Descriptive analysis was used to assess socio-demographic characteristics of the survey respondents, and summarize their knowledge and awareness of housing improvement as a malaria-control intervention. Univariate and multivariate analyses were used to determine influence of the respondents' socio-demographic characteristics on the main outcome variable, i.e. their perceptions of housing improvement as a malaria control intervention. Binary logistic regression was used to determine the association between the independent variables and outcome variable; odds ratio was calculated at 95% confidence intervals (CIs).

A five-point Likert-scale was used to assess individual-level perception of community members towards housing improvement by measuring the level of agreement towards positive statements on housing improvement, ranging from strongly agree (1) to strongly disagree (5). Internal validity of the scale was measured by calculating Cronbach's alpha (153). The statements were: i) housing improvement is effective for malaria control, ii) housing improvement fills gaps left by other interventions, iii) housing improvement is safe for humans, animals and the environment, iv) housing improvement is easy to implement, v) materials and supplies for housing improvement are easily accessible, vi) housing improvement is affordable to community members, and vii) housing improvement is acceptable in the community. To calculate community members' perceptions towards housing improvement for malaria control, sum of the scores of the seven statements was calculated for each survey respondent and a median of these scores calculated. The final perception level was determined by comparing individual perception scores against the median score, and the community's perception level was determined

Weaving approach was used, in which both qualitative and quantitative findings were presented and interpreted together (142). 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. In some cases, direct quotations from participants were used to support the claims.

7.4. Results

7.4.1. Characteristics of study respondents

A total of 524 people participated in this study altogether; 490 community members responded to the community-based survey and 16 community leaders participated in two focus group discussion sessions. About a half (42.9%, n=210) of the survey respondents were men and 57.1% (n=280) were women. The average age was 42 years, ranging from 18 to 88 years. Nearly three quarters (73%, n=358) of the respondents had primary education (7 years of formal education) and 13.9% (n=68) had secondary education (11 – 13 years of formal education). Nearly nine percent (8.8%, n=43) had no formal education and 4.3% (n=21) had college education (13 or more years of formal education). Most (84.3%, n=413) of the respondents were primarily small-scale farmers, but some also reported conducting small businesses, fishing and animal husbandry on the side. Likewise, a majority (n=13) of the FGD participants had completed primary school education, and three had completed secondary school education.

The average reported household income was 1,573,126 Tanzanian shillings (TZS), equivalent 684.0 USD (In this cases, in January 2021, 1 USD was converted to 2300 TZS). The average household size was 5.4, ranging from 2 to 8 people per household. Houses with brick walls and metal roof were the most common house type (Figure 7.1), so were flush toilets located outside the main living houses (Table 7.1). Electricity was the main source of light found in 40.8% of the households. Approximately two thirds (63.1%, n=309) of the respondents used pump water located at community centers, and a majority (84.9%, 416) used wood charcoal for cooking (Table 7.1).

Figure 7.1: Common house types 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 and thatched roof.

7.4.2. Perception of risk and burden of malaria

More than a half (51.6%, n=253) of the survey participants responded that the country was doing a very good job in controlling malaria. This aspect was explored further in the FGD where participants spoke of their experiences, noting that the frequency and severity of malaria had significantly decreased over the years. The participants explained that other diseases like typhoid and urinary tract infections were now more common than malaria, and that a year could pass without a malaria incidence in their households. Severity of malaria was also said to have decreased as this participant said:

> *"I know malaria has decreased now because in the past when people got sick of malaria, they really got sick, and many died. I know people who went crazy, and some became deaf and dumb because of malaria. This happens when the malaria parasites get into your brain. But now this does not happen much. If you get malaria you do not even need to be hospitalized, you can just buy medicine from the drug stores and you are fine. In the past you would be hospitalized and you could die."* (Female community leader)

Table 7.1: Characteristics of households surveyed during the community-based survey

Variable	Category	Percentage (n)
Average household income	684.0 USD	
Average household size	5.4 people	
House type	Brick walls & metal roof	77.6% (380)
	Mud walls & thatched roof	13.1% (64)
	Brick wall & thatched roof	7.3% (36)
	Mud walls & metal roof	2.0% (10)
Toilet	Flush toilet outdoors	62.8% (308)
	Flush toilet indoors	14.3% (70)
	Pit latrine outdoors	22.9% (112)
Source of light**	Electricity	40.8% (200)
	Solar	30.6% (150)
	Rechargeable lamps/torches	28.0% (137)
	Others	3.1% (15)
Main source of water**	Pump water away from home	63.1% (309)
	Pump water at home	17.1% (84)
	Tap water away from home	9.6% (47)
	Tap water at home	8.6% (42)
	Other sources	8.0% (39)
Main source of cooking energy	Wood charcoal	84.9% (416)
	Fire wood	64.3% (315)
	Gas	9.8% (48)
	Others	0.4% (2)

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

The participants further explained that people are more educated now compared to the past; nearly everyone has and sleeps under a bed net, and people understand and control mosquitoes' aquatic habitats. Malaria diagnosis and treatment was said to be more widely available and affordable, and there are more options for controlling as this participant said:

"Yes. People are quite educated these days. They use bed nets faithfully, but also they know where mosquitoes' breeding sites are and they destroy them and get rid of trash around their houses. People are more aware of this disease now than in the past." (Female community leader)

On the other hand, however, 43.9% (n=215) of the survey respondents replied that the country was making a slow progress, and it would not lead to malaria elimination without additional efforts. Further discussing this, the FGD participants explained that although the risk and severity of malaria was not as high as in the past, the current efforts would not lead to elimination as this participant said:

"I really do not think that the insecticide-sprays or the bed nets are enough, because if they were we would not still have any malaria. We have been using these for a really long time now, and still we get malaria, even though it is not as much as in the past. If even a few people still get malaria, that means that what we currently have is not enough." (Female community leader)

Insecticide-treated nets (ITNs), the main malaria prevention intervention expressed by 99.4% (n=487) were said to have limitations, such as the fact that they do not kill mosquitoes as they are supposed to, and that they large holes that let mosquitoes in. About two thirds (61.3%, n=300) of the survey participants responded that mosquitoes were increasingly biting outdoors and earlier in the evening, further limiting effectiveness of the currently available interventions. A majority (86.1%, n=422) of the survey participants responded that alternative tools would be necessary to supplement current interventions and speed up malaria elimination efforts as these participants said:

"I also think that what we currently have is not enough to eliminate malaria because we have been told that mosquitoes are clever and have changed their behaviors, they no longer wait until late at night to come and bite people, they come early in the evening when people are still outside. They will keep coming early until they make sure that they get what they want. This way then the bed nets or sprays are not really enough." (Female community leader)

I have made a lot of efforts to kill mosquitoes with insecticide sprays like Rungu*, but always the outcome is that Rungu will finish, and then mosquitoes are still there because soon as you leave your door open mosquitoes come in"* (Male community leader).

7.4.3. Poverty is a risk factor of malaria

About two thirds (65.1%, n=319) of the respondents said that rural settings have the highest risk of malaria transmission, and 63.9% (n=313) said that poor communities were carrying a disproportionately higher burden of the disease (Table 2). This point was further evident during the FGDs where nearly all participants said that the poorest in the community were experiencing the highest burden of malaria, as they live in poorly constructed traditional houses that provide little protection against malaria. The houses were said to have a lot of holes in the walls and roof through which mosquitoes get inside. They are normally dark and cluttered hence providing a lot of hiding places for mosquitoes, and they are generally very small, forcing people to conduct household chores outdoors. The participants also explained that it was difficult to use mosquito control interventions in these houses as these participants 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)

> *"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)

7.4.4. Domestic activities put people at an increased risk of malaria transmission

About two thirds (61.3%, n=300) of the survey respondents said that most of malaria transmission occurs outdoors, and 36.7% (n=180) said it occurs indoors (Table 2). Participants of FGDs elaborated that some of the activities that kept people outside during the high risk hours included household chores such as cooking, washing, eating and chatting with friends and neighbors. These activities were mostly done outdoors due to cultural reasons partly, but also due to house sizes as these participants elaborated:

> *"Another problem that I'm thinking of, I think maybe is caused by poverty, is that people do all their chores outside the house because their houses are too small, and there is no enough air or light. So then all the evening chores like cooking, washing, eating and other things are done outside, then people go inside only when it is time to sleep."* (Female community leader)

"It is just the culture of people here. You see even in the past when people cook inside, they would always bring the food outside to eat. Back then people only cooked inside because they were afraid of their enemies, but for us these social activities are done outside. If you eat inside then your neighbors will think you are stingy, and you do not like to share with your friends. So then we cook and eat outside so that when someone passes and sees that you are cooking or eating, then you can welcome them to join. That is important for us." (Male community leader)

Table 7.2: Perceptions of risk and severity of malaria among community members who participated in the community-based survey

Questions asked	**Variables**	**Percentage (n)**
Settings with the highest risk	Rural settings	65.1% (319)
	Urban settings	7.6% (37)
	Equal in rural and urban settings	23.7% (116)
	Do not know	3.7% (18)
Communities most affected	Low-income communities	63.9% (313)
	All communities are equally affected	33.7% (165)
	Do not know	2.5% (12)
Where most transmission occur**	Outdoors at home	73.9% (362)
	Outdoors away from home	59.2% (290)
	Indoors at home	54.7% (268)
	Indoors away from home	30.8% (151)
	Don't know	2.0% (10)

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

7.4.5. The ideal proper house

More than two thirds (69.6%, n=341) of respondents were aware that improved housing provides protection against malaria. When asked about their source of this information, a majority of the respondents said that they knew from their daily experiences, but others listed 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 complaints were that it was expensive to have modern houses, and that modern houses alone would not provide complete protection against malaria as mosquitoes could still get in through open doors or windows, and people would still spend time outdoors. When asked to define what a proper or 'modern' house means to them, FGD participants listed many features including large size, large windows, screened doors and windows, brick walls, metal roof and electricity as these participants explain:

> *A modern house has a lot of things; but three main important things are brick walls and metal roof 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)

7.4.6. High cost of building materials is a key issue

A majority of the survey respondents agreed that an improved house would be effective in malaria control, would fill gaps currently left by current interventions, and would be acceptable by community members. However, a majority of the respondents disagreed that materials and supplies for housing improvement are easily accessible or affordable by the community members (Table 3). The issue of affordability also dominated the FGDs with community leaders, who explained that everyone dreams to live in a modern house, but the cost is too high. Some of the most costly materials were said to be doors, windows and metal roof. The leaders further elaborated that when people build modern houses, they normally put a lot of big windows because they want light and air in their houses. But it takes long time for people to afford proper screening for all the doors and windows so then they cover the openings with bricks until they can afford to put proper doors and windows as these participants explained:

> *"You know, it is not like people do not want to have proper houses; it is just so expensive to have a proper house. Ah, you know people do not have much. If someone manages to put a wooden door, then there's no money left for adding the screen door. Wooden door is expensive, but it protects you from many other dangers. If you have money for just one*

door then you have to put a wooden door, isn't that the case even for you?" (Male community leader)

"If people cannot afford to screen their windows then they normally just 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 let in fresh air, 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 with no netting. We know that netting would provide protection against mosquitoes, we just cannot afford it." (Male community leader)

Table 7.3: Perception of community members regarding housing improvement for malaria control (N = 490).

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Effective	26.6%	44.7%	21.8%	4.7%	2.2%
Fills gaps left by ITNs	22.5%	44.9%	22.8%	6.3%	3.5%
Safe for humans, animals and environment	47.3%	22.0%	18.6%	8.2%	3.9%
Easy to use	25.1%	19.4%	21.8%	20.6%	13.1%
Materials and supplies are easily accessible	9.6%	6.5%	21.4%	29.2%	33.3%
Affordable to residents	1.4%	3.7%	21.2%	26.3%	47.4%
Acceptable in community	31.6%	29.4%	22.2%	9.4%	7.4%

7.4.7. Little hope for migrant communities

Community leaders participating in the FGDs discussed the prospects of housing improvement for migrant communities such as pastoralists and migratory farmers, and agreed that this would not be an ideal intervention for these communities. The leaders explained that due to their nature of not staying in one place for long, or preferring places with pasture for their livestock, building houses for pastoralists would not work as they cannot be made to stay in one place for a long time, as this participant explained:

"Ah, those pastoralists are doomed; I do not know how they can be helped. Where they live there is a lot of grass because that is what they need for their cattle, so you cannot

say we get rid of water and long grass. They are also moving around a lot, so I do not see how building a house for them can solve the problem." (Male community leader)

Similarly for the migratory farmers, a majority of FGD participants discussed that building proper houses in the rice fields would also not be an ideal intervention as most of the farmers do not own the farms, they rather rent them for the farming season, and there is no guarantee that they would get the same farm the following season. As a result, the farmers often build make-shift huts that provide minimal protection against animals and insects, to survive the farming season as this participant elaborated:

> *"The reason people do not build permanent houses in the farms is that most people rent those farms; the farms are not theirs to start with. So then when people migrate to the farms they build temporary shacks, stay there for one or six months and go back to their homes in the village. The following year they rent another farm, so it is always like that. Maybe people who have their own farms can build their houses, and farmers can rent the farms and the houses."* (Male community leader)

However, there are participants that proposed working with land owners to build proper houses that migratory farmers can rent during the farming season, thereby providing proper protection against not only malaria, but also other dangers. The participants acknowledged that it would be challenging to build houses in the farms, but advised that if possible, the farm houses need to have elevated base in order to prevent flooding, which is an even bigger problem during the farming season as these participants said:

> *"It is hard though to build houses in the farms because there is a lot of water in the rainy season, which is when most of the people migrate there, and when most of the people get malaria. Now people only build seasonal shacks which provide minimal protection against mosquito bites or any other animals. Maybe if you build houses for them, you have to raise the base so that they are not flooded. I do not think it is very easy to build houses in the farms. "*(Male community leader)

> *"But for the farmers, we can build brick houses with metal roofs in the farms, and different families can share those, because not everyone migrates to the farm at the same time."* (Male community leader)

7.4.8. Opportunities for government support

Most (88.8%, n=435) of the respondents said they would support housing improvement as a malaria control intervention; 6.5% (n=32) and 47% (n=23) were either neutral or did not support the intervention respectively. In a univariate analysis, support for housing improvement was significantly associated with educational level and average household annual income level as indicated on table 7.4. Respondents with secondary education and above were more than thrice as likely to support housing improvement compared to those with no formal education, as were respondents with average annual household income of above 869.6 USD compared to those with household income of below 217.4 USD (Table 7.4). In a multivariate analysis, significant support for housing improvement was associated with respondents aged between 31 and 40 years (OR = 2.56, p-value = 0.04), having a secondary education and above (OR=3.55, p-value =0.05) and having an average annual income of between 217.4 and 434.8 USD (OR = 2.9, p-value = 0.02).

The strong support for housing improvement was also expressed by the FGD participants, all of whom preferred housing improvement to other malaria control interventions. The FGD participants explained that housing improvement made sense to them more than the other malaria control interventions such as larviciding, spatial repellents, space spraying and use of genetically modified mosquitoes. Improved houses were also said to provide protection against more than just malaria vectors as it protects against many other diseases and dangers. The participants further explained that no other technology would be fully effective if people continue to live in poorly constructed houses as these participants explained:

> *"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)

Table 7.4: Socio-demographic factors associated with support for housing improvement among the community members surveyed

Category	Variable	Odds ratio (95% CI)	p-value
Sex	Male	1.00	-
	Female	0.95 (0.54 – 1.68)	0.87
Age category (in years)	Below 30	1.00	-
	31 - 40	2.35 (0.98 – 5.63)	0.055
	41 - 50	1.37 (0.62 - 3.04)	0.44
	Above 50	1.02 (0.53 – 2.17)	0.84
Education Level	No formal education	1.00	-
	Primary school	2.14 (0.94 – 4.71)	0.07
	Secondary school and above	3.66 (1.21 – 11.08)	0.02
Annual household income in USD	Below 217.4	1.00	-
	217.4 – 434.8	3.13 (1.40 – 7.00)	0.006
	434.9 – 869.6	2.37 (1.14 – 4.92)	0.02
	Above 869.6	2.49 (1.08 – 5.73)	0.03
House type	Brick walls & metal roof	1.00	-
	Brick wall & thatched roof	0.94 (0.31 – 2.79)	0.91
	Mud walls & metal roof	0.47 (0.10 – 2.29)	0.35
	Mud walls & thatched roof	0.72 (0.33 – 1.56)	0.41

However, the major concern for housing improvement as a malaria control intervention expressed by nearly three quarters (73.7%, n= 361) of the survey respondents was affordability by community members. Community leaders participating in FGDs explained that if left for people to do this on their own, the poorest in the communities would not be able to afford to improve their houses. The leaders discussed various options that the government could consider to help 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 the government 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)

Other participants 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) (248), 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 this participant said:

> *"I tell you, if I was to build a house alone, I would never be able to build it. I think it would be good if the government can help. You know, like they are helping with REA electricity, they look at people that are poor and they reduce electricity price 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 all of us 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 pay the government back. The participants gave an example of *Nyumba ni Choo* (*A house is a toilet*), a country-wide campaign to improve health status of the people by controlling water and sanitation related diseases (249); the government in collaboration with international partners had built proper latrines for the poorest people in the communities, and people paid back the government slowly. Similar approach was proposed for housing improvement as these participants said:

> *"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. The community leaders helped follow up and everyone paid back. Now most people in the villages have modern toilets but very poor houses."* (Female Community leader)

> *"If the government could listen, I would advise them to assist people, especially the poor people to build modern houses. The government can maybe build the houses, and people can repay the government slowly, everyone can pay according to what they can afford. Then if a person moves out of the house or dies the government can take back the house or pass it to another person. This way then the government can ensure that its citizens live in safe and protective environment."* (Female community leader)

7.5. Discussion

This study indicates a strong support for housing improvement for malaria control among community members in a malaria endemic setting in southern Tanzania. These community members expressed their strong preference for housing improvement, explaining that no other intervention would be able to achieve its optimal effectiveness if people continue to live in poorly constructed houses. This sentiment has been indicated in various studies that have shown that even when ITN use and ownership was constant, people living in modern houses experienced lower risk of malaria transmission (26,52), lower odds of malaria infection and lower malaria cases compared to those who live in poorly constructed houses (37,38). Similar findings have also been reported from Equatorial Guinea (106), The Gambia (108,250), and Uganda (107) among other countries.

In this study, the definition of an improved or a modern house was uniform among the community members. It included larger space compared to the traditional houses, built with brick walls, metal roofs and big screened doors and windows. Electricity was also listed as an essential. While these characteristics are modest, previous studies have indicated that they can significantly reduce the risk and burden of malaria; several studies in Tanzania and across sub Saharan Africa have indicated lower risk of malaria transmission in houses with brick walls, metal roof and electricity compared to the those with mud walls, thatched roof and that lack electricity (26,37,38,52,106–108,250).

Community members were well aware of the value of an improved house in reducing the risk of malaria transmission. They were aware that poorly constructed houses provided little protection against mosquito entry, and made it difficult to use the currently available mosquito control tools. Small house sizes and lack of windows also made it difficult to do household chores indoors, forcing people to spend the most of their waking hours outdoors exposed to mosquito bites. Interestingly, a different study in the same communities indicated that the highest risk of exposure to malaria transmission occurred during the early night hours when a majority of people were outdoors in peridomestic settings (26). However, the community members had concerns over the perceived high costs associated with housing improvement, which was the reason that people lived in the traditional houses or incomplete houses. A previous study by Kaindoa *et al* (2018) in the same communities also indicated that community members were awareness of the association between house structure and risk of malaria transmission, but poverty and competing priorities prevented them from building better houses or improving their current houses (244).

While a majority of the community members in this study lived below poverty line (average annual household income was 684 USD), they still manage to build their ideal houses, as more than three quarters of the houses surveyed had brick walls and metal roofs, and 40% used electricity as their main source of light. While it is encouraging that community members are already making the move towards building better homes, a great deal of efforts is needed to ensure that people complete building or improving their houses in good time, as often this process took decades to complete. While not formally recorded in this survey, a majority of the houses had either windows covered completely with bricks and eave spaces left open, or had most of the windows covered with bricks, leaving small holes on the walls for air to pass through (Figure 7.1). These openings offered minimal protection against mosquitoes, maintaining the risk of malaria transmission even in the houses that would be considered improved. High price for proper windows and doors was listed as among the major limitations as to why it took so long for people to complete their homes.

Community members stressed that support from the government would be crucial in helping people live in safe and protective environment. They offered a range of suggestions for the government to help its citizens achieved the goal of building malaria out. These included providing building loans, subsidizing the cost of building materials, or building standard houses and renting to the poor at an affordable price. The concept of government supporting communities to build improved houses was highly opposed by policy makers in a previous study, who indicated this was not affordable or sustainable for the government (134). However, this lack of support from the government officials may be due to lack of understanding the magnitude of the actual need for housing improvement. Lindsay *et al* (2021) proposes that a range of facilitators, both in the public and private sectors be involved when discussing the prospects of housing improvement. These may include microfinance institutions, government ministries, town planners, architects and community members among others, to ensure that citizens live in disease-free houses (251). 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.

With regards to the migrant communities, community members acknowledged that these would be difficult to protect with housing interventions due to their mobile nature, and for the migratory farmers, due to the environment in the farm that provides little opportunity for building houses. These challenges have also been previously observed by researchers at Ifakara Health Institute, who have developed several possible interventions for these communities including potable mosquito-proof huts (145) and the use of repellent-treated eave ribbons (148). More intense studies are needed to extensively explore the potential of these interventions in migrant communities.

This study did have a number of limitations. In assessing the house structure, our survey was limited to assessing wall and roof materials. We did not assess the quality of these materials, or what was used to cover doors and windows, or the presence of eave spaces in the homes. We propose that future studies conduct a more comprehensive assessment of house structures and the state of the materials in order to obtain a more accurate estimation of the magnitude and need of housing improvement. Additionally, the qualitative component of this study had only two FGD sessions, which is a relatively small sample size. However, this was part of a larger study that included eight FGD sessions with four stakeholder groups, community members being one of the groups (134). In this paper we are reporting findings from the FGDs and survey done with community members only. We recommend that any future studies increase the sample size to obtain more diverse inputs from the targeted groups.

7.6. Conclusion

Housing improvement for malaria control is a well understood and acceptable intervention among communities living in malaria endemic settings. While people in these settings are making a great deal of efforts to build or improve their houses, without additional support the process is slow, and maintains them at a risk of malaria transmission. It is crucial to bring together all the key players in housing sector to come up with solutions that can reduce barriers that communities living in malaria endemic settings face in building mosquito-proof houses.

Chapter 8: Discussion and Conclusions

The past two decades have witnessed significant scaling up of malaria control interventions worldwide, and a significant decline in malaria cases and mortality globally (1). However, the success in malaria control and elimination has not been uniform globally, as more than 90% of the current malaria cases and deaths are in sub Saharan African countries like Tanzania (1,16). Despite the great efforts to control and eliminate malaria in Tanzania, this disease continues to be one of the leading causes of morbidity and mortality in the country, the highest burden being faced by pregnant women and children under five years of age (1,16). While the current malaria control methods have worked well up to this point, relying on just these methods may delay the plans to achieve elimination by 2030, which emphasizes the need to consider novel alternative means to speed up the efforts (1). Furthermore, recent WHO report shows that the progress made has plateaued over the past three years, and with this trend the case and mortality reductions could be missed by 37% and 22% respectively (1). While there are a number of recommended alternative interventions under consideration (2), there is an urgent need for Tanzania to carefully consider interventions that are effective, affordable, acceptable and fit for the country (1,2).

In this study a need and potential of six alternative interventions to complement the current malaria control tools in order to speed up malaria control and elimination efforts was explored. This study was a stakeholder engagement process that sought perceptions and recommendations of key stakeholders on the need and potential of alternative interventions to complement current tools to help speed up malaria control and elimination efforts. The study further explored recommendations of the stakeholders on how effective stakeholder engagement can be implemented to help speed up malaria control and elimination efforts. Stakeholder groups involved in this study were policy makers, regulators, research scientists and community members. This was an exploratory sequential mixed methods study approach that explored and assessed stakeholders' perceptions of the alternative interventions for malaria control and their recommendations on interventions that would be best fit to invest in, and the best approaches to maximize impact of the interventions in malaria control and elimination in the country. This study resulted in three published articles and one manuscript, and results from the articles is describes in subsections below.

8.1. Awareness and perceptions of alternative interventions for malaria control and elimination in Tanzania

There was a near-universal agreement across the stakeholder groups that Tanzania had made tremendous efforts in controlling malaria, which was evident in the overall decline in malaria prevalence over the past decade (15,16). However, there was also an agreement across the stakeholder groups that it would not be possible to achieve malaria elimination if the country relied on the current interventions alone at the current levels of utilization (134). There was an overall consensus that challenges with current interventions such as insecticide resistance and outdoor biting exposure could not be overcome with current interventions, and that novel complementary interventions would be needed to help speed up malaria elimination efforts in the country. While the different stakeholder groups had varying degrees of support for the different alternative interventions presented to them, larviciding, mosquito-modification technologies and housing improvement were deemed the most potential overall. The need for alternative interventions to supplement current malaria control interventions with novel tools is supported by Rogers' diffusion of innovations theory, particularly the relative advantage attribute (141,143). Stakeholders' perceptions of limitations of current interventions influenced their need for alternative interventions to for effective malaria control and elimination in the country.

8.2. Support for larviciding for malaria elimination across stakeholder groups

Larviciding was generally the most preferred alternative intervention across the stakeholder groups. The main attribute for this intervention was that the Tanzanian government had already started investment in it through construction of a biolarvicides-production plant, Tanzania Biotech Products Limited (TBPL) (252), which is responsible for a large scale production and distribution of two types of biolarvicides, *Bacillus thuringiensis* var. *israelensis* (Bti) and *Bacillus sphaericus* (Bs) (252,253). Larviciding was also believed to have the highest potential to overcome challenges of the current interventions such as insecticide resistance and outdoor and early-night biting. These findings are in line with WHO recommendation for larviciding as a complementary intervention for malaria control, although so far WHO recommends this intervention for settings where larval habitats are few, fixed and findable (29). While knowledge and awareness for larviciding was generally low among the community members (133), their support for this intervention was relatively high. Community members had concerns over the possibility of larvicides getting in to the water and possibly harm people and domestic animals (133,134), however, they proposed that larviciding should be done in the dry season to avoid the likelihood of contaminating water that is used for domestic needs (134). The general support for larviciding is supported by the attributes of the diffusion of innovation theory.

Although the specific knowledge on how it works was relatively lower among the community members, general concept of larviciding was well understood by a majority of the stakeholders. Larviciding was perceived as relatively easy to use and efficacious as it targets mosquitoes in their larval habitats, as opposed to currently available interventions that passively wait for mosquitoes to come to human dwellings. While community members did not perceive larviciding as compatible to their values and experiences as it was perceived to likely be harmful to people and their environment, community members provided their input on how larviciding could be done in the dry season for minimal harm to the environment, indicating a high perceived degree of triability (141,143).

8.2.1. Knowledge gaps among district and local malaria control officials

Significant knowledge inadequacies on implementation of larviciding were observed among the local and district malaria control officials including malaria focal persons, vector surveillance officers and ward health officers. While the officials did understand that mosquitoes' life cycle involves an aquatic stage, which is the target of larviciding, a majority could not point out specific habitats of malaria vectors or differentiate them from other non-vector mosquitoes. Other knowledge gaps included inability to conduct proper application of larvicides according to WHO guidelines (220). While some of the officials reported receiving some training on the application of the larvicides, the training was said to be theoretical, and failed to provide the officials with practical skills needed in the field settings (231).

8.2.2. Inadequate involvement of local organizations on implementation of larviciding

Insufficient support from local organizations was also listed as an obstacle towards effective implementation of larviciding. Malaria control officials expressed the need to involve public and private organizations in planning and implementation of larviciding. It was believed that doing so could be beneficial in generating local financial support to properly and effectively implement this intervention. This multisectoral approach to malaria control has been recommended by both the WHO and Roll Back malaria (RBM) (14,254). Stakeholders to involve may include, but not limited to, environment, agriculture, water and sanitation, housing, education, education and local government authorities (14,254). Proper engagement of these stakeholders can help obtain diverse opinions, improve sense on ownership and encourage financial contribution on various aspects of malaria control efforts.

8.3. Varying viewpoints on mosquito modification technologies

The possibility of releasing modified mosquitoes, particularly the gene drive technology, generated a great deal of interest and polarized viewpoints among the stakeholders. To our surprise, there was no opposition to this technology among community members, policy makers and regulators, when it was presented to them during the FGDs. While a number of concerns were raised, such as a possibility of mutations in both the mosquitoes and the parasites, or disruption of the ecology, this technology was seen as environmentally friendly. The fact that it required minimal work by people was praised by the stakeholders, particularly community members. Community members, regulators and policy makers indicated that they rely on information from scientists to make informed decision; this emphasizes the need to have local scientists on board in this technology as they have a persuasive power to convince other stakeholder groups (45). Scientists on the other hand expressed skepticism about this technology, expressing their doubts on its safety, lack of strong evidence of its effectiveness and inadequate involvement of local scientists in the research on this technology. Similar concerns have been expressed elsewhere in Mali (179), Nigeria (178) and USA (45). It is critical that these concerns are given careful considerations are responded to in order to avoid further controversy.

8.3.1. The concept of genetic modification is not new in the community

Although knowledge and awareness of mosquito modification technology was relatively low among community members, once this technology was explained to them during the focus group discussions, community members associated the technology with their common practices of using hybrid crop seeds and cross-breeding domestic animals to select for preferred traits and better yield. This association allowed them to use their lived experiences to balance potential risks and benefits of this technology. It is important to pay attention to people’s culture, values, experiences and interests is crucial when explaining the attributes of this technology (46,48). Understanding perceptions and interpretations of public health interventions is also crucial in ensuring support for the interventions. The analogies associated with mosquito modification technology provide a strong basis for which to build up awareness-raising information.

8.3.2. Population-suppression gene drive technology was a preferred technology

Although several forms of mosquito modification technology were explained to the community members, the community members showed a strong preference for a population-suppression gene drive technology, particularly male-biased sex distorter gene drive (198,255). Some of the perceived attributes of this technology included the fact that it involved release of male mosquitoes which were believed to be safer than females, and the fact that this technology required fewer mosquito releases relative to other mosquito modification technologies (34,35,255). However, suppressing just one mosquito species was perceived as a setback for this technology. Drawing from their lived experiences, community members explained that generally effectiveness of malaria control interventions is measured by decreased mosquito density, hence presence of any mosquitoes could imply to people that the technology does not work. This is a valid concern from the community members, as malaria vectors in the region where this study was done are estimated to account for less than 10% of the overall mosquito population (26,160), hence suppression of just one vector may not result in overall decline in mosquito population. Mosquitoes were also considered a nuisance regardless of whether they transmit diseases or not. This concern was also expressed by scientists who pointed out that in most of the country there are more than one malaria vector species, and suppressing one could possibly increase vectorial capacity of the other vector species (134). This concern has also been expressed by other stakeholders in Nigeria (178) and Uganda (256). While its possibility has not been addressed by gene drive experts, recent publication by the experts indicate that advances in the technology makes it possible to introduce germline modification to a range of malaria vectors (255).

8.4. Preference for housing improvement by community members

Housing improvement was the most understood and most preferred intervention among community members, who emphasized that it was a more sustainable approach for elimination of malaria and many other infectious diseases. Community members emphasized that no other intervention would be able to achieve its optimal potential if people continue to live in poorly-constructed houses. This point of view is supported by historical evidence that links successes against malaria with improved housing conditions in Europe and North America (104,105). More recent studies across sub Saharan Africa have associated children living in improved houses with lower odds of being infected with malaria compared to those living in unimproved houses (38,106,107). Other studies have also indicated higher densities of malaria vectors in unimproved houses compared to improved houses (52,108,109). On the other hand, research scientists, regulators and policy makers expressed skepticism over the prospect of government investment on housing improvement for malaria control due to its perceived high cost and lack of political feasibility. However, community members offered a range of affordable suggestions for the government to help its citizens, including providing building loans, subsidizing the cost of building materials, or building standard houses and renting to the poor at an affordable price. The definition of an ideal improved house was also relatively modest; it included features like bigger space, brick walls, metal roofs and big and windows. Screen on windows and doors and electricity were also listed as essentials. While these characteristics are modest, previous studies have indicated that they can significantly reduce malaria cases and severity (38,106,107), and overall risk of malaria transmission (52,108,109).

8.5. Stakeholder engagement is essential for effective implementation of alternative interventions

There is an increasing recognition of the importance of stakeholder engagement to improve the success of malaria control programs (127,257). Effective stakeholder engagement is also recognized as one of the most crucial determinants of success of malaria control interventions as it influences the performance of the interventions as it offers means to navigate social, economic, cultural, political and ethical issues (44,45,127,257). Yet, there is limited evidence on effectiveness of stakeholder engagement, or evidence on effective stakeholder engagement techniques in improving malaria control and elimination efforts (127,257,258). Likewise, there is limited evidence on the clear role of stakeholder engagement in malaria control and elimination in SSA (127,257,258). This study explored and assessed perceptions of several stakeholder groups on the country's progress on malaria control and elimination, and on the need and potential of alternative interventions to help speed up malaria control and elimination efforts. In this study, there was a common consensus among all stakeholder groups that proper stakeholder engagement was needed to ensure that any new interventions coming into the country are understood, accepted and comply with the needs of the country and the targeted communities.

Several concerns regarding alternative interventions for malaria interventions were brought to light in this study. These included environmental concerns, safety and perceived high cost. Addressing these concerns will require more than just raising awareness of the interventions; more efforts are needed to develop partnerships with the communities, and to generate transparency in all aspects of the alternative interventions for malaria control. This will give the stakeholders a chance to have their views included in the development and implementation of the alternative interventions, and will in turn improve on the sense of ownership and acceptance of the interventions (44). However, Scheufele (2013) emphasizes that merely explaining scientific technologies to stakeholders does not automatically result in support for the technology (46), as different people may interpret information given differently based on their culture, values, experiences and interests (46). In this study different stakeholders expressed their opinions on different malaria control interventions based on their values and experiences. While community members were concerned about how the interventions could affect their day-to-day activities, their livestock and surrounding environment, policy makers were more concerned about the overall cost of the interventions, and scientists spoke more of the need to generate evidence of effectiveness and safety. This finding further emphasizes on the need to approach different stakeholders differently and focusing engagement messages on the values and experiences of different stakeholders (44,46)

The stakeholders, particularly community members requested that the prospects of the alternative interventions be practically demonstrated rather than just communicated. This is a crucial concern as people have different levels of understanding, and merely informing them of an intervention may not necessarily improve their levels of awareness. In the national larviciding program for example, despite efforts by local and district-level malaria control officials to inform and sensitize the residents on larviciding, a majority of the community members surveyed were not aware of this intervention and its potential in malaria control efforts. Similar findings were previously reported in the same region where only 17% of community members were aware of larviciding as a malaria control intervention (236). The lack of community awareness despite reported community engagement indicates that stakeholder engagement efforts need to be demonstrated differently to different stakeholders, and needs to take into account people's experiences, values and interests (46,48). Costa *et al* (2020) recommends that that public engagement needs to be more than an exercise in the provision of information, and should create opportunities for genuine exchange with affected communities (200). This study provides an opportunity to demonstrate prospects of a stakeholder-informed stakeholder engagement intervention, one that involves stakeholders in selection of a malaria control intervention that fits their needs, values and experiences, and involves stakeholders in deciding how they should be effectively involved in the implementation of the malaria control intervention.

Facilitators of engagement and particularly the source of information is a vital stakeholder engagement aspect to consider (46,69) when engaging stakeholders in research or implementation of these interventions. In this study, when asked about trusted sources of malaria-related information, community members ranked health researchers and health care workers higher than government officials or politicians. This made sense in our case as Ifakara Health Institute has built a trusting relationship with the communities over the decades. Furthermore, policy makers and regulators also indicated that they rely on information from scientists to make decisions about malaria control interventions to invest in. This trust and dependence on scientists provides an easy entry point when engaging the stakeholders on new interventions for malaria control. The manner of communication is also a critical aspect to consider (46). It is crucial to consider language to be used and framing of technologies to avoid miscommunications and misunderstandings. Scheufele proposes that media plays an important role in reaching to the public and pass on the public health information of interest, hence they are an important stakeholder group to work with (46)

Timing of stakeholder engagement is also an important factor to consider (69). Thizy *et al* (2019) recommends engaging the public at the onset of a project, and to continue throughout its implementation (47). They further recommend that stakeholders' inputs be taken on incremental basis based on the stage of research or implementation an intervention (47). Stakeholders need to be actively engaged from early on, in the selection, research and implementation of the interventions, to make sure that the interventions selected are appropriate and meet the needs of the country and targeted communities (47,69). In this study the stakeholders were provided with an opportunity to weigh in on benefits and drawbacks of a number of alternative interventions for malaria control and elimination in the country, and were given an opportunity to select an intervention they would prefer. The decision to focus on larviciding was supported by a majority of the study participants, who also recommended on who would be the key players to engage and how to engage them. This is an important aspect of this study as it gives the decision making power to the stakeholders; decision on the best intervention to invest in, key players to engage and how to engage them.

8.6. Implication of the findings

8.6.1. Influence on policy review on new malaria control interventions

The need for policy review to incorporate new malaria control interventions was recommended by both policy makers and regulators in this study. It was noticed that it had been a while since research scientists had sat together with regulators and policy makers. A number of changes in malaria dynamics such as mosquitoes' resistance to insecticides used in bed nets and changes in mosquito behaviours were unknown to a majority of the policy makers and regulators. It was therefore recommended that such round table discussions between scientists, regulators and policy makers be made regular in order to bridge the gap between these three groups, and provide a means for an easy and efficient knowledge sharing, which would in turn influence timely updates on the policy and regulations around malaria research and control in the country.

Regulators also indicated that there are currently no regulations for governance of genetically modified mosquitoes, and that more evidence would be required from scientists in order to put policies and regulations in place. It was noted that there were regulations around genetically modified crops that could be built upon, but more research-based evidence would be needed to adapt these for malaria research and control.

8.6.2. Collaborations with regional, district and local malaria control officials

A collaboration between Ifakara Health Institute and regional and district malaria control officials was also recommended to improve implementation of larviciding program. IHI has a wealth of expertise in malaria vector research, and control. It was recommended that IHI partners with the regional, district and local malaria control officials to share knowledge on the biology and behaviours of malaria vectors. A training program has therefore been prepared to equip regional, district and local malaria control officials on understanding the dynamics of malaria vectors, such as their biological and behavioural difference from other non-vector mosquitoes. This training program will be largely hands-on, and is aimed at equipping the malaria control officials with expertise in effective control of malaria vectors through larviciding and any other malaria control interventions in the future. A draft of the training manual for this program is included in appendix 1.

8.6.3. Similar studies across sub–Saharan Africa

This study generated interest in several countries across SSA. A similar study is ongoing in Kenya, and preparations for similar studies are underway in Nigeria and Cameroon. In 2020 we also received funding from the Foundation for National Institute of Health (FNIH) to expand this study and include stakeholders from across SSA. This however, is focusing only on gene drive technologies for malaria control. Similarly, we have received funding from the British Academy of Sciences to further explore and assess the need, magnitude and potential of housing improvement for malaria control in Tanzania.

8.7. Limitations of the study

This study had a number of limitations. To start with, this study was conducted in southern Tanzania where communities have long been associated with public health and entomological research campaigns, and are generally knowledgeable about malaria transmission and control (26,196,259). The levels of awareness of malaria transmission and control can therefore not be generalizable to the rest of the country or SSA. Additionally, the different interventions assessed in this study were in different levels of research or implementation. For example, the role of housing improvement was well understood by community members based on their lived experiences, so the awareness and support for it was understandably high. Similarly, larviciding on the other hand had already been researched and implemented in Dar es Salaam (218), and the government had started preliminary work in some communities when this study had was conducted. Due to this there was a degree of awareness and support for it.

On the other hand, no research in mosquito modification technologies had ever been done in the country and more specifically in the communities where this study was done. Other interventions such as spraying of mosquito swarms and MDA with ivermectin were new to a majority of the study participants, so their support was understandably lower. These differences in levels of research or implementation of the different interventions may have resulted in the different perceptions of the interventions, and need to be taken into account when comparing stakeholder support for the interventions.

A number of the new or less known interventions were briefly described by the facilitator during the focus group discussions, which may have necessarily influenced perceptions. However, to minimize information bias, participants were first asked to list what they knew about the interventions first, and the facilitators filled in the knowledge gaps. During the survey positive statements used to assess perceptions towards the different alternative interventions may have also influenced positive responses, although this was not observed.

Lastly, only eight FGD sessions were conducted, two per stakeholder group. This is a relatively small number, and did not allow us to reach saturation. However, we were still able to generated a wealth of qualitative data on stakeholders' preferences, and were able to use this data to generate a quantitative component. We propose for future studies to expand on the qualitative component to gather more diverse opinions of stakeholders

8.8. Key messages and recommendations from the study

The main messages based on work from this thesis are summarized below:

- All stakeholders agreed that alternative interventions are needed in order to achieve malaria elimination in Tanzania by 2030
- Different stakeholders had different preferences for different malaria control interventions
- Housing improvement was most preferred by community members as it best fits their needs and experiences, but was least preferred by other stakeholder groups due to perceived high cost and lack of sustainability
- Mosquito modification technology was supported by all stakeholder groups except scientists, who were sceptical of inadequate evidence of safety and effectiveness
- Larviciding was overall the most supported intervention across the stakeholder groups, and was recommended as an intervention on which to build stakeholder-engagement intervention.
- Implementation of larviciding had already began across the country, but several challenges were identified including inadequate knowledge among district and local malaria control officials, insufficient funding, lack of involvement of local stakeholders and inadequate community awareness and involvement
- Stakeholder engagement is a long-term process; it needs to starts early at the onset of the intervention and continue throughout the lifetime of the malaria control interventions
- Stakeholder engagement needs to go beyond raising information, it needs to be a two-way process that involves genuine exchange of views and information and build partnerships with the affected communities
- Different stakeholders need to be engaged differently based on their need, values and experiences. It needs to set clear roles and scope and activities that need to be achieved by each stakeholder group

8.9. Conclusion

While it seems inevitable that new tools will be needed for Tanzania to achieve malaria elimination by 2030, careful thoughts need to be placed in selection of interventions that will meet the need of the country and local communities. Different stakeholders reported preferences for different interventions based on their knowledge, values and experiences. Stakeholders recommended that any malaria control interventions need to take into account not only the needs of the country and communities of target, but also to complement the efforts that the country is making.

My PhD gathered opinions and recommendations of various stakeholders in Tanzania on best strategies to speed up malaria elimination efforts in the country. The stakeholders recommended that significant investment be put on larval source management, particularly larviciding. Some of the recommendations for improving this program included building partnerships with local public and private organizations, improving knowledge on effective larviciding among regional, district and community malaria control officials and involving the communities in the actual implementation of larviciding.

Stakeholder engagement was proposed to be a crucial component in ensuring that malaria control targets are met in the country. It was recommended that stakeholder engagement be a long-term process that involves building partnerships and equal sharing of information between key actors. I recommend that similar studies be conducted in more diverse settings and diverse stakeholder groups. Future studies also need to focus more vigorously on exploring and acting on solutions for the queries and concerns from various stakeholders.

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Appendices

Appendix 1: Training Manual on Larval Source Management for community members

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Training Manual on Larval Source Management

For Community Members in Ulanga and Kilombero Districts

Module 1: Introduction to Control and Biology of Malaria Vectors

General description of the module

This module will provide a basic understanding of biology of major malaria vectors within Kilombero and Ulanga districts, and key components to consider towards control interventions. Through this module, participants will gain an insight into the progress and challenges in malaria control, particularly in Kilombero and Ulanga districts.

Key topics

1. Basic biology of malaria vectors present in Kilombero and Ulanga districts.
2. Morphological identification of mosquitoes at both larval, pupal and adult stages
3. Basic introduction to malaria transmission (i.e. mosquito and parasite's life cycles).
4. Overview of malaria burden and historical transitions (control, challenges and opportunities in malaria control).
5. Overview of malaria control interventions (core and complementary interventions, and their contributions in malaria control).

Delivery

Prior deliverance of this module, participants will be required to undertake a survey to assess their knowledge on biology of malaria vectors, malaria transmission and its control. This module will be delivered through practical sessions. At the end of the module, participants will be required to sit for a post-test to assess the impact of training.

Facilitators: Salum Mapua, Japhet Kihonda, Ismail Nambunga and Marceline Finda.

Materials required (at least two pieces per item type)

- Centers for Diseases prevention and Control (CDC) miniature light traps, Prokopack aspirators, Biogents-Sentinel traps, Suna traps.
- Flip charts, flip chart board and marker pens.
- Mosquito samples and tools for morphological identification such as forceps and sorting trays.

Module 2: Understanding and controlling mosquitoes in their aquatic habitats

General description of the module

Whilst challenges such as insecticide and behavioral resistance of major malaria vectors hinder the full potential of the backbone control interventions such as long lasting insecticidal bed nets (LLINs) and indoor residual spraying (IRS). Larval source management as a supplementary strategy targeting immature stage of the vectors offers a plausible opportunity towards malaria control. The government of Tanzania has recently been extending its larviciding initiative to the rural settings. This module aims at providing basic understanding on larval source management to the community members to ensure sustainability of the programme. Prior this module, the pre-test will be done to assess the knowledge of the participants on larval source management. The post-test will also be conducted to assess the effectiveness of the training. This module will be delivered through two sub-modules;

i) Identification and characterization of the aquatic habitats of malaria vectors in Kilombero and Ulanga districts.
ii) Effective implementation of larval source management particularly with bio-larviciding.

Identification and characterization of the aquatic habitats of malaria vectors in Ulanga and Kilombero districts

This sub-module will focus on identifying and characterizing aquatic habitats of *Anopheles* mosquitoes. The participants will cover the following;

1. Identification and characterization of the aquatic habitats of the major malaria vectors present in these districts.
2. Larval survey.
3. Mapping of aquatic habitats of the major malaria vectors, this will simply involve use of GPS.

Delivery

1. **Class session:** The facilitator will provide the information regarding aquatic ecology of the major malaria vectors, and how best larval density can be estimated and various sampling techniques. The pin-pointing of the aquatic habitats by using GPS will also be described by the facilitator.

2. **Practical session:**
    i) Participants will have an opportunity to visit the selected field sites for identification of the aquatic habitats, learning sampling techniques and estimation of the larval density.
    ii) The participants will also learn how to process and store collected immature mosquitoes for transportation, and recording larval survey data on paper-based platform.
    iii) Participants will learn how to properly characterize aquatic habitats of the *Anopheles* mosquitoes based on their physical features and physicochemical parameters.

Facilitators: Salum Mapua, Japhet Kihonda, expert from Tanzania Biotech Product limited (TBPL), Ismail Nambunga and Marceline Finda.

Materials required (at least three pieces per item type)

- Standard mosquito dipper
- Pipettes
- 10 liters buckets
- Transporting containers (Bottles/ larger containers)
- Personal protective equipment such as gum boots
- Handheld GPS devices
- Label/ Masking tapes
- Mosquito collection forms (for larvae)
- Notebooks

Larval source management

This sub-module will provide community members with a capacity to effectively implement larval source management specifically larviciding. The module will cover the following topics;

1. Appropriate larval source management strategies for different areas and different habitat types
2. Planning, proper selection of larvicides and the optimum doses for larviciding.
3. Preparation of the selected larvicides for deployment.
4. Monitoring effectiveness of larviciding.

Delivery

1. **Class session:** The facilitator will provide different approaches of deploying larval source management. Importance of effective planning, larval surveillance and mapping of aquatic habitats in larviciding will also be described. Participants will have an opportunity to learn pros and cons of different WHO's approved larvicides.
2. **Practical session:**
    i) Participants will demonstrate in the field on how to select appropriate larvicides and the optimum dose based on the identified and characterized aquatic habitats
    ii) Participants will demonstrate their knowledge on how to prepare the larvicides and its deployment methods.

Facilitators: Salum Mapua, Japhet Kihonda, expert from Tanzania Biotech Product limited (TBPL), Ismail Nambunga and Marceline Finda.

Materials required (at least three pieces per item type)

- Twenty liters of larvicide (i.e. *Bti*)
- Backpack sprayers fitted with a solid stream nozzle
- Personal protective equipment (overall, gloves, and gum boots)
- Handheld GPS devices

Appendix 2: Training Manual on surveillance and control of malaria for district malaria control officials

a training program for district-level malaria control implementers

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Introduction

As malaria-endemic countries move toward malaria elimination, they need to enhance efforts for effective vector control and surveillance. This should allow evidence-based decisions to maximize the impact of existing and new interventions. The process of generation of evidence faces several limitations, including the lack of human capacity to collect, analyze, interpret, and report meaningful entomological data. The national control programs must, therefore, develop and deploy appropriate training programs to impart the necessary skills for vector surveillance and monitoring of vector interventions. Such programs should be tailored to the needs of different districts depending on current and projected epidemiological profiles. Similarly, the main focus of the training should be the district-level implementers including both the malaria focal persons and the surveillance officers.

Goal

This training program aims to enhance the capacity of district-level malaria control implementers in conducting effective entomological surveillance and control programs. This program will provide hands-on experience to the participants to enable them to generate evidence for decision making in vector control. In addition, there will be specific on-demand training programs tailored to meet the demand of specific districts.

Intended participants

District-level malaria control implementers (malaria focal persons and surveillance officers), researchers, and early career staffs aiming to participate in malaria elimination efforts and other public health officers at district and national level. Where feasible, participants from the private sector and non-governmental organizations will be included.

Mode of operation

The training program will consist of four parts as follows: i) 2-4 week in-residence sessions including both theoretical sessions and hands-on practical sessions conducted at designated research facilities and malaria-endemic villages, ii) continued support and follow-up for the participants over several months after initial training, iii) targeted support for individuals wishing to take advanced-level training and iv) longer-lasting support program for the implementers depending on need and resource availability

A complementary online version of the course will be made available for all registered participants

Lesson 1: Introduction to malaria burden and control

Description of the module

This module will provide an introduction to the current burden of malaria, historical transitions and the ongoing efforts to control it. This will give participants an insight into the progress and challenges in malaria control. The module will also highlight the importance of this training in different contexts and help participants identify gaps in their current knowledge. Key topics in this module will be:

6. Identification of knowledge gaps: a pre-test followed by group discussions will help identify key knowledge gaps and priority areas for training (all tutors and participants to participate directly or indirectly).
7. Basics of malaria: an introduction to malaria transmission (vectors, parasites, and transmission cycles).
8. Introduction to the burden of malaria and historical transitions: Where we are in malaria control, challenges, and opportunities in malaria control.
9. Malaria control interventions: Current interventions and their contributions to malaria, with emphasis on vector control.
10. Stratification in malaria: The concept of stratification for vector control interventions.
11. Importance of malaria surveillance: case studies of previous surveillance efforts
12. Delivery of malaria prevention services in emergencies: the safety of personnel, sustaining gains and preventing rebounds; deployment of extraordinary measures in emergencies.
13. Novel alternative technologies for malaria control

Delivery

This module will be delivered in a class session, where the facilitator will provide descriptions on the key topics of this module, and allow for discussions. The facilitator will use videos, pictures, and graphs to explain concepts and demonstrate trends. For novel interventions, where possible the facilitator will need to demonstrate real intervention tools, and allow discussions with participants on how novel interventions fit in different contexts. For the first session, there will be an open test to participants followed by a group discussion to identify knowledge gaps.

Facilitators: Experts in malaria biology and control, with the understanding of deployment of vector control interventions.

Materials required

- LCD projector
- Flip chart board
- Flip charts

Recommended readings

1. WHO. Guidelines for Malaria Vector Control. Geneva: World Health Organization; 2019
2. WHO. World Malaria Report 2019. Geneva: World Health Organization; 2019
3. Bhatt S, Weiss DJ, Cameron E, Bisanzio D, Mappin B, Dalrymple U, et al. The effect of malaria control on *Plasmodium falciparum* in Africa between 2000 and 2015. Nature. 2015;526:207–11.

4. WHO. Tailoring malaria interventions in the COVID-19 response. Geneva: World Health Organization; 2020.
5. Beier JC, Wilke ABB, Benelli G. Newer Approaches for Malaria Vector Control and Challenges of Outdoor Transmission. Toward Malaria Elimination - A Leap Forward. IntechOpen; 2018.
6. Matthews G. Integrated Vector Management: Controlling Vectors of Malaria and Other Vector Borne Diseases. Chichester: Wiley-Blackwell; 2011.

Lesson 2: Mosquito trapping and identification

Description of the module

Mosquito trapping and identification form an important basis of malaria vector surveillance. It helps determine the mosquito species composition in a given area and at any given time. Moreover, it helps identify the mosquito species that are responsible for the transmission of different disease pathogens. Of the more than 400 species of genus *Anopheles*, only about 40 can transmit malaria. In Africa, the four main malaria vectors include *Anopheles gambiae, Anopheles funestus, Anopheles coluzzi*, and *Anopheles arabiensis*, though there may be several other species playing minor roles in different locations. This module aims to familiarize participants with skills for trapping mosquitoes, handling the specimen, and identification of the major *Anopheles* species in their localities. The participants will be trained on:

1. Mosquito trapping methods
2. Preparation of mosquito samples for identifications (pinning, preservation, and storage)
3. Use of microscopes, to visualize structures of mosquitoes
4. Distinguishing between male and female mosquitoes,
5. Examining physiological status of female mosquitoes (unfed, partly fed, fully fed, semi-gravid, and gravid)
6. Distinguish immature stages (egg, larvae, and pupae) of anopheline from culicine mosquitoes
7. Distinguish adult anopheline mosquitoes from culicine mosquitoes
8. Morphologically identify different *Anopheles* mosquito species (using identification key for *Anopheles* mosquitoes. This will also cover the use of digital keys for *Anopheles* mosquitoes)
9. Molecular identification of anopheline mosquitoes (a demonstration)

Delivery

1. **Class session:** In this session participants will learn on the biology of mosquitoes, particularly the external anatomy of mosquitoes to enable participants to master the main structures used for identification. The facilitator will use large and clear images and videos to present concepts. The facilitator will also describe the concept of mosquito species complexes and groups, and the rationale of distinguishing individual mosquito species from their complexes or groups. The facilitator will also describe molecular methods for the identification of mosquito species. Also, the facilitator will provide a brief description of mosquito.

2. **Practical session**
    - i) Field sessions will be organized to collect mosquitoes using CDC-Light traps for adults and standard dippers for larvae
    - ii) First, participants will sit in groups of not more than three, where they will learn how to use stereomicroscopes, using actual microscopes.
    - iii) The facilitator will demonstrate distinctions between egg, larvae, pupa, and adult of anopheline from culicine mosquitoes. Then, participants will perform exercises on distinguishing different aspects of the mosquito identification
    - iv) Once participants are able to isolate anopheline mosquitoes, they will learn and exercise step by step identification of species of anopheline mosquitoes using the morphological identification keys

v) Participants will visit the molecular laboratory for the demonstration of molecular identification of sibling species of *Anopheles*.
vi) The final session will involve learning how to use the digital keys for Anopheles mosquitoes in sub-Saharan Africa.

Assessment

Participants will be provided with *Anopheles* mosquitoes of different species, physiological status, and sex. They will be required to distinguish male from female mosquitoes, identify physiological status. They will also be required to demonstrate the ability to identify mosquito species using morphological identification keys.

Facilitators: Medical biologists with working experience on *Anopheles* mosquitoes

Materials required

- Key to the females of Afrotropical *Anopheles* mosquitoes by Coetzee M. (2020) and A supplement to the Anophelinae of Africa south of the Sahara (Afrotropical Region) by Gillies MT, Coetzee M. (1987)
- Intact adult mosquitoes (both male and female anopheline and culicine mosquitoes of different physiological status)
- Eggs, larvae, and pupa of both anopheline and culicine mosquito
- Mosquito traps (CDC-Light Traps)
- Standard mosquito dipper
- Stereomicroscopes and microscope slides
- Forceps and dissecting needles
- Petri dishes

Recommended readings

1. Becker N, Petric D, Zgomba M, Boase C, Madon M, Dahl C, et al. Mosquitoes and their control. J. Chem. Inf. Model. London: Springer; 2010.
2. Service M. Medical entomology for students. Fifth Edit. Med. Entomol. Students, Fourth Ed. Cambridge: Cambridge University Press; 2008.
3. Koekemoer LL, Kamau L, Hunt RH, Coetzee M. A cocktail polymerase chain reaction assay to identify members of the *Anopheles funestus* (Diptera: Culicidae) group. Am J Trop Med Hyg. 2002;66:804–11.
4. Scott JA, Brogdon WG, Collins FH. Identification of Single Specimens of the *Anopheles gambiae* Complex by the Polymerase Chain Reaction. Am J Trop Med Hyg. 1993;49:520–9.
5. Coetzee M. Key to the females of Afrotropical *Anopheles* mosquitoes (Diptera: Culicidae). BioMed Central; 2020;19:1–20.
6. Gillies MT, Coetzee M. A supplement to the Anophelinae of Africa south of the Sahara (Afrotropical Region). Johannesburg: South African Medical Research Institute; 1987.

Lesson 3: Introduction to data collection

Description of the module

Data collected during vector surveillance is essential for generating evidence to support making decisions related to vector control. The collection of high-quality data is, therefore, a critical element in vector surveillance. Thus, when conducting surveillance, the people involved in surveillance should have the necessary skills to collect high-quality data and to record, store, and handle the data in ways that do not compromise its quality. This module will train participants on how to capture and manage entomological data in ways that guarantee its value.

The module will cover the following:

1. Paper-based methods for capturing mosquito data and related metadata.
2. Methods for capturing geographically-referenced data, using GIS-based approaches
3. Use mosquito management database system (mosquitoDB, http://mosquitodb.io) and its mobile App for capturing and manage entomological data in different entomological activities/ studies
4. Screen for errors in dataset/ data cleaning

Delivery

1. **Class session:** Facilitators will provide descriptions of the concept of data collection and management and tools for data management. Participants and facilitators will have joint discussions on different attributes to capture during entomological data collection.

2. **Practical session:**
   i) Participants will learn about the main attributes to capture and record during field data collection; this will also include essential metadata
   ii) Participants will practice how to capture GIS data using GPS devices and smartphones.
   iii) Participants will install mosquitoDB App into smartphones or tablets. They will register into the mosquito database management system, and practice how to enter data in this system using archived data. Further practice on this will be conducted in other modules.
   iv) They will also learn and practice techniques for screening errors and cleaning datasets using MS excel.

Facilitators: Experts in data management and GIS analysts with working experience in entomological data.

Materials required

- Mosquito collection forms
- Android smartphones or tablets capable of capturing geospatial data and loaded with mosquitoDB App
- Forms for collecting other relevant data, e.g. human behavior data in communities (i.e. occupations, peri-domestic activities, and agricultural activities.)

Recommended readings

1. Ross SM. Introductory statistics. J. Chem. Inf. Model. California: Elsevier; 2018
2. Kiware SS, Russell TL, Mtema ZJ, Malishee AD, Chaki P, Lwetoijera D, et al. A generic schema and data collection forms applicable to diverse entomological studies of mosquitoes. Malar J. BioMed Central Ltd.; 2016;11
3. Finda MF, Moshi IR, Monroe A, Limwagu AJ, Nyoni P, Swai JK, et al. Linking human behaviours and malaria vector biting risk in south-eastern Tanzania. PLoS One.

2019;14:e0217414.
4. Monroe A, Moore S, Koenker H, Lynch M, Ricotta E. Measuring and characterizing night time human behaviour as it relates to residual malaria transmission in sub - Saharan Africa: a review of the published literature. Malar J. 2019;18:6
5. Silver JB. "Designing a Mosquito Sampling Programme." Mosquito Ecology: Field Sampling Methods. 3rd Edition. Springer. Dordrecht: Springer; 2008

Lesson 4: Adult mosquito surveillance

Description of the module

Understanding the occurrence, composition, distribution, seasonality, and mosquito behaviors during mosquito surveillance is essential for the success of vector control interventions. Such information can be used in targeting and timing vector control interventions, thereby, providing the opportunity for effective mosquito control interventions. It also alerts on gaps in mosquito control interventions, and identify the most important *Anopheles* mosquito species in an area. The occurrence of multiple *Anopheles* mosquito species in one area does not necessarily mean that they are all important in malaria transmission. Instead, only a few of these mosquitoes can be of major importance. Therefore, surveillance officers need to collect and identify which mosquitoes are of major importance in malaria transmission. This module will help participants to understand the procedures, methods, and techniques used in mosquito surveillance.

This module aims to:

- i) familiarize participants with skills for designing and deploying adult mosquito collection programs and determining the occurrence, composition, and distribution of mosquitoes.
- ii) familiarize participants on methods for assessing mosquito behaviors of importance to vector control interventions.

Thus, this module will cover the following key topics:

1. Plan for mosquito collection (this will cover choosing the design of the survey, choosing and estimating sampling unit for mosquito collection, choosing sampling strategy and mosquito collection methods)
2. Methods for collecting adult mosquito vectors
3. Analyzing and reporting mosquito surveillance data
4. Estimating mean nightly mosquito densities
5. Mapping distribution of mosquito vectors
6. Methods for identifying mosquitoes infected with malaria parasites
7. Host-preferences of mosquito vectors
8. Determining where do mosquito bites frequently occur (indoor vs outdoors)
9. Determining the time of peak biting activity of mosquitoes
10. Determining the resting location of different mosquito species (indoor vs outdoor)

Delivery

1. **Class session:**

   In this session, the facilitator will first introduce the concept of vector competence and describe the rationale of mosquito surveillance. The facilitator will also describe different concepts of surveillance and adult mosquito collection: sampling designs (cross-sectional and longitudinal), types of entomological surveillance, sampling units and methods for selecting representative sampling units, and methods collecting adult mosquitoes.

   The facilitator will describe *Plasmodium* parasite development in mosquitoes, and how transmission of the parasite occurs. Participants will learn about different methods used in the assessment of *Plasmodium* parasite in mosquitoes. They will also learn about the basic principles of ELISA and PCR in entomology. In this session, the facilitator will also describe the rationale of understanding daily survival/ age structure of mosquitoes, and insemination status and a description of methods used for age grading and assessment of insemination status.

Participants will also learn about different behaviors of different mosquito species such as blood meal/ host preferences, biting behaviors, and resting behaviors. The facilitator will describe the relevance of understanding these behaviors during vector surveillance.

Other discussions on important aspect of vector surveillance

i) Establishment of district wide vector surveillance: Participants will learn about vector surveillance operating within the country and discuss how to develop mosquito surveillance within their districts and integrate it with national systems

ii) Malaria Surveillance in Emergency Situations and Pandemics: A discussion between participants and the facilitator will be on the following:
   - With case studies participants and the facilitator will discuss the importance of performing mosquito surveillance during emergency situations and pandemics
   - How to ensure the safety of all when conducting mosquito surveillance during emergency situations and pandemics
   - Participants and facilitators will discuss entomological surveillance indicators to be collected during emergency situations and pandemics

2. Practical session:

a) Mosquito collections

i) Participants will practice planning for mosquito collection. They will practice selecting sampling units and mosquito collections methods for indoor and outdoor collections of both host-seeking mosquitoes resting mosquitoes in the selected villages.

ii) Participants will learn how to set different traps, conduct mouth aspirations, and mechanical aspirations of mosquitoes before conducting field mosquito collections.

iii) Participants will conduct a community entry/ stakeholder engagement session. Participants will engage community leaders to seek for their advocacy in conducting entomological surveillance. Also, the participant will meet with household heads to ask for their consent to include their households in entomological surveillance.

iv) Participants will visit selected villages and deploy traps for nightly collection of indoor and outdoor mosquitoes. In the morning participants will participate in the retrieval of collected mosquitoes and conduct aspirations of resting mosquitoes both indoor and outdoor. In this practice, participants will be required to capture GIS data.

v) The participant will be required to conduct mosquito identification, sorting, recording, and data entry using MosquitoDB App. Participants will also learn how to store mosquitoes for further laboratory analysis (for dissections, PCR, and ELISA analysis).

vi) Participants will learn how to conduct dissections for ovary and spermatheca assessments and how to interpret results of dissections to determine daily survival and age composition of mosquitoes.

vii) Using the generated dataset, participants will learn how to estimate nightly densities of mosquitoes using simple excel functions and how to interpret these results.

b) Identifying malaria-infected mosquitoes

viii) Participants will practice salivary gland and midgut dissections for determining the presence of oocyst and sporozoite in mosquitoes. Live, *Plasmodium*-infected mosquitoes will be required for this demonstration). If *Plasmodium*-infected mosquitoes are inaccessible, dissections can be conducted using *Plasmodium*-free mosquitoes while videos and pictures can be used to demonstrate how oocyst and sporozoite can be observed in a mosquito.

ix) Using the collected data on nightly catches of biting mosquitoes, participants will learn how to estimate human biting rates.

x) Participants will visit the laboratory for a demonstration of PCR or ELISA techniques for the detection of sporozoite.

xi) Using the result of the human-biting rate and sporozoite infection in mosquitoes, participants will estimate and interpret the entomological inoculation rate of mosquito species analyzed.

c) Understanding mosquito behaviors

xii) Participants will learn how to determine where mosquito bites frequently occur (indoors or outdoors), using a dataset on nightly catches of indoor and outdoor host-seeking mosquitoes.

xiii) Using a dataset on indoor and outdoor resting mosquitoes, participants will learn how to analyze data to determine the preferred resting location of different mosquito species.

xiv) Participants will learn how to analyze host preferences of mosquitoes through blood meal analysis and host choice tests. Whereby, a demonstration of blood meal analysis using ELISA and PCR will be conducted, and participants will learn how to determine host preference from ELISA or PCR results. Participants will learn about the strength and weaknesses of both ELISA or PCR for blood meal analysis. Also, participants will learn and practice how to deploy baited traps (human and human baited traps) for host choice tests. Participants will also learn how to estimate human blood indices and how to interpret the data with respect to malaria transmission

xv) To determine the peak biting time of different mosquito species, participants will set a separate experiment involving hourly collections of biting mosquitoes. Participants will learn how to analyze these data and determine hours when peak biting activities of different mosquitoes occur.

Assessment

Participants will be required to conduct a one-week mock-surveillance exercise, and produce a technical report (in groups) to demonstrate their understating of the adult mosquito surveillance. The report should demonstrate skills learned on the different aspects of training acquired.

Facilitators: Medical entomologists and/ or Mosquito biologists with working experience in mosquito surveillance and incrimination.

Materials required

- Traps (CDC light traps, BG sentinel traps, DN-Mini, Animal baited traps)
- Prokopack aspirators or backpack aspirator
- Female *Anopheles* mosquitoes (*Plasmodium*-infected mosquitoes, if possible)

- Tablets loaded with MosquitoDB App
- Mosquito collection forms for surveillance and laboratory analysis
- Collection bags (such as those used in BG sentinel trap)
- Mouth aspirators
- Flashlights
- Mosquito cages (15 Cm ×15 Cm)
- Forceps
- Handheld GPS Units
- Notebooks
- Microcentrifuge tubes (2 ml)
- Label/ Masking tapes
- Pen
- Cotton wool
- Sorting trays
- Towel (for use in transporting live mosquitoes)
- Glucose
- Chloroform
- Silica gel
- Computers
- Disposable cups
- Timer
- Stereomicroscope
- Light microscope
- Dissecting needles
- Microscope slides
- Distilled water/ saline solution
- Mercurochrome
- Giemsa stain
- Coverslips

Recommended readings

1. WHO. Manual on Practical Entomology in Malaria, Parts I. WH. Geneva: World Health Organization; 1975.
2. WHO. Manual on practical entomology in malaria, Part II. Geneva: World Health Organization; 1975.
3. WHO. Malaria surveillance, monitoring & evaluation: a reference manual. WHO Press. World Heal. Organ. Geneva: World Health Organization: World Health Organization; 2018.
4. Eldridge BF, Edman JD. The Epidemiology of Arthropodborne Diseases. Medical Entomology: Medical Entomology: A Textbook on Public Health and Veterinary Problems. Springer; 2004. p. 165–85.
5. Wirtz RA, Zavala F, Charoenvit Y, Campbell GH, Burkot TR, Schneider I, et al. Comparative testing of monoclonal antibodies against *Plasmodium falciparum* sporozoites for ELISA development. Bull World Health Organ. 1987; 65:39–45.
6. Durnez L, Van Bortel W, Denis L, Roelants P, Veracx A, Trung HD, et al. False positive circumsporozoite protein ELISA: A challenge for the estimation of the entomological inoculation rate of malaria and for vector incrimination. Malar J. 2011; 10:195
7. WHO. Tailoring malaria interventions in the COVID-19 response. Geneva: World Health Organization; 2020.

Additional readings

1. Becker N, Petric D, Zgomba M, Boase C, Madon M, Dahl C, et al. Mosquitoes and their control. J. Chem. Inf. Model. London: Springer; 2010.
2. Silver JB. Mosquito Ecology: Field Sampling Methods. 3rd Edition. Springer. Dordrecht: Springer; 2008.
3. Clements A. Biology of Mosquitoes: Sensory Reception and Behaviour. CABI Publishing; 1999.

4. WHO. The Garki project: research on the epidemiology and control of malaria in the Sudan savanna of West Africa. Geneva: World Health Organization; 1980.

Lesson 5: Understanding and controlling mosquitoes in their aquatic **environments**

Description of the module

ITNs and IRS are increasingly compromised by challenges such as insecticide resistance, high costs, outdoor-biting tendencies, and poor user compliance. This has led to increased demand for complementary tools to improve malaria control. Larval source management presents one opportunity for the control of malaria vectors at source, thus avoiding many of the challenges if the intervention is done at scale. However, for larval source management to be cost-effective, implementers need to have a good understanding of larval ecology and dynamics of mosquito populations in aquatic stages. Larval surveys can give an understanding of larval ecology of mosquitoes, and inform the proper implementation of larval source management initiatives. Such surveys can also be useful in performing evaluations of different interventions targeting malaria vectors. It can also serve as a method to determine mosquito species composition and distribution. This module will, therefore, provide participants with skills to conduct larval surveys and larval source management. This module will be divided into two sub-modules:

iii) Identifying and characterizing aquatic habitats of immature mosquitoes
iv) Larval source management

Lesson 5a: Identifying and characterizing aquatic habitats of immature mosquitoes

This sub-module aims to provide participants with skills to identify and characterize aquatic habitats of *Anopheles* mosquitoes. This sub-module will cover the following:

4. Identifying aquatic habitats of important malaria mosquitoes
5. Collecting immature mosquitoes (larvae and pupa) from different aquatic habitats
6. Estimating abundance or density of immature mosquitoes in aquatic habitats
7. Determine the spatial distribution of aquatic habitats for mosquito species
8. Mapping important habitats in specific locations to aid surveillance and control efforts

Delivery

3. **Class session:** The facilitator will describe the rationale of larval surveys and how information generated in these surveys can be used in vector control. The facilitator will also describe the aquatic ecology of mosquito and sampling methods of mosquito larvae. Examples from previous larval surveys will be used, with specific attention to habitats for key malaria vectors. The facilitator will also describe methods for determining larval densities in aquatic habitats.

4. **Practical session:**
    iv) The facilitator and participants will plan for larval surveys before initiating the survey. The plan will include timing for larval surveys, making approximations for the locations of larval habitats in the survey area, and on how to conduct transect walk during the survey. The facilitator will also emphasize on the key characteristics of *Anopheles* habitats.
    v) Participants together with the facilitator will visit selected villages and identify mosquito aquatic habitats. Participants will practice different mosquito sampling techniques on identified habitats.

vi) The participants will also process and store immature mosquitoes for transportation. Participants will learn how to record larval survey data; they will also learn how to enter and manage these data on a computer system using the mosquitoDB App.
vii) Also, participants will characterize each aquatic habitat according to the physical features and vegetation and document these characteristics.
viii) Participants will learn to estimate larval densities and interpret these estimations
ix) Participants will practice visualizing the distribution of aquatic habitats in maps.
x) A discussion session will be held, where participants provide experiences from their areas of work regarding mosquito habitats.

Assessment

Participants will be required to produce reports of larval surveys conducted during practical sessions to demonstrate their understating (individual task)

Facilitators: Medical entomologists and/ or Mosquito biologists with working experience in studying aquatic stages *Anopheles* mosquitoes

Materials required

- Standard mosquito dipper
- Ladle
- Pipettes
- Buckets
- Transporting containers (Bottles/ larger containers)
- Personal protective equipment (waterproof breathable chest waders, and wading boots)
- Handheld GPS devices
- Label/ Masking tapes
- Mosquito collection forms (for larvae)
- Notebooks
- Tablets loaded with MosquitoDB App
- Computers (participants will be required to bring their computers to the training)

Recommended readings

1. WHO. Manual on Practical Entomology in Malaria, Parts I. WH. Geneva: World Health Organization; 1975.
2. WHO. Manual on practical entomology in malaria, Part II. Geneva: World Health Organization; 1975.
3. Gillies MT, De Meillon B. The Anophelinae of Africa south of the Sahara (Ethiopian Zoogeographical Region). Johannesburg: South African Institute for Medical Research, P.O. Box 1038, S. Africa.; 1968.

Additional readings

4. Becker N, Petric D, Zgomba M, Boase C, Madon M, Dahl C, et al. Mosquitoes and their control. J. Chem. Inf. Model. London: Springer; 2010.
5. Silver JB. Mosquito Ecology: Field Sampling Methods. 3rd Edition. Springer. Dordrecht: Springer; 2008.

6. WHO. Malaria surveillance, monitoring & evaluation: a reference manual. WHO Press. World Heal. Organ. Geneva: World Health Organization: World Health Organization; 2018.

Lesson 5b: Larval source management

This sub-module aims to build capacity for participants to be able to conduct effective larviciding. This sub-module will cover the following topics:

5. Choosing appropriate larval source management strategies for implementation in different areas and different habitat types
6. Planning for personnel, equipment, and cost needed to deploy larviciding
7. Selecting larvicides and determining the optimum doses for larviciding
8. Estimating larvicide quantities needed for larviciding
9. Preparing larvicides for deployment and conduct larviciding
10. Monitoring effectiveness of larvicides in the field: collecting data and build evidence for the impact of larviciding on mosquito population densities (both larvae and adults)

Delivery

3. **Class session:** In this session, the facilitator will describe larval source management and methods (both conventional and innovative) of conducting larval source management to the participants. The facilitator will describe requirements for effective larval source management, planning for larviciding, and the advantages of conducting larval surveillance and mapping aquatic habitats in larviciding. Participants will also learn about different types of larvicide available on the market, larvicides approved by WHO, and the advantages and disadvantages of each larvicide. This session will also include descriptions of formulations of larvicides and the suitability of these formulations for different aquatic habitats.

   The facilitator will also describe the case studies of successful larval source management from Dar es Salaam (Dar es Salaam Urban Malaria Control Program), Khartoum (Malaria Free Initiative in Khartoum State) and Brazil (elimination of *Anopheles gambiae* from Brazil in 1940), the facilitator will describe advantages of effective larval source management

4. **Practical session:**
   iii) Once habitats have been identified and characterized, participants will demonstrate how to select larvicides formulations depending on habitats present in the area.
   iv) Participants will conduct experiments in the field/ semi-field to determine the suitability of larvicides and optimum dose for larviciding, and estimate larvicides needed for larviciding.
   v) Participants will learn how to prepare larvicides and conduct larviciding using different methods
   vi) Participants will learn different conventional methods for larvicide applications. A demonstration of innovative methods for larvicide applications will also be conducted in this session.

Assessment

Participants (in groups) will be required to produce technical reports of larviciding to demonstrate their understating of the larviciding conducted. The report should demonstrate skills learned on the different aspects of larviciding.

Facilitators: Medical entomologists with working experience in larval source management (especially larviciding) for *Anopheles* mosquitoes.

Materials required

- Larvicides
- Compression or backpack sprayers fitted with a solid stream nozzle
- Personal protective equipment (overall, gloves and wading boots)
- Handheld GPS devices

Recommended readings

1. WHO. Larval source management: a supplementary measure for malaria vector control. Geneva: World Health Organization; 2013.
2. WHO. Guidelines for laboratory and field testing of mosquito larvicides. Geneva: World Health Organization; 2005.
3. Soper FL, Wilson DB. *Anopheles gambiae* in Brazil 1930–1940. New York: The Rockefeller Foundation; 1943.
4. Majambere S, Lindsay SW, Green C, Kandeh B, Fillinger U. Microbial larvicides for malaria control in The Gambia. Malar J. 2007;6.
5. Geissbühler Y, Kannady K, Chaki PP, Emidi B, Govella NJ, Mayagaya V, et al. Microbial larvicide application by a large-scale, community-based program reduces malaria infection prevalence in urban Dar Es Salaam, Tanzania. PLoS One. 2009;4.
6. Soper FL, Wilson DB. *Anopheles gambiae* in Brazil 1930–1940. New York: The Rockefeller Foundation; 1943.
7. Elkhalifa SM, Mustafan IO, Wais M, Malik EM. Malaria control in an urban area: A success story from Khartoum, 1995-2004. East Mediterr Heal J. 2008;14:206–15.
8. Caldas De Castro M, Yamagata Y, Mtasiwa D, Tanner M, Utzinger J, Keiser J, et al. Integrated urban malaria control: A case study in Dar es Salaam, Tanzania. Am J Trop Med Hyg. 2004;71:103–17.

Additional readings

9. Becker N, Petric D, Zgomba M, Boase C, Madon M, Dahl C, et al. Mosquitoes and their control. J. Chem. Inf. Model. London: Springer; 2010.
10. Killeen GF. Following in Soper's footsteps: Northeast Brazil 63 years after eradication of Anopheles gambiae. Lancet Infect Dis. 2003; 3: 663–6.

Lesson 6: Rearing of mosquitoes

Description of the module

Mosquito rearing is an important aspect in vector control and surveillance, it can be involved in several activities in vector control and surveillance. For example, activity insecticide resistance monitoring requires rearing of mosquitoes to prepare them for bioassays. This sub-module will cover the two topics:

i) How to set-up an insectary for mosquito rearing
ii) How to rear mosquitoes

Delivery

Class session
The facilitator will explain the importance of mosquito rearing on vector control and surveillance to the participants. This will session will cover details on how to set-up an insectary for the rearing of mosquitoes (which will cover equipment, basic conditions, and methods for maintaining conditions for mosquitoes rearing) and on how to rear mosquitoes (which will cover procedures for mosquitoes rearing, how to handle and feed mosquitoes of different stages, and how to ensure reared mosquitoes remains free from infections)

Practical session
Using mosquitoes collected as larvae, participants will practice rearing mosquito from larvae to adults. Also using adult mosquitoes, participants will learn how to rear adults to obtain the following generation of mosquitoes.

Facilitator
Medical entomologists and/ or Mosquito biologists with working experience in mosquito rearing

Materials required
- Mosquito cages covered with mesh gauze or net
- An animal
- Membrane feeders
- Glucose
- Cotton wools
- Mouth aspirator
- Rearing basins or plastic trays
- Pipettes
- Data loggers
- Label
- Paper cups
- Petri dishes and filter papers
- Towel
- Food for mosquito larvae

Recommended readings

1. Spitzen J, Takken W. Malaria mosquito rearing – maintaining quality and quantity of laboratory-reared insects. Proc Netherlands Entomol Meet. 2005;16:95–100.
2. Das S, Garver L, Dimopoulos G. Protocol for mosquito rearing (A. gambiae). J Vis Exp. 2007;15–6.
3. WHO. Manual on practical entomology in malaria, Part II. Geneva: WHO; 1975.

Lesson 7: Monitoring insecticide resistance of mosquitoes

Description of the module
For vector control to remain effective it is important to monitor and respond immediately to insecticide resistance profiles of local mosquito populations. This will give an early warning on the development of resistance and will allow for better strategies to manage insecticide resistance in mosquitoes. Vector control practitioners need to understand how to monitor, interpret, and report insecticide resistance of mosquitoes. This module aims to acquaint participants with the skills for

conducting insecticide resistance monitoring for mosquitoes in both adult and larvae stages. The information gained from this module will be integrated to respond effectively to the current challenges of resistance:

1. Collecting and rearing mosquitoes for insecticide resistance bioassays (Larval Collections and Adult Collections)
2. Determining insecticide susceptibility of mosquitoes using discrimination concentration (for both adults and larvae)
3. Determining the intensity of insecticide resistance in mosquitoes
4. Assess insecticide resistance mechanisms using insecticide synergists (using piperonyl butoxide, an inhibitor of monooxygenase enzyme)
5. Reporting results of insecticide susceptibility monitoring

Delivery

1. **Class session:** The facilitator will provide an introduction to insecticides used in mosquito control, their mode of actions, insecticide resistance, and mechanisms of insecticide resistance. Also, the facilitator will be required to describe historical trends and impacts of insecticide resistance in malaria vector control. A session on the importance of monitoring insecticide resistance and methods for determining insecticide resistance (CDC and WHO insecticide bioassays) will then follow. The facilitator will have to ensure to describe the differences between CDC and WHO insecticide bioassays and the feasibility of these methods in insecticide monitoring. This session shall also cover basic mosquito rearing techniques for mosquitoes collected as larvae or adults.

2. **Practical session:**
   i) Participants will learn how to collect, handle, and rear mosquitoes for insecticide resistance testing.
   ii) Using field-collected mosquitoes (preferably resistant mosquitoes, if present), participants will conduct insecticide susceptibility bioassays using discrimination concentration, 5×, and 10× discrimination concentration. This will include data recording and interpretation
   iii) Participants will also conduct synergist-insecticide bioassays using WHO testing guidelines. This will include data recording and interpretation
   iv) Participants will conduct additional tests using CDC bioassay guidelines for testing insecticide resistance. This will include data recording and interpretation
   v) Using field-collected mosquito larvae, participants will practice on conducting larvicide susceptibility bioassay of larvae.
   vi) Participants will have a joint session to interpret the resistance test findings and discuss their implications for vector control
   vii) Participants will be guided through the steps to procure the essential materials for conducting the tests.

Assessment

Participants will be required to produce reports of the insecticide resistance testing conducted to demonstrate the understanding of monitoring insecticide resistance (individual task).

Facilitators: Medical entomologists and/ or Mosquito biologists with working experience in studying insecticide resistance in mosquito vectors.

Experts of insecticide resistance vector with experience of working on the resistance of mosquitoes.

Materials required

- WHO insecticide resistance test tubes
  - Insecticide impregnated papers (pyrethroid)
  - CDC insecticide resistance test kits
  - Clean white papers
  - Aspirators
  - Gloves
  - Timer
  - Instruction sheets
  - Mosquito cages
  - Label
- Filter papers and insecticides
- pipette capable of delivering 100–1000 µl
- 100 µl pipette disposable tips
- 500 µl disposable tips
- droppers with rubber suction bulbs
- Small strainer
- Disposable cups
- Graduated measuring cylinder
- Data recording forms
- Log–probit paper
- Alcohol (or organic solvent)
- Net
- Rubber bands
- Data collection forms for insecticide resistance
- Tablets loaded with MosquitoDB App

Recommended readings

1. WHO. Test procedures for insecticide resistance monitoring in malaria vector mosquitoes Second edition. Geneva, World Health Organization: World Health Organization; 2016.
2. WHO. Monitoring and Managing Insecticide Resistance in Aedes mosquito Populations. Geneva, World Health Organization: World Health Organization; 2016.
3. WHO. Instruction for determining the susceptibility or resistance of mosquito larvae to insecticide. Geneva: World Health Organization; 1981.
4. CDC. Guideline for Evaluating Insecticide Resistance in Vectors Using the CDC Bottle Bioassay. Centers for Disease Control and Prevention;

Additional readings

5. Becker N, Petric D, Zgomba M, Boase C, Madon M, Dahl C, et al. Mosquitoes and their control. J. Chem. Inf. Model. London: Springer; 2010.
6. WHO. Malaria surveillance, monitoring & evaluation: a reference manual. WHO Press. World Heal. Organ. Geneva: World Health Organization; 2018.
7. Brogdon WG, Mcallister JC. Simplification of adult mosquito bioassays through use of time-mortality determinations in glass bottles. Journal of the American Mosquito Control Association. 1998;14:159–64.

Lesson 8: Understanding of human behaviors associated with the risk of mosquito bites and malaria transmission

Description of the module

Human behaviors and activities are important drivers of persistent malaria transmission, even in areas where core interventions such as ITNs are already widely used. It has been shown that human behavior plays an important role in sustaining human-vector contacts. Examples of these behaviors include late-night activities, sleeping away or out of houses, and staying out late. Others are occupational activities such as migratory farming in distant river valleys, fishing, or night-guard activities. These behaviors, practices, and activities enable important overlaps of humans and mosquitoes in space and time, sustaining interactions necessary for biting and pathogen transmission. These aspects must be investigated and quantified to assist in targeting interventions and the development of complementary interventions. This module aims to equip participants with essential skills to assess human behaviors that influence human-mosquito interactions and the risk of pathogen transmission. In this module, participants will learn how to:

1. Collect human behavior and activities data and explore links with mosquito data
2. Conduct effective communication to prevent risky behaviors and activities
3. Identify potential complementary interventions that can be introduced to address the gaps associated with human activities and behaviors

Delivery

1. **Class session:** In this session, the facilitator will describe the rationale of understanding and monitoring human behaviors in vector control. With examples and case studies, the description will be provided on how human behaviors, activities, and occupations can contribute to the persistence of residual malaria transmission. The facilitator will describe methods for collecting data on human behaviors and activities such as the use of interventions such as bed nets, late-night outdoor activities, time to sleep, and occupations. Participants will also be given an overview of the potential interventions to control malaria and other vector diseases when human behavior increases the risk of sustaining human-vector contacts.

2. **Practical session:**
   i) Participants will be given case studies and required to practice in groups to identify specific complementary interventions that can be used in different settings to improve malaria control after ITNs or IRS are already implemented.
   ii) Participants will learn how to formulate questions and to collect qualitative data related to human behavior
   iii) In this session, participants will conduct a field pilot to assess human behaviors that increase human-vector contacts.
   iv) Participants will use data generated in this session and on entomological survey sessions (such as hourly biting collections of mosquitoes) to explore links between human behaviors and exposure to mosquito vectors.

Facilitators: Medical entomologists and social scientists with experience of working in mosquito control.

Assessment

Based on field pilot results participants (in groups) will be required to plan and document a vector control program for malaria control based on behaviors observed on the community observed.

Materials required

- Observation checklist and/ or a questionnaire
- Dataset generated in module 4 on the hourly biting activity of mosquitoes
- Computer (participants will be required to bring their computers to the training)

Recommended readings

1. Service MW. Demography and Vector-Borne Diseases. Florida: CRC Press; 1989.
2. Finda MF, Moshi IR, Monroe A, Limwagu AJ, Nyoni P, Swai JK, et al. Linking human behaviours and malaria vector biting risk in south-eastern Tanzania. PLoS One. 2019;14:e0217414.
3. Monroe A, Moore S, Koenker H, Lynch M, Ricotta E. Measuring and characterizing night time human behaviour as it relates to residual malaria transmission in sub - Saharan Africa: a review of the published literature. Malar J. 2019;18:6
4. Eldridge BF, Edman JD. The Epidemiology of Arthropodborne Diseases. Medical Entomology: Medical Entomology: A Textbook on Public Health and Veterinary Problems. Springer; 2004. p. 165–85.
5. Moshi IR, Manderson L, Ngowo HS, Mlacha YP, Okumu FO, Mnyone LL. Outdoor malaria transmission risks and social life: A qualitative study in South-Eastern Tanzania. Malar J. BioMed Central; 2018;17:1–11. Available from: https://doi.org/10.1186/s12936-018-2550-8

Lesson 9: Monitoring vector control interventions

Description of the module

A major task of malaria control officers and managers is to monitor vector control interventions and assess whether the investments are having the desired impact on the vector and/ or disease. Monitoring also helps in detecting deviations in vector control and informs on measures to be taken to ensure vector control interventions remain effective. This activity is therefore of critical importance for the success of vector control interventions. People involved in the implementation of malaria control should know how to conduct vector control interventions. This module, therefore, aims to strengthen the skills of participants in assessing progress made in the vector control interventions and areas that require improvement or change. This module will cover the following key topics:

- Monitoring durability of insecticide-treated bed nets (attritions, bio-efficacy, chemical content, physical integrity or durability)
- Monitoring coverage and quality of IRS spraying operations
- Monitoring the residual activity of indoor residual spraying (IRS)
- Calculating access, coverage, and use of ITNs
- Assessing coverage and equity achieved by different modes of ITN delivery, i.e. Mass Campaigns, ANC campaigns, and School Net Distribution
- Monitoring Larval Source Management programs

Delivery

1. **Class session:** the facilitator will describe the rationale of monitoring vector control interventions and methods used to monitor the performance of vector control interventions. The facilitator will describe the methods used to monitor ITNs, IRS, and larval source management. This will include how to the importance of monitoring vector densities and insecticide susceptibility during the implementation of interventions. In addition, they will be lectured on specific steps for different interventions: for ITNs, they will be lectured on how to assess access and its use, and the attrition, physical integrity, and bioefficacy of ITNs. For IRS they will be taught how to monitor the residual activity of IRS. For larviciding, they will be taught how to monitor the activity of larvicides in aquatic habitats, and if personnel in the field are applying larvicides correctly and timely.

2. **Practical session:**
    i) Participants will visit the selected villages to sample bed nets. Participants will provide replacements of bed nets to all sampled bed nets. If there will be accurate information on the number of nets originally distributed to each household in these villages, participants will assess the survival/ attrition of bed nets during this visit.
    ii) Collected nets will be used by participants to assess physical integrity of bed nets.
    iii) Also, participants will use collected bed nets to conduct WHO cone bioassay to assess bio-efficacy of the bed nets.
    iv) Participants will practice to conduct WHO cone bioassay on walls sprayed with residual insecticides to assess the residual activity of the insecticide either on walls of village houses, experimental huts, or training wall.

v) In the villages involved in this training, participants will learn to estimate sample size and conduct a survey in the villages to assess access and use or acceptability of interventions (insecticide-treated nets and IRS).
vi) Participants will practice tracking the activity of larvicide applied to mosquito aquatic habitats in rural settings or semi-field settings.
vii) Discussion on possible approaches for monitoring/ evaluating potential new or complementary interventions other than ITNs or IRS.

Facilitators: Malaria control experts with working experience in implementation and monitoring vector control interventions (ITNs, IRS, and larviciding).

Assessment
Participants in groups will be required to produce reports for one of the interventions assessed (durability and coverage of ITNs, or monitoring of IRS or larviciding).

Materials required

- Susceptible mosquitoes (*Anopheles*)
- Long-lasting insecticide-treated nets
- WHO cones
- Holding cups (Disposal cups)
- Larvicides
- Adulticides
- Pipettes
- Basins
- Standard mosquito dipper
- Pipettes
- Sugar solution
- Cotton wool
- Mouth aspirator
- Mosquito data collection forms for cone bioassays
- Tablets loaded with MosquitoDB App
- Data collection forms for cone bioassays
- Questionnaire/ Data collection forms for monitoring the durability of bed nets

Recommended readings

1. WHO. Guidelines for laboratory and field-testing of long-lasting insecticidal nets. Geneva: World Health Organization; 2013.
2. WHO. Guidelines for monitoring the durability of long-lasting insecticidal mosquito nets under operational conditions. Geneva: World Health Organization; 2011.
3. WHO. An Operational Manual for Indoor Residual Spraying (IRS) for Malaria Transmission Control and Elimination. Geneva, World Health Organization: WHO; 2015
4. WHO. Guidelines for testing mosquito adulticides for indoor residual spraying and treatment of mosquito nets. Geneva: World Health Organization; 2006.

Additional reference

1. Becker N, Petric D, Zgomba M, Boase C, Madon M, Dahl C, et al. Mosquitoes and their control. J. Chem. Inf. Model. London: Springer; 2010.
2. WHO. Malaria surveillance, monitoring & evaluation: a reference manual. WHO Press. World Heal. Organ. Geneva: World Health Organization; 2018

Lesson 10: Introduction to the analysis of surveillance data

Description of the module

What follows after data collection is to perform analysis to find patterns in the dataset and extract meaningful information. To be able to extract meaningful information from the data one needs to have skills to conduct data analysis. To enable participants to have the skills for appropriate data analysis. This module will provide essential training on statistical and geospatial analysis of entomological data. The aim is to ensure participants can perform appropriate analysis of surveillance data, to extract useful information for decision making. This module will be divided into two sub-modules:

1. Geospatial techniques in entomological surveillance
2. Statistical and qualitative data analysis

Lesson 10a: Geospatial techniques in entomological surveillance

This sub-module aims to familiarize participants with mapping techniques in entomological surveillance. In this part participants will be trained on the use of open-source GIS software for i) Data importation in GIS systems, ii) Data visualization and processing in GIS systems, and iii) Use GIS systems in the selection of study units. Participants will also learn how to use maps to reporting malaria-related data to different stakeholders at the district or national level

Delivery

3. **Class session:** Facilitators will provide descriptions of introduction to GIS, different data structures used in GIS, projection systems, and software used in GIS.

4. **Practical session:**
   i) Using GIS data capture in other modules, participants will learn how to import captured data into GIS systems and produce simple maps
   ii) Then, the facilitator will demonstrate different GIS methods used to conduct sampling, and participants will practice these methods.
   iii) Using the generated dataset, participants will practice to map different attributes of mosquitoes such as, distribution of mosquitoes, aquatic habitats distribution of resistant mosquitoes and using open source GIS software
   iv) More practical sessions on mapping shall be conducted in other modules where participants shall utilize skills obtained in this module to link GIS data to entomological data and map different aspects of entomological surveillance.
   v) Identification of important online data sources and formats
   vi) Using maps in reporting and presentations

Facilitators: GIS analysts with working experience in entomological studies.

Recommended readings

1. McHaffie P, Hwang S, Follett C. GIS: An introduction to mapping technologies. Boca Raton: CRC Press; 2019.
2. Cromley EK, McLafferty SL. GIS and Public Health. J. Chem. Inf. Model. New York: The Guilford Press; 2012.

3. Online data sources and archives
    - National bureau of statistics (eg. Tanzania: https://www.nbs.go.tz)
    - Facebook population density maps (https://dataforgood.fb.com/tools/population-density-maps)
    - Google maps (https://www.google.com/maps)
    - WorldPop (https://www.worldpop.org)
    - Malaria Threats Map (https://apps.who.int/malaria/maps/threats/)
    - VectorBase (https://www.vectorbase.org/)

Lesson 10b: Statistical and qualitative data analysis

This sub-module aims to introduce participants to data management, summarization, and analysis. In this module, participants will learn how to:

i) Explore dataset and summarizing the data
ii) Presentation of summaries of the dataset
iii) Review of current data capture and management systems, e.g. DHIS2
iv) Linking epidemiological data with entomological surveillance data
v) Linking human behavior data with mosquito data
vi) Interpretation of key indicators for malaria entomology and epidemiology
vii) Conduct qualitative data analysis

Delivery

This module will mainly be practical:

i) By using data generated in this training, participants will learn to explore datasets and producing summaries of data using simple functions in MS excel, they will also learn how to visualize summary in graphical presentations
ii) Using data generated in this training, participants will learn how to link entomological surveillance data with epidemiological data.
iii) Basic R-codes will be developed to generate basic information and summaries. This will be introductory but participants will access continued support for several months after this initial training
iv) They will learn how to select the analytical technique for qualitative data analysis. They will use the data they collected in previous sessions to practice how to analyze, interpret, and present qualitative data.

Facilitators: Statistical analyst with the experience of working in entomology.

Materials required

- Computer pre-installed with GIS software (ArcGIS or QGIS) (participants will be required to bring their computers)
- Existing entomological datasets
- Existing epidemiological datasets
- GPS devices
- Access to major databases; e.g. VectorBase, DHIS2

Recommended readings

1. Ross SM. Introductory statistics. California: Elsevier; 2018

2. Rosner B. Fundamentals of Biostatistics. 7th editio. Boston,: Brooks/ Cole Cengage Learning; 2010.
3. WHO. Malaria surveillance, monitoring & evaluation: a reference manual. WHO Press. World Heal. Organ. Geneva: World Health Organization: World Health Organization; 2018.
4. WHO. Manual on practical entomology in malaria, Part II. Geneva: World Health Organization; 1975.

Lesson 11: Using mathematical modelling to guide modelling malaria control

There are times when it is not easy to conduct field study because it is either expensive or unethical. However, evidences may be needed for making informed decisions. Mathematical modeling is useful in situations such these. In this module participants will learn about mathematical modeling in the control and elimination of malaria. This module will cover:

i) Introduction to mathematical modelling
ii) Using models to solve problems/ inform decisions in malaria control

Delivery

Class session
The concept of what exactly are mathematical models will be defined to the participants, as well as the history of mathematical modeling in malaria control, and why opt for (role of) mathematical modeling. They will also learn about basics of mathematical modelling (i.e. types of mathematical modeling, and mathematical modeling cycle). Examples of mathematical models for guiding malaria control and elimination will be presented and described to participants (particularly ones used in malaria vector control). Then the facilitator will explain how to create, choose and use mathematical models for malaria control and elimination. Lastly, participants will learn how to interpret of the results of mathematical models.

Practical session

i) Participants will discuss the potentials of mathematical modeling in malaria control and how they envision its used in decision making on their area of work
ii) The facilitator and participants will identify a malaria vector control-related problem in the country, region or district and conduct a mathematical modelling to inform decision making.
iii) Participants will use the data they collected on mock surveillance (during Adult mosquito surveillance or larval surveys) to conduct mathematical modeling for the selection of vector control intervention or combination of vector control interventions that will be most relevant to the area surveyed.

Facilitator: Mathematical modular in malaria control with working experience in modelling vector control interventions

Materials required

- Computers
- Datasets for modeling

Recommended readings

1. Brauer F, Castillo-Chávez C. Mathmatical Models in Population Biology and Epidemiology. 2nd editio. London: Springer; 2010.
2. Lord CC. Modeling and biological control of mosquitoes. J Am Mosq Control Assoc. 2007;23:252–64.
3. WHO. Mathematical Modelling to Support Malaria Control and Elimination. Geneva: World Health Organization; 2010.

Lesson 12: Introduction to stakeholder engagement

Malaria control and elimination require efforts from multiple actors and partners. When their efforts are synergized, the impact on malaria control and elimination can be maximized. It is important to have healthy relationships with all stakeholders to achieve the intended goals of malaria control activities. Such relationships can be achieved through stakeholder engagement. Effective stakeholder engagement can lead to the acceptance of malaria control activities and strategies by stakeholders and smoothen the decision-making process. It can also ensure sustainable malaria control interventions. This module aims to train on how to carry out stakeholder engagement, and will cover two topics:

i) How to map stakeholders in malaria control at the district level
ii) Planning and implementing engagement of the key stakeholders

Delivery

Class session:
First, the facilitator will describe the benefits of stakeholder engagement in control malaria. The facilitator will also describe how to set goals for stakeholder engagement activities, and how to identify and engage stakeholders in malaria vector control. The descriptions will also address the planning process in stakeholder engagement and choosing effective methods for stakeholder engagement. Then facilitator will describe how to choose effective methods for stakeholder engagement.

To promote understanding, the facilitator will present a case/ scenario to participants related to vector control, and then a discussion will be conducted on the purpose of stakeholder engagement. It will also include identifying and analyzing all stakeholders in the case/ scenario and robust methods to engage them.

Practical session:
Participants will conduct a behavioral change communication (BCC) program to sensitize the proper use/ acceptability of interventions being carried-out or planned to be carried out in the community. This activity will be conducted in the village where surveillance was conducted.

Assessment

From the activities taught in this previous session, the facilitator will select one of the activities and ask participants to carry-out stakeholder analysis and planning for engagement.

Recommended readings

1. WHO. Multisectoral Approach to the Prevention and Control of Vector-Borne Diseases. Geneva: World Health Organization; 2020.
2. Elkhalifa SM, Mustafan IO, Wais M, Malik EM. Malaria control in an urban area: A success story from Khartoum, 1995-2004. East Mediterr Heal J. 2008;14:206–15.
3. Caldas De Castro M, Yamagata Y, Mtasiwa D, Tanner M, Utzinger J, Keiser J, et al. Integrated urban malaria control: A case study in Dar es Salaam, Tanzania. Am J Trop Med Hyg. 2004;71:103–17.

4. Thizy D, Emerson C, Gibbs J, Hartley S, Kapiriri L, Lavery J, et al. Guidance on stakeholder engagement practices to inform the development of areawide vector control methods. PLoS Negl Trop Dis. 2019;13:1–11.

Lesson 13: Integrated approaches to malaria control and elimination

When participants complete all the above module it is expected that they will have an understanding of how to conduct vector surveillance and implement vector control interventions. Another important thing is that participants should know is how to use the information generated in surveillance to ensure the effectiveness of interventions and proper allocation of resources. This module aims to strengthen the skills of participants to be able to use vector surveillance information in making decisions regarding interventions to serve different areas. This module will cover the topic on the adoption of various techniques to control mosquito vectors and making evidence-based decisions in vector control to optimize the use of resources for malaria control and elimination.

Delivery

This module will be delivered in a class where the facilitator will first introduce the concept of integrated vector control. Followed by discussions between all participants and facilitators. The discussions will be on how all the above lessons can be put together and design an integrated malaria control. This session will include:

i) Discussion on vector control interventions such as house improvement, and environmental management, and other new tools. It will cover how to adapt these tools to ensure sustainable and sound malaria control and elimination strategy. This will go parallel with a discussion on how best to implement the core vector. The aim of the discussion will be aligned on how to select vector control interventions based on knowledge generated from vector surveillance.

ii) Discussions will also be conducted on financing for vector control which will include how to solicit/ lobby for finances, and the best ways to allocate and manage resources including finances to vector control.

iii) Discussions on how to mobilize and involve multiple actors from both public and private sectors to bring about combined efforts in vector control and surveillance for the control and elimination of malaria.

Facilitators: Integrated malaria control expert together with and all facilitators who participated in the training.

Materials required

- Projector
- Flip chart board
- Flip charts
- Notebooks

Participants evaluation:

a post-training test will be conducted to assess participants' understanding of mosquito surveillance and control after training

Recommended readings

1. Matthews G. Integrated Vector Management: Controlling Vectors of Malaria and Other Vector Borne Diseases. Chichester: Wiley-Blackwell; 2011.
2. WHO. Guidelines for Malaria Vector Control. Geneva: World Health Organization; 2019
3. WHO. Multisectoral Approach to the Prevention and Control of Vector-Borne Diseases. Geneva: World Health Organization; 2020.

Appendix 3: Original paper I

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Malaria Journal

RESEARCH Open Access

Opinions of key stakeholders on alternative interventions for malaria control and elimination in Tanzania

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Abstract

Background: Malaria control in Tanzania currently relies primarily on long-lasting insecticidal nets and indoor residual spraying, alongside effective case management and behaviour change communication. This study explored opinions of key stakeholders on the national progress towards malaria elimination, the potential of currently available vector control interventions in helping achieve elimination by 2030, and the need for alternative interventions that could be used to supplement malaria elimination efforts in Tanzania.

Methods: In this exploratory qualitative study, Focus group discussions were held with policy-makers, regulators, research scientists and community members. Malaria control interventions discussed were: (a) improved housing, (b) larval source management, (c) mass drug administration (MDA) with ivermectin to reduce vector densities, (d) release of modified mosquitoes, including genetically modified or irradiated mosquitoes, (e) targeted spraying of mosquito swarms, and (f) spatial repellents.

Results: Larval source management and spatial repellents were widely supported across all stakeholder groups, while insecticide-spraying of mosquito swarms was the least preferred. Support for MDA with ivermectin was high among policy makers, regulators and research scientists, but encountered opposition among community members, who instead expressed strong support for programmes to improve housing for poor people in high transmission areas. Policy makers, however, challenged the idea of government-supported housing improvement due to its perceived high costs. Techniques of mosquito modification, specifically those involving gene drives, were viewed positively by community members, policy makers and regulators, but encountered a high degree of scepticism among scientists. Overall, policy-makers, regulators and community members trusted scientists to provide appropriate advice for decision-making.

Conclusion: Stakeholder opinions regarding alternative malaria interventions were divergent except for larval source management and spatial repellents, for which there was universal support. MDA with ivermectin, housing improvement and modified mosquitoes were also widely supported, though each faced concerns from at least one stakeholder group. While policy-makers, regulators and community members all noted their reliance on scientists to make informed decisions, their reasoning on the benefits and disadvantages of specific interventions included factors beyond technical efficiency. This study suggests the need to encourage and strengthen dialogue between research scientists, policy makers, regulators and communities regarding new interventions.

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Background

Morbidity and mortality due to malaria has significantly declined worldwide over the past two decades, most significantly in sub Saharan Africa [1, 2]. Between 2000 and 2017 the number of malaria cases recorded in the region has decreased by 41%, and mortality by 62%, a success attributable to both public health efforts and improvements in socioeconomic conditions [1]. In Tanzania, malaria prevalence has gone down by more than 50% over the past decade, from 18% in 2008 to just 7.3% in 2017, mainly as a result of near universal coverage with long-lasting insecticide-treated bed nets (LLINs), indoor residual sprays (IRS), reliable and affordable diagnosis and treatment, and improved livelihoods [3].

The interventions behind this success in malaria control are however rapidly reaching their limits, as malaria continues to persist. A significant slowdown in the decline of malaria cases and deaths has been observed over the past decade; between 2010 and 2018, the rate of malaria cases and deaths have only declined by 22% and 30%, respectively [2]. Mosquito resistance to insecticides used in indoor residual spraying and bed nets is now widely documented worldwide [4, 5]. An increasing disposition of malaria vector to bite during the early-evening hours and the early morning, and to do so outdoor, is also well documented [6, 7], threatening the success of the major interventions for malaria control. *Plasmodium* resistance to the commonly used drugs is also increasingly evident across Africa and Asia [8, 9], further threatening the progress.

In 2015, the World Health Assembly adapted the Global Technical Strategy for Malaria 2016–2030, which aimed to provide a framework to reduce malaria incidence and mortality by 90% worldwide by 2030, and to eliminate malaria in 35 countries by the same year [10]. Tanzania is one of the countries currently pursuing malaria elimination by 2030, building on the significant gains achieved since the late 1990s [11]. To achieve malaria elimination, the National Malaria Control Programme has adopted a strategy to ensure adequate coverage of vector control interventions, primarily the use of LLINs and IRS [11]. The strategy also includes improved malaria diagnosis and case management, as well as rollout of new complementary interventions where there is sufficient local evidence for impact [11].

Several complementary vector control interventions are currently being discussed as possible candidates to accelerate the malaria elimination efforts [12]. Examples include: (a) larval source management (LSM), including larviciding and environmental management [13, 14], (b) topical repellents for personal protection [15, 16], (c) mass drug administration with endectocides such as ivermectin [17, 18], (d) use of mosquito modification techniques, either to suppress or replace vector populations [19, 20], (e) outdoor targeting of male mosquitoes through insecticide-spraying of mosquito swarms [21–23], (f) housing improvement measures such as better window screening and improved house designs [24–26], (g) spatial repellents able to protect multiple individuals over wide areas [27, 28], (h) attractive toxic sugar baits targeting sugar-seeking mosquitoes [29, 30], and (i) mosquito-killing fungal spores and toxins [31, 32].

Unfortunately, most of these interventions are not ready for deployment at scale; significant investments, as well as strong multi-sectorial collaborations will be needed to complete their development and evaluation. To ensure that these potential alternative interventions meet user needs and are sustainable, it is crucial to consider, early on in their development, the views and opinions of key stakeholders. This study sought to explore opinions of key stakeholders regarding Tanzania's progress towards malaria elimination, the potential of currently available vector control interventions to achieve elimination by 2030, and the potential and acceptability of additional vector control interventions that could supplement current elimination efforts. This study is a part of a larger investigation seeking to assess the awareness and perceptions of alternative strategies for malaria control and elimination in Tanzania, and to design appropriate pathways for the development of new intervention packages.

Methods

Study site and stakeholder selection

This study was done in Tanzania between December 2018 and May 2019, and involved four groups of stakeholders: (a) policy-makers, (b) regulators, (c) research scientists, and (d) community members. The stakeholders were all involved either directly or indirectly in malaria control in Tanzania.

Research scientists were selected from two leading research institutes in the country: Ifakara Health Institute (IHI), and National Institute for Medical Research (NIMR). The group included entomologists, economists, health systems and policy researchers, molecular biologists and ethicists involved in the design of malaria control strategies in Tanzania. The group of policy-makers included senior officials from government ministries in Dodoma, Tanzania's administrative capital, all of them with direct or indirect influence on malaria control activities. The government ministries represented were: (a) Ministry of Health, Community Development, Gender, Elderly and Children, (b) Ministry of Education and Vocational Training, (c) Ministry of Agriculture, (d) Ministry of Livestock and Fisheries Development, (e) Ministry of Water and Irrigation, (f) Ministry of Housing and Infrastructure and (g) President's Office-Regional Administration and Local Government. The group of regulators included officials from the Tanzania Medicines & Medical Devices Authority, the Tanzania Commission for Science and Technology, and the National Environmental Management Committee.

Lastly, community members were comprised of local community leaders drawn from 10 rural and urban wards in Ulanga and Kilombero districts in the Kilombero valley, in south-eastern Tanzania. Residents in the area are mostly subsistence farmers, pastoralists or small business owners [33, 34]. Malaria prevalence in these districts is highly heterogeneous, ranging from <1% in the urban and peri-urban sites to >40% in some of the villages (Swai et al., unpublished). Transmission intensities are also highly diverse, varying from less than 1 to ~20 infectious bites per person per year [33, 34].

Study procedures and interventions evaluated

This was an exploratory qualitative study; moderated Focus group discussions (FGDs) [35] were used to explore opinions of the stakeholders on the suitability and potential of alternative interventions. The alternatives discussed were: (a) improved housing, (b) larval source management, (c) mass drug administration (MDA) with ivermectin to reduce vector densities, (d) release of modified mosquitoes, including genetically modified strains, (e) targeted spraying of mosquito swarms, and (f) spatial repellents. These interventions were selected because of their pertinence for policy discussions, whether it is being considered for large scale implementation for malaria vector control in the country, undergoing large clinical trials in the country, or gaining interest worldwide as potential tools to help achieve malaria elimination. Table 1 shows summaries of these interventions, including some evidence on their potential.

A total of eight focus group discussion sessions, two per stakeholder group, were conducted, each with 6–10 participants. During the FGDs with community members, men and women were separated to maximize the participation of women [35]. This separation was considered unnecessary for the other stakeholder groups. To avoid framing the discussions too narrowly, a semi-structured discussion guide was used. Participants were first asked open-ended questions about their opinions on the country's progress towards malaria elimination, their views on the effectiveness of current malaria control interventions, and the need for alternative interventions for malaria control. The facilitator then presented a brief overview of the alternative interventions for malaria elimination, by way of PowerPoint slides. The presentations were delivered in English with the expert groups, but the language was adapted to Swahili (the main language spoken in Tanzania) for the two FGDs with community members. Participants were given time to ask questions following the presentation of each intervention, and when they were satisfied with the answers the discussions about that specific interventions began. The FGD sessions lasted 120–150 min each and were audio-recorded with participants' consent. Additionally, detailed notes were taken during the discussions.

Participants from each stakeholder group were purposively selected with help from their institutional leaders. It was important that stakeholders with expertise in malaria control were identified. With regards to the experts, invitation letters were sent to heads of institutions were the participants were based, and these heads then recommended staff members for the discussions. With the community members, ten wards were randomly selected in the Kilombero Valley in south-eastern Tanzania, and invitation letters were sent to ward leaders to recommend one male and one female community leaders to participate in the discussions.

The discussions were facilitated by two research scientists from Ifakara Health Institute, both of whom have extensive knowledge of malaria control. While the scientists were known to some of the participants because of their work, there were no subordinate relationships between facilitators and participants. FGDs with research scientists and policy makers were undertaken in their respective institutes. In the case of community members and regulators, the discussions were done centrally at Ifakara Health Institute offices. The feedback sessions were also done at Ifakara Health Institute.

Data processing and analysis

Audio recordings of the FGDs were transcribed immediately following the discussions, then translated from Swahili to English when needed. Field notes were incorporated in the written transcripts as additional data. The final transcripts were reviewed in detail then imported to Nvivo 12 Plus software [36] for further processing and analysis. Deductive analysis was used to categorize codes based on the FGD guide, which explored participants' opinions on: (a) the country's progress towards malaria elimination, (b) potential of current interventions for malaria elimination, (c) need for alternative approaches and techniques to support elimination efforts, (d)

Table 1 Descriptions of alternative interventions to complement current malaria control and elimination efforts, as discussed with key stakeholders in Tanzania

Intervention	Description
Improved housing	House improvement as malaria control intervention involves mosquito-proofing houses to limit mosquito entrance into the house [26, 37]. General housing improvement was a key factor in the elimination of malaria in developed countries [24]. In developing countries, simple modifications like screening windows and doors and closing eave spaces have resulted in some cases, in a 50% decline in entomological inoculation rates [38]. In Tanzania for example, housing improvement was linked to significant historical declines of malaria in Dar es Salaam [39], and was likely a major factor in more than 99% decline in malaria in Ifakara town, the main town in the area of our study [33]
Larval source management	Larval source management (LSM) refers to environmental manipulations to target mosquito larval habitats [13]. LSM can include the use of larvicides as well as environmental management methods [13, 14, 40]. In Tanzania, large-scale larviciding resulted in 21% reduction in malaria prevalence in Dar es Salaam between 2006 and 2008 [41]. The Tanzanian government is currently conducting targeted larviciding in urban and rural settings as a means to reduce malaria incidence and speed up the elimination agenda [42]
Mass drug administration of ivermectin	Ivermectin is an anti-helminthic drug commonly used to control parasitic nematodes in humans and animals [43]. It has been extensively used in mass campaigns for the elimination of lymphatic filariasis and onchocerciasis in Tanzania [44, 45]. Ivermectin is currently being evaluated as a malaria control tool, since it significantly reduces female mosquito fecundity and survival when mosquitoes blood-feed on hosts that have taken the drug [18, 43, 46]
Targeted spraying of mosquito swarms	Male mosquitoes aggregate in swarms as they compete for attention of female mosquitoes searching for mating partners [47]. Swarms usually occur at approximately the same time, usually at sunset, and repeatedly at same locations throughout the year [47]. Studies done in Burkina Faso and Tanzania have shown that *Anopheles* mosquito swarms can be located and targeted, and are effective in reducing overall mosquito density [21–23]
Modified mosquitoes	This intervention refers to alterations of mosquito genes or physiology for the purpose of reducing their competence in diseases transmission. The modified mosquitoes are released into the environment so that they can interbreed with the wild mosquitoes and, depending on the trait they carry, either reduce the density of malaria vectors or replace its population with mosquitoes unable to transmit the pathogen. Interventions currently under study include Sterile Insect-technique, which relies on irradiation of mosquitoes to make them sterile [48], genetic modification of mosquitoes to introduce sterility or other disadvantageous traits [49], and use of gene drive systems to spread novel traits (e.g. lethality or refractoriness to pathogen transmission) in mosquito populations [19, 50]. While the technology has never been integrated into a malaria control programme, laboratory studies, mathematical models and preliminary field trials indicate its potential [51]
Spatial repellents	Spatial repellents prevent host-seeking mosquitoes from entering certain areas, thus limiting contact between humans and mosquitoes [27]. SP can be based on a variety of botanical products and chemical compounds, such as citronella, transfluthrin and metofluthrin [27, 52]. They can be delivered in different formats, such as mosquito coils, repellent-treated clothing, repellent sandals (Finda et al. unpublished), kerosene lamps [53], and eave ribbons [27, 28, 54]. Compared to widely available topical repellents, some SP can provide long-lasting repellency, requiring minimal participation from the users

potential of the alternative interventions, and (e) their potential applications as complementary interventions in the efforts towards the 2030 malaria elimination target. Preliminary findings of the study were presented back to the participants. Quotes from participants were used to support the themes.

Results

Altogether, 60 people participated in the FGD discussions from across the stakeholder groups, 33 of whom were males and 27 females. Demographic characteristics of the FGD participants are presented on Table 2. Results on the opinions of key stakeholders of malaria elimination in Tanzania are presented based on the FGD guide points listed on the "Data processing and analysis" section.

Table 2 Gender distribution of the participants of Focus group discussions

Stakeholder group	Males	Females	Total
Community members	8	8	16
Policy makers	7	8	15
Regulators	7	7	14
Research scientists	11	4	15

Opinions on progress towards malaria elimination in Tanzania

Research scientists, regulators and policy makers discussed the progress made by Tanzania towards malaria elimination in terms of declining rates of malaria prevalence. Community members in contrast, discussed the progress in terms of their daily life experiences.

Two major arguments emerged in relation to this issue across the stakeholder groups. On the one hand, it was agreed that the country had made good progress and was on the right track. On the other hand, it was similarly noted that the progress was too slow and inadequate for elimination by 2030 as planned. Participants who emphasized that the country was on track referred to the significant reduction in malaria prevalence over the past decade, noting that malaria has reduced by more than 50% since 2000. As one policy maker stated:

> *"Of course we have come far from when prevalence was as high as 20% in the whole country. Back then, when you look at the map, it was all red, all red I tell you. There was malaria everywhere. But now you can see quite a lot of places that have prevalence of less than 1%, so when I see that I know that we are doing well."* (Policy-maker; female).

For community members, their idea of progress was informed mostly by their lived experiences. They noted, for example, that the frequency and severity of malaria attacks has greatly declined over the years. Unlike in the past, when malaria infections were very frequent, several months could now go by without their children getting sick. And when they did get sick, it was likely not to be malaria. As one participant said:

> *"Ten years back there was a lot of malaria. During that time, every time you did not feel well and went to the hospital you would be told that you have malaria. Kids were getting sick very often. But now we can go for even six months without our children getting sick or needing to go to the hospital. And when we do go we hear about other diseases, like urinary tract infections or typhoid. So then I know that malaria is not a big disease like it used to be."* (Community members; female).

Some participants, particularly policy makers and research scientists asked for caution, noting that, while there has been significant progress, it was nevertheless too slow and did not reflect the amount of effort that the country was putting into place. They also noted that the decline in malaria prevalence was not uniform across the country. As one policy maker reported:

> *"I think we are doing well, but not as well as I would like. As a country we have put a great deal of efforts to finish off this disease, but I am sad to see that there are areas in the country where prevalence is as high as 40%. We should not be in a situation like this."* (Policy maker; male).

Opinions on the potential of current interventions for malaria elimination

Two main viewpoints were expressed regarding the potential of current interventions in leading the country to elimination by 2030. One viewpoint, expressed by a majority of participants across the stakeholder groups, was that current interventions would not be sufficient to achieve elimination, even if they were utilized fully and effectively. One key reason given was that current interventions do not address growing challenges, such as insecticide resistance, or changes in mosquito biting behaviours. As one community member explained

> *"I really do not think that the insecticide-sprays or the bed nets are enough, because if they were enough we would not have malaria anymore. I sleep under a bed net every night, but mosquitoes still bite me when I am outside cooking or chatting with my family and friends. Sometimes I also spray my house with insecticides, but when I go inside to sleep, I see there are mosquitoes still. So then I know that these sprays are useless."* (Community member, female).

The opposite viewpoint was also expressed, namely that currently available interventions would be enough for elimination if they were utilized to their maximum potential. As pointed out by one research scientist:

> *"We already have what it takes to achieve elimination. If bed nets were properly made, properly distributed and properly used, why would we not eliminate the disease? If they killed mosquitoes as they are supposed to, if the universal distribution was actually universal, and if people actually slept under bed nets, I do not think we would need anything else..."* (Scientist, female).

Other participants pointed out that the current interventions are passive rather than active. That is, they only target female mosquitoes coming into human dwellings to feed, rather than actively targeting mosquitoes in their larval habitats and hiding places. As one policy maker stated:

> *"We need means to target and eliminate all the mosquitoes, not just the ones that get inside the house. If we decide to kill mosquitoes, then we should really kill all of them. We should target them at larval stage and adult stage to make sure that we are not leaving any windows for escape."* (Policy maker, male).

Opinions on the need for alternative interventions for malaria elimination

There were diverse inputs from participants on the need for complementary interventions for malaria elimination in Tanzania, although a majority participants agreed that it would be necessary to complement strategies. The insights that emerged most clearly were: (a) the importance of learning from countries that have been successful in achieving elimination; (b) the importance of knowing more about current interventions, including where or why they have failed or succeeded; and (c) the need to consider combinations of interventions as a more holistic approach to achieve malaria elimination.

Those participants who emphasized the value of learning from other successful countries argued that there was no need to develop interventions from scratch, and that the country should follow in the footsteps of those who had been successful in eliminating malaria. Other participants noted that, since malaria prevalence was not homogeneous across the country, it would be essential to employ different interventions in different settings based on the specific conditions. As one participant from the regulators' group stated:

> *"Malaria prevalence is not the same in all the country. There are parts of the country that are near elimination, and there are parts that have prevalence in double digits. This should tell you that one single method is not enough for the whole country. You need to look at different places and figure out what can work where."* (Regulator, female).

Participants who recommended combinations of interventions argued that we now have greater knowledge of mosquito behaviours than in the past, and that this knowledge can be used to target them from multiple angles to accelerate elimination. In one of the policy-makers' FGDs, one participant noted that:

> *"In order to really eliminate mosquitoes we need a combination of different strategies...We need to target all the water bodies to get rid of the larval stages, then all the hiding places like long grass and bushes, and then in the houses where they go to look for people to bite. If we do all of this, can you tell me how we can still have malaria in our country?"* (Policy-maker, male).

There were also participants who suggested that it was not wise to rush to new interventions without learning from the limitations of the current ones, and possibly addressing those first. In one session with policy-makers, a participant noted:

> *"Why aren't the bed nets killing mosquitoes? Why are the indoor insecticide sprays not killing mosquitoes? We have heard a lot about mosquitoes being resistant to the insecticides, but I still think we have not answered the question of where the resistance is coming from; what causes it and how it can be prevented or corrected. And also, do people know that the insecticides no longer kill mosquitoes? And if this is already a common knowledge, why are we still using these insecticides? I am sure that it costs a great deal of money to treat all the bed nets in the country with insecticides; but if these insecticides no longer work as insecticides, then why are we still using them?"* (Policy-maker, female).

Opinions on the potential of alternative interventions for malaria elimination

Discussions on alternative interventions for malaria elimination were based on participants' opinions about their effectiveness, sustainability, safety, as well as on their views on Tanzania's readiness to adopt them. There was a wide diversity of opinions, as described below.

Improved housing

All stakeholder groups associated improved housing conditions with reduced malaria risk. However, there were disagreements on whether the government should support the transition towards better living conditions in malaria endemic areas. While community members were strongly supportive of this idea, policy-makers were hesitant, pointing out issues of sustainability, affordability, and competing government priorities.

Community members argued that no intervention would be fully effective without adequate housing. Specifically, they noted that none of the other interventions under discussion would be particularly useful if people continued to live in poorly-constructed houses with gaps on walls, roofs, doors and eave spaces. They further stressed that the government could indeed afford providing better housing for the poorest community members living in areas with high malaria burden. Community members proposed several ways that the government could assist, such as by providing loans for people to build improved houses, subsidizing prices for building materials, or building and renting houses to the poorest at a reduced price. As one community member said:

> *"If the government could listen, I would advise them to assist people, especially the poor people, to build improved houses. They can maybe build the*

houses, and people can repay the government slowly, everyone can pay according to what they can afford." (Community member, female).

Policy-makers agreed that improved houses provide extra protection against malaria-transmitting mosquitoes. However, they were against the idea of the government building or modifying houses for poor people living in areas of high malaria transmission. They argued that it is not the responsibility of the government to build houses for citizens, and that given the required magnitude, the programme would be expensive and unsustainable. As one policy maker said:

"You know, our country is still poor, which means that a lot more people live in poverty than not. If you say that we start building or improving houses for all the poor people, then we will not have money for any of the other important things like health care and education." (Policy-maker, female).

Policy-makers also indicated that building better houses alone would not be enough to eliminate malaria—a lot of effort would still be needed to ensure that mosquitoes are controlled in their larval habitats and hiding places.

Research scientists and regulators also agreed that it would be advantageous if poor people in malaria endemic areas had access to better housing. Nonetheless, they too noted that it would not be sustainable for the government to support this initiative, or even to get funding to investigate its potential. As one scientist noted:

"For house improvement, no one denies that this works. The only problem is cost implications; that could be one of the reasons that this has not been taken up. Also, the way our research is organized and funded does not help in things like house improvement. It is difficult to get funding for [researching] this" (Scientist, male).

Larval source management

Two strategies were discussed: environmental management and larviciding (Table 1). However, most of the interest was directed towards larviciding. One major issue voiced by all stakeholder groups was the lack of clear regulations and enforcement on environmental management regulations, especially in relation to settlement planning and waste water management. Community members complained about lack of regulations on where people build, cultivate crops or manufacture bricks for construction, which often results in the accumulation of standing water near settlements, increasing the risk of malaria and other mosquito-borne diseases. In the words of a community member:

"The town is rapidly growing now. There were parts of the town that people were allowed to make bricks in the past; no one lived there at the time. But now many people live there, and it is not safe because there are so many brick-pits, hence so many mosquito breeding places... It would be important if there were requirements, [for example] *that the brick makers move to other unoccupied places, or* [that] *they should be required to fill in the pits"* (Community member, female).

The use of larvicides for malaria control was perceived positively across the stakeholder groups, but with some caveats. Policy-makers strongly supported the use of bio-larvicides, stating that the government had invested on the creation of a bio-larvicide plant as part of the national strategy towards malaria elimination, but that use of the bio-larvicide remained low as one policy maker reported:

"The bio-larvicides we are producing are designed to only affect mosquitoes, so they are relatively safe on the environment. We expected a high uptake from community and civil organizations, but I am sad to say that we are getting more customers from outside the country than within the country...." (Policy-maker, female).

Research scientists were also supportive of larviciding for malaria elimination, but they noted that the efficacy of the locally produced bio-larvicides should be thoroughly evaluated, since any perception of low efficacy might cause low uptake.

While a majority of the community members were in favour of larviciding for malaria control, a few members expressed concerns that there were so many water pools in their villages, particularly in the rainy season, that it would be difficult to treat all of them with larvicides without harming the environment, particularly the fish. One person stated:

"I would also like to stress that I do not trust this idea of putting chemicals in water. We all know that all of this water makes its way into the river where we get our fish. If we treat all the pools then that means a lot of chemicals will be going to the river. Now, are you telling me that it will not harm the fish? Most of us are fishermen here and our fish is part of who we are. Anything that can harm the fish will not be welcomed here. Maybe if you want to put these chemicals, you can do it

during the dry season, but then there are not many mosquitoes during this time, so it will just be a waste" (Community member, male).

Mass drug administration (MDA) of the endectocide ivermectin

Mass drug administration with ivermectin is currently undergoing trials in Tanzania as a potential vector control tool but several already completed trials suggest the potential impact of this intervention on mosquito density and malaria burden [18, 55]. When given to humans and/or cattle, the drug is effective in killing the mosquitoes that bite these hosts. The drug was widely known among all stakeholder groups as it is already widely distributed for control of lymphatic filariasis in humans [44, 45] and for several cattle diseases [56].

Community members referred to ivermectin as *Usubi*, and remembered health workers going from house to house every year encouraging people to take the drug for the control of *Matende* (elephantiasis) and *Mabusha* (hydrocele), conditions commonly associated with lymphatic filariasis. Despite the high awareness of this drug, there were mixed views among the stakeholder groups on its use for malaria control. Regulators, policy-makers and research scientists were hopeful and supportive of the approach, given its safety and effectiveness for the control and treatment of lymphatic filariasis in Tanzania. They argued that deploying it for the control of malaria-carrying mosquitoes would represent an important advantage at relatively low cost. They also stressed the need to spend time and resources to educate and raise awareness of the benefits of ivermectin use among target communities.

Community members on the other hand, had strong objections to this intervention, reporting negative experiences with previous mass drug administration (MDA) campaigns, particularly of praziquantel, commonly used for the treatment and control of schistosomiasis among school children. They reported that a number of children who receive the drug suffer fainting spells in schools. They also noted that people often avoided taking medicines. One participant stated:

> *"I really must tell you that these medicines that you have to swallow have a challenge. When they brought Usubi, even with all the education and the advocacy they had provided, people still did not take the medicines. Some people just picked it so as not to make the health workers feel bad, but after they* [health workers] *left people threw the medicine away."* (Community member, male).

Targeted spraying of mosquito swarms

A great deal of scepticism was expressed by all stakeholder groups about the sustainability and feasibility of targeted swarms of *Anopheles* mosquitoes with insecticide spraying. It was noted that the approach would require extensive community participation to locate the swarms, and would be expensive. One participant stated

> *"The setback with this is that you need a lot of people to do that, so it may also be expensive. But I agree maybe you use less insecticides, but if you are worrying about the cost of the insecticides, you will still be spending more in paying people to spray"* (Policy-maker, male).

Community members also pointed out that it would be inconvenient to spray at the time of the day when mosquitoes swarm—around sunset—and in most of the locations where they do so: *"...it will be difficult to find someone at home during that time, people will still be at work, or they will be too tired to accept more work."* (Community member, male).

Mosquito modification technologies

The possibility of releasing modified mosquitoes generated a lot of discussions and resulted in polarized viewpoints among all stakeholder groups. Although groups were introduced to different approaches to mosquito modification (i.e., sterile insect technique, genetically modified-sterile mosquitoes, and gene drive technology), most of the interest centered on implications of gene drive technologies, particularly those used for suppression of malaria vector populations.

Scientists expressed the most pointed criticisms of gene drive technology. They questioned its safety and the country's readiness for this type of innovation. They also pointed out that there are still a lot of unknowns, and that long-term research would be needed to provide evidence on various aspects of the technology. They expressed concerns about the possibility of mutations in either the *Plasmodium* parasite or the modified mosquitoes themselves. Specific concerns in this case were that the modified malaria vectors could become vectors for other diseases, or that the parasite could mutate and survive in other mosquito species. The fact that the technology would target a single species of malaria vectors was also seen as a risk, as it could increase the prevalence or vectorial capacity of other species. Targeting one mosquito species was also seen as a drawback in securing community acceptance. One participant stated:

> *"For the people, no malaria means no mosquitoes. They still cannot distinguish between malaria-transmitting and non-malaria transmitting*

mosquitoes, so if you tell them that you are controlling malaria then they need to see the mosquitoes gone." (Scientist, female).

Scientists were also concerned by the fact that there were not many African and particularly Tanzanian scientists taking leading roles in this sort of research. As one scientist stated:

"There are more fears than certainty regarding this technology. It is mainly being driven by foreigners. I worry that there are not many African researchers participating in the detailed research of this technology" (Scientist, female).

Policy-makers were divided in their views regarding gene drives. Some were in favour of the technology, pointing out that it was environmentally friendly and required little compliance from communities, yet others were skeptical, noting that there is currently a great deal of controversy over genetically-modified food products, and that it might, therefore, be unwise to introduce another genetically-modified organism (GMO). One policy-maker said:

"We are already struggling with acceptance of GM crops. Adding yet something like this may bring havoc in the country. Let them [other countries] *try it first, let us learn from our neighbours, and go last in this"* (Policy maker, female). The policy makers also recognized that the technology is not yet ready, and cannot be considered in the context of a 2030 malaria elimination target.

In contrast, and perhaps surprisingly, community members expressed a great deal of fascination with the technology. They were struck in particular by the fact that it would require little work or participation from local residents, compared to traditional malaria interventions. They also expressed a preference for this technology since it seemed to pose the least harm to the environment, particularly to fish. One participant said:

"I like that it does not have any chemicals, so the environment and the fish are all safe, but the malaria-mosquitoes will be gone (Community member, male).

Regulators pointed out that, while the potential of gene drive technologies ought to be explored, there are currently no adequate policies and regulations for their governance. Before those can be put in place, more research is needed to assure short- and long-term safety. One participant said:

"There are regulations for GMOs, but this technology you have is not GMO, rather gene-edited organisms. Gene-edited is not the same as GMO. We do not have policies or regulations for that. I believe you [the scientists] *can advise us on this; provide all the information needed and the evidence of its safety and we can add this into the regulations concerning GM organisms"* (Regulator, female).

Spatial repellents

All stakeholder groups agreed that this technology would be appropriate as a complementary (rather than primary) intervention for malaria control and elimination. Scientists however indicated that there was still insufficient evidence to determine the best spatial repellents, their availability, cost and feasibility of use.

Community members spoke positively about spatial repellents, saying they were most useful when people were outdoors in early night hours, cooking, eating and relaxing with their family and friends before going indoors to sleep. They alleged that it would be best if the government could distribute bed nets together with spatial repellents as a package, in order to tackle the problem of changes in mosquito behaviour. One participant stated:

"We have been told that mosquitoes are clever and have changed their biting times, so we have to be smart too and respond to that change using these repellents. If the government can provide these repellents to every household and teach them when, where and how to use them, I think we can make a very big progress in ending the malaria problem." (Community member, female).

Discussion

This study explored opinions of key stakeholders on Tanzania's progress towards malaria elimination, and on the suitability and potential value of six alternative interventions that might be used to complement current efforts to achieve that goal in the future. The stakeholders weighed the pros and cons of alternative technologies for malaria control and elimination, rather than focusing their discussions on a single approach.

The findings reveal a considerable agreement across the stakeholder groups on the extent of progress achieved in the control of malaria in Tanzania over the last decade. It was also noted that policy makers, regulators and scientists pointed to statistical evidence of declining malaria prevalence, as reported in recent Tanzania's malaria indicator surveys [3, 57], while community members pointed mostly to the lived experiences of witnessing fewer episodes of malaria and reduced severity of the disease. All participants commended the country's efforts in providing universal coverage with LLINs, reliable diagnosis and affordable treatment, whose effectiveness has been demonstrated in various studies [7, 58, 59]. There was also a general but not unanimous agreement that current interventions will not be sufficient to achieve further reductions of the malaria burden. Participants listed various challenges, such as insecticide resistance and outdoor biting exposure, which have been registered in many field studies [5, 7].

While there was a general consensus that new, complementary interventions or technologies will be needed to push the country further towards elimination, opinions differed on what technologies deserved prioritization and investment. The interventions with broadest support were larviciding and spatial repellents. Participants favoured spatial repellents for their low cost and ability to provide temporary relief against early-evening and outdoor-biting mosquitoes, thereby complementing LLINs. Support for larviciding could be found in all stakeholders as well, and it was the most preferred option among policy makers, regulators and research scientists. Community members did not object strongly to it, but expressed concerns over its environmental impact, particularly on fish stocks, and favoured its use during the dry season to minimize the likelihood of water contamination. Current national policy already includes an expansion of larviciding as a means of achieving further reductions in malaria incidence [11].

Insecticide-spraying of mosquito swarms was the least preferred option for all stakeholder groups, due to perceived environmental harm, high cost, and the assumed difficulty of area-wide implementation and scaling up. This view contrasted with a previous survey conducted in the Ulanga and Kilombero district on the same topic, which showed wide acceptance for the targeting of mosquito swarms [60]. This difference in opinions is likely due to the fact that the community members involved in the FGDs had no real experience with the intervention, compared to the community members who had been interviewed for the survey, all of whom had volunteered in a swarm targeting trial.

One surprising outcome of this study was the degree of skepticism that scientists expressed about the prospect of mosquito modification technologies, particularly those based on gene drive constructs—and, by the same token, the comparatively positive view expressed by community members. This is a potential important observation since any introduction of gene drive-based methods for malaria control in Tanzania will require strong support by local scientists, because of basic operational reasons and the influence that scientists have on the perceptions of all the other stakeholder groups. Some of the concerns discussed by scientists, such as their doubts about safety or the possibility undesirable mutations, can be addressed by further scientific research, but others, in particular their complaint about inadequate involvement of African scientists in the development of the technology, will require changes in the social and political organization of gene drive research for the control of vector-borne diseases. Similar concerns were observed in a recent study that explored perceptions of scientists in Nigeria on the potential release of genetically modified mosquitoes [61]. In this study, policy-makers and regulators repeatedly noted they will rely on the advice of scientists to make informed decisions. This emphasizes the persuasive power of scientists, and stresses the need to expand involvement of local scientists in the development of the technology, and the need for further collaboration between scientists, policy-makers and regulators in the development and evaluation of this technology.

Community members, in contrast, expressed support for gene drive technology. They perceived it as being environmentally safer, and noted that it would require little work by communities, a welcome contrast to most current interventions. This was an unexpected finding for us, and contrasts with studies conducted elsewhere that suggest significant opposition to the release of modified mosquitoes. A recent study from Mali, for instance, reveals the reluctance of community members to accept experimental releases of genetically modified mosquitoes in their villages, arguing that the technology should be first tried elsewhere to show evidence of safety [62]. A recent US study has shown that nearly two-thirds of respondents trusted universities and the department of agriculture (but not the private sector or the Department of Defence) to develop gene drives [63]. This study further attests to the importance of gaining approval from local scientists, and the need to strengthen communication between scientists and communities in deliberating over the appropriateness of this technology. For interventions such as gene drives, this study also demonstrates that additional engagement and training for local scientists will be necessary before the intervention trials proceed.

Community members expressed a strong preference for improvement in the built environment. They emphasized that improving houses was a more sustainable approach to malaria prevention, and would have a similarly positive impact on many other vector-borne diseases. This point of view is not surprising, and is supported by historical evidence linking successes against malaria to improved housing conditions in Europe and North America [64]. They also find support in recent studies showing significant reductions in malaria transmission following improved housing materials or house screening [26, 37]. In contrast, scientists and policy makers were skeptical about investing on housing improvement as a malaria control technology, mostly because of the perceived high cost and lack of political feasibility.

Mass drug administration with ivermectin also generated polarized views among the stakeholder groups. Policy-makers, regulators and scientists expressed a strongly positive view on this technology. In contrast, it generated significant opposition from community members, who reported negative previous experiences with MDAs campaigns in primary schools for the treatment and control of schistosomiasis. This observation echoes studies conducted in Tanzania and Cameroon showing that adherence to ivermectin MDA was strongly associated with previous experiences of MDAs, even when they involved other drugs [65, 66]. Community members also pointed out that people did not generally like taking drugs, particularly when they did not suffer symptoms, which would limit the adoption of this approach.

This study had a number of limitations. Some of the interventions discussed in the FGDs were new or not very well known to some participants, and required a summary introduction by the facilitator. To minimize the influence of the facilitator on the discussion, participants were first asked to list and discuss the approaches they were familiar with, and only after they had exhausted what they knew were they offered an introduction to the other interventions. That introduction was generic; questions were often reverted back to the participants themselves to elucidate the reasons for their queries. In the discussion, an equal amount of time and information was given to each technology. Participants were generally very engaged with the discussion, and asked many questions before giving their opinion.

Conclusion

While it seems inevitable that new tools will be needed to achieve malaria elimination in Tanzania by 2030, it remains to be seen which particular combination of interventions will be adopted in the near future. Different stakeholders perceive differently the advantages and disadvantages of each individual approach to malaria control and elimination, and assess individual options in the context of existing methods and other potential alternatives. All stakeholder groups, however, claimed that they rely on the advice provided by scientists to make informed decisions. This shows the critical role scientists play as gate-keepers for new interventions, and suggests the importance of a robust dialogue and clear communication between scientists, policy-makers, regulators and community members. Community members shared multiple thoughts on how the alternative interventions might work for them. Their willingness and in some cases eagerness to participate in efforts towards malaria elimination emphasizes the need to actively involve citizens in the design, development and implementation of strategies to eliminate malaria, in Tanzania and elsewhere. While scientists, regulators and policy-makers describe progress against malaria in terms of declining parasite prevalence, community members describe that same progress in terms of their daily life experiences. It is, therefore, vital to create an on-going dialogue between scientists, policy-makers, regulators and communities on any new interventions being considered for malaria control and elimination. Lastly, the need for local scientists to engage in development and evaluation of new technologies such as gene drives is desirable to promote uptake, should such technologies prove effective.

Abbreviations

LLINs: Long-lasting insecticide-treated bed nets; IRS: Indoor residual sprays; LSM: Larval Source Management; FGDs: Focus group discussions; MDA: Mass drug administration; GMO: Genetically Modified Organisms; IHI: Ifakara Health Institute; NIMR: National Institute for Medical Research.

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Authors' contributions

MFF was involved in study design, data collection, entry and analysis, interpretation of the results and drafting of the manuscript. FOO, NC and JL were involved in study design supervision and critical revision of the manuscript. AHK, BT, PC, NK, PK and BE were also involved in study design, data collection revision of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data for this study will be available upon request.

Ethics approval and consent to participate

This study is nested as a public engagement component under two larger studies at Ifakara Health Institute titled "*Anopheles funestus gene flow studies and rearing methods*" and "*Demonstrating complete disruption of residual malaria transmission by eliminating Anopheles funestus mosquitoes from Tanzanian villages*". Ethical approvals for this project were obtained from Ifakara Health Institute's Institutional Review Board (Protocol ID: IHI/IRB/EXT/No: 007 - 2018) and the Medical Research Coordinating Committee at the National Institute for Medical Research, in Tanzania (Protocol ID: NIMR/HQ/R.8a/Vol.IX/2895), as well as the University of the Witwatersrand in South Africa (Clearance certificate No. M180820). Meetings were held with leaders of each stakeholder groups to request their consent to conduct this study prior to the recruitment of participants. Upon consent, formal letters were sent to each of the participants to invite them to the discussions. Written consents were also sought from all participants of this study, after they had understood the purpose and procedure of the discussions.

Consent for publication

Permission to publish this study was obtained from NIMR (Ref: NIMR/HQ/P.12 VOL XXIX/37).

Competing interests

The authors declare that they have no competing interests.

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Publisher's Note

Appendix 4: Original paper II

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Malaria Journal

RESEARCH

Open Access

Hybrid mosquitoes? Evidence from rural Tanzania on how local communities conceptualize and respond to modified mosquitoes as a tool for malaria control

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Abstract

Background: Different forms of mosquito modifications are being considered as potential high-impact and low-cost tools for future malaria control in Africa. Although still under evaluation, the eventual success of these technologies will require high-level public acceptance. Understanding prevailing community perceptions of mosquito modification is, therefore, crucial for effective design and implementation of these interventions. This study investigated community perceptions regarding genetically-modified mosquitoes (GMMs) and their potential for malaria control in Tanzanian villages where no research or campaign for such technologies has yet been undertaken.

Methods: A mixed-methods design was used, involving: (i) focus group discussions (FGD) with community leaders to get insights on how they frame and would respond to GMMs, and (ii) structured questionnaires administered to 490 community members to assess awareness, perceptions and support for GMMs for malaria control. Descriptive statistics were used to summarize the findings and thematic content analysis was used to identify key concepts and interpret the findings.

Results: Nearly all survey respondents were unaware of mosquito modification technologies for malaria control (94.3%), and reported no knowledge of their specific characteristics (97.3%). However, community leaders participating in FGDs offered a set of distinctive interpretive frames to conceptualize interventions relying on GMMs for malaria control. The participants commonly referenced their experiences of cross-breeding for selecting preferred traits in domestic plants and animals. Preferred GMMs attributes included the expected reductions in insecticide use and human labour. Population suppression approaches, requiring as few releases as possible, were favoured. Common concerns included whether the GMMs would look or behave differently than wild mosquitoes, and how the technology would be integrated into current malaria control policies. The participants emphasised the importance and the challenge of educating and engaging communities during the technology development.

Conclusions: Understanding how communities perceive and interpret novel technologies is crucial to the design and effective implementation of new vector control programmes. This study offers vital clues on how communities with no prior experience of modified mosquitoes might conceptualize or respond to such technologies when

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deployed in the context of malaria control programmes. Drawing upon existing interpretive frames and locally-resonant analogies when deploying such technologies may provide a basis for more durable public support in the future.

Keywords: Malaria elimination, Genetically-modified mosquitoes, Gene drives, Public perceptions, Community engagement

Background

Malaria is thought to have killed between 150 million and 300 million people worldwide during the twentieth century [1]. Although the situation has improved in the last two decades, malaria remains one of the leading causes of death and ill-health globally [2]. In 2019 more than 200 million people were diagnosed with malaria and nearly half a million died, more than 90% of whom lived in sub-Saharan Africa (SSA) [2]. Interventions such as insecticide-treated nets (ITN) and indoor residual spraying (IRS), combined with improved diagnosis and treatment account for most of the reductions in malaria burden [3]. Yet these interventions appear to have reached the limit of their efficacy in many regions [4–7]. Achieving further gains and not losing ground in the fight against the disease will require the development of novel and complementary interventions [8–10].

Mosquito modification technologies have garnered a great deal of public interest, particularly in SSA, where their impact is expected to be highest as a tool for malaria control and elimination [9, 11–13]. While experiments with some of these technologies, particularly the Sterile Insect Technique (SIT), go back several decades [14], significant progress has been made recently in the development and evaluation of novel approaches [15, 16] such as the Release of Insects carrying a Dominant Lethal genes (RIDL) [17], gene-drive technologies [15, 18–21], or the release of mosquitoes infected with *Wolbachia* bacteria and other endosymbionts [22–24].

These technologies are at different stages of development, and face specific questions from the perspective of communities considering their introduction. One important distinction is between interventions aiming to eliminate the relevant mosquito species (population suppression), and those intended to permanently introduce a novel mosquito strain that will block or interfere with pathogen transmission (population replacement) [15]. These differences suggest the need for distinct communication strategies, and imply a very different set of expectations on the coexistence between modified mosquitoes and the communities hosting the intervention [25].

Given the promise attributed to these technologies, their purported high-impact, and the numerous uncertainties that still surround their future deployment, extensive stakeholder engagement is essential in order to identify potential obstacles and concerns in malaria-endemic regions [15, 26, 27]. Opposition to the release of genetically modified mosquitoes in south-east Asia and the Americas [28–30], and evidence of concerns among stakeholders in Mali [31], Nigeria [32] and Tanzania [33] suggest the importance of proceeding with caution [26, 27]. Robust social scientific research into how these novel technologies are perceived in areas where they might be deployed is a prerequisite for an effective public engagement strategy [34].

This study investigated community awareness and perceptions of genetically-modified mosquitoes (GMMs) and their potential for malaria control in south-eastern Tanzanian villages where no research or campaign for the introduction of such technologies is currently underway. To examine how a typical malaria-endemic community might respond to the introduction of GMMs technologies, the study explored the different conceptual frameworks and analogies that communities use to make sense of modified mosquitoes as a tool for malaria control.

Methods

This study was part of a larger public engagement process aiming to understand and improve public awareness and community evaluation of alternative interventions for malaria control and elimination. This particular study was carried out in ten randomly selected villages in two districts in south-eastern Tanzania between May and December 2019 (Fig. 1). Detailed description of the villages is provided by Finda et al. [5, 35], Kaindoa et al. [36] and Mmbando et al. [37]. Although this area has previously hosted numerous malaria research projects, there had not been any research on modified mosquitoes of any kind up to that point. Previous studies in the area have demonstrated high levels of knowledge about mechanisms and patterns of malaria transmission [5, 38, 39].

Study design and data collection

An exploratory sequential mixed-methods approach [40] was used. Focus group discussions (FGDs) were held with community leaders from each of the ten selected villages to explore in detail their perceptions of mosquito modification. Community leaders are governmental officials elected by the community members every 2 years, and represent their respective communities in several district- and regional-level meetings. They do not belong to any political party; their responsibilities include resolving

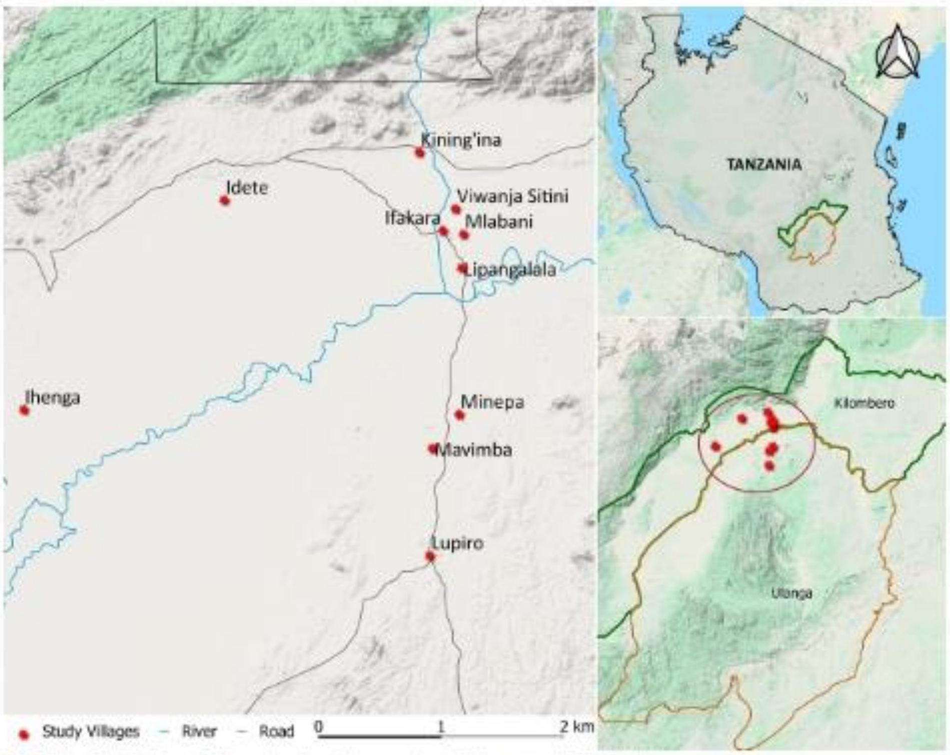

Fig. 1 Map of the districts and villages where the study was conducted. Map prepared by Najat Kahamba

conflicts, authorising property sales, and monitoring migration in and out of their communities. Two community leaders, one male and the other female, were selected per village. Two separate FGD sessions were conducted, one with female and another one with male leaders, and were facilitated by MFF and a research assistant in Swahili language. The sessions were held in May 2019. Each session took around 2 h. The discussions were structured to elicit vernacular modes of reasoning about mosquito modification and the prospect of releasing altered mosquitoes to combat malaria. Specific attention was paid by the moderator to the analogies and examples that participants used to characterize GMMs.

Due to the low levels of awareness of mosquito modification technologies, FGD participants were provided with a brief PowerPoint presentation on mosquito modification to prompt and facilitate informed discussions. The presentation covered different approaches (i.e., sterile insect technique, male RIDL mosquitoes, and gene drive technology). The presentations also included basic information on how the mosquitoes are modified and released, and the current stage of development of each approach. These materials were designed to avoid any value judgment on the potential of any particular approach, so as to preempt, to the extent possible, any interpretive bias among participants. The discussions were guided to elicit participants' views on each of the mosquito modification technologies, including any perceived risks and benefits, and on the factors that might determine acceptance by the local community.

Preliminary findings from the FGDs were used to develop a structured questionnaire to measure prior awareness, knowledge and perceptions of mosquito modification technologies for malaria control among the broader community. The survey was administered to community members in the ten selected villages. According to data from the Ifakara Health and Demographic Survey System [41], the selected villages encompass a total of 11,000 households. Assuming a response rate of 80% and 95% confidence interval, it was estimated that a sample size of 463 household representatives would be needed. This number was rounded to 500 representatives to account for lack of consent. The 500 households were equally divided between the villages; 50 households were randomly selected in each of the ten villages, and were visited by the study team accompanied by community leaders. One consenting adult in each household was interviewed. The survey was carried out between November and December 2019, and was administered using Kobotoolbox™ software [42] on electronic tablets. The study team asked the respondents questions and recorded their answers on the tablets.

Data processing and analysis

The proceedings of the FGDs were transcribed and analysed by MFF, EM, RN and WM. Verbatim transcriptions of the FGDs were translated from Swahili to English, and imported into NVIVO 12 Plus software [43] for coding. Both deductive and inductive coding were used. The FGD guide was used to develop deductive codes, but since the technologies under discussion were new to the participants most of the codes were generated inductively after extensive reviews and coding of the transcripts. Recurrent themes were extracted from the emergent patterns. Direct quotes from FGD participants are used below to illustrate some of the key themes.

R statistical software version 4.0.0 [44] was used to analyse the socio-demographic characteristics of the survey respondents, and to summarise their knowledge and awareness of GMMs. Since a vast majority of respondents lacked knowledge and awareness regarding the technology, no further analyses were necessary. Instead, lay presentations about the technologies were provided to prime further discussions in the FGDs.

Results

Characteristics of study respondents

A total of 506 people participated in this study; 16 community leaders who took part in the two FGD sessions, and 490 community members who responded to the survey. Three of the FGD participants had secondary school education (12 years of formal education), and the rest had primary school education (7 years of formal education).

A detailed description of the survey respondents is provided in Table 1. The mean age was 42.5 years (range: 18–88), and were about equally divided between men and women. A majority of the respondents were married, had primary school education, and reported farming as their main income generating activity (Table 1). The reported average monthly household income was 132,155 Tanzanian shillings (~ 60 USD).

Table 1 Socio-demographic characteristics of the survey respondents

Characteristics	Category	n (%)
Age (in years)	18–35	186 (37.9%)
	36–55	207 (42.3%)
	56–88	97 (19.8%)
Marital status	Married	321 (65.5%)
	Not married	82 (16.7%)
	Divorced/separated	39 (8.0%)
	Widow/widower	48 (9.8%)
Highest educational level achieved	No formal education	43 (8.8%)
	Primary school	358 (73.0%)
	Secondary school	68 (13.9%)
	College/university	21 (4.3%)
Main income generating activities[a]	Farming	413 (84.3%)
	Entrepreneurship	174 (35.5%)
	Fishing	12 (2.4%)
	Animal husbandry	23 (4.7%)
	Formal employment	13 (2.7%)

[a] The totals add up to more than 100% because some participants chose to report more than one income generating activities

Community awareness of malaria burden

Previous surveys in the study area have shown high levels of awareness among residents of these communities about malaria and its transmission by *Anopheles* mosquitoes [5, 45, 46]. In this study, two thirds of the respondents (65.1%, n = 319) believed that rural communities experienced higher burden of malaria, 63.9% (n = 313) believed that poor communities experienced a higher burden of malaria, and 61.3% believed that transmission occurred mostly outdoors. However, when asked about specific details, only 15.3% (n = 75) had a good estimate of current malaria prevalence in the country (as reported in the 2018 Malaria Indicator Survey report [47]). Half (51.6%, n = 253) of all respondents believed that the country was making good progress in malaria control. 59.6%, (n = 292) believed that it was possible to achieve elimination with the current interventions, but 86.1% (n = 422) of respondents indicated that alternative interventions would be necessary to accelerate elimination efforts.

Community views on novel interventions for malaria control

All survey participants responded that any new technologies for malaria control should be effective, affordable, meet in-country regulations and community preferences, and be safe to people, animals and the environment. When asked about trusted sources of malaria-related information, health researchers and health care workers were ranked higher than government officials or politicians (Table 2).

Awareness of mosquito modification technologies for malaria control

A vast majority of survey participants (94.3%, n = 462) reported no prior awareness of mosquito modification technologies for malaria control. For the 13 respondents who were aware, the primary sources of information were Ifakara Health Institute staff, and radio or television. Likewise, nearly all participants 97.3% (n = 477) reported no knowledge of how any of these technologies worked. When asked if they thought modified mosquitoes had ever been released in their communities, 83.5% (n = 409) said they did not know and 16.5% (n = 81) said they had not been released.

Community leaders' perceptions of mosquito modification

None of the community leaders who participated in the focus group discussions reported any prior knowledge of mosquito modification technology. They were able to discuss the subject at length and in detail, however, once they were provided with a brief presentation of issue. They often expressed a great deal of fascination over this approach to malaria control, preferring it over other malaria control interventions. Key attributes of the technology mentioned to justify this preference were the improvement of environmental safety (as a result of reducing the use of chemical insecticides), and the little effort the technology appeared to require from local residents (in contrast to other malaria control methods, such as larviciding or home improvements, deemed more labor intensive).

Table 2 Community members' levels of trust for sources of information on malaria control interventions (N = 490)

Variables	Highly trusted (%)	Somewhat trusted (%)	Somewhat distrusted (%)	Strongly distrusted (%)
Health researchers	91.2	7.6	0.4	0.8
Health care workers	91.2	8.2	0.4	0.2
Government officials	84.9	12.7	1.6	0.8
Politicians	55.3	26.1	9.0	9.6

Although three distinct approaches of mosquito modification were presented to FGD participants, participants showed a clear preference for discussing gene drive technologies, and in particular the male-biased sex distorter gene drive that is currently being considered for deployment in several sub-Saharan countries at the moment [48]. Gene drive technology was preferred because it was seen to require fewer releases of modified mosquitoes compared to the other two, a fact that participants thought would help reduce community skepticism towards the intervention.

> *"It is better if you do not release mosquitoes all the time. Even if people agree that you release mosquitoes, if you do it a lot they may start asking questions again, then you have to spend a lot of time convincing them. But I like this one that does not kill mosquitoes, but makes them have male babies. With this one you can do it just one time, then it is good."* (Female).

As the above quote suggests, several participants were intrigued by the idea of eliminating mosquitoes by biasing the sex distribution of their offspring, rather than by killing them directly. This was in some cases considered a more humane way of eliminating the mosquitoes.

> *"I really like the idea of making them have just male babies, because, you see, males do not bite, and without females they cannot have babies. This way even your consciousness is clean, you have not killed them directly, you have just manipulated them and they will eventually die off. This is a very good and very advance technology"* (Male).

Framings and analogies used to describe mosquito modification

Although FGD participants were unfamiliar with mosquito modification, they immediately grasped its public health logic by reference to their knowledge of crossbreeding and hybridization. Several participants indicated that the best way to explain this technology to people in the community would be to describe it as a form of '*kupandikiza*', a term that can be literally translated as transplantation but is commonly used to describe hybrid plants. The term was used, without any prompt from the facilitator, in both FGD sessions. Participants used the example of the hybrid maize seeds that they buy in agricultural shops, which have a relatively higher yield and can better withstand drought than local maize varieties. FGD participants also referred to the technology as '*kubadilisha mbegu*', the practice of 'changing seeds.'

The term is generally used to describe the introduction of desirable traits in crop seeds and domestic animals through cross-breeding. Several participants mentioned for example that they often borrow or pay for the use of their neighbours' male animals in order to get offspring with the desired traits.

> *"I do it often with my chickens. I don't have a strong rooster, but my neighbour has a very big one. So I ask my neighbour for her rooster to spend time with my chickens, then I can get its seeds. Everyone does that." (Female).*

> *"It is very common with pigs. Sometimes there is one person in the village who has a very big boar, so then, if you want to get its seeds you pay that person money so that the boar can mate with your sows. Sometimes you pay money or sometimes you pay him with a litter. But we do that so that we can have the seed for big pigs." (Male).*

Will the modified mosquitoes look and behave differently?

Participants expressed curiosity and concern over the appearance and behaviour of the modified mosquitoes. They wondered, for example, whether or not the mosquitoes would look the same as 'local' mosquitoes. Participants drew again an analogy with their experience of selectively-bred animals or hybrid maize, and concluded that the modified mosquitoes would necessarily look different.

> *"Yes, they always look different. Even when we plant the hybrid maize, it does not look the same as our local maize, it has better yield, and you can tell just by looking that it is different kind of maize." (Female).*

Village leaders were also keen to know whether modified mosquitoes would still bite people, and whether or not current mosquito control tools could or should be applied to them.

> *I would like to know, if you want those traits to pass to their offspring, will we still need to kill these modified mosquitoes? Will they still bite people? If they bite, people will still want to kill them, and if they do, then it may not work." (Male).*

All mosquitoes are a nuisance; why not just eliminate all of them?

A majority of FGD participants suggested that technologies of mosquito modification should target all mosquitoes, and not just those transmitting malaria. This line of argument was particularly relevant for genetic modification approaches aimed at population replacement, and participants expressed the fear that modified mosquitoes, if they became a feature of the environment, would still be able to carry other pathogens. Additionally, participants stressed the fact that mosquitoes are always a nuisance, regardless of the species; their bites are itchy, painful and cause allergies, so it would be beneficial to just eliminate them altogether. Some participants drew a direct analogy with their experience of jiggers (*Tunga penetrans*) and lice, which were once prevalent in the region but have been eliminated altogether in their communities. They expected a similar sort of objective should be pursued in the case of mosquitoes.

> *"We should just eliminate all mosquitoes, the way jiggers were eliminated. In the past there were so many jiggers; as kids we had to go to the hospital to get them removed from our feet. But then something was done and they all disappeared. These days you never hear about them, and the children these days do not even know what jiggers are. I would like that to be the case with mosquitoes, all of them. I would be happy if the future generations do not know anything about mosquitoes, maybe they should only see them in the pictures." (Male).*

FGD participants drew a direct connection between the effectiveness of the intervention and a reduction in the overall density of mosquitoes. They argued that people would only have faith in the merits of the technology if they saw a substantial reduction in nuisance biting. They further noted that most people are unable to distinguish between malaria vector and non-vector mosquito species, and thus would fail to appreciate the impact of the intervention if it was limited to a single species.

> *"But why would you want the other mosquitoes to remain? For me that is a challenge, that there will still be mosquitoes. People may think that it is not working. The other technologies kill mosquitoes, so then you will know that mosquitoes are not as many. But with this technology there will still be mosquitoes – even if they do not spread malaria, but people will not know that." (Female).*

A few participants, however, did note that mosquitoes also have a place in the ecosystem, and thus supported the idea of eliminating only those responsible for malaria transmission. They pointed out that it would be impossible to eliminate all mosquitoes, because they had never been to or heard of a place where they are completely absent. They further expressed the view that it would be highly important to inform the community that not all mosquitoes would be eliminated, just the ones that spread malaria, so as to prevent mistrust of the technology.

"I do not think there is a need to eliminate all the others if they are not transmitting anything. Remember, there are other birds and other insects that feed on mosquitoes, so it is no use to kill something that is harmless. You know, even in countries that do not have malaria there are still mosquitoes. I know this. So then it is okay to have mosquitoes that do not have malaria. You just need to teach people to differentiate malaria mosquitoes from other mosquitoes so that they know the difference." (Male).

Importance of engaging and educating community members

All FGD participants stressed the importance of educating and engaging the community in the development of these technologies. They emphasized that this should be done not just once but repeatedly until their level of awareness and knowledge was such that they could participate in any decision to bring the technology into the community.

"It is just very important to make sure that people are well aware of this technology. You have to educate them well. Tell people the benefits of this science, and the risks of continuing to have malaria mosquitoes. I think people should know what can happen if people agree to have these mosquitoes released, and what will happen if they do not. For example, you can talk to people maybe two or three times every month, and do it like that until it becomes a common thing that people talk about. That is when you can come with the modified mosquitoes. It is like that. If you do not do this then it may bring very big problem, and people may even attack you, chase you or embarrass you" (Female).

FGD participants advised that, in order to win the trust of people, researchers would need to come up with means to show people the attributes of this technology, rather than just tell them. Village leaders explained that more efforts are still needed to educate people on different mosquito species, and on how to differentiate between malaria-transmitting and other mosquitoes. Without a degree of familiarity with these issues, it was noted that it would be impossible to convince people that the mosquitoes being released were harmless.

"When you go there with your mosquitoes and tell them that you want to release them, they will ask you if the mosquitoes can harm them, and you will say that these are harmless mosquitoes. They will then ask you to prove it. How will you do that? You will have to find a way of demonstrating to people that these mosquitoes are harmless. If you just tell people that any mosquitoes are harmless you are in for trouble. We all know that all mosquitoes spread diseases, and that all mosquitoes are bad." (Male).

Discussion

Historically, the release of modified mosquitoes has received a mixed response from the communities hosting these interventions [49, 50]. Current field research projects on mosquito modification include extensive campaigns of public information and engagement [30, 51, 52]. It has become abundantly clear that these campaigns must start well in advance of the deployment of the technology, and that they should be preceded by research into the concerns, expectations and interpretive frames that local residents bring to bear on the prospect of making disease control reliant on the introduction of altered mosquitoes into the environment [13, 27, 53].

This study attempted to explore perceptions of mosquito modification technologies in a region of southern Tanzania where no trials of modified mosquitoes have yet taken place, but where the epidemiology of malaria might in the near future recommend their use. This is a region, furthermore, where many other malaria control interventions have been piloted in the past, and where a significant proportion of the population is familiar with entomological research, thanks to the long-term presence of the Ifakara Health Institute [5]. This study provides the first social scientific evidence on public perspectives on mosquito modification in Tanzania.

Nearly all community members that responded to the survey reported no knowledge or prior awareness of mosquito modification technologies for malaria control. This is understandable, since no releases have taken place in the country to date, and local and national media have offered very limited coverage of debates on this issue elsewhere in the region. Similar findings have been observed in Mali and Nigeria [32, 54], for example, as well as in high-income countries such as the USA, where a 2016 survey indicated that 46% of respondents reported no prior information about gene-edited mosquitoes [55]. The generalized lack of knowledge and awareness made it difficult to assess in detail public perceptions of the technology, at least through a standardized survey questionnaire. FGDs were introduced to allow us to explore mosquito modification technologies in some detail with a select group of local residents, so as to study in depth the specific conceptual frames that might be used to make sense of the technology.

Although all FGD participants had never before heard about mosquito modification, they all expressed a great deal of fascination over this approach to malaria control once the discussions got underway. FGD participants associated the technology to several aspects of their lived experiences, specifically the practice of cross-breeding domestic animals to select for preferred traits, or the adoption of hybrid crop seeds that provide better yield and drought protection. The prospect that similar techniques could be used to eliminate malaria appeared, therefore, intuitively plausible, even before the specific principles of each form of mosquito modification were discussed.

The analogy with forms of biological modification familiar to local residents also shaped their initial consideration of risk, as it allowed them to balance any potential hazards the technology might carry with the promise of a direct benefit. Similar findings have been reported in the US, where support for genetic modification increased once the potential risks and benefits of the technology were communicated to the people [56]. A study by Widmar et al., for example, indicated that genetic modification was most acceptable when used in human medicine and in disease control [57]. In this case, participants were relatively supportive of the approach once mosquito modification was contrasted with other malaria control interventions, partly because it was seen as requiring less direct participation from the community, and because it was thought to reduce environmental risks they associated with other interventions (i.e. extensive use of chemicals in IRS, ITNs, or larviciding).

After being presented with several forms of modification, participants expressed the greatest interest in gene drive applications, particularly male-biased sex-distorting alterations. This was due to the low perception of risk associated with male mosquitoes and the high perception of risk associated with female mosquitoes. Previous research in the study site indicate near universal awareness in the community that malaria is transmitted by female *Anopheles* mosquitoes, and that male mosquitoes do not transmit any diseases [38, 58]. The participants also pointed out that the gene drive approach would require fewer and smaller releases compared to other mosquito modification technologies [15, 18].

FGD participants contemplated the possibility that modified mosquitoes would look or behave differently than local mosquitoes, and sought further clarification on this particular point. These concerns, although expressed mildly in this case, have led to major controversies over the release of modified mosquitoes in the past. Examples include fears that mutations in the mosquito itself, or in the pathogen, could result in higher rates of disease transmission in the future, or that the modification introduced in the mosquito could be transmitted to humans through biting [32, 33, 59]. It is crucial that these concerns are given careful consideration, and that researchers and sponsors of these technologies are in a position to allay these fears with adequate scientific evidence.

Participants in our FGDs also expressed the concern that eliminating just one mosquito species would not be enough, and would fail to garner sufficient public support for the intervention. This concern can be explained by the fact that people are generally unable to differentiate between malaria vectors and other mosquito species, and that the effectiveness of most other malaria vector control interventions is assessed against a reduction of overall mosquito density. It is estimated that malaria vectors in this region account for less than 10% of the overall mosquito population [5, 60], and some key vector species, such as *Anopheles funestus*, represent a small proportion of anophelines. A technology targeting only a key vector species might be seen as not working if the community experiences little difference in their overall exposure to mosquito nuisance.

Addressing these perceptions and concerns will require a proactive strategy of public outreach. Community engagement in public health research needs to go beyond simply providing the community information or consulting users for their views. An effective program demands building durable partnerships between researchers and the community, eliciting and addressing concerns in terms that resonate locally, and through a process that is embedded within, rather than abstracted from, their everyday lives [27].

Participants in our study emphasized that it would not be enough to simply raise awareness about these technologies; people needed to be fully engaged in order to make sense of the technology in their specific context. They stressed the need to demonstrate, rather than tell, the safety and effectiveness of the intervention. Similar findings have been observed in studies carried out in Mali and Nigeria, where respondents asked that evidence of the technology's safety and effectiveness be provided before they could allow it in their settings [32, 54]. These discussions suggest that education is an iterative process, and that the provision of the facts of how the technology works is only a first step. To truly grasp the public health potential and significance of mosquito modification, communities would need to be able to contextualise these technologies within their everyday life, to translate abstract technical operations into practical concerns.

This study is not without limitations. Only two FGD sessions were conducted, which is a rather small sample size, and the community leaders that participated in the discussions represent a particular segment of the population. Additionally, the study was conducted among communities that have long been associated with public health and entomological research campaigns through Ifakara Health Institute and, therefore, are knowledgeable about malaria transmission and prevention. These limitations to generalizability notwithstanding, the two groups still generated a wealth of qualitative data on the preferred interpretive frames and the most salient concerns that local residents in a rural, malaria-endemic region of Tanzania express in relation to the prospect of using modified mosquitoes as a public health tool. Further studies should be undertaken in communities that may be less familiar with malaria control practices, and to explore in greater depth responses to specific forms of mosquito modification. This study can serve as a baseline from which to develop more granular investigations of local concerns and perceptions, and upon which to build a robust and effective set of tools for public engagement.

Conclusions

Understanding how communities perceive and interpret new public health technologies is crucial in generating durable support for these interventions. This study offers vital clues on how rural communities without prior awareness of mosquito modification technologies respond to the prospect of using genetically-modified mosquitoes as a tool for malaria control. Despite the lack of prior knowledge, FGD participants offered a set of distinctive interpretive frames to interpret mosquito modification technologies, referring in particular to their experiences selecting preferred traits in domestic plants and animals through cross-breeding. These interpretive frames and locally resonant analogies provide a basis for effective community engagement to address any specific concerns, support further social scientific research, and potentially aid in the future development and deployment of such technologies for malaria elimination. The findings of this study may find broader application in other settings where GMMs or similar approaches are being planned.

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Authors' contributions

MFF was involved in study design, data collection, entry and analysis, interpretation of the results and writing the manuscript. NC, FOO, AHK and JL were involved in study design, supervision and critical revision of the manuscript. EGM, RN, WMP, BT and PC were also involved in data collection and revision of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data for this study will be available upon request.

Declarations

Ethics approval and consent to participate

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. Permission to publish this study was obtained from NIMR, ref: NIMR/HQ/P.12 VOL XXX71.

Competing interests

The authors declare no competing interests.

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Appendix 5: Original paper III

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RESEARCH

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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

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Abstract

Background: Larval source management was historically one of the most effective malaria control methods but is now widely deprioritized in Africa, where insecticide-treated nets (ITNs) and indoor residual spraying (IRS) are preferred. However, in Tanzania, following initial successes in urban Dar-es-Salaam starting early-2000s, the government now encourages larviciding in both rural and urban councils nationwide to complement other efforts; and a biolarvicide production-plant has been established outside the commercial capital. This study investigated key obstacles and opportunities relevant to effective rollout of larviciding for malaria control, with a focus on the meso-endemic region of Morogoro, southern Tanzania.

Methods: Key-informants were interviewed to assess awareness and perceptions regarding larviciding among designated health officials (malaria focal persons, vector surveillance officers and ward health officers) in nine administrative councils (n = 27). Interviewer-administered questionnaires were used to assess awareness and perceptions of community members in selected areas regarding larviciding (n = 490). Thematic content analysis was done and descriptive statistics used to summarize the findings.

Results: A majority of malaria control officials had participated in larviciding at least once over the previous three years. A majority of community members had neutral perceptions towards positive aspects of larviciding, but overall support for larviciding was high, although several challenges were expressed, notably: (i) insufficient knowledge for identifying relevant aquatic habitats of malaria vectors and applying larvicides, (ii) inadequate monitoring of programme effectiveness, (iii) limited financing, and (iv) lack of personal protective equipment. Although the key-informants reported sensitizing local communities, most community members were still unaware of larviciding and its potential.

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Conclusions: The larviciding programme was widely supported by both communities and malaria control officials, but there were gaps in technical knowledge, implementation and public engagement. To improve overall impact, it is important to: (i) intensify training efforts, particularly for identifying habitats of important vectors, (ii) adopt standard technical principles for applying larvicides or larval source management, (iii) improve financing for local implementation and (iv) improve public engagement to boost community awareness and participation. These lessons could also be valuable for other malaria endemic areas wishing to deploy larviciding for malaria control or elimination.

Keywords: Malaria control, Malaria elimination, Larviciding, Larval source management, Biolarvicides, Stakeholders, Public perception, Tanzania, Ifakara Health Institute

Background

The world has witnessed a significant reduction in malaria burden since 2000 [1], most of these gains being attributed to insecticide-treated bed nets (ITNs), indoor residual spraying (IRS) and effective case management [2, 3]. Yet, there were still more than 200 million cases, and 405,000 deaths globally in 2018, 90% in sub-Saharan Africa [1]. Ongoing malaria control efforts are increasingly compromised by several factors, chief among them, parasite resistance to anti-malarial drugs [4, 5], behavioural adaptation of mosquitoes to ITNs and IRS [6, 7] and growing insecticide resistance in malaria vectors [8, 9]. Anthropological factors also play a crucial role in mediating transmission, as human behaviours, economic practices and perceptions of risk can increase dangers of infectious malaria vectors [10–13]. Malaria vector control in Tanzania has also focused mainly on provision and use of ITNs and IRS [14–18]. This is complemented with other efforts such as increased access to reliable and affordable diagnostics and treatment [19], and universal distribution of prophylaxis for pregnant women [20]. These efforts, combined with a general improvement in economic opportunity, have led to a tremendous decline in malaria burden throughout the country [20, 21].

Environmental management to eliminate mosquito breeding habitats was among the first malaria control strategies attempted in Tanzania. Efforts included improving drainage systems and the elimination of the permanent bodies of stagnant water near large human settlements [22, 23]. In recent times, the first major use of larviciding in Tanzania was in Dar-es-Salaam in early 2000s [24, 25], when regular application of biolarvicides by community-owned resources persons (CORPs) achieved as much benefit as ITNs [25].

The Tanzania National Malaria Strategic Plan, 2014–2020 recommended implementation of larviciding in selected urban settings [26], in line with guidance from the World Health Organization to consider only settings where aquatic habitats of malaria vectors are few, fixed and findable [27]. This policy initially focused on just urban populations, but in recent years the government has encouraged extension of larviciding to include rural settings [28].

The nationwide expansion of larviciding follows the creation in 2014 of Tanzania Biotech Products Limited (TBPL), which is responsible for production and distribution of biolarvicides [29]. Since 2017, TBPL has been manufacturing two types of biolarvicides, *Bacillus thuringiensis* var. *israelensis* (*Bti*) and *Bacillus sphaericus* (*Bs*) [29]. These products are procured by the district councils across the country, and distributed to all administrative wards. Councils often reserve budgets to compensate community-health workers (CHWs) and volunteers involved in community initiatives such as larviciding [30].

The recent developments by Tanzania to expand larviciding are excellent examples of the much-needed ownership for sustainable vector control, especially given the use of the domestic resources. If sustained, it could yield significant gains over current accruals from the core interventions, and in the process generate important lessons for other countries. Unfortunately, given its extensive scale and novelty as well as the inclusion of predominantly rural councils, there are still multiple challenges that must be addressed to achieve maximum impact. For example, the major malaria vectors in the country use a wide variety of aquatic habitats, which still need to be sufficiently characterized [31]. Moreover, larviciding is also labour-intensive and requires active community involvement.

This study, therefore, aimed to identify and characterize important gaps as well as opportunities for improving the implementation of larviciding in Tanzania. The study examined perceptions and experiences of key actors of larviciding in different district and municipal councils. The study focused on the mostly meso-endemic region of Morogoro, southeastern Tanzania.

Methods

Study area

The study was conducted in nine administrative councils in the Morogoro region in southern Tanzania between October 2019 and March 2020 (Fig. 1). The area

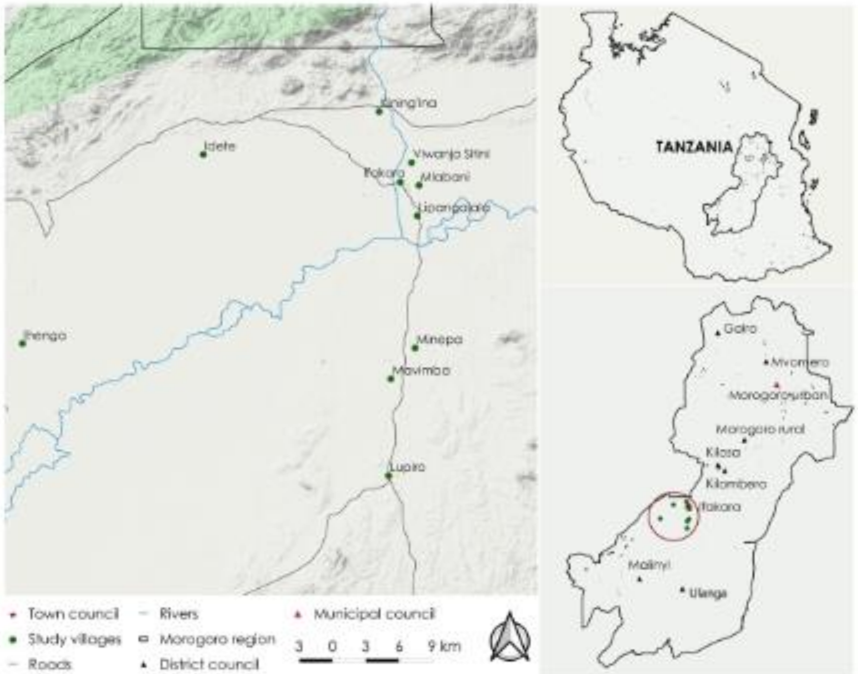

Fig. 1 Map of Morogoro Region, Tanzania, showing the districts, wards and villages where the study was conducted. Map prepared by Najat Kahamba

has a total population estimated at 2.2 million people [32], and is currently classified as meso-endemic, with malaria prevalence estimated at ~10% according to the most recent estimates [33]. The councils were: Gairo, Mvomero, Kilombero, Ulanga, Kilosa, Morogoro and Malinyi district council, Morogoro municipal council and Ifakara town council (Fig. 1). The community members surveyed were from Ulanga and Kilombero districts only.

Selection of stakeholders

Stakeholders selected for this study included district health officials and community members. The health officials included district malaria focal persons (MFPs), vector surveillance officers (VSOs) and ward health officers.

Malaria focal persons were either medical doctors or environmental health specialists in charge of all malaria related-matters at the district level. In this study, all the MFPs had been at their current position for at least two years. They are responsible for all aspects of malaria control, including monitoring trends of malaria cases, deaths and control. Vector surveillance officers on the other hand were environmental health specialists with a diploma in environmental health science and a special training in disease-vector control. The VSOs are responsible for organizing, supervising and executing disease-vector control programmes at the district level. Lastly, the ward health officers were also environmental health specialists and were responsible for all health-related issues at the ward level. They had a diploma or certificate training in environmental health science, and their responsibilities included planning, supervising, monitoring and evaluating overall health services at the ward level. Each district has one MFP, one VSO and multiple ward health officers, but in some cases one ward health officer could serve multiple wards within the district.

Malaria focal persons and VSOs were recruited from all districts as well as the municipal and town councils within Morogoro region. However, the ward health officers were recruited from a randomly selected ward in each district, municipal or town council. Each of seven districts had between 8 and 38 wards.

For the community survey, households were randomly selected from ten randomly selected wards in Ulanga and Kilombero districts in the region (Fig. 1), and the survey was administered to the household heads.

Study design and procedures

A concurrent triangulation mixed method study design was used [34], incorporating key informant interviews (KII) and survey questionnaires. Key informant interviews were done with MFPs, VSOs and ward health officers to obtain information on the degree of awareness as well as experiences and perceptions of these officers regarding larviciding. These interviews were conducted by the authors, SAM, MFF and IHN, between February and March of 2020 at the respective council offices. The interviews were audio-recorded following consent of the participants. The audio recordings were supplemented by hand-written notes. Each interview lasted between 15 and 60 min and were done in Swahili language.

The questionnaire surveys were conducted with community members from Ulanga and Kilombero district. These were done in Swahili language, and used to gather data on awareness and perceptions of larviciding as a malaria control intervention. Kobotoolbox™ software [35] was used to administer the surveys via electronic tablets, between November and December 2019. The individual-level perception of community members towards larviciding was assessed by measuring the level of agreement towards positive statements on larviciding using a 5-point Likert-scale, ranging from strongly agree (1) to strongly disagree (5). The main statements were as follows: (i) larviciding will be effective for malaria control, (ii) larviciding will fill gaps left by other interventions, (iii) larviciding is safe for humans, animals and the environment, (iv) larviciding will be easy to perform, (v) larviciding supplies and equipment will be easily accessible, (vi) larviciding will be affordable to community members and (vii) larviciding will be acceptable in the community. The final perception level was determined by comparing individual perception scores against the median score (see "Data processing and analysis" section).

In addition, one joint stakeholder engagement meeting was conducted at the regional office, where all the MFPs and VSOs from the nine administrative councils participated, together with Ifakara Health Institute researchers. Discussions at this meeting involved options for improving larviciding operations in the respective councils, and what roles different stakeholders could play.

Data processing and analysis

Audio recordings of the key informant interviews were transcribed immediately following the discussions and translated from Swahili to English language. Field notes were added in the written transcripts. The written transcripts were analysed using NVIVO 12 Plus software [36]. Deductive and inductive coding were used to categorize the codes items. A KII guide was used to develop the deductive codes while the inductive codes were generated based on thorough reviews of the transcripts. Similar codes were grouped and emergent patterns used to identify themes. The extracted themes included: (i) knowledge about larval habitats of malaria vectors, (ii) awareness of larviciding as a malaria control intervention and (iii) challenges facing the implementation of larviciding. Direct quotation from participants were used to support the themes. Information from the key informant interviews and survey were triangulated during the discussion of the findings [37].

The quantitative data on the other hand was analysed using R statistical software version 4.0.0 [38]. The sum of the scores of the seven statements was calculated for each survey respondent, after which a median of these scores calculated. Perception level was determined by comparing individual perception scores against the median perception score; scores above the median were considered negative while those at or below the median were considered positive. Internal validity of the scale was measured by calculating Cronbach's alpha [39]. Univariate analysis was used to determine influence of the respondent sex, age group, education level and degree of previous awareness of larviciding on the main outcome variable, i.e. their perceptions of larviciding. Binary logistic regression was used to determine the association between the independent variables and the outcome variable; odds ratio was calculated at 95% confidence intervals (CIs).

Results

Characteristics of study respondents

A total of 517 people (43% men and 57% women) participated in this study. These included the 27 key informants who participated in the in-depth interviews, and 490 community members responding to the administered questionnaires. Nineteen of the 27 KII participants were men, and all participants had a college or university degrees. The average age of participants in KII was 45 years, ranging from 33 to 60 years. Average duration of employment in their current position and at their current location was 7 years, ranging from 6 months to 35 years (Table 1).

Average age of the community members who participated in the survey was 42 years (range: 18–88 years) and two thirds (66%, n = 321) were married. About three

Table 1 Characteristics of Key Informant Interviewees

Key informants	Mean age (years)	Average no. years in service	Males	Females	Total
Malaria Focal Persons	40.1	4.5	6	3	9
Vector Surveillance Officers	47.9	7.4	6	3	9
Ward Health Officers	47.2	9.2	7	2	9
All Participants	45.1	7.0	19	8	27

quarters (73.1%, n = 358) had primary school education, 8.8% (n = 43) had no formal education, 13.9% (n = 68) had secondary education and 4.3% (n = 21) had college-level education. A majority (84.3%, n = 413) of the respondents reported small-scale farming as their main income-generating activity, but people also practiced small retail businesses, fishing, animal husbandry or had formal employment.

Perception regarding malaria burden

Table 2 summarizes the respondent perceptions regarding malaria burden in Tanzania. Nearly a half of the survey respondents reported not knowing the current malaria prevalence range in Tanzania. Only 15.3% identified correct range of nation-wide prevalence (6–10% based on 2018 Malaria Indicator Survey [33]). Two thirds believed that rural communities or poor households suffer the heaviest burden. More than a half of respondents believed the country was progressing well towards elimination, and that it could achieve elimination with current interventions. However, a majority of the survey respondents noted that alternative interventions would be necessary to speed up these efforts (Table 2).

Awareness of community members regarding larviciding as a malaria intervention

Only a quarter of survey respondents were aware of the government policy to include larviciding as a malaria intervention (Table 3), and more than half did not know whether the intervention was ongoing in their districts. Three quarters also did not know the mode of action of larvicides despite knowing what the interventionitself is. Older respondents (46–55 years) were more aware of larviciding than those 25 years or younger.

General perception of larviciding and its potential as a malaria intervention

Perception of community members towards larviciding was assessed based on levels of agreement towards positive statements on a 5-point Likert-scale, ranging from strongly agree to strongly disagree. The median score of

Table 2 Community perceptions regarding malaria risk and burden (N = 490)

Questions asked	Variables	Percentage (n)
Which settings are at highest risk of malaria?	Rural settings	65.1 (319)
	Urban settings	7.6 (37)
	Equal in rural and urban settings	23.7 (116)
	Do not know	3.7 (18)
Which communities are most affected by malaria?	Low-income communities	63.9 (313)
	All communities are equally affected	33.7 (165)
	Do not know	2.5 (12)
Where does most malaria transmission occur?	Outdoors	61.3 (300)
	Indoors	36.7 (180)
	Do not know	2.0 (10)
What is your opinion regarding country's progress towards malaria elimination	Very good	51.6 (253)
	Good but slow	43.9 (215)
	Very slow	4.5 (22)
Can malaria be eliminated	Possible	59.6 (292)
	Not possible	40.4 (198)
Do we need alternative interventions?	There is a need	86.1 (422)
	No need	13.9 (68)

Table 3 Knowledge and awareness of larviciding in the communities (N = 490)

Variable assessed	Response	Percentage (n)
Awareness of larviciding (n = 490)	Yes	26.1 (128)
	No	73.9 (362)
Sources of information (n = 128)	Friends/family	48.1 (76)
	Radio/TV	21.5 (34)
	IHI scientists	10.8 (17)
	Community meetings	7.6 (12)
	Saw on a visit in Dar es Salaam	7.6 (12)
	Community health workers	4.4 (7)
Has larviciding been implemented in the community (n = 490)	Yes	4.5 (22)
	No	43.5 (213)
	Do not know	52.2 (255)
Larviciding works by killing mosquitoes in their juvenile stage (n = 490)	Agree	23.9 (117)
	Do not agree	2.0 (10)
	Do not know	74.1 (363)

the seven statements was 21. Reliability assessment of the perception scale yielded a Cronbach alpha score of 0.77, indicating acceptable reliability of the scale and minimum redundancy.

Of all survey participants, 40.4% agreed that larviciding would be acceptable in their community as new intervention. The rest of the community members had neutral perceptions on effectiveness, safety, feasibility, accessibility, affordability or acceptability of larviciding (Table 4). Community members who were already aware of larviciding were more likely to welcome larviciding compared to respondents without previous knowledge prior to the survey ($p = 0.029$), Table 5). However, three quarters (74.2%, $n = 364$) of respondents said they would support larviciding if introduced to their communities.

Awareness, perceptions and experiences of district and ward-level health officials regarding larviciding for malaria control

Important aquatic habitats of malaria vectors

In the initial analysis, most KII participants reported that they knew the general characteristics of mosquito aquatic habitats, but not all were able to distinguish between habitats of key malaria vectors and habitats of other mosquitoes. When asked to describe the aquatic habitats of important malaria vectors, respondents used terminologies such as fresh waters, standing waters, pit latrines, trash pits, septic pits, used tires, long grass and bushes.

When considered separately, most malaria focal persons and vector surveillance officers were able to distinguish between aquatic habitats of malaria vectors. They pointed out that *Anopheles* mosquitoes prefer fresh water. A small number of MFPs however were unable to make this distinction, despite knowing that some

Table 4 Perception of community members regarding effectiveness, feasibility, affordability and acceptability of larviciding for malaria prevention (N = 490)

Statement	Strongly agree (1) (%)	Agree (2) (%)	Neutral (3) (%)	Disagree (4) (%)	Strongly disagree (5) (%)
Will be effective	29.8	14.7	54.5	0.4	0.2
Will fill gaps left by ITNs	28.4	13.1	56.1	1.2	1.2
Will be safe for humans, animals and environment	7.1	8.4	76.9	3.9	3.7
Will be easy to use	19.6	4.7	72.5	2.0	1.2
Will be easily accessible	2.6	2.2	84.1	4.1	6.9
Will be affordable to residents	2.9	1.4	86.7	1.6	7.4
Will be acceptable in community	34.3	6.1	56.7	2.2	0.6

Table 5 Association between the community perception towards larviciding and their socio-demographic characteristics

Category	Variable	Odds ratio (95% CI)	p-value
Sex	Male	1.00	–
	Female	0.74 (0.32, 1.70)	0.470
Age category (in years)	18–25	1.00	–
	26–35	0.53 (0.14, 2.58)	0.382
	36–45	0.56 (1.34, 2.76)	0.428
	46–50	0.42 (0.07, 2.36)	0.300
	Above 50	0.60 (0.14, 3.04)	0.497
Education level	No formal education	1.00	–
	Primary (7 years)	2.09 (0.41, 38.20)	0.478
	Secondary (12 years)	1.94 (0.24, 39.90)	0.752
	Tertiary (> 12 years)	7.00 (0.83, 146.87)	0.102
Awareness of larviciding	Aware	1.00	–
	Not aware	0.40 (0.17, 0.93)	0.029*

The odds and p values represent likelihood of certain groups having a favourable opinion of larviciding as a malaria intervention

*Statistically significant difference

mosquitoes preferred fresh water. They were unable to specify key characteristics of the actual malaria vectors as distinguishable from the habitats of non-vectors. On the other hand, a majority of the ward health officers were not aware of the differences in breeding habitats between malaria and non-malaria vectors. This group only knew that mosquitoes breed in water. They identified ponds, streams and river banks, septic tanks and pit latrines as possible breeding habitats for all mosquitoes. They conceded that differentiating larval habitats was too technical a task for their capacities; their focus was on identifying places with standing water and treating them with larvicides.

> *"It is not too easy to differentiate between the larval habitats, except if you see a place with a lot of water, then you just know that there will be mosquito larvae there, because we know mosquitoes like to lay their eggs in water. In my ward, for example, we have water ponds that last a whole year, so I know mosquitoes breed there. There are also communities where people still use pit latrines, but the holes are not covered and the toilets do not have doors or roofs. So I also know that mosquitoes can breed in those." (Ward Health Officer, Male).*

The term 'fresh water' generated great discussion among the key informants. Those who reported that malaria vectors preferred clean and fresh water also listed water storage buckets or pots and morning dew as potential habitats for malaria vectors.

> *"What I know is that there are different types of mosquitoes; I know there are Anopheles, Culex and Aedes mosquitoes. I know that Anopheles prefers to breed in clean and fresh water, so they can be found in buckets of clean water, in the clean morning dew. Culex on the other hand likes dirty water; they like to lay their eggs in septic pits and in other dirty places." (Vector Surveillance Officer, Male).*

Knowledge of larviciding

All MFPs, VSOs and ward health officers knew that larviciding involved killing mosquitoes with chemicals during their larval stages. They also knew of two types of biolarvicides (i.e. *Bti* and *Bs*) available for large-scale implementation in Tanzania, one used to treat fresh and clean water, and the other one used to treat dirty water. Many could however not name the biolarvicides, nor specify which types were applicable for malaria-vector control.

> *"Larviciding it is the killing of the second stage of mosquito's life cycle using chemicals called larvicides. In Tanzania we have biological larvicides, so they are called biolarvicides. I understand that these biolarvicides are some kind of bacteria; when they are put in water that contains mosquito larvae, the larvae feed on the bacteria, which kills them." (Malaria Focal Person, Male).*

Supply and distribution of larvicides

MFPs reported having received two types of biolarvicides (totaling 720 l per council) from the government to distribute to the wards within their districts through ward health officers. The first supply was delivered in 2018, and another supply delivered in 2019. It was noted that the distribution of the biolarvicides had been prioritized on wards with the highest reported malaria cases compared to others.

Implementation of larviciding

To support larviciding, the ward health officers recruited and trained community health workers (CHW), local residents who had previously participated in a community health training course. Where no CHWs were available, the ward health officers recruited volunteers, who were typically young male residents. The CHWs or volunteers were responsible for actual application of larvicides, with supervision from the ward health officers. The ward health officers would accompany the implementers to identify water bodies within their wards and during the first application. Unfortunately, a majority of the ward health officers had received no specific training on how to implement the larviciding. Moreover, in some districts one ward health officer was responsible for overseeing larviciding in up to four wards, thus they were unable to effectively supervise the CHWs.

> *"I supervised this work throughout. I recruited community health workers from different communities in my ward and gave them larvicides. This way I made sure that every community in my ward had larvicides." (Ward Health Officer, Male).*

> *"We were told to involve the community when we received the larvicides, so we spoke with village and community leaders, and with their help we found young men in the communities to help with this work. We then instructed the young men on how to apply the larvicides." (Ward Health Officer, Male).*

Training on application of bio-larvicides

Malaria focal persons reported that they had participated in at least one seminar on how to apply the larvicides, in 2018 and or 2019. Some of the MFPs were not holding their current positions in 2018 and had therefore only received one training session. The training, provided jointly by the Muheza College of Health and Allied Sciences [40] at Muheza district and Kibaha Biotech Products Limited (TBPL) [29], was described as largely theoretical, providing information on the two types of biolarvicides and where to use them. There had been no practical training on identification of aquatic habitats, application of larvicides or monitoring of programme effectiveness. Fortunately, all MFPs had been given written guidelines for biolarvicides application.

> *"I participated in this year's [2019] seminar. We were given a formula on how to calculate the amount of larvicides per liter, and they promised to share with us the template with the specific formula for the amount of diluted larvicides to apply in a breeding habitat. It was a PowerPoint presentation; it was all theoretical." (Malaria Focal Person, Male).*

Unlike the MFPs, the VSOs and ward health officers reported not to have participated in the training programmes, but had instead received information on dilution and application methods from the MFPs. Ward health officers then passed on the information to the CHWs and the community volunteers who were responsible for the hands-on implementation of the larviciding.

> *"I called the volunteers to my office and explained how to dilute the larvicides and how to apply them to the breeding habitats. I did the training in my office. Then I provided them with the larvicides as well as masks to protect themselves." (Ward Health Officer, Female).*

Monitoring efficacy of the larvicides

There was no formal mechanism of monitoring effectiveness of the larviciding. Some ward health officers stated that they kept track of the number of malaria cases at the health centers, and assumed that reduced cases meant that the larviciding was working. Other ward health officers reported that they asked community members if they had experienced a reduction in mosquito annoyance. Others relied on their own experience living in the communities to detect a reduction in mosquito abundance. All respondents reported that they believed that larvicides were effective based on these factors.

Challenges during implementation of larviciding

Key challenges that district and ward health control officers faced during implementation of larviciding are summarized on Table 6 below. The challenges listed included insufficient technical knowledge on identifying habitats of malaria vectors and application of the larvicides, insufficient knowledge on safety of the larvicides, inadequate funding, inadequate supply of larvicides, some resistance from community members, late-involvement of VSOs and ward health officers and inadequate collaboration from non-governmental organizations in the districts or wards.

Discussion

Larviciding is considered as complementary option to be used alongside current major malaria control approaches, notably ITNs, IRS and case management [41]. To accelerate malaria elimination efforts, the Tanzanian government has invested significantly in larviciding, including the establishment of a national production capacity and adoption of larviciding in both rural and urban settings [26]. This study investigated some of the practical obstacles that limit the effective roll-out of this strategy across the country, with a particular focus on the perceptions and experiences of key stakeholders of malaria control in southern Tanzania.

The key-informant interviews revealed significant knowledge inadequacies among MFPs, VSOs and ward health officers towards implementation of the larviciding.

Table 6 Key challenges facing larviciding programs in Morogoro region, southern Tanzania

	Challenges	Description	Examples of respondent quotes
1	Insufficient technical knowledge on habitat identification and larviciding	Malaria Focal Persons, District Surveillance Officers and Ward Health Officers reported that they did not have adequate technical knowledge for assessing whether specific water bodies were likely to contain mosquito larvae, and whether those larvae were likely to belong to *Anopheles* species or other mosquitoes. As a result, ward health officers reported that they often treated all the water bodies they could find in their wards The MFPs also reported that they did not have accurate information on the proper amount of larvicides to apply in specific water bodies. Instead, they often just guessed the amount, based on their perceived volumes of the habitats There was also no uniformity on methods of monitoring efficacy of the larvicides. Some reported that they used number of malaria cases at the health centers as an indicator of efficacy and some used community testimonials on reduced mosquito nuisance bites	*"It is not easy to differentiate mosquito breeding sites, however, there are areas that you can recognize as breeding sites upon seeing. For example, we have areas with ponds that last the whole year and a great example is an area close to the secondary school where brick laying created ponds which obvious attract mosquitoes as a breeding site."* (Ward Health Officer, Male) *"Like I said, we lack knowledge on this aspect. We do not even know how much larvicides to spray in a water pond for example. Even if you ask the VSO he will tell you the same. So then we do a lot of guess work, but we do not know for sure if we are putting too much or too little."* (Malaria Focal Person, Female) *"We do monitoring by asking community members, they are the ones who report sleeping comfortably."* (Ward Health Officer, Female) *"We look at the statistics, as to whether number of malaria patients increasing or decreasing."* (Ward Health Officer, Female)
2	Lack of knowledge regarding safety of the larvicides	There were also inconsistencies in knowledge about risks posed by the larvicides. MFPs and VSOs claimed that the larvicides did not pose any harm to people or their livestock, but were not sure whether the larvicides could cause harm to other aquatic organisms. In contrast, most ward health officers believed the larvicides could harm people or animals, since they smelled like poison and turned the color of the water	*"I know that it is safe on humans, but I really do not know if they pose any harm on other insects in the water, on animals or on vegetation around the water. I only know that it does not have any harm on humans."* (Malaria Focal Person, Male) *"It has to have harm, I can just tell from the smell that comes when you apply it, the water also turns milky, so it just looks poisonous. So I advise people to not use the water immediately after the application, but if they wait after a while the smell disappears and the color goes back to normal."* (Ward Health Officer, Female)
3	Inadequate funding	All participants reported that lack of sufficient funding was a significant obstacle for successful implementation of larviciding. Funding was needed to provide compensations and wages to the CHWs or the volunteers, procure personal protective gear and application equipment and for transportation In some cases the participants reported limiting larviciding activities due to limited financial support	*"When you ask people in the community to help with this exercise, they expect to get a wage. But when we were implementing this there wasn't any money set aside for paying the volunteers or the CHWs. Sometimes I had to give them my own money, because I saw how hard they were working."* (Ward Health Officer, Male) *"In my district we had to stop before finishing because we just did not have any money to implement this project. We had the larvicides only, but nothing else. We requested money for protective gear, transportation, or for paying people that were doing the application but we did not receive it, so after some time we just had to stop."* (Vector Surveillance Officer, Female) *"For an example, my district has 31 wards, and it is not like the breeding habitats are at the headquarters of the wards. You have to go deep into the villages. It is hard to walk with a can containing 20-liters of larvicide. There is only one car at the district, and even that is currently not functioning."* (Vector Surveillance Officer, Male)

Table 6 (continued)

	Challenges	Description	Examples of respondent quotes
4	Inadequate supply of larvicides	Some of the ward health officers reported that the larvicides they received were not enough to treat all mosquito breeding habitats in their area of jurisdiction. In particular, communities living in swampy areas, needed a lot more supplies than they received	*"I will tell you that the larvicides were not enough. In all the breeding habitats that I had surveyed, we could not cover all of them before running out of the larvicides. We needed more, but there was none."* (Ward Health Officer, Female) *"In 2018, I have received two cans of twenty liters which cannot be enough for my ward. In another round, I had received two cans of twenty liters per village which was not enough either, so we decided to prioritize the most significant settings."* (Ward Health Officer, Female)
5	Some resistance from members of the community	Key informants reported initially facing resistance from some community members who feared that the larvicides would be poisonous to chicken, livestock or fish. This was mostly due to the smell of the larvicides, and by the fact that the water turned milky immediately after application. This initial resistance was however reported to ease once the health officials spent time explaining the benefits and safety of the larvicides. Community sensitization was primarily done by ward health officers with assistance from CHWs	*"The uptake was not very good in the beginning as people were not educated on what larvicides are, how they work or their safety. So they were always reluctant to let people spray near their homes."* (Vector Surveillance Officer, Female) *"Once people were sensitized, the uptake improved. People would even follow us and ask when we would be spraying again, or point me to breeding habitats that I had missed."* (Ward Health Officer, Male)
6	Inadequate involvement of VSOs and Ward health officers in early stages	VSOs and ward health officers reported to not being involved in the initial planning of the larviciding programme at the district level, but rather receiving implementation plan from malaria focal person. This overshadows their significant inputs as they have spent more time in the settings on average compared to malaria focal persons	*"I was not involved in the planning and these larvicides are new which requires training but we have only been given pamphlets. Only if we can be involved from the early stages, I think it will improve the practice."* (Vector Surveillance Officer, Female)
7	Insufficient collaboration with non-governmental organizations	Key informants reported inadequate involvement of the non-governmental organizations (NGOs) in the implementation of the larviciding programme. This has been attributed to larviciding not being priority among these NGOs	*"Providing awareness to the community, maybe we could try but even Boresha Afya indicated disease prevention is not in their priorities but rather case management. SolidarMed priorities are in behavioural change, so we have no stakeholders in disease prevention."* (Malaria Focal Person, Male)

The table provides a brief description of each identified challenge, as well as examples of direct statements from the study respondents

For instance, all participants knew that mosquitoes have an aquatic habitat stage; but a majority could not easily differentiate the aquatic habitats typical of malaria vector species. Moreover, these health officials reported that malaria vectors do prefer "fresher" water compared to other mosquitoes, but what majority meant by fresh water was any water that looked clean such as water in clay pots or buckets. Ward health officers, who are closely anchored in the community and provide guidance to the community health workers and volunteers during the larviciding, could not differentiate between malaria and non-malaria vectors' aquatic habitats and reported to use different methods to apply and monitor effectiveness of the larvicides. This lack of adequate knowledge and uniformity might be attributable to the lack of training on how, where and when to apply the larvicides as accorded by WHO guidelines [41]. Some of these malaria control officials particularly MFPs and VSOs reported to have attended at least one theoretical training on larviciding. However, this training proved to be insufficient as acquiring necessary expertise would require practical, "on the job" training rather than a presentation of theoretical principles [42]. No formal training to the actual implementers (i.e. ward health officers, CHWs and volunteers) was reported, this could undermine the overall impact of the programme.

Insufficient funding to assist with implementation of larviciding was one of the practical obstacles reported by the MFPs, VSOs and ward health officers. Funding was needed to offer incentives, cover transportation and larvicides costs, and provide personal protective gears to the CHWs and volunteers who did the actual job of applying the larvicides. A successful large-scale larviciding trials conducted in Dar-es-Salaam [25, 43] in early 2000s had demonstrated the cost-effectiveness of the approach [44]. However, larviciding is deemed operationally and financially infeasible in the rural settings [41]. Fortunately, a recent study by Nambunga et al. in rural Tanzania highlighted the possibility of minimizing the unnecessary costs, if larviciding could be species-specific [31].

In Kilombero valley, *Anopheles funestus* accounts for over 80% of the ongoing malaria transmission [8], its aquatic habitats have found to be few and highly distinctive [31]. Thus, effective targeting of *An. funestus* aquatic habitats alone could potentially reduce malaria transmission by 80% in Kilombero valley. In this valley, *An. funestus* aquatic habitats adhere to WHO criteria (i.e. few, fixed and findable) for larviciding implementation [41]. The application of larvicides for malaria control in Morogoro region is often directed towards all stagnant water bodies, thus undermining the intended amount of larvicides. Understanding the ecology of major malaria vectors in each district within Morogoro region could cut the unnecessary costs and provide effective larviciding approach. However, studies shows that control of Culicine mosquitoes that are responsible for enormous biting nuisance could maximize community acceptance and support towards malaria control programme [45, 46].

This present study also revealed the need to strengthen engagement of key stakeholders including the community. Despite efforts by district-level malaria control officials to inform and sensitize the residents, a majority of the community members surveyed were not aware of larviciding, did not know its function within malaria control efforts, and were not aware whether or not it had been implemented in their settings. This finding was in agreement with a previous study by Mboera et al.. in Mvomero district within Morogoro region, where only 17% of the survey respondents were aware of larviciding as a malaria control intervention [47]. Both findings indicate inadequate community engagement methods during the implementation stage. However, community members in both studies showed willingness to support the implementation of larviciding in their communities. In the present study, age, gender and educational level of the survey respondents did not seem to influence their level of awareness and perception towards larviciding, but the contrary was observed in other studies [48, 49]. The majority of the districts in Morogoro region have at least one local radio station, which may be relied upon to further strengthen the community engagement.

Insufficient support from local stakeholders within Morogoro region might have been among the obstacles towards effective implementation of larviciding. Engagement of other stakeholders particularly non-governments organizations (NGOs) have shown to yield fruitful impact in the malaria control. For instance, collaboration between Urban Malaria Control Programme (UMCP) and Ifakara Health institute (IHI) in Dar-es-Salaam during early 2000s towards malaria control through larval source management led to a significant impact [25]. Thus, effective engagement of these NGOs such as IHI will somewhat ensure smooth implementation of larviciding through resources provision and/or capacity building.

The present study also revealed insufficient "early-on" involvement of VSOs and ward health officers during the budgeting and implementation planning. MFPs attend all council's meeting that involve malaria control initiatives through district technical committee [50], and often instruct the VSOs and ward health officers on the way forward. This could lower the sense of ownership towards the larviciding programme. Adequate involvement of VSOs and ward health officers could strengthen the implementation of the programme, apart from VSOs holding a special training on disease-vectors control but also majority have spent significant number of years in the localities.

The study results should be interpreted in the light of several limitations. A response bias may have resulted partially inaccurate responses on the survey. Social desirability bias may have resulted in respondents saying 'I don't know' to most of the statements that assessed their perceptions of larviciding as a majority had early-on indicated that they were not aware of this intervention. Demand characteristics may have also resulted from both the key informants who may have reported insufficient knowledge or lack of resources hoping that these would be provided to them. In addition, the present study did not include district medical officers (DMO) who also plays a crucial role in planning, coordinating and implementing the delivery of health services at the district level [30].

Conclusions

Both communities and district-level malaria control officials widely supported the larviciding programme, however, there were gaps in technical knowledge, implementation and stakeholder engagement. To maximize the overall impact of the programme, training efforts should be intensified, particularly for identification of aquatic habitats for important vectors and formal training should be given to the actual implementers (i.e. CHWs and volunteers) not just MFPs, VSOs and ward health officers. Standard technical principles for application of larvicides should strictly be adopted and improvement on financing at a district-level implementation. Furthermore, engagement of community members and other stakeholders such as NGOs should be improved to maximize awareness, participation and sustainability of the programme. These lessons learnt from Morogoro region shed the light for other malaria endemic areas on the possibility of deploying larviciding for malaria control or elimination.

Abbreviations

KI: Key informant; KII: KeyInformant Interview; MFP: Malariafocal person; VSO: Vectorsurveillance officer; NMSP: NationalMalaria Strategic Plan; ITN: Insecticide-Treatedbed Net; IRS: IndoorResidual Spraying; *Bti*: *Bacillus thuringiensis* var.*israelensis*; *Bs*: *Bacillus sphaericus*; IHI: IfakaraHealth Institute.

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Authors' contributions

SAM, MFF, FOO, NC, AHK and JL were involved in study design. SAM, MFF and IHN were involved in data collection. SAM and MFF conducted data analysis. SAM and MFF wrote the manuscript. KU and BJM facilitated initial meeting with Morogoro region malaria control officials. FOO, NC, AHK, JL, FT, PC, KU and BJM provided thorough review of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The data will be made available by the corresponding author upon reasonable request.

Ethics approval and consent to participate

Ethical approvals for this project were obtained from Ifakara Health Institute's Institutional Review Board (Protocol ID: IHI/IRB/EXT/No: 007-2018) and the Medical Research Coordinating Committee (MRCC) at the National Institute for Medical Research, in Tanzania (Protocol ID: NIMR/HQ/R.8a/Vol.IX/2895), as well as University of the Witwatersrand (UW) in South Africa (Clearance certificate No. M180820). Written consents were sought from all participants of this study, after they had understood the purpose and procedure of the discussions.

Consent for publication

Permission to publish this study was obtained from National Institute for Medical Research, in Tanzania (NIMR/HQ/F.12 VOL XXXI/67).

Competing interests

The authors declare no competing interests.

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Publisher's note

Appendix 6: Original paper IV

Perceptions and recommendations for housing improvement for malaria control in south-eastern Tanzania

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Abstract

Housing improvement has been associated with reduced risk of malaria transmission and lower odds of malaria infection in sub Saharan Africa. However, there is limited information on how communities in malaria endemic settings perceive housing improvement as a malaria control intervention. This study aimed to explore perceptions and recommendations for housing improvement as a malaria control intervention among community members in malaria endemic settings in southern Tanzania. A mixed-methods study design was used, involving 1) structured questionnaires administered to 490 community members to assess awareness and perceptions of housing improvement as a malaria control intervention, and 2) focus group discussions (FGD) with community leaders to get insights on the potential of housing improvement as a malaria control intervention. About two thirds of the survey respondents indicated that rural and poor communities faced the highest burden of malaria transmission. Poorly constructed houses, i.e., small, with holes on walls and roof and lack windows were linked to increased risk of malaria transmission, as they forced people to spend time outdoors exposed to malaria-transmitting mosquitoes. High awareness (69.6%) and strong support (88.9%) for housing improvement for malaria control was observed among the survey respondents. However, high building costs slowed down house improvement initiatives. Community members proposed several options for the government to support housing improvement including providing building loans, subsidizing building costs, or building standard houses and renting to the poor community members. It is crucial to bring together all the key players in housing sector to come up with solutions that can reduce barriers that communities living in malaria endemic settings face in building mosquito-proof houses.

Keywords: Housing improvement; malaria transmission; community perceptions

Introduction

Malaria is often recognized as a disease of poverty (51,239). At a global level, more than 90% of malaria cases and deaths are concentrated in the world's poorest countries (240). At more local levels, malaria is concentrated in places that are more rural and poorer (26,52), where poor housing is a common factor. More than 80% malaria transmission in sub Saharan Africa occurs indoors (241), making house quality one of the vital factors associated with malaria risk. Housing improvement such as screening windows and doors is one of the oldest reported malaria control interventions in world, dating back to the 19th and 20th century in Europe and America (105), and is linked to malaria elimination in different parts of Europe and America (104,105).

However, interest in housing improvement for malaria control declined following the discovery of insecticide methods for killing mosquitoes, which were considered simpler, more affordable and highly effective (105,242). Housing improvement for malaria control started regaining interest following the emergence and spread of insecticide resistance in malaria vectors; interventions not relying on insecticides were given consideration as one of the strategies to manage insecticide resistance (243).

More recent studies across sub Saharan Africa have associated modest improvement in housing quality with decreased mosquito density and decreased malaria incidence (38,50,106,107). Children living in improved houses made with brick walls, metal roof and closed eave space had lower odds of being infected with malaria compared to those living in unimproved houses made with mud walls and thatched roof across sub Saharan Africa (38,106,107). Other studies have also indicated higher densities of malaria vectors in unimproved houses compared to improved houses (52,108,109).

A few studies have been conducted to assess whether community members living in malaria endemic settings understand the association between housing structure and malaria transmission. In Southern 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 (244). In a different survey done in western Kenya to assess community knowledge and perceptions on malaria prevention and house screening, Ng'anga *et al* (2019) reports low awareness of the impact of housing screening for malaria control among communities in malaria endemic settings in western Kenya (245). In a similar study done in

Tanzania, Ogoma et al (2009) reports that a majority of community members were able to associate housing improvement with lower risk of malaria transmission (246).

While there is adequate information on the impact of housing improvement in malaria control, and on whether communities are able to associate housing structure to the risk of malaria transmission, there is fairly limited information on how communities in malaria endemic settings define housing improvement, how they perceive its importance in malaria control and available opportunities for housing improvement in malaria endemic settings. This study therefore aimed to explore how community members in a malaria endemic setting in southern Tanzania define housing improvement, their perceptions about its impact in malaria control and their perceived opportunities for housing improvement in malaria endemic communities.

Methods

This study adapted an explanatory sequential mixed-methods approach (142) to explore and assess knowledge, awareness and perceptions of housing modification as a malaria control intervention in southern Tanzania. Field work was conducted by the first author (MFF), EM, RN and WM, and the study was conducted in Swahili, the local language. The study was approved by Ifakara Health Institute's institutional review board and National Institute for Medical Research. The study was conducted in ten randomly selected wards in Ulanga and Kilombero districts in southern Tanzania. Detailed description of the study site and participants is provided by Finda et al (2021).

For the qualitative component, two focus group discussions were conducted with community leaders from the same wards, to further discuss their insights on the potential of housing improvement as a malaria control intervention. Each FGD session included eight participants; men and women were separated to maximize participation by women. The two discussion sessions lasted for 110 minutes and 122 minutes. A semi-structured discussion guide was used to facilitate the discussions. The sessions were audio-recorded and detailed notes were taken.

For the quantitative component, five hundred households were randomly selected across the ten wards, and the study team, accompanied by community leaders administered a survey questionnaire to one adult representative of each household. The survey was administered using Kobotoolbox™ software (149) on electronic tablets. Altogether 490 household heads agreed to participate in the survey. The survey was a structured questionnaire that aimed to assess their knowledge, awareness and perceptions of housing improvement as a malaria control intervention.

Data processing and analysis

For the qualitative data, audio recordings from the IDIs and FGDs were transcribed immediately following the discussions and translated from Swahili to English language. The written transcripts were reviewed and analyzed using NVIVO 12 Plus software (151). 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.

Quantitative data was analyzed using R statistical software version 4.0.0 (229). Descriptive analysis was used to assess socio-demographic characteristics of the survey respondents, and summarize their knowledge and awareness of housing improvement as a malaria control intervention. Univariate and multivariate analyses were used to determine influence of the respondents' socio-demographic characteristics on the main outcome variable, i.e. their perceptions of housing improvement as a malaria control intervention. Binary logistic regression was used to determine the association between the independent variables and outcome variable; odds ratio was calculated at 95% confidence intervals (CIs).

A 5-point Likert-scale was used to assess individual-level perception of community members towards housing improvement by measuring the level of agreement towards positive statements on housing improvement, ranging from strongly agree (1) to strongly disagree (5). Internal validity of the scale was measured by calculating Cronbach's alpha (153). The statements were: i) housing improvement is effective for malaria control, ii) housing improvement fills gaps left by other interventions, iii) housing improvement is safe for humans, animals and the environment, iv) housing improvement is easy to implement, v) materials and supplies for housing improvement are easily accessible, vi) housing improvement is affordable to community members, and vii) housing improvement is acceptable in the community. To calculate community members' perceptions towards housing improvement for malaria control, sum of the scores of the seven statements was calculated for each survey respondent and a median of these scores calculated. The final perception level was determined by comparing individual perception scores against the median score, and the community's perception level was determined

Weaving approach (142) was used to interpret and present findings from the quantitative and qualitative components of the study. 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. In some cases, direct quotations from participants were used to support the claims.

Results

Characteristics of study respondents

A total of 524 people participated in this study altogether; 490 community members responded to the community-based survey and 16 community leaders participated in two focus group discussion sessions. About a half (43%, n=211) of the survey respondents were men and 57% were women. The average age was 42 years, ranging from 18 to 88 years. A majority (73%, n=358) of the respondents had primary education (7 years of formal education) and 13.9% (n=68) had secondary education (11 – 13 years of formal education). Nine percent (n=43) had no formal education and 4.3% (n=21) had college education (13 or more years of formal education). A majority (84.3%, n=413) of the survey respondents were primarily small scale farmers, but some also reported conducting small businesses, fishing and animal husbandry on the side. Likewise, a majority (n=13) of the FGD participants had completed primary school education, and three had completed secondary school education.

The average reported household income was 1,573,126 Tanzanian shillings (TZS), equivalent of 684.0 USD (In this cases we 1 USD was converted to 2300 TZS). The average household size was 5.44, ranging from 2 to 8 people per household. Houses with brick walls and metal roof were the most common house type (Figure 1), so were flush toilets located outside the main living houses (Table 1). Electricity was the main source of light found in 40.8% of the households. About two thirds (63.1%, n=309) of the respondents used pump water located at community centers, and a majority (84.9%, 416) used wood charcoal for cooking (Table 1).

Figure 1: Common house types 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 and thatched roof.

Perception of risk and burden of malaria

More than a half (51.6%, n=253) of the survey participants responded that the country was doing a very good job in controlling malaria. This aspect was explored further in the FGD where participants spoke of their experiences, noting that the frequency and severity of malaria had significantly decreased over the years. The participants explained that other diseases like typhoid and urinary tract infection were now more common than malaria, and that a year could pass without a malaria incidence in their households. Severity of malaria was also said to have decreased as this participant said:

> *"I know malaria has decreased now because in the past when people got sick of malaria, they really got sick, and many died. I know people who went crazy, and some became deaf and dumb because of malaria. This happens when the malaria parasites get into your brain. But now this does not happen much. If you get malaria you do not even need to be hospitalized, you can just buy medicine from the drug stores and you are fine. In the past you would be hospitalized and you could die."* (Female community leader)

Table 1: Characteristics of the surveyed households

Variable	Category	Percentage (n)
Average household income	684.0 USD	
Average household size	5.4 people	
House type	Brick walls & metal roof	77.6% (380)
	Mud walls & thatched roof	13.1% (64)
	Brick wall & thatched roof	7.3% (36)
	Mud walls & metal roof	2.0% (10)
Toilet	Flush toilet outdoors	62.8% (308)
	Flush toilet indoors	14.3% (70)
	Pit latrine outdoors	22.9% (112)
Source of light**	Electricity	40.8% (200)
	Solar	30.6% (150)
	Rechargeable lamps/torches	28.0% (137)
	Others	3.1% (15)
Main source of water**	Pump water away from home	63.1% (309)
	Pump water at home	17.1% (84)
	Tap water away from home	9.6% (47)
	Tap water at home	8.6% (42)
	Other sources	8.0% (39)
Main source of cooking energy	Wood charcoal	84.9% (416)
	Fire wood	64.3% (315)
	Gas	9.8% (48)
	Others	0.4% (2)

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

The participants further explained that people are more educated now compared to the past; nearly everyone has and sleeps under a bed net, and people understand and control mosquitoes' aquatic habitats. Malaria diagnosis and treatment was said to be more widely available and affordable, and there are more options for controlling as this participant said:

“Yes. People are quite educated these days. They use bed nets faithfully, but also they know where mosquitoes’ breeding sites are and they destroy them and get rid of trash around their houses. People are more aware of this disease now than in the past.” (Female community leader)

On the other hand however, 43.9% (n=215) of the survey respondents replied that the country was making a slow progress, and it would not lead to malaria elimination without additional efforts. Further discussing this, the FGD participants explained that although the risk and severity of malaria was not as high as in the past, the current efforts would not lead to elimination as this participant said:

“I really do not think that the insecticide-sprays or the bed nets are enough, because if they were we would not still have any malaria. We have been using these for a really long time now, and still we get malaria, even though it is not as much as in the past. If even a few people still get malaria, that means that what we currently have is not enough.” (Female community leader)

Insecticide-treated nets (ITNs), the main malaria prevention intervention expressed by 99.4% (n=487) were said to have limitations, such as the fact that they do not kill mosquitoes as they are supposed to, and that they large holes that let mosquitoes in. About two thirds (61.3%, n=300) of the survey participants responded that mosquitoes were increasingly biting outdoors and earlier in the evening, further limiting effectiveness of the currently available interventions. A majority (86.1%, n=422) of the survey participants responded that alternative tools would be necessary to supplement current interventions and speed up malaria elimination efforts as these participants said:

“I also think that what we currently have is not enough to eliminate malaria because we have been told that mosquitoes are clever and have changed their behaviors, they no longer wait until late at night to come and bite people, they come early in the evening when people are still outside. They will keep coming early until they make sure that they get what they want. This way then the bed nets or sprays are not really enough.” (Female community leader)

I have made a lot of efforts to kill mosquitoes with insecticide sprays like Rungu*, but always the outcome is that Rungu will finish, and then mosquitoes are still there because soon as you leave your door open mosquitoes come in”* (Male community leader).

Poverty is a risk factor of malaria

About two thirds (65.1%, n=319) of the survey respondents said that rural settings have the highest risk of malaria transmission, and 63.9% (n=313) said that poor communities were carrying a disproportionately higher burden of the disease (Table 2). This point was further evident during the FGDs where nearly all participants said that the poorest in the community were experiencing the highest burden of malaria, as they live in poorly constructed traditional houses that provide little protection against malaria. The houses were said to have a lot of holes on the walls and roof through which mosquitoes get inside. They are normally dark and cluttered hence providing a lot of hiding places for mosquitoes, and they are generally very small, forcing people to conduct household chores outdoors. The participants also explained that it was difficult to use mosquito control interventions in these houses as these participants 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)

> *"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)

Domestic activities put people at an increased risk of malaria transmission

About two thirds (61.3%, n=300) of the survey respondents said that most of malaria transmission occurs outdoors, and 36.7% (n=180) said it occurs indoors (Table 2). Participants of FGDs elaborated that some of the activities that kept people outside during the high risk hours included household chores such as cooking, washing, eating and chatting with friends and neighbors. These activities were mostly done outdoors due to cultural reasons partly, but also due to house sizes as these participants elaborated:

> *"Another problem that I'm thinking of, I think maybe is caused by poverty, is that people do all their chores outside the house because their houses are too small, and there is no enough air or light. So then all the evening chores like cooking, washing, eating and other things are done outside, then people go inside only when it is time to sleep."* (Female community leader)

"It is just the culture of people here. You see even in the past when people cook inside, they would always bring the food outside to eat. Back then people only cooked inside because they were afraid of their enemies, but for us these social activities are done outside. If you eat inside then your neighbors will think you are stingy, and you do not like to share with your friends. So then we cook and eat outside so that when someone passes and sees that you are cooking or eating, then you can welcome them to join. That is important for us." (Male community leader)

Table 2: Perceptions of risk and severity of malaria among community members

Questions asked	**Variables**	**Percentage (n)**
Settings with the highest risk	Rural settings	65.1% (319)
	Urban settings	7.6% (37)
	Equal in rural and urban settings	23.7% (116)
	Do not know	3.7% (18)
Communities most affected	Low-income communities	63.9% (313)
	All communities are equally affected	33.7% (165)
	Do not know	2.5% (12)
Where most the transmission occur**	Outdoors at home	73.9% (362)
	Outdoors away from home	59.2% (290)
	Indoors at home	54.7% (268)
	Indoors away from home	30.8% (151)
	Don't know	2.0% (10)

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

The ideal of a proper house

More than two thirds (69.6%, n=341) of the respondents were aware that improved housing provides protection against malaria. When asked about their source of this information, a majority of the respondents said that they knew from their daily experiences, but others listed 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 complaints were that it was expensive to have modern houses, and that modern houses alone would not provide complete protection against malaria as mosquitoes could still get in through open doors or windows, and people would still spend time outdoors. When asked to define what a proper or 'modern' house means to them, FGD participants listed many features including large size, large windows, screened doors and windows, brick walls, metal roof and electricity as these participants explain:

> *A modern house has a lot of things; but three main important things are brick walls and metal roof 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)

High cost of building materials is a key issue

A majority of the survey respondents agreed that an improved house would be effective in malaria control, would fill gaps currently left by current interventions, and would be acceptable by community members. However, a majority of the respondents disagreed that materials and supplies for housing improvement are easily accessible or affordable by the community members (Table 3). The issue of affordability also dominated the FGDs with community leaders, who explained that everyone dreams to live in a modern house, but the cost is too high. Some of the most costly materials were said to be doors, windows and metal roof. The leaders further elaborated that when people build modern houses, they normally put a lot of big windows because they want light and air in their houses. But it takes long for the people to afford proper screening for all the doors and windows so then they cover the openings with bricks until they can afford to put proper doors and windows as these participants explained:

> *"You know, it is not like people do not want to have proper houses; it is just so expensive to have a proper house. Ah, you know people do not have much. If someone manages to put a wooden door, then there's no money left for adding the screen door. Wooden door is expensive, but it protects you from many other dangers. If you have money for*

just one door then you have to put a wooden door, isn't that the case even for you?" (Male community leader)

"If people cannot afford to screen their windows then they normally just 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 let in fresh air, 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 with no netting. We know that netting would provide protection against mosquitoes, we just cannot afford it." (Male community leader)

Table 3: Perception of community members regarding housing improvement for malaria control (N = 490).

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Effective	26.6%	44.7%	21.8%	4.7%	2.2%
Fills gaps left by ITNs	22.5%	44.9%	22.8%	6.3%	3.5%
Safe for humans, animals and environment	47.3%	22.0%	18.6%	8.2%	3.9%
Easy to use	25.1%	19.4%	21.8%	20.6%	13.1%
Materials and supplies are easily accessible	9.6%	6.5%	21.4%	29.2%	33.3%
Affordable to residents	1.4%	3.7%	21.2%	26.3%	47.4%
Acceptable in community	31.6%	29.4%	22.2%	9.4%	7.4%

There is little hope for the migrant communities

Community leaders participating in the FGDs discussed the prospects of housing improvement for migrant communities such as pastoralists and migratory farmers, and agreed that this would not be an ideal intervention for these communities. The leaders explained that due to their nature of not staying in one place for long, or preferring places with pasture for their livestock, building houses for pastoralists would not work as they cannot be made to stay in one place for a long time, as this participant explained:

"Ah, those pastoralists are doomed; I do not know how they can be helped. Where they live there is a lot of grass because that is what they need for their cattle, so you cannot

say we get rid of water and long grass. They are also moving around a lot, so I do not see how building a house for them can solve the problem." (Male community leader)

Similarly for the migratory farmers, a majority of FGD participants discussed that building proper houses in the rice fields would also not be an ideal intervention as most of the farmers do not own the farms, they rather rent them for the farming season, and there is no guarantee that they would get the same farm the following season. As a result, the farmers often build make-shift huts that provide minimal protection against animals and insects, to survive the farming season as this participant elaborated:

"The reason people do not build permanent houses in the farms is that most people rent those farms; the farms are not theirs to start with. So then when people migrate to the farms they build temporary shacks, stay there for one or six months and go back to their homes in the village. The following year they rent another farm, so it is always like that. Maybe people who have their own farms can build their houses, and farmers can rent the farms and the houses." (Male community leader)

However, there are participants that proposed working with land owners to build proper houses that migratory farmers can rent during the farming season, thereby providing proper protection against not only malaria, but also other dangers. The participants acknowledged that it would be challenging to build houses in the farms, but advised that if possible, the farm houses need to have elevated base in order to prevent flooding, which is an even bigger problem during the farming season as these participants said:

"It is hard though to build houses in the farms because there is a lot of water in the rainy season, which is when most of the people migrate there, and when most of the people get malaria. Now people only build seasonal shacks which provide minimal protection against mosquito bites or any other animals. Maybe if you build houses for them, you have to raise the base so that they are not flooded. I do not think it is very easy to build houses in the farms. "(Male community leader)

"But for the farmers, we can build brick houses with metal roofs in the farms, and different families can share those, because not everyone migrates to the farm at the same time." (Male community leader)

Opportunities for government support

A majority (88.8%, n=435) of the survey responded said they would support housing improvement as a malaria control intervention; 6.5% (n=32) and 47% (n=23) were either neutral or did not support the intervention respectively. In a univariate analysis, support for housing improvement was significantly associated with educational level and average household annual income level as indicated on table 4. Respondents with secondary education and above were more than thrice as likely to support housing improvement compared to those with no formal education, as were respondents with average annual household income of above 869.6 USD compared to those with household income of below 217.4 USD (Table 4). In a multivariate analysis, significant support for housing improvement was associated with respondents aged between 31 and 40 years (OR = 2.56, p-value = 0.04), having a secondary education and above (OR=3.55, p=value =0.05) and having an average annual income of between 217.4 and 434.8 USD (OR = 2.9, P-value = 0.02).

The strong support for housing improvement was also expressed by the FGD participants, all of whom preferred housing improvement to other malaria control interventions. The FGD participants explained that housing improvement made sense to them more than the other malaria control interventions such as larviciding, spatial repellents, space spraying and use of genetically modified mosquitoes. Improved houses were also said to provide protection against more than just malaria transmitting mosquitoes as it protects against many other diseases and dangers. The participants further explained that no other technology would be fully effective if people continue to live in poorly constructed houses as these participants explained:

> *"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)

Table 4: Factors associated with support for housing improvement

Category	Variable	Odds ratio (95% CI)	p-value
Sex	Male	1.00	-
	Female	0.95 (0.54 – 1.68)	0.87
Age category (in years)	Below 30	1.00	-
	31 - 40	2.35 (0.98 – 5.63)	0.055
	41 - 50	1.37 (0.62 - 3.04)	0.44
	Above 50	1.02 (0.53 – 2.17)	0.84
Education Level	No formal education	1.00	-
	Primary school	2.14 (0.94 – 4.71)	0.07
	Secondary school and above	3.66 (1.21 – 11.08)	0.02
Annual household income in USD	Below 217.4	1.00	-
	217.4 – 434.8	3.13 (1.40 – 7.00)	0.006
	434.9 – 869.6	2.37 (1.14 – 4.92)	0.02
	Above 869.6	2.49 (1.08 – 5.73)	0.03
House type	Brick walls & metal roof	1.00	-
	Brick wall & thatched roof	0.94 (0.31 – 2.79)	0.91
	Mud walls & metal roof	0.47 (0.10 – 2.29)	0.35
	Mud walls & thatched roof	0.72 (0.33 – 1.56)	0.41

However, the major concern for housing improvement as a malaria control intervention expressed by nearly three quarters (73.7%, n= 361) of the survey respondents was affordability by community members. Community leaders participating in FGDs explained that if left for people to do this on their own, the poorest in the communities would not be able to afford to improve their houses. The leaders discussed various options that the government could consider to help 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 the government 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)

Other participants 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) (248), 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 this participant said:

> *"I tell you, if I was to build a house alone, I would never be able to build it. I think it would be good if the government can help. You know, like they are helping with REA electricity, they look at people that are poor and they reduce electricity price 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 all of us 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 pay the government back. The participants gave an example of *Nyumba ni Choo* (*A house is a toilet*), a country-wide campaign to improve health status of the people by controlling water and sanitation related diseases (249); the government in collaboration with international partners had built proper latrines for the poorest people in the communities, and people paid back the government slowly. Similar approach was proposed for housing improvement as these participants said:

> *"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. The community leaders helped follow up and everyone paid back. Now most people in the villages have modern toilets but very poor houses."* (Female Community leader)

> *"If the government could listen, I would advise them to assist people, especially the poor people to build modern houses. The government can maybe build the houses, and people can repay the government slowly, everyone can pay according to what they can afford. Then if a person moves out of the house or dies the government can take back the house or pass it to another person. This way then the government can ensure that its citizens live in safe and protective environment."* (Female community leader)

Discussion

This study indicates a strong support for housing improvement for malaria control among community members in a malaria endemic setting in southern Tanzania. These community members expressed their strong preference for housing improvement, explaining that no other intervention would be able to achieve its optimal effectiveness if people continue to live in poorly constructed houses. This sentiment has been indicated in various studies that have shown that even when ITN use and ownership was constant, people living in modern houses experienced lower risk of malaria transmission (26,52), lower odds of malaria infection and lower malaria cases compared to those who live in poorly constructed houses (37,38). Similar findings have also been reported from Equatorial Guinea (106), Gambia (108,250), and Uganda (107) among other countries.

In this study, the definition of an improved or a modern house was uniform among the community members. It included larger space compared to the traditional houses, built with brick walls, metal roofs and big screened doors and windows. Electricity was also listed as an essential. While these characteristics are modest, previous studies have indicated that they can significantly reduce the risk and burden of malaria; several studies in Tanzania and across sub Saharan Africa have indicated lower risk of malaria transmission in houses with brick walls, metal roof and electricity compared to the those with mud walls, thatched roof and that lack electricity (26,37,38,52,106–108,250).

Community members were well aware of the value of an improved house in reducing the risk of malaria transmission. They were aware that poorly constructed houses provided little protection against mosquito entry, and made it difficult to use the currently available mosquito control tools. Small house sizes and lack of windows also made it difficult to do household chores indoors, forcing people to spend the most of their waking hours outdoors exposed to mosquito bites. Interestingly, a different study in the same communities indicated that the highest risk of exposure to malaria transmission occurred during the early night hours when a majority of people were outdoors in peridomestic settings (26). However, the community members had concerns over the perceived high costs associated with housing improvement, which was the reason that people lived in the traditional houses or incomplete houses. A previous study by Kaindoa *et al* (2018) in the same communities also indicated that community members were awareness of the association between house structure and risk of malaria transmission, but poverty and competing priorities prevented them from building better houses or improving their current houses (244).

While a majority of the community members in this study lived below poverty line (average annual household income was 684 USD), they still manage to build their ideal houses, as more than three quarters of the houses surveyed had brick walls and metal roofs, and 40% used electricity as their main source of light. While it is encouraging that community members are already making the move towards building better homes, a great deal of efforts is needed to ensure that people complete building or improving their houses in good time, as often this process took decades to complete. While not formally recorded in this survey, a majority of the houses had either windows covered completely with bricks and eave spaces left open, or had most of the windows covered with bricks, leaving small holes on the walls for air to pass through (Figure 1). These openings offered minimal protection against mosquitoes, maintaining the risk of malaria transmission even in the houses that would be considered improved. High price for proper windows and doors was listed as among the major limitations as to why it took so long for people to complete their homes.

Community members stressed that support from the government would be crucial in helping people live in safe and protective environment. They offered a range of suggestions for the government to help its citizens achieved the goal of building malaria out. These included providing building loans, subsidizing the cost of building materials, or building standard houses and renting to the poor at an affordable price. The concept of government supporting communities to build improved houses was highly opposed by policy makers in a previous study, who indicated this was not affordable or sustainable for the government (134). However, this lack of support from the government officials may be due to lack of understanding the magnitude of the actual need for housing improvement. Lindsay *et al* (2021) proposes that a range of facilitators, both in the public and private sectors be involved when discussing the prospects of housing improvement. These may include microfinance institutions, government ministries, town planners, architects and community members among others, to ensure that citizens live in disease-free houses (251). 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.

With regards to the migrant communities, community members acknowledged that these would be difficult to protect with housing interventions due to their mobile nature, and for the migratory farmers, due to the environment in the farm that provides little opportunity for building houses. These challenges have also been previously observed by researchers at Ifakara Health Institute, who have developed several possible interventions for these communities including potable mosquito-proof huts (145) and the use of repellent-treated eave ribbons (148). More intense studies are needed to extensively explore the potential of these interventions in migrant communities.

This study did have a number of limitations. In assessing the house structure, our survey was limited to assessing wall and roof materials. We did not assess the quality of these materials, or what was used to cover doors and windows, or the presence of eave spaces in the homes. We propose that future studies conduct a more comprehensive assessment of house structures and the state of the materials in order to obtain a more accurate estimation of the magnitude and need of housing improvement. Additionally, the qualitative component of this study had only two FGD sessions, which is a relatively small sample size. However, this was part of a larger study that included eight FGD sessions with four stakeholder groups, community members being one of the groups (134). In this paper we are reporting findings from the FGDs and survey done with community members only. We recommend that any future studies increase the sample size to obtain more diverse inputs from the targeted groups.

Conclusion

Housing improvement for malaria control is a well understood and acceptable intervention among communities living in malaria endemic settings. While people in these settings are making a great deal of efforts to build or improve their houses, without additional support the process is slow, and maintains them at a risk of malaria transmission. It is crucial to bring together all the key players in housing sector to come up with solutions that can reduce barriers that communities living in malaria endemic settings face in building mosquito-proof houses.

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Appendix 7: Ethical clearance from University of the Witwatersrand

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R14/49 Marceline Finda et al

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M180820

NAME: (Principal Investigator)	Marceline Finda et al
DEPARTMENT:	Public Health Ifakara Health Institute,Tanzania
PROJECT TITLE:	Exploring and assessing awareness and acceptance of alternative technologies for malaria control among stakeholders in Tanzania
DATE CONSIDERED:	31/08/2018
DECISION:	Approved Unconditionally
CONDITIONS:	
SUPERVISOR:	Prof Nicola Christofides
APPROVED BY:	Doctor CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	11/12/2018

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on the Third Floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed in **August** and will therefore be due in the month of **August** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature ______________________ Date ______________________

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix 8: Ethical clearance from Ifakara Health Institute

IFAKARA HEALTH INSTITUTE
research | training | services

INSTITUTIONAL REVIEW BOARD
P O BOX 78373 DAR ES SALAAM, TANZANIA
Tel +255 (0) 22 2774714, Fax: + 255 (0) 22 2771714 Email: irb@ihi.or.tz

25th October, 2017

National Institute for Medical Research
P O Box 9653
Dar Es Salaam
Email: headquarters@nimr.or.tz

Dr. Nicodem James Govella
Ifakara Health Institute
P O Box 78373
Dar es Salaam

IHI/IRB/No: 19-2017

INSTITUTIONAL CLEARANCE CERTIFICATE FOR CONDUCTING HEALTH RESEARCH

On 16th October 2017, the Ifakara Health Institute Review Board (IHI-IRB) reviewed from study titled: ***"Anopheles funestus gene flow studies and rearing methods"*** submitted by Principal Investigator: Dr. Nicodem James Govella.

The following documents were reviewed:

1. Protocol
2. Informed Consent Forms
3. Budget
4. Tools
5. CVs

The study has been approved for implementation after IRB consensus. This certificate thus indicates that; the above- mentioned study has been granted an Institutional Ethics Clearance to conduct the above named study in the regions of Morogoro, Ruvuma, Tanga, Dodoma and Kagera.

The Principal Investigator of the study must ensure that, the following conditions are fulfilled during or after the implementation of the study:

1. PI should submit a six month progress report and the final report at the end of the project
2. Any amendment, which will be done after the approval of the protocol, must be communicated as soon as possible to the IRB for another approval
3. All research must stop after the project expiration date, unless there is prior information and justification to the IRB.
4. There should be plans to give feedback to the community on the findings
5. Any publication needs to pass through the IRB
6. The approval is valid until 25th October 2018

The IRB reserves the right to undertake field inspections to check on the protocol compliance

Deputy IRB Chairperson
Dr Saidi Mpendu

Deputy IRB Secretary
Bakar Fakih

Dar es Salaam	Ifakara	Bagamoyo	Rufiji	Mtwara	Kigoma
PO Box 78373	PO Box 53	PO Box 74	PO Box 40 Ikwiriri	PO Box 1048	PO Box 1077
Tel: 022 2774756	Tel: 0232 625164	Tel: 0232 440065	Tel: 0787 384521	Tel: 0232 333487	Tel: 0282 803655
Fax: 022 2771714	Fax: 0232 625312	Fax: 0232 440064	Fax: 0232 010001		

www.ihi.or.tz

Appendix 9: Ethical clearance from National Institute for Medical Research

THE UNITED REPUBLIC OF TANZANIA

National Institute for Medical Research
3 Barack Obama Drive
P.O. Box 9653
11101 Dar es Salaam
Tel: 255 22 2121400
Fax: 255 22 2121360
E-mail: ethics@nimr.or.tz

Ministry of Health, Community Development, Gender, Elderly & Children
University of Dodoma, Faculty of Arts and Social Sciences
Building No 11
P.O. Box 743
40478 Dodoma

NIMR/HQ/R.8a/Vol. IX/2697

19th February 2018

Dr. Nicodem Govella
Ifakara Health Institute
P.O. Box 78373
Dar es Salaam

RE: ETHICAL CLEARANCE CERTIFICATE FOR CONDUCTING MEDICAL RESEARCH IN TANZANIA

This is to certify that the protocol entitled: *Anopheles funestus* gene flow studies and rearing methods (Govella N. *et al*) has been granted ethical clearance to be conducted in Tanzania.

The Principal Investigator of the study must ensure that the following conditions are fulfilled:

1. Progress report is submitted to the Ministry of Health, Community Development, Gender, Elderly & Children and the National Institute for Medical Research, Regional and District Medical Officers after every six months.
2. Permission to publish the results is obtained from National Institute for Medical Research.
3. Copies of final publications are made available to the Ministry of Health, Community Development, Gender, Elderly & Children and the National Institute for Medical Research.
4. Any researcher, who contravenes or fails to comply with these conditions, shall be guilty of an offence and shall be liable on conviction to a fine as per NIMR Act No. 23 of 1979, PART III Section 10(2).
5. Site: Morogoro, Tanga, Ruvuma and Kagera.

Approval is valid for one year: 19th February 2018 to 18th February 2019.

Name: Prof. Yunus Daud Mgaya

Signature
CHAIRPERSON
MEDICAL RESEARCH COORDINATING COMMITTEE

Name: Prof. Muhammad Bakari Kambi

Signature
CHIEF MEDICAL OFFICER
MINISTRY OF HEALTH, COMMUNITY DEVELOPMENT, GENDER, ELDERLY & CHILDREN

cc: RMO of Morogoro, Tanga, Ruvuma and Kagera.
DMO/DED of selected district

Appendix 10: Focus Group Discussion Guide

Focus group discussion guide - English

Awareness and acceptance of alternative technologies for malaria control among stakeholders in Tanzania: a community engagement process

Introduction: Malaria is one of the leading causes of mortality in Tanzania, especially among children of under 5 years of age. Although there have been many interventions that have resulted in a great reduction in number of malaria cases and deaths over the past decade, these interventions, such as the Long-lasting insecticidal nets and indoor residual spraying, have not been sufficient in a successful control and elimination of this disease. Malaria-transmitting mosquitoes have been observed to change the time they bite people; they come earlier in the evening when people are still outside, or not yet under the protection of bed nets. There have also been a growing number of mosquitoes that are resistant to the insecticides that are put in bed nets. These challenges make the complete elimination of malaria, and there is a need to consider other alternative interventions that can be used to target mosquitoes at the time when the current interventions are inadequate.

The need to understand community's needs for alternative tools: In this study we are going to assess community's awareness and perceptions regarding several alternative methods for the control and elimination of malaria vectors, that if used with the current existing interventions may lead to a successful control and elimination of malaria.

We need your help: Before we can go to the general community, we would like to get your insight on what may be community's perceptions towards these interventions; what concerns the community may have and the best ways we can approach them. We would also like to get your insights on appropriate terminologies that we can use to refer to these interventions, that we can use with the community members without leading them on. We thank you for your time and insights on this discussion. We will provide you with an overview of the alternative technologies, and together we will discuss various issues associated with them. We will have some guiding questions, but please do not let them limit your participation in this discussion.

Discussion guide

Section 1: Perceptions about the current malaria control interventions

1. *What do you think about the malaria control in the country?*

   What is working / not working?

   What are the challenges with current malaria control strategies?

2. What are the alternatives for malaria control?

   a. If we think specifically about mosquito control what would the alternatives be?

Section 2: Perception about the alternative technologies

Begin with the alternative strategies mentioned (if any).

For each new (alternative) technology:

3. *To what extent would this technology/strategy work in our country?*

   how, and if not why?

4. *What would it take to introduce this technology/strategy in our country?*
   a. *What would it take to get people to accept the technology / strategy*

5. *How scalable would this technology/strategy be?How easy would it be to implement everywhere in the country?*

6. *What steps need to be taken before we adapt or scale up on this intervention? Policies? regulations?*

7. *What do you think are benefits or risks/threats associated with this technology?*

8. *How do you think this technology complements the existing interventions, if at all?*

9. *What terminologies would be appropriate to describe the intervention in the community?*

We thank you again for your time and your valuable inputs. We will consult you again once we have inputs from all other stakeholder groups, and together we will discuss our findings and the way forward. Thank you again and kind regards,

Study team.

Focus group discussion guide - Swahili

Kuelewa maoni na uelewa wa watu kuhusu mbinu mpya ya kuzuia malaria Tanzania

Utangulizi: Ugonjwa wa malaria ni miongoni mwa magonjwa yanaoongoza kwa vifo Tanzania, hasa kwa watoto wa chini ya miaka mitano. Igawa baadhi ya mbinu za kuzuia ugonjwa huu, kama vile vyandarua vilivotiwa viatilifu vya kuua mb una dawa za kupuliza ndani zimechangia katika kupunguza ugonjwa huu kwa kiasi kikubwa, ugonjwa huu bado unaendelea kuwa kikwazo kikubwa. Mbu waenezao ugonjwa huu wamejenga usugu dhidi ya viatilifu vinavyotumika katika vyandarua, na wengi wamekuwa wanakuja mapema jioni, wakati ambapo watu hawajaingia ndani ya vyandarua. Changamoto hizi zinafanya utokomezaji wa malaria kuwa mgumu, hivyo kuna haja ya kutumia mbinu mbadala ambazo, kama zikichanganywa na mbinu zilizopo, zitasaidia katika kuutokomeza ugonjwa huu.

Tunahitaji kujua maoni ya watu kuhusu uhitaji wa mbinu mbadala: Katika utafiti huu tungependa kupata maoni yako kuhusu mbinu zilizopo sasa za kuzuia malaria, na kuhusu uhitaji wa mbinu mpya za kutokomeza ugonjwa huu nchini kwetu.

Tunahitaji msaada wako: Tungependa kupata maoni yako kabla hatujaenda kuongea na wananchi, kuhusu mtazamo wa mbinu zilizopo, kama zinatosheleza mahitaji a watu katika ulinzi dhidi ya malaria, na kama mbinu mpya zinahitajika, n ani namna gani tunaweza kuongea na watu kuhusu mbinu hizi mpya. Tungependa kujadiliana na wewe kuhusu mambo haya, na tunashukuru kwa kukubali kwako kushirikiana na sisi.

Muongozo wa majadiliano

Sehemu ya 1: Maoni kuhusu mbinu za sasa za ulinzi dhidi ya malaria

1. *Ni nini mawazo yenu kuhusu mbinu zinazotumika sasa katika ulinzi dhidi ya malaria? Zipi zinafanya kazi vizuri, na zipi hazitimizi malengo?*

   Kuna changamoto gani dhidi ya mbinu hizi?

2. *Unajua mbinu gani mbadala za kuzuia malaria?*

   a. *Tukiangalia zaidi katika mbinu za kuzuia mbu waenezao malaria, unajua mbinu gani mbadala?*

Sehemu ya 2: Maoni kuhusu mbinu mbadala za kuzuia maambukizi ya malaria

(Anza na mbinu zilizotajwa).

Kwa kila mbinu mbadala:

1. *Mbinu hii inaweza kufanya kazi kwa kiasi gani nchini kwetu? Kivipi? Kama haifai, unafikiri ni kwanini?*
2. *Nini kinahitajika ili kuileta mbinu hii nchini?*
3. *Unafikiri inaweza kukuzwa?*
4. *Hatua gani zinahitajika ili kuweza kuingiza mbinu hii nchini? Sheria gani?*
5. *Unafikiri mbinu hii ina faida gani? Athari gani?*
6. *Unafikiri mbinu hii inaendana vipi na mbinu zilizopo sasa?*
7. *Tunaweza kutumia lugha gani katika kuelezea mbinu hii kwa watu ili waweze kuelewa?*

Tunakushukuru sana kwa muda wako, na maoni yako. Tuawasiliana na wewe tena tutakapomaliza zoezi hili, ili kukupatia marejesho. Asante sana

Appendix 11: Key Informant Interview Guide

Perceptions of district and ward malaria focal persons towards implementation of larviciding in Morogoro region, south-eastern Tanzania

1. **Perceptions on ecology of malaria vectors**

   Please tell me what you know about mosquito aquatic habitats? **Tafadhali, niambie unachofahamu kuhusu mazalia ya mbu?**

   Probe:

   - Where do mosquitoes breed? **Je, ni wapi mbu huzaliana?**
   - What different mosquito species are present in your settings? **Je, ni aina gani ya mbu wanapatikana katika eneo lako?**
   - What are characteristics of their aquatic habitats, and how are the aquatic habitats different between the different species? **Je, zipi ni sifa za mazalia yao na kwa kiasi gani yanatofautiana kulingana na aina ya mbu?**
   - What different species of malaria vectors do you know? What are their specific aquatic habitats? **Je, kuna aina tofauti za mbu waenezao malaria? Je, wana mazalia maalumu?**
   - How are malaria-vector-aquatic habitats different than other non-vector mosquitoes? **Je, mazalia ya mbu waenezao malaria yana tofauti gani na mbu wasioeneza malaria?**
   - When are the aquatic habitats most abundant? Are they mainly temporary or permanent? **Je, ni kipindi/msimu upi mazalia ya mbu huwa mengi? Je, hayo mazalia ni ya msimu au muda mrefu?**

2. **Perception on larviciding for malaria vector control**

   Please tell me what you know regarding larviciding? **Tafadhali, niambie unachofahamu kuhusu upigaji viwatilifu mazalia ya mbu?**

   Probe:

   - What type of larvicides are available? What is the difference between the different types? **Je, kuna aina tofauti za viwatilifu? Je, tofauti za viwatilifu hivyo ni zipi?**
   - What is the mechanism of action of the different larvicides? **Je, unafahamu hufanyaji kazi wa hivyo viwatilifu?**
   - What are the potential benefits of larviciding over other malaria control interventions? **Je, kuna faida za upigaji viwatilifu mazalia ya mbu kulinganisha na njia nyingine za kupambana na malaria?**

- What are potential risks of larviciding over other malaria control interventions? **Je, kuna madhara yoyote ya kiafya yatokanayo na upigaji wa viwatilifu mazalia ya mbu kulinganisha na njia nyingine za kupambana na malaria?**
- In your opinion, how effective is larviciding in control of mosquitoes? **Kwa maoni yako, kwa kiasi gani upigaji viwatilifu mazalia ya mbu yana manufaa?**

Have you ever conducted larviciding in your setting? **Je, umewahi kutekeleza upigaji viwatilifu mazalia ya mbu katika eneo lako?**

Probe

- If yes, what type did you use? Why did you use that type? How was it done? **Kama ndio, aina gani ya kiwatilifu ulitumia na kwanini ulitumia kiwatilifu hiko?Je, zoezi lilitekelezwaje?**
- Who did the larviciding? **Je, ni nani alipiga kiwatilifu mazalia ya mbu?**
- Did you measure effectiveness or impact of the larviciding? If yes, how did you measure that? What parameters were assessed? Who measured it? **Je, ulipima matokeo ya upigaji kiwatilifu mazalia ya mbu katika eneo lako? Je, ulipimaje hayo matokeo?Je, vigezo gani vilitumika kupima? Nani alipima?**
- How effective was it in controlling mosquitoes in general? How effective was it in controlling malaria vectors? **Je, kwa kiasi gani ilisaidia kudhibiti mbu kwa ujumla? Je, kwa kiasi gani ilidhibiti mbu waenezao malaria?**
- What challenges (if any) did you face when implementing larviciding? **Je, kuna changamoto zozote wakati wa zoezi la upigaji kiwatilifu mazalia ya mbu?**

Have you ever received any training on conducting larviciding? **Je, umewahi kupata mafunzo yoyote kuhusu upigaji viwatilifu mazalia ya mbu?**

Probe:

- What did the training involve? What skills did you learn? **Je, mafunzo yalikuwa yamehusisha vitu gani? Je, kipi ulijifunza?**
- When was the training took place? **Lini mafunzo haya yalifanywa?**
- Who facilitated the training and who attended? **Wakufunzi na wanafunzi walikua wakina nani?**
- Was the training practical or theoretical? **Je, mafunzo yalikua ya nadharia au vitendo?**
- How long did the training took? **Je, mafunzo yalikua ya muda gani?**

Are you planning on conducting larviciding in your settings in the next 12 months? **Je, una mpango wa kupiga kiwatilifu katika eneo lako ndani ya miezi 12 ijayo?**

Probe:

- If yes, what type of larvicides will you use? Why? Do you already have the larvicides? How much do you have? **Kama ndio, Je, aina gani ya kiwatilifu utatumia na kwanini? Je, una kiwatilifu tayari? Je, kiasi gani?**
- Are you aware of the amount of larvicides that you will need? How do you know how much you need? **Je, unafahamu kiasi gani unahitaji kwa eneo lako? Je, njia gani umetumia kufahamu kiasi unachohitaji?**
- What mosquito aquatic habitats will you target? Why? **Je, mazalia yote yatapigwa kiwatilifu? kama hapana, kwanini?**
- Are you aware of how many mosquito aquatic habitats are out there in your settings? If yes how do you know? If no, how do you plan to know? **Je, unafahamu idadi ya mazalia ya mbu ambayo unayo katika eneo lako? Kama ndio, njia gani umetumia kupata idadi yake? Kama hapana, Je umepanga kutambua idadi ya mazalia hayo? Je, njia gani utatumia?**
- Who will do the actual larviciding? Have/will they receive any training? If yes, when did/will they receive the training? Who facilitates the training? What did/will they learn in the training? Theoretical or practical? **Je, ni nani atafanya zoezi la upigaji viwatilifu mazalia ya mbu katika eneo lako? Je, kuna mafunzo yoyote yatatolewa? Nani atatoa hayo mafunzo na kipi watajifunza katika hayo mafunzo?**
- How will you monitor the implementation of larviciding? How often will you monitor? Exactly who will monitor? Will you have a checklist for the monitoring? What will the checklist involve? **Je, ufatiliaji wa zoezi la upigaji viwatilifu mazalia ya mbu utatekelezwaje? Je, utakua na orodha ya vitu vya kufatilia? Je, vitu gani vitakua katika hiyo orodha/ muongozo?**
- When do you plan to conduct the larviciding? Why? **Je, ni lini inatarajiwa kuanza zoezi la upigaji viwatilifu mazalia ya mbu katika eneo lako? Je, ni kwanini kipindi hiki?**

What challenges (if any) do you anticipate when conducting the larviciding? **Je, changamoto zipi unatarajia kukumbana nazo wakati wa utekelezaji wa zoezi la upigwaji viwatilifu mazalia ya mbu katika eneo lako?**

Probe:

- Community acceptance? Knowledge on mosquito breeding sites? Knowledge on breeding sites of malaria vectors? Knowledge on how to do dilutions? Knowledge on how to do the actual larviciding? Knowledge on the amount of time spent in conducting the larviciding? Knowledge on amount of larvicides needed per aquatic habitat? Knowledge on the frequency of application? Protective gear? Funding? Human resource? **Muitikio wa jamii? Elimu ya mazalia ya mbu hususani waenezao malaria?Elimu ya uchanganyaji wa kiwatilifu? Elimu ya kutekeleza zoezi la upigaji kiwatilifu? Elimu ya kiasi gani cha kiwatilifu kinahitajika kwa zalia la mbu? Je, kwa kipndi gani zoezi liwe linarudiwa? Je, jinsi ya kujikinga kiafya kwa mpigaji kiwatilifu?Fedha? Nguvu kazi?**

How will you overcome these challenges? **Je, kipi kitafanyika kutatua changamoto hizi?**

This is the end of our interview. We thank you for your valuable time, and we will be in touch with you shortly. Huu ni mwisho wa majadiliano yetu, tunashukuru kwa muda wako na natumai tutaendelea kuwasiliana.

Appendix 12: Link to electronic survey

https://ee.kobotoolbox.org/x/3enYTWnY

Appendix 13: Plagiarism report

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