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Method Article

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A Pilot Implementation Study of a Community-Led Integrated Malaria Elimination Model in Busoga, Uganda: Protocol for a Mixed-Methods Implementation Research Study

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Abstract

Introduction: Malaria remains one of the leading public health challenges globally, with over 95% of the disease burden occurring in sub-Saharan Africa. In 2023, approximately 263 million malaria cases and 597,000 deaths were reported worldwide, most of them in Africa. Uganda continues to experience a high burden of malaria, particularly in transmission hotspots such as the Busoga sub-region in Eastern Uganda, where children under five years and pregnant women are disproportionately affected. Although proven interventions, including insecticide-treated nets, indoor residual spraying, intermittent preventive treatment during pregnancy, effective case management, and malaria vaccination, have been widely implemented, malaria remains a leading cause of morbidity and mortality among young children. This persistence reflects gaps in community uptake, behavioral factors, and challenges in implementing interventions effectively within local contexts. To address these challenges and contribute to the achievement of Sustainable Development Goal (SDG) 3.2 and related development goals, this study will pilot and assess a community-led integrated malaria elimination model in Nawanyingi Sub-county, Iganga District, Uganda.

Methods: The study will employ a mixed-methods implementation research design guided by the Reach, Effectiveness, Adoption, Implementation, and Maintenance (RE-AIM) framework. A prospective pre- and post-implementation approach will be used to evaluate the feasibility, acceptability, implementation processes, and preliminary outcomes of the intervention. The model comprises four integrated components: community engagement and mobilization, indoor and outdoor residual spraying combined with larviciding, modified mass testing and treatment (MMTaT), and strengthened malaria surveillance and reporting through existing community and health system structures. Data will be collected during formative, implementation, and evaluation phases using household surveys, key informant interviews, focus group discussions, in-depth interviews, vector surveillance, DHIS2 data abstraction, and implementation monitoring tools.

Changes in malaria transmission dynamics will be assessed through routine mosquito density monitoring and entomological observations. Quantitative data will be entered using Epi Info and analyzed using STATA version 17, while qualitative data will undergo thematic content analysis to identify implementation experiences, barriers, facilitators, and sustainability considerations.

Ethics and dissemination: Ethical approval will be obtained from a recognised Research Ethics Committee in Uganda. Findings will be disseminated through peer-reviewed publications, stakeholder workshops, policy briefs, scientific conferences, and community feedback meetings. Lessons generated on feasibility, acceptability, and implementation challenges will inform for future scale-up and adaptation of the integrated malaria elimination model in similar high-burden settings.

Keywords: *Malaria elimination, Implementation research, Community engagement, Mass out-and indoor spraying, larviciding, Mass testing and treatment, Uganda*

Strengths and limitations of this study

- Evaluates a novel community-led integrated malaria elimination model in a high-transmission setting.
- Uses implementation science methods guided by the RE-AIM framework.
- Combines epidemiological, entomological, economic, and implementation outcomes.
- Generates evidence to inform future scale-up of malaria elimination programmes.
- As a pilot study, findings may have limited generalisability beyond similar high-transmission settings.

Introduction

Malaria remains one of the world's most significant infectious diseases and a major barrier to achieving global health and development goals. Despite substantial progress in malaria control over the past two decades, the disease continues to impose a considerable burden on health systems, economies, and vulnerable populations worldwide. According to the World Health Organization (WHO), an estimated 263 million malaria cases and 597,000 malaria-related deaths occurred globally in 2023, representing an increase from previous years and highlighting stagnation in progress towards malaria elimination targets [1]. Although malaria is preventable and treatable, the disease continues to disproportionately affect low- and middle-income countries, particularly children under five years of age and pregnant women, who account for the majority of malaria-related morbidity and mortality [1].

The burden of malaria is overwhelmingly concentrated in sub-Saharan Africa, which accounted for approximately 94% of global malaria cases and 95% of malaria deaths in 2023 [1]. Six African countries, namely Nigeria, the Democratic Republic of Congo, Uganda, Ethiopia, Mozambique, and Niger, contribute more than half of the global malaria burden [1]. Malaria remains a major impediment to social and economic development across the region through its contribution to childhood mortality, maternal complications, school absenteeism, reduced labour productivity, and increased healthcare expenditures [1, 2, 3]. Although several African countries have made substantial progress in reducing transmission through expanded vector control, improved case

management, and strengthened surveillance systems, gains have been uneven and fragile, with several high-transmission settings experiencing persistent or resurgent malaria transmission [1].

Uganda remains among the countries with the highest malaria burden globally and continues to rank among the leading contributors to malaria cases and deaths worldwide [1]. Nearly 90% of the Ugandan population lives in areas of stable malaria transmission and remains at risk of infection throughout the year [4]. Malaria remains the leading cause of outpatient attendance, hospital admissions, and under-five mortality in the country. National Health Management Information System data indicate that malaria accounted for approximately 29.4% of outpatient visits and 29.9% of hospital admissions during the 2023/2024 financial year [4]. Beyond its health consequences, malaria imposes a substantial economic burden on households and the national economy through treatment costs, lost productivity, school absenteeism, and premature mortality [3, 4, 5].

Despite widespread implementation of evidence-based interventions, including long-lasting insecticidal nets (LLINs), indoor residual spraying (IRS), intermittent preventive treatment during pregnancy (IPTp), malaria vaccination, and prompt diagnosis and treatment using artemisinin-based combination therapies (ACTs), malaria transmission remains persistently high in several regions of Uganda [1, 2]. Progress has been constrained by factors such as insecticide resistance, suboptimal utilization of preventive measures, weak surveillance systems, fragmented implementation of interventions, counterfeit and substandard antimalarial products, and inadequate community engagement in malaria control efforts [1, 6]. Furthermore, many interventions continue to be implemented through vertical programmes with limited integration and community ownership, raising concerns regarding sustainability and long-term impact [7].

The malaria burden is not uniformly distributed across Uganda. Considerable geographical heterogeneity exists, with eastern Uganda, particularly the Busoga sub-region, consistently reporting among the highest malaria incidence and mortality rates nationally [4]. During the 2023/2024 financial year, Busoga recorded more than 1.5 million confirmed malaria cases, making it one of the highest-burden regions in the country [4]. Persistent transmission in the region is driven by favourable climatic conditions, extensive mosquito breeding habitats, high population density, poverty, limited uptake of preventive interventions, and weaknesses in community-level surveillance and response systems. Consequently, malaria continues to place a substantial burden on households, health facilities, and local government resources within the region.

Within Busoga, Nawanyingi Sub-county in Iganga District represents a typical high-transmission rural setting characterized by perennial malaria transmission, abundant breeding sites, and a predominantly agrarian population. Although routine malaria control interventions are implemented through existing health system structures, the area continues to experience substantial malaria morbidity, indicating the need for innovative approaches that complement existing strategies and strengthen community participation in malaria prevention and elimination.

Evidence from countries that have successfully achieved malaria elimination, including China, Sri Lanka, El Salvador, and Paraguay, demonstrates that elimination is possible when multiple interventions are implemented simultaneously through strong community engagement, active surveillance systems, effective vector control, and rapid case detection and response mechanisms

[8, 9]. Integrated malaria elimination approaches that combine vector control, community mobilization, behaviour change communication, active case detection, and surveillance have consistently demonstrated greater effectiveness than isolated interventions. However, evidence regarding the feasibility, acceptability, and implementation of community-led integrated malaria elimination models remains limited in high-transmission African settings, where contextual, operational, and health-system challenges differ substantially from low-transmission environments.

Addressing this evidence gap is essential for informing malaria elimination strategies in Uganda and similar endemic settings. Therefore, this pilot implementation study aims to assess the feasibility, acceptability, implementation processes, and preliminary impact of a community-led integrated malaria elimination model in Nawanyingi Sub-county, Iganga District, Uganda. The intervention combines community mobilization and behaviour change communication, indoor and outdoor residual spraying (IRS/ORS), larviciding, modified mass testing and treatment (MMTaT), and strengthened malaria surveillance within existing community and health system structures. Findings from this study will generate implementation evidence to inform future scale-up, adaptation, and policy decisions aimed at accelerating malaria elimination efforts in Uganda and other high-burden settings.

General objective

To pilot and assess the feasibility, acceptability, implementation processes, and preliminary impact of a community-led integrated malaria elimination model in Nawanyingi Sub-county, Iganga District, Uganda, in order to inform future scale-up and policy implementation.

Specific objectives

- 1) To assess the acceptability, feasibility, and coverage of a community-led integrated malaria intervention package comprising larviciding, indoor and outdoor residual spraying (IRS/ORS), modified mass testing and treatment (MMTaT) and routine surveillance.
- 2) To evaluate the feasibility of selecting, training, deploying, and supervising community volunteers to implement IRS/ORS, larviciding, MMTaT, surveillance and behaviour change communication (BCC) activities.
- 3) To identify key barriers and enablers influencing implementation of the community-led integrated malaria elimination model at community level.
- 4) To assess changes in malaria burden and mosquito density before and after implementation of the integrated malaria elimination intervention.

Integrated malaria elimination framework

This study is guided by the Consolidated Framework for Implementation Research (CFIR) developed by Damschroder et al. [10], which provides a comprehensive framework for understanding and evaluating the implementation of complex health interventions. CFIR offers a systematic lens through which the feasibility, acceptability, and implementation of the proposed Integrated Malaria Elimination Model can be examined within the Busoga context. The framework comprises five interrelated domains, namely Intervention Characteristics, Outer Setting, Inner

Setting, Characteristics of Individuals, and Process, which collectively influence implementation success. At the centre of the framework is the Integrated Malaria Elimination Model, representing the intervention package whose adoption, scale-up, and outcomes are shaped by interactions among these domains within the specific social, environmental, and health system context of Busoga.

The Integrated Malaria Elimination Model combines community mobilization and behavioural change communication, indoor and outdoor residual spraying (IRS/ORS), larviciding, modified mass testing and treatment (MMTaT), and strengthened malaria surveillance and response systems. The model is informed by evidence demonstrating that integrated malaria interventions are more effective in reducing transmission than isolated interventions implemented independently. Pluess et al. demonstrated the effectiveness of indoor residual spraying in reducing malaria transmission, while Fillinger and Lindsay highlighted the contribution of larval source management in reducing mosquito breeding and vector density [11, 12]. Furthermore, Bousema et al. and Stresman et al. demonstrated that identifying and treating asymptomatic malaria infections can substantially reduce parasite reservoirs and interrupt transmission within endemic communities [13, 14].

The Intervention Characteristics domain focuses on the evidence base, complexity, adaptability, and resource requirements of the intervention. According to Damschroder et al., interventions perceived as evidence-based, adaptable, and compatible with local contexts are more likely to be successfully adopted and sustained [10]. In this study, the integrated intervention package comprises multiple evidence-based malaria elimination strategies whose effectiveness has been demonstrated in various endemic settings. Studies by Pluess et al., Fillinger and Lindsay, and the World Health Organization provide strong evidence supporting the effectiveness of IRS, larviciding, and integrated vector management approaches [11, 12, 15]. However, successful implementation will depend on the ability of local structures to coordinate multiple intervention components while ensuring technical quality and operational feasibility. Consideration of costs, logistical requirements, and adaptability to rural and peri-urban communities in Busoga will therefore be critical.

The Outer Setting captures the broader environmental and contextual factors that influence implementation. These include community needs, malaria burden, national malaria policies, donor priorities, and socio-economic conditions. The World Health Organization and Uganda Ministry of Health have consistently identified eastern Uganda as one of the country's highest malaria transmission zones, with Busoga contributing substantially to the national malaria burden [1, 4]. Studies by Talisuna et al., Rek et al. and Nankabirwa et al. further highlight the persistent challenges posed by high transmission intensity, poverty, limited intervention uptake, and weak surveillance systems in Uganda [6, 16, 17]. These contextual realities provide a strong rationale for exploring integrated and community-owned malaria elimination approaches. The outer setting further encompasses the extent to which national policies, district leadership, and development partners support and facilitate implementation of the intervention.

The Inner Setting refers to the characteristics of the organizations and systems responsible for delivering the intervention. These include leadership engagement, availability of infrastructure and resources, organizational culture, communication systems, and readiness for implementation.

Damschroder et al. emphasize that organizational readiness and leadership support are among the strongest predictors of successful implementation [10]. In the context of this study, the preparedness of health facilities, Village Health Teams (VHTs), district health teams, and community leadership structures will significantly influence implementation success. Strong coordination mechanisms and institutional commitment will be essential for ensuring intervention fidelity and sustainability.

The Characteristics of Individuals domain focuses on the knowledge, attitudes, beliefs, motivations, and experiences of individuals involved in or affected by implementation. This includes community members, VHTs, youth volunteers, local leaders, and healthcare workers. Studies by Musoke et al. and Abdul Rahim et al. (2020) have shown that community perceptions of malaria risk, trust in health interventions, and previous experiences with malaria control programmes strongly influence participation and uptake [18, 19]. Similarly, Kok demonstrated that motivation, self-efficacy, community trust, and adequate support systems are important determinants of community health worker performance [20]. In highly endemic communities where malaria is often perceived as a normal illness, behavioural factors may affect acceptance of interventions such as spraying, testing, and treatment. Understanding these perceptions is therefore critical for improving intervention acceptability and community engagement.

The Process domain describes the activities required to implement the intervention effectively. According to Damschroder et al., implementation success depends on careful planning, stakeholder engagement, execution, monitoring, and continuous feedback [10]. Glasgow and Estabrooks similarly emphasize the importance of implementation fidelity, adaptation, and learning in achieving sustainable programme outcomes [21]. In this study, implementation processes will include community mobilization, volunteer recruitment and training, supervision, implementation monitoring, data-driven decision-making, and adaptive learning mechanisms. These activities are intended to ensure high-quality implementation while allowing for continuous refinement of intervention strategies based on emerging findings.

Collectively, the five CFIR domains provide a comprehensive framework for understanding how contextual, organizational, individual, and intervention-related factors interact to influence implementation outcomes. The framework aligns closely with the study objectives by facilitating assessment of feasibility, acceptability, coverage, barriers, and enablers of the Integrated Malaria Elimination Model. By grounding the study in CFIR, the research will generate a deeper understanding of the processes required to implement complex malaria elimination interventions in resource-constrained settings.

Ultimately, the Integrated Malaria Elimination Model seeks to reduce malaria transmission through simultaneous targeting of mosquito vectors, human parasite reservoirs, and behavioural determinants of malaria risk. Evidence from countries that have successfully eliminated malaria, including China, Sri Lanka, and El Salvador, demonstrates that integrated approaches combining vector control, surveillance, active case detection, and community engagement are critical for achieving elimination [22, 23, 24]. By combining evidence-based interventions within a community-led implementation framework, the model aims to improve community ownership, intervention coverage, sustainability, and effectiveness. The insights generated through this framework will not only inform malaria elimination efforts in Iganga District and Busoga region

but will also provide transferable lessons for other high-transmission settings across Uganda and sub-Saharan Africa. See Fig 1.

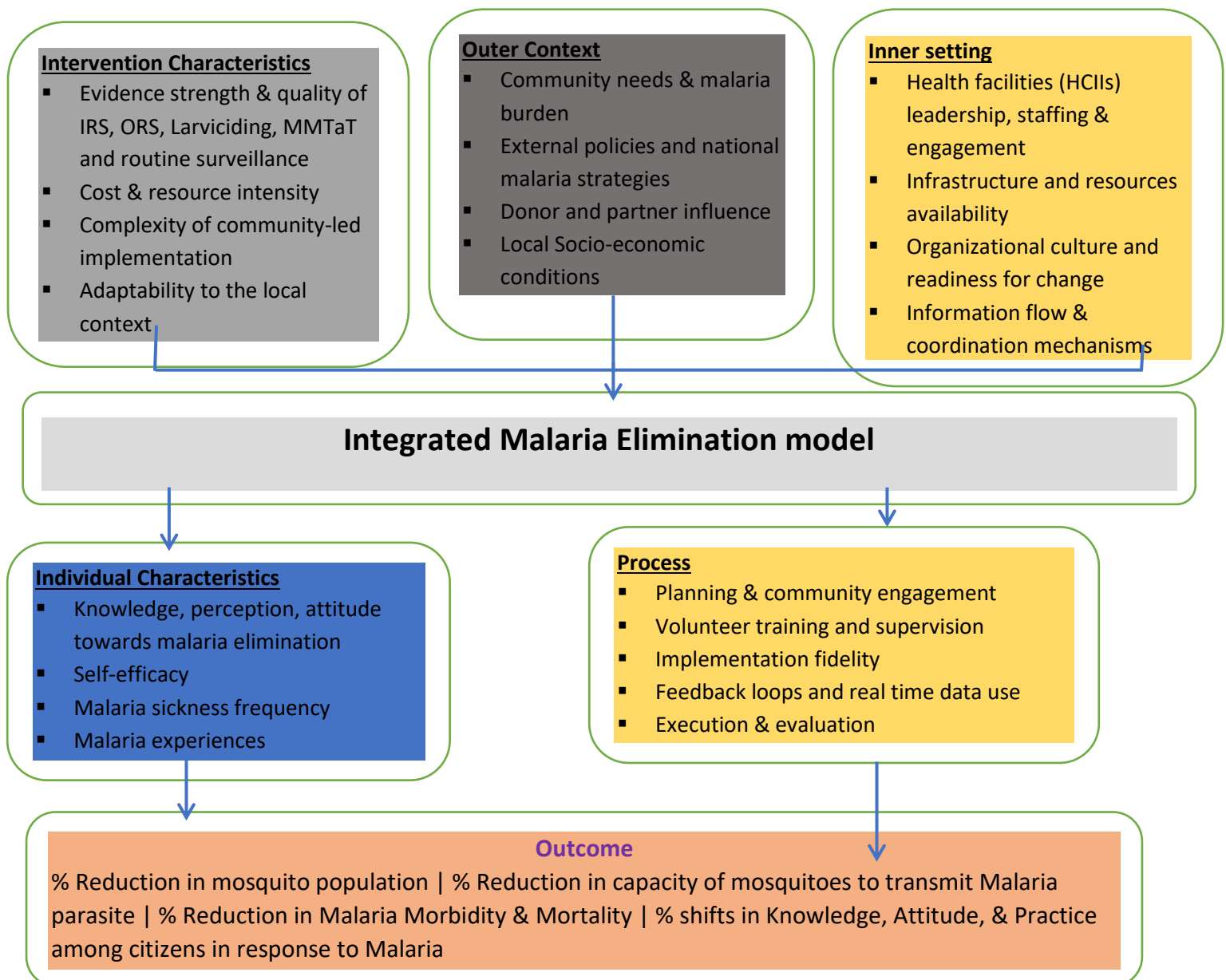


Figure: Integrated malaria elimination framework

Methods

Study setting



Figure 2: Map of Busoga region indicating all the 12 districts including Jinja city

The study will be conducted in Busoga region in Eastern Uganda (see Fig. 2), one of the regions with the highest malaria burden in the country. Busoga consists of 12 districts and experiences persistent malaria transmission throughout the year due to favorable climatic and environmental conditions for mosquito breeding. According to the Ministry of Health Uganda, Busoga remains among the regions contributing the highest burden of malaria cases nationally [4]. Within Busoga region, a pilot study will specifically be implemented in Iganga District, particularly in Nawanyingi Sub-county, to assess the feasibility of the proposed community-led integrated malaria elimination model before potential scale-up to other districts in the region.

Iganga District is located approximately 135 km east of Kampala, Uganda's capital city, along the busy Kampala–Busia/Malaba highway. The district covers approximately 1,046.75 square kilometers and has an estimated population of 426,958 people. Administratively, the district comprises three constituencies, namely Kigulu North, Kigulu South, and Iganga Municipality. It

also consists of 11 sub-counties including one town council and two municipal divisions, 53 gazetted parishes, and 235 villages. Iganga Municipality serves as the district's political and administrative headquarters and hosts the district hospital and major commercial activities, most of which are agricultural-based.

Iganga District lies at an elevation of approximately 1,128.57 meters above sea level and experiences a tropical monsoon climate characterized by warm temperatures and high rainfall throughout the year. The district has an average annual temperature of 23.12°C and receives an average annual rainfall of approximately 237.14 mm, with rainy conditions occurring on most days of the year. As reported by Mubiru and Komutunga, climatic conditions in Eastern Uganda favor year-round mosquito breeding and sustained malaria transmission [25]. These climatic conditions create a favorable environment for mosquito breeding and sustained malaria transmission.

The district has a total of 58 health facilities, including both public and Private Not for Profit (PNFP) facilities. These comprise one General Hospital, two Health Centre IVs, 15 Health Centre IIIs, and 40 Health Centre IIs distributed across the district's sub-counties. According to the Ministry of Health Uganda, health services are delivered through both facility-based and community-based systems, including Village Health Teams (VHTs) and Community Health Extension Workers (CHEWs), which support malaria prevention, diagnosis, treatment, and community mobilization activities [4].

The pilot study will specifically be conducted in Nawanyingi Sub-county, one of the malaria high-burden areas within Iganga District. Nawanyingi consists of three parishes and is served by three health facilities, including one public Health Centre III, one public Health Centre II, and one PNFP Health Centre II. The sub-county was selected because it represents a typical rural high-transmission setting within Busoga region, characterized by favorable mosquito breeding conditions, active community structures, and an existing health system capable of supporting integrated malaria interventions. The mix of facility levels and ownership within Nawanyingi provides an appropriate setting for piloting community- and facility-based malaria elimination strategies before potential scale-up to other sub-counties and districts within Busoga region.

Study population

The study population will comprise primary and secondary participants drawn from district, sub-county, parish, and community levels within the study area. The primary study population will include households and community members residing in the intervention areas of Nawanyingi Sub-county. The secondary study population will include healthcare workers, Village Health Teams (VHTs), Community Health Extension Workers (CHEWs), political leaders, district and sub-county management committee members, as well as cultural and religious leaders.

Households and institutional eligibility criteria

Inclusion

All households, institutional structures (churches, mosques, schools, hotels, lodges, amongst others), and other shelters in their compounds in Nawanyingi sub-county will be recruited into the study.

Exclusion

All households with no occupants will be excluded for IRS and MMTaT.

All households whose occupants decline participation / consenting in any of the study components will be excluded.

Study design

This study will employ a controlled before-and-after mixed-methods implementation research design conducted in Busoga region, Eastern Uganda, one of the regions with the highest malaria burden in the country [26, 27]. The study will be guided by the Reach, Effectiveness, Adoption, Implementation, and Maintenance (RE-AIM) framework, as illustrated in Fig. 3, and conducted as a prospective baseline, midline, and end line assessment to evaluate implementation outcomes and changes in malaria-related indicators following implementation of a community-led integrated malaria elimination model [21].

The study is part of a broader Busoga regional malaria elimination initiative aimed at strengthening community-led malaria prevention, surveillance, and control strategies across high-transmission settings within the region. As part of this broader implementation strategy, a pilot phase will first be conducted in Nawanyingi Sub-county, Iganga District, a rural high malaria transmission setting within Busoga region. The pilot will provide preliminary evidence on the feasibility, acceptability, operational processes, and early effectiveness of the intervention package before potential scale-up to other sub-counties and districts within Busoga region.

The intervention will comprise integrated malaria elimination approaches including community mobilization and engagement, indoor and outdoor residual spraying (IRS/ORS), larviciding, modified mass testing and treatment (MMTaT), and strengthened malaria surveillance and reporting systems. The intervention area will be compared using repeated measurements collected before and after implementation within the same population over time. Both quantitative and qualitative methods will be used to assess changes in malaria burden, mosquito density, community participation, implementation processes, barriers, enablers, and sustainability of the intervention under real-world implementation conditions.

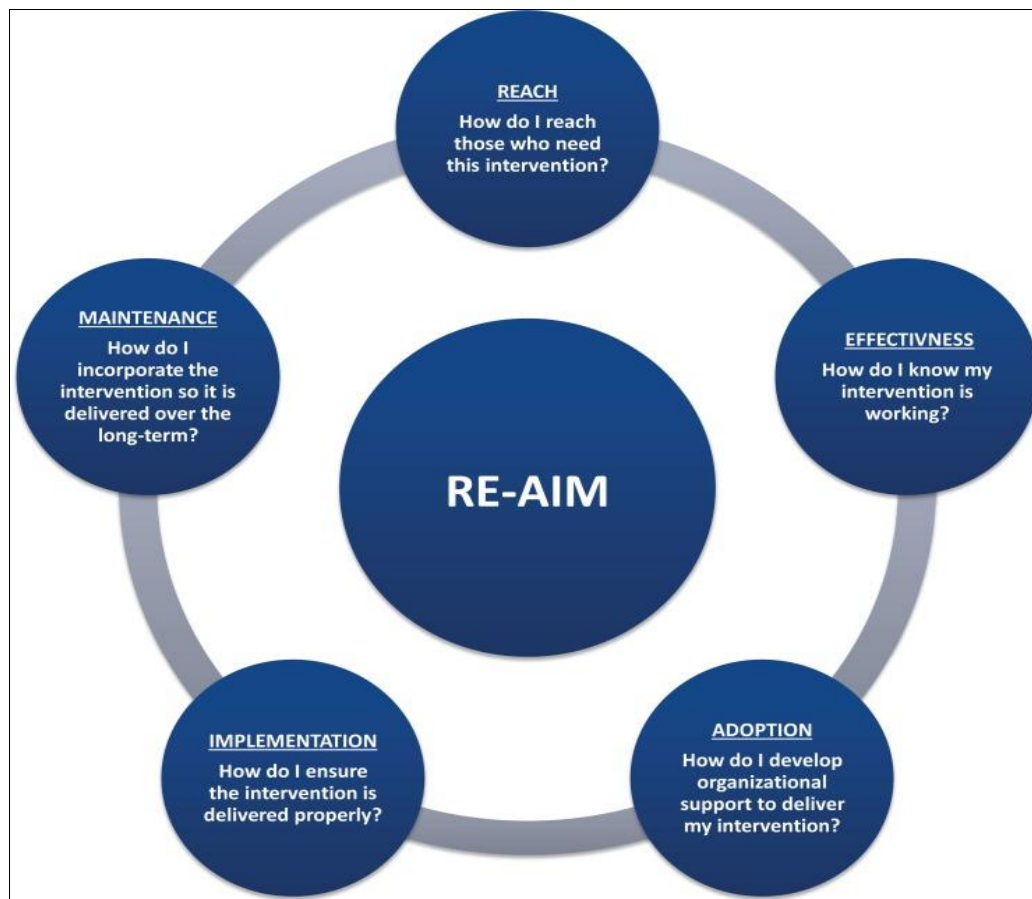


Figure 3: The RE-AIM framework

To avoid misconceptions often associated with the application of the RE-AIM framework, in this context, all the dimensions of this framework will be utilized and evaluated with regards to malaria elimination [21]. The RE-AIM framework has been applied in several implementation studies, including prevention and control of diseases in public health and other disciplines, as demonstrated by many studies [28, 29]. With regards to this malaria elimination project, the dimensions of the framework as seen in Fig. 3, will be studied as follows;

- 1) **Reach:** To make sure the planned intervention (community mobilization and engagement, indoor and outdoor residual spraying, larviciding, modified mass testing and treatment, and strengthened malaria surveillance and reporting systems) reach the desired beneficiaries, the population will be reached through an ongoing mass community mobilization exercise through the lowest local council administrative units (villages), local leadership, religious leaders and through the lowest healthcare units-Health center IIIs and IIs.
- 2) **Effectiveness:** A number of indicators will be developed, including monthly malaria incidence, vector surveillance (vector intensity) and annual malaria mortality, morbidity indicators.

- 3) **Adoption:** A fully-fledged organizational support will be developed to foster the delivery of the planned intervention as below. Busoga health forum (BHF), a local non-government organization with prior experience working within Busoga sub-region will primarily coordinate all the activities, mobilize all the partners including NGOs directly and indirectly working with malaria, local government players in the region, villages, local council leaders, and house households, work with Busoga chiefdom and its leadership, the district local government, Ministry of Health Uganda and partners through a bottom up approach, as illustrated in Fig. 4 below.

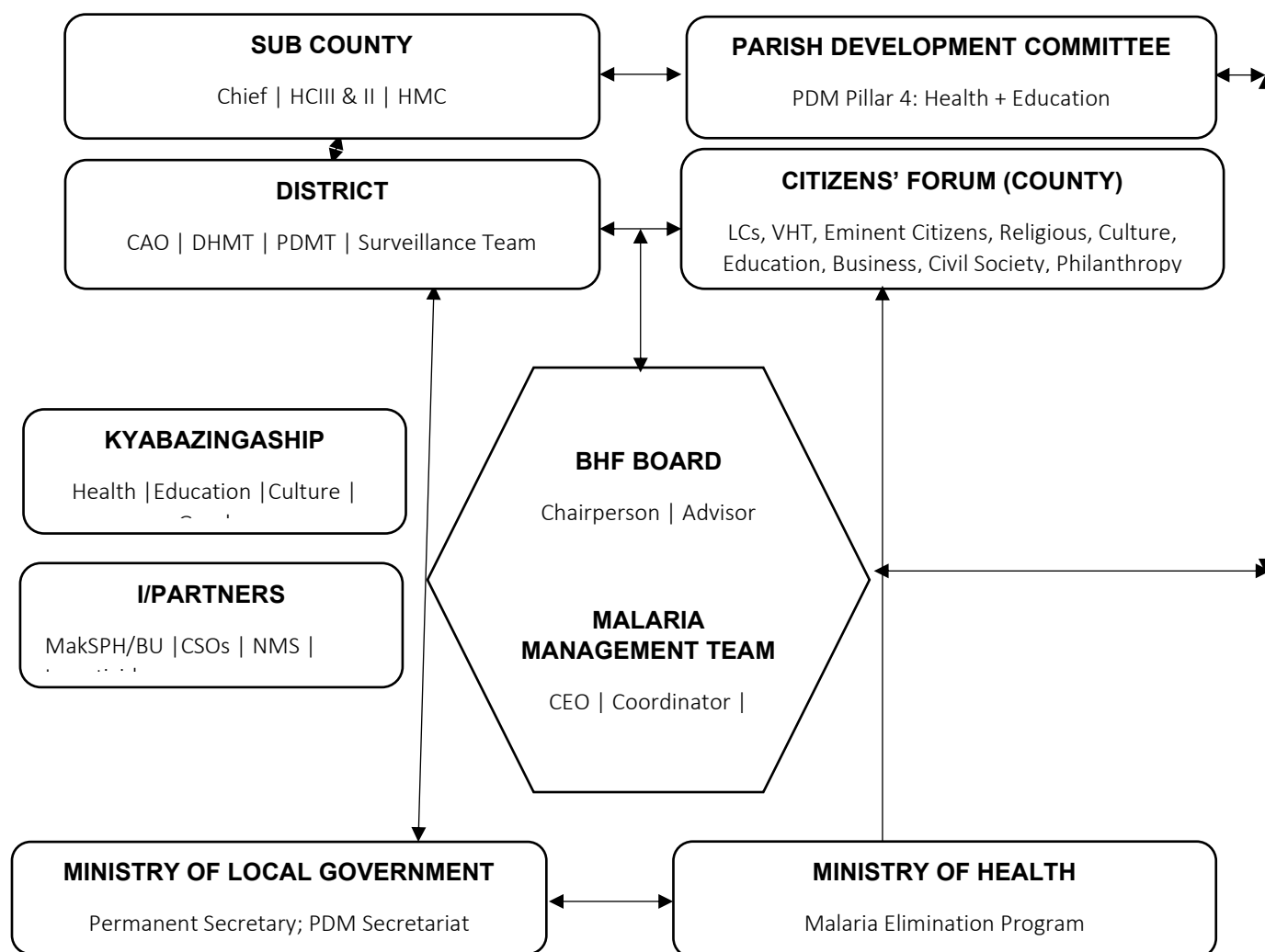


Figure 4: Busoga Malaria Elimination Program Organogram

The BMEP Program Management Team led by BHF, will comprise of five technical officers. These will include a Program Coordinator, a Community Mobilizer, an M&E and Surveillance Officer, a Community Development Officer, an Administration and Finance Officer, and a representative from the Ministry of Health. This team, under BHF's oversight, will play a central role in the program's management and execution. It will initiate, facilitate, and catalyze actions, supervise and engage with communities and their respective community actors.

While BHF remains central to the BMEP, the program's core activities will be conducted at the community level, specifically at the household, village, parish, and Sub County levels. Local Councils (LCs), Village Health Teams (VHTs), Community Health Workers (CHWs), Parish Development Committees (PDCs), and Sub County Health Unit Management Committees (HUMC) will lead direct program actions at these levels. These entities are all part of the Citizens Forums clustered at the parish level but administratively coordinated at the Sub County level.

However, Health Unit Management Committees (HUMCs) at health centre III and II will coordinate VHTs, CHEWs, and in turn, are coordinated by District Health Management Committees (DHMTs). DHMTs and HUMCs will collaborate with private sector actors such as private hospitals and clinics, schools, local NGOs and CBOs, religious, traditional, and cultural institutions.

- 4) **Implementation:** To ensure a smooth and proper implementation of the planned malaria elimination activities, the project will ensure bringing together an adequate technical team of experts and will be implemented with guidance from MoH malaria control division and the malaria consortium of Uganda that will directly form the advisory and working group of the project. In addition, the academia (Makerere University and Busoga University) will lead the project design and evaluation process.
- 5) **Maintenance and/or sustainability:** The maintenance/sustainability of the BMEP will be built on a comprehensive approach that promotes more preventive measures and community ownership in managing malaria. While the government will continue to provide test kits and anti-malaria medications, the people of Busoga have pledged to contribute towards spraying, particularly by purchasing the spray-insecticide. They have also pledged to volunteer their labour during spraying exercises and gradually purchase their own village-owned and individual-owned spray pumps, enabling them to re-spray as needed. Notably, the budget for the first year of this program is larger than the budgets for the subsequent years because it is anticipated that after one year of mass spraying, mass testing, and mass treatment, the prevalence of malaria will decrease, making the overall intervention increasingly affordable over time. The establishment of new and the rejuvenation of existing Citizens' Forums and patriotic groups, as envisioned by the Parish Development Model (PDM) of the NRM Government in Uganda, will ensure program sustainability.

Learning from settings that have recently eliminated malaria, notably China, the project will apply the 1-3-7 approach that was successfully used in China and subsequently adapted in several malaria elimination settings for surveillance and response to achieve a sustained malaria-free Busoga region [30, 31]. The 1-3-7 approach recommends reporting malaria cases within one day of diagnosis, completing case investigation within three days, and conducting foci investigation and response within seven days, as illustrated in Figure 5 below [30]. This approach will ensure that no residual infection remains within the target communities.



Figure 5: Flow chart of the 1-3-7 malaria elimination strategy

Implementation and monitoring design

The study will be implemented in 3 phases, that is, 1) formative phase (community awareness, household and stakeholder mapping, formulating indicators, baseline household survey, entomological baseline survey, recruitment and training of community volunteers, review of malaria trends using DHIS2 data and development of education and information materials); 2) Design and implementation phase (delivery of IRS, ORS, and MMTaT, community mobilization and health education, monitoring and adaptive feedback) 3) Evaluation phase (end line survey assessing knowledge and perception towards malaria elimination, reach of the interventions, surveillance, DHIS2 trend analysis of malaria cases, acceptability, sustainability assessment and economic and equity evaluation) and will follow a pre-conceptualized BMEP model as detailed in Fig. 6 below.

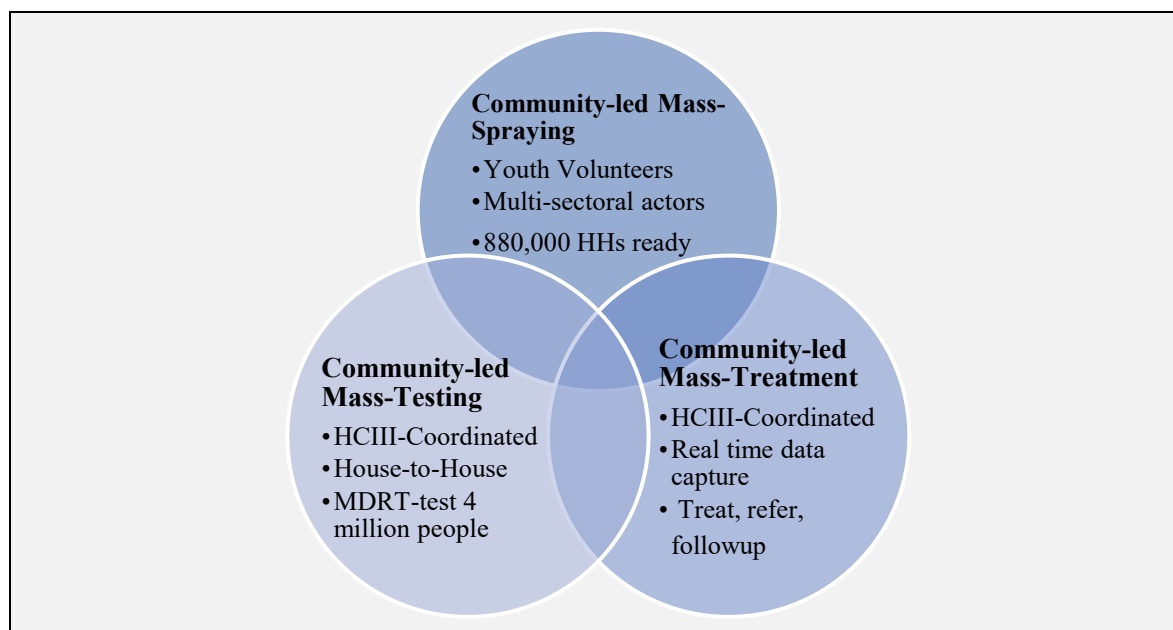


Figure 6: The triple-tenets of the BMEP Model

The BMEP model, a community-driven initiative, targets malaria elimination in the Busoga region. It will simultaneously implement three or four core tenets: mass IRS, ORS, Larviciding and MMTaT. The simultaneous deployment of these strategies is crucial because each alone is insufficient to achieve significant progress in the fight against Malaria. By combining spraying, testing, and treatment on a massive scale, the model hypothesizes the power to depopulate and disempower malaria-transmitting mosquitoes within and around homesteads, as well as significantly destroying the malaria-causing parasites in people's bodies, paving the way for elimination.

To enhance the model's effectiveness, an enabling environment will be designed to facilitate its operationalization. This will include effective communication, community mobilization, and engagement strategies, with community-led implementation and resource mobilization as key sustainability measures. Key stakeholders will be effectively coordinated to play their roles. Combining resource mobilization and program sustainability into a single strategy will involve building community forums where domestic financial and non-financial resources are harnessed to support the BMEP.

Description of the study's planned activities and core interventions

1) Communication, community mobilization, and participation

The BMEP's strength lies in community engagement, mobilization, and communication. The program team assembled diverse individuals, groups, and institutions to participate in the program's conceptualization and design. Ongoing community engagement will be crucial during the piloting and implementation phases. The conceptualization process will commence with a series of face-to-face community consultative meetings held at parish, sub-county, and district levels. These meetings will involve representatives from various sectors, including youth, women, teachers, boda-boda operators, religious leaders, cultural practitioners, and business owners,

amongst others. The community-led and participatory design process followed, involving technical meetings, workshops, and seminars where the program's content will be actively written agreed upon by the community. While the BMEP team will diligently mobilize and coordinate stakeholders' inputs and commitments. Key stakeholders to be involved in the BMEP will include District Health Officers (DHOs) for overall technical supervision, biostatisticians and planners for data management, Chief Administrative Officers (CAOs) for logistical coordination, Resident District Commissioners (RDCs) for security and monitoring, and Local Council Five (LCV) for council resolutions. Other key stakeholders will include environmentalists, Bishops, Sheikhs, Pastors, academicians, civil society practitioners, and hospital directors and in-charges.

During the BMEP design phase, one cluster (Nawanyingi Sub County) in Iganga district will be chosen as a pilot area to test the effectiveness of communication, community mobilization, and engagement strategies centered around the program's core interventions: mass IRS, ORS, Larviciding and MMTaT. The insights gained from conducting the process-pilot in Nawanyingi will inform the overall design of the communication, mobilization, and engagement strategy. To ensure the localized relevance of the information, education, and communication (IEC) materials, they will be disseminated to households, neighborhoods, schools, markets, and prominent village locations. The IEC materials will be translated into the local language with the "Communication Expert". The IEC materials will encompass a diverse range of formats, including audio, print (narration and illustration), and video. To reach a broader audience, media campaigns will be conducted through radio talk shows, community radios, and television.

In addition to traditional media platforms, the Local Council one (LCI) "Publicity Secretaries" as a virgin resource will play a crucial role in the transmission of information in the villages / trading centres using megaphones / simple loudspeakers. Similarly, community-based platforms including schools, churches, mosques, youths and sports centers, formal and informal gatherings, funerals, weddings, marriage introductions, and other community events will play a crucial role in effectively reaching the target audience. By utilizing these platforms, the message of eliminating Malaria in Busoga will be effectively communicated to the people in their villages and neighborhoods.

2) Community-led mass-vector-spraying (IRS and ORS)

Mass-vector spraying, a labour-intensive activity, will utilize voluntary labour of individual youth and youth groups termed as "Youth Brigade" across villages in Busoga. In collaboration with these youth, local village leaders, and technical supervisors, the BMEP aims to support and coordinate cost-effective and sustainable actions to reduce the malaria-causing mosquito population through mass-vector spraying in approximately 880,000 homesteads across 101 Sub Counties, 43 Town Councils, and 8 City Divisions in 11 districts of the Busoga sub-region.

The proposed Mass Vector Spraying (MVS) differs from the conventional Indoor Residual Spraying (IRS). Unlike IRS, which is confined to indoor structures, MVS will be conducted both indoors and outdoors of all houses and structures on the compound, and after six or more months. The MVS aligns with recommendations from an assessment that revealed mosquitoes do not exclusively reside indoors or on walls [32]. Therefore, MVS aims to substantially reduce the mosquito population in habitable and other structures within and around the homestead.

To ensure the effectiveness and efficiency of the MVS, the technical teams will first procure the necessary and high-quality inputs, such as insecticides (Actellic and Colum), pumps, protective

gear, first-aid packs, and an experienced team of supervisors. Subsequently, they will conduct thorough training sessions for the spraying teams, including the youth attached to their villages of residence, on how to carry out the spraying process effectively.

Standard Operating Procedures (SOPs)

Standard Operating Procedures (SOPs) will be developed and provided to guide all spraying activities, including the recommended spraying methods, timing, dosage, and insecticide specifications. The SOPs will also outline quality assurance measures, safety precautions, supervision procedures, and environmental protection guidelines to ensure effective and standardized implementation of the spraying activities. Detailed SOPs will be attached as an annex to this strategy document.

Environmental Safeguards

Environmental safeguards will be implemented to minimize potential risks associated with mass-vector spraying activities. All spraying activities will follow Ministry of Health Uganda and WHO-recommended standard operating procedures for safe handling, storage, transportation, application, and disposal of insecticides and related materials. Spraying teams will be trained on environmental protection measures, proper use of personal protective equipment (PPE), spill management, and safe disposal of insecticide containers to prevent contamination of water sources, soil, domestic animals, and non-target organisms. Community sensitization will also be conducted before spraying to promote household safety, environmental protection, and responsible handling of sprayed areas during and after implementation.

3) Community-led larviciding

Larviciding activities will include community mobilisation and sensitisation, village mapping and larvicide application [33]. Cost-effective, human safe and environmentally friendly larvicide (chemical like Temephos/Abate or biological like *Bacillus thuringiensis israelensis*) will be applied on a weekly basis during the transmission season, focusing on urban / peri-urban settings and / or areas with relatively low malaria transmission as recommended by WHO Pesticide Evaluation Scheme (WHOPES). Prior entomological surveillance will be required to guide decisions on when and where larviciding is appropriate. Dosage will be determined by the active ingredient concentration per volume or surface area of the water. The WHO protocol for larvicides application [34] (includes guidelines for assessing risk for operators and residents coming into contact with treated water) will be used.

4) Community-led modified mass testing and treatment (MMTaT)

As opposed to the WHO mass testing and treatment (MTaT) approach that strictly targets treatment of only positive participants, the modified mass testing and treatment (MMTaT) will involve testing, treating positive participants and offering chemoprevention to all household members in all households that will be found with positive case(s). This is intended to minimize transmission from the infected household members to the rest of the occupants. This approach will be conducted in a community-led participatory manner, coordinated by the officers in charge of public health centre IIIs. The centre III heads will collaborate directly with Health Management Committees (HMCs), Sub County Chiefs, LCIII chairpersons, women and youth committees, Village Health

Teams (VHTs), and with the LCI chairpersons as village mobilizers. Prior to MMTaT, the capacity of District Health Teams (DHTs), Community Health Extension Workers (CHEWs), Village Health Teams (VHTs), and political teams will be enhanced. The BMEP will provide support and coordination for a phased Malaria testing using Rapid Diagnostic Tests (MRDT) and administration of treatment and Prophylactic drugs (Dihydroartemisinin / Piperaquine, DHA / PPQ), aiming to reach approximately 4 million people in nearly 880,000 homesteads across 101 Sub Counties, 43 Town Councils, and 8 City Divisions in 12 districts. The mass testing and treatment will be conducted 6 months apart or more, largely depending on the circulating parasite load among the population including children 5 years and below.

Before conducting MMTaT, the technical teams will ensure that the necessary quality and quantity of testing kits and drugs are stocked. A central storage facility will be established at district health departments, while health centre IIIs will be responsible for storing and distributing testing kits and drugs as per defined schedules. Standard Operating Procedures (SOPs) detailing the MMTaT process, including the types of kits and drugs to be used, dosage specifications, precautions, resurgence scenarios, referral processes, emergency case handling, and managing side effects, will be attached as an annex.

5) Community-led resource mobilization and program sustainability

The key resources required for the BMEP are finances, malaria rapid diagnostic testing kits and drugs. Financial resource mobilization will involve direct and active participation of the community, particularly through offering their own meagre financial contributions. Platforms specifically known as “Investment Forums” will be established to raise funds from the communities. Additionally, a comprehensive resource mobilization strategy will be developed to engage with key stakeholders, especially the Ministry of Health (MoH), Ministry of Finance Planning and Economic Development (MFPED), Ministry of Education and Sports (MoES), and other relevant ministries to ensure the appropriation of national resources for the BMEP.

The BMEP necessitates substantial quantities of MRDT and Dihydro-artemisinin Piperaquine (DHAP-PQ). The resource mobilization team will actively collaborate with the Ministry of Health (MoH), international donors, and manufacturers to secure the necessary supplies of test kits and drugs over the next three years. BHF anticipates that UGX 154 billion can catalyse the elimination of Malaria in the Busoga region through a comprehensive and simultaneous approach. The detailed resource mobilization strategy is attached as an annex.

The study will run for three years, from January 2025 to December 2027, capturing malaria burden (monthly morbidities) and (annual mortalities), including variations in seasonal transmission intensity and cumulative effects on vector populations and resistance.

6) Malaria surveillance

Surveillance data is central for planning, monitoring and evaluating planned malaria elimination interventions. Surveillance will further aid in identification of trends in malaria cases and deaths that may require other innovative approaches other than the planned activities and ultimately lay a backbone for the assessment of the overall intervention impact.

Since Busoga sub-region is currently classified as a high malaria transmission area, surveillance in this context will span all the three phases of transmission, that is, high to moderate (parasite prevalence of >10%), low (parasite prevalence of <10%) and very low (parasite prevalence of <5%) transmission with adaptation of different surveillance approaches according to the stage of achievement [35, 36].

Table 1: Surveillance approaches for different phases of transmission will be adapted depending on the transmission intensity as below [36].

No	Transmission phase	Surveillance approach	Indicator (s)
1	High to moderate	Disaggregated health facility data analysis (DHIS2)	Monthly malaria cases, case positivity rates and deaths.
2	Low	Weekly case-based surveillance of malaria cases and deaths mapped by village.	Malaria cases and deaths
3	Very low	Case based surveillance based on the 1-3-7 approach and entomological investigations.	Malaria cases, sources and entomological Characteristics of the vector

Sample size and sampling strategy

A census of the households will be conducted in Nawanyingi Sub-county during the mapping exercise to establish a comprehensive household register, generate the intervention denominator, support planning for mass spraying and test-and-treat activities, and obtain baseline community-level data. According to UBOS, 6,955 households will be covered, across 20 villages in three parishes [37]. This provides a reliable sampling frame for selecting households for baseline, midline, and end line assessments.

For household surveys, the sample size will be calculated using the Kish Leslie formula for cross-sectional studies [38], assuming a 50% expected proportion for key implementation outcomes such as acceptability, coverage, and uptake of malaria interventions, since this gives the maximum sample size. Using a 95% confidence level, 5% margin of error, and adjusting for non-response, the estimated minimum sample will be approximately 423 households.

A multistage sampling approach will be used. First, the three parishes in Nawanyingi Sub-county will be included. Secondly, households will be allocated proportionately to the 20 villages based on the number of mapped households in each village. Finally, households will be selected using systematic random sampling from the household mapping list. Only one household member per household will be interviewed. In this approach, we shall use a sampling interval and a random start. Given the total population size of the sub-county, N , and the required sample size, n , then the sampling interval, k will be given by:

$$k = \frac{N}{n}$$

Every k^{th} unit (household) will be selected in this case. The random start, r , which is a single random number between 1 and k , inclusively will then be selected. In this case, each household will have the same probability of being selected.

For qualitative data, purposive sampling will be used to select key informants and focus group discussion participants, including household heads, VHTs, CHEWs, health workers, youth brigade members, local council leaders, religious and cultural leaders, and district or sub-county officials. Participants will be selected based on their involvement in malaria prevention, community mobilization, spraying, testing and treatment, supervision, or decision-making. About 4 groups of KIIs will be contacted; 1) program implementers, 2) chairpersons of DHMT, 3) DHMTs, and 4) HUMC following a purposive sampling approach or until data saturation. About 8 FGD will be conducted with; 1) household members, 2) youth volunteers (sprayers), 3) VHTs, 4) CHWs, 5) PDCs, 6) HUMCs, 7) DHMT, 8) religious and local council leaders or until data saturation.

For implementation monitoring, all households reached during IRS/ORS, larviciding, MMTaT, and community mobilization activities will be documented using routine implementation logs. This will allow measurement of actual intervention coverage against the mapped household denominator of 6,955 households.

Data collection methods

Data collection procedure will follow a systematic and phased approach based on the study's three implementation phases of formative, implementation and evaluation. While using implementation research methodologies involving both quantitative and qualitative data collection methods, the dimensions of the RE-AIM framework (reach, effectiveness, adoption, implementation and maintenance / sustainability will be an area of focus during data collection.

Phase 1: Formative phase

1) Quantitative / Household baseline survey

Pre-and post-intervention household surveys will be conducted in the randomly selected villages and households to assess community perceptions and knowledge towards malaria prevention and elimination in Uganda.

2) Entomological baseline, midline and post-intervention survey

An entomological survey focusing on female *Anopheles* mosquito vectors will be conducted to track mosquito density before the intervention, midway and post-intervention. The survey will also track vector resistance to insecticide over the three years of the proposed mass outdoor and indoor spraying. This will be carried out in three sentinel sites in each of the three parishes of Nawanyingi sub-county. Mosquito density survey will focus on mosquito density per house, species composition and malaria transmission intensity one month before the intervention, midway and after every 3 years of mass spraying.

3) Secondary data analysis (Routine facility DHIS2 data)

The purpose of the secondary data analysis will be to measure malaria burden/incidence pre and post intervention. The analysis will focus on; 1) Annual malaria cases, 2) Test positivity rate, and 3) malaria deaths in the study area.

Phase 2: Design and implementation phase

4) Program monitoring logos

Program implementation logos will be used to monitor the overall delivery of IRS, ORS, and MMTaT, community mobilization and health education, monitoring and adaptive feedback. Tracking will be done on a daily, weekly, monthly, quarterly and annually, focusing on; 1) number of structures sprayed, 2) number of people tested, 3) number of people treated, 4) number of anti-malaria doses administered, 5) number of villages reached, and 6) number of community engagements conducted, amongst others.

Phase 3: Evaluation phase

5) Mosquito sample collection, preparation and resistance assessment

Sample collection, preparation and resistance assessment will be approached according to Tielong Xu and colleagues in their paper comparing three mosquito sample collections and preparation methods and mosquito age in resistance measurements [39]. The purpose of this assessment will be to monitor vector (mosquito) resistance partners to insecticides.

Three mosquito sample collections and preparation methods will be used: 1) adult mosquitoes collected from the fields; 2) F1 adults from field collected, blood fed mosquitoes; and 3) adult mosquitoes reared from field collected larvae. For the first method, 1,000 female *Anopheles* mosquitoes will be collected from the cow shelters between 7:00 pm and 9:00 pm using aspirators. Using wing geometric morphometrics, mosquitoes to species morphology will be identified (de Souza et al., 2020); half of these *Anopheles* female mosquitoes will be randomly selected for the resistance bioassay, using 0.05% Colum (Thiamethoxam + Lambda Cyhalothrin)) and 0.25% Actellic (Pirimiphos-methyl) test papers using the standard WHO tube assay [40, 41].

For the second method, the remaining field-caught and blood fed mosquitoes, about 500 mosquitoes will be transferred to a mosquito cage to lay eggs. After hatching, the larvae will be reared in spring water with Tetramin fish food. Immediately after emergence, male and female mosquitoes will be separated, and all adults will be fed on 10% sucrose solution. F1 female adults at about 5 days post emergence will be used for the 0.05% Colum (Thiamethoxam + Lambda Cyhalothrin)) and 0.25% Actellic (Pirimiphos-methyl) resistance bioassay in the standard WHO tube test [41]. For the third method, adult mosquitoes reared from field-collected larvae, 1,000 larvae from more than 50 larval habitats will be collected using the standard 350 ml dippers. The larvae will be transported to the local rearing facility and reared to adults, and female adults, about 5 days post emergence will be tested for 0.05% Colum (Thiamethoxam + Lambda Cyhalothrin))

and 0.25% Actellic (Pirimiphos-methyl) resistance using the standard WHO tube. A laboratory susceptible strain with no insecticide exposure will be used as the reference susceptible strain.

Purpose of mosquito sample collection

- 1) To measure mosquito density, species composition and malaria transmission intensity, post intervention

Mosquito sample collection methods

The human-biting mosquito densities will be monitored using CDC light traps run from rechargeable batteries. CDC light traps set beside occupied, untreated bed nets will catch mosquitoes proportional to what would have bitten humans in the same room/house [42].

Entomological surveys will be carried out by a team of trained community members to determine the mosquito species, abundance and malaria transmission intensities. Mosquitoes will be sampled from houses in selected villages in each study site using the battery-operated CDC light traps. In each house, a room occupied by one person will be used for mosquito collection. A standard miniature CDC light trap with incandescent light bulb (Model 512; John Hock Company, Gainesville, FL) will be hung beside a bed net (untreated) with the shield of the trap touching the side of the net and the trap entrance in the foot end of the bed. The traps will be set at 18:00hr and the owner of the house will be instructed to put off the trap and tie the mosquito collecting bag at 06:00 hr. in the next morning. Three traps will be set in each village, one trap being set in one house randomly selected from houses near a water body and upland. They will start the traps at dusk. Cotton wool soaked with sugar solution will be placed in the trap collection bag so as to minimize the death of trapped mosquitoes by the action of the fan. Trapping will be done for 4 consecutive nights in each of the houses.

People living in the house/room should be protected under their bed net (if they have them), and as hungry mosquitoes persist in their attempts to look for a blood meal, they will get near to the trap and will be caught by it.

Sampled adult mosquitoes will be placed in plastic tubes/bottles with covers and marked with date and location of capture. They will be counted and identified in the laboratory and recorded as number of mosquitoes caught/ trap/night. Catches of the *Anopheles* mosquitoes will later be treated for *plasmodium falciparum* circum- sporozoite protein using sporozoite ELISA method described by Wirtz and colleagues [99], that is, *Plasmodium falciparum* Circumsporozoite (*P.f.* CSP) ELISA. The Entomological Inoculation Rates and *p.f.* transmission intensity will be calculated as follows: Annual Entomological Inoculation Rate, AEIR = Annual Human Biting Rate, AHBR (Ma) x Sporozoite Rate (S), [Where AHBR = Mean Daily Human Biting Rate (calculated as mean bites per person per night) x 365 days] [43].

Mosquito surveillance will be repeated in the same 18 houses every second week of the four consecutive Months post-IRS/ORS/Larviciding intervention.

6) Mixed methods (both quantitative and qualitative methods) in line with RE-AIM framework

To evaluate the acceptability, feasibility and coverage of community-led IRS ORS, larviciding and modified mass testing and treatment, data collection and evaluation will follow a mixed methods approach and following the RE-AIM framework [21], as illustrated below.

RE-AIM Dimension	Evaluation Focus	Data Collection Methods	Analysis Plan
Reach	Proportion and characteristics of the population who received the intervention (IRS, ORS, larviciding, MMTaT)	1) Household survey (coverage, demographics) 2) Service registers/logbooks 3) Observation checklists	1) Descriptive statistics (e.g., % of households and individuals reached by each intervention)
Effectiveness	Knowledge, perception, prevention practices, Malaria incidence, mosquito density, malaria positivity rates, mortality and morbidity rates	1) Pre/post household survey 2) DHIS2 data review 3) Vector surveillance	1) Mortality and morbidity trend analysis 2) Thematic analysis for qualitative responses
Adoption	Proportion and characteristics of settings (HCIIIs, villages) and personnel (VHTs, youth volunteers) who initiated the interventions	1) Key informant interviews (HCIII in-charges, supervisors, program implementers) 2) Training attendance logs	1) Descriptive stats on % HCIIIs, and villages adopting the interventions 2) Qualitative content analysis on motivators and barriers
Implementation	Fidelity to the intervention protocol; quality and consistency of delivery	1) Structured observation during spraying/larviciding/testing/treatment 2) Supervisor checklists 3) Interviews with implementers	1) Fidelity scoring (e.g., checklist adherence %) 2) Qualitative analysis of challenges and adaptations
Maintenance	Potential for continued practice/scale-up after initial implementation	1) End line KIIs with program implementers, local and district leaders, HCIII staffs 2) FGDs with volunteers and community members	1) Thematic content analysis to assess sustainability prospects, integration into existing systems

7) Proportion pilling

Proportion pilling will be used to; 1) To develop programs and education/communication materials for behavioral change for malaria elimination in Uganda, and 2) To carry out community mobilization and sensitization about malaria in Uganda. The focus of this assessment will be to

collect data on 1) drivers of malaria, 2) predisposing factors and 3) impact of malaria on individuals, families/households and the community at large.

Proportional pilling will be conducted through focus group discussions (FGDs), one in each parish for the three parishes in Nawanyingi sub-county. Proportional pilling (PP) technique will be used to rank the proportional importance of the drivers of malaria in the communities, and malaria predisposing risk factors to form basis for the development of IEC materials. With this technique, participants will be asked to list the perceived drivers of malaria in their communities. After this process, ten circles will be drawn on a flipchart, with each circle representing a driver of malaria. A total of 100 stones will be provided to the participants to pile them in the circles based on the proportional relative effect on occurrence of malaria in their communities [44]. The study team will then count the stones in each circle to give a proportion of each driver with regards to the occurrence of malaria.

Participants will also be asked to list the most common infectious diseases in their communities and rank them according their impact in terms of frequency of illness, deaths, time and money lost during care for the sick using the same procedure described above.

8) Problem tree analysis and ranking exercises

The purpose of this method will be to identify barriers and enablers to the implementation of the integrated malaria elimination model, and will be stratified into system and community level barriers. These methods will be conducted using KIIs and FGDs by document reviewing using progress reports, registers, and BMEP implementation logs, spray reports, testing and treatment registers, and supervision checklists.

These approaches will aid in visualizing the root causes of poor implementation to prioritize most important enablers and barriers guided by semi structured interviews using open ended questions anchored on the four tenants of BMEP model (community IRS, ORS, Larviciding and MMTaT)

Data collection tools

Data collection tools will include; 1) Structured questionnaires for the household surveys, 2) Key informant, 3) in-depth and 4) focus group discussion guides, 5) data abstraction tools for DHIS2 secondary data analysis and 6) daily implementation tracking logs for ORS, IRS, larviciding and MMTaT delivery, and community engagements, 7) spray reports, 8) testing and treatment registers, and 9) supervision checklists.

All the tools will also be pretested in a district that is not part of the selected study area. The pre-test will be part of the training activities for the research assistants in order to enable the team understand the flow of questions and make modifications in the questionnaires and guides where necessary. Pre-testing will also enable the study team to know if the intended study participants are able to understand and respond to the questions appropriately. Some of the data collection tools will be adapted from validated malaria research tools, national malaria control guidelines and published RE-AIM evaluation templates [21].

Data management

This will include data processing, entry and analysis.

Data processing

Data collected will be standardized using various quality control measures, including checking for consistency, completeness and outliers before the data entry process. Trained data entrants will be used and double data entry will be conducted. Each questionnaire will be given a unique identification number. Data will be stored in password protected soft copies only accessible to the study team. Qualitative data will be audio recorded, transcribed verbatim and backed with filed notes.

Data entry and analysis

Quantitative data will be entered using Epi-info software and analyzed using STATA *version 17* for frequencies, trends, etc. Basic descriptive analysis will be conducted. Data will be disaggregated according to villages to identify the most vulnerable population groups. Analysis will be used to compare existing situation with desired standards as prescribed by Ministry of health and World Health Organization.

Analytical measurement indicators

The primary indicators will be stratified as; health outcomes / effectiveness indicators and implementation outcomes [21, 45].

Table 4: Health Outcome and Implementation Outcome Indicators for the Integrated Malaria Elimination Intervention

Category	Indicator	Definition / Measurement
Health Outcomes / Effectiveness Indicators	Malaria incidence rate	Measured as the number of confirmed malaria cases per 1,000 population.
	Malaria test positivity rate	Measured as the proportion of positive malaria tests among the total number of malaria tests conducted per month.
	Malaria-related under-five mortality rate	Measured as the proportion of deaths due to malaria among children under five years per 1,000 population.
	Knowledge and perception towards malaria prevention and elimination	Measured as the proportion of the target population with improved knowledge and positive attitudes towards malaria prevention and elimination.
	Mosquito density/abundance	Measured as the number of mosquitoes collected per unit area or sampling site.
Implementation Outcome Indicators	Fidelity	Measured as the proportion of households reached with IRS/ORS and the percentage of eligible persons tested and treated according to the intervention protocol.
	Reach	Measured as the proportion and characteristics of the target population that received the interventions, including IRS, ORS, larviciding, and MMTaT.
	Adoption	Measured as the proportion and characteristics of settings (e.g., HCIIIs, villages) and personnel (e.g., VHTs, youth volunteers) that initiated implementation of the interventions.

Category	Indicator	Definition / Measurement
	Feasibility	Assessed through documentation of logistical and operational challenges encountered and how they were resolved during implementation.
	Cost	Measured as the cost associated with each intervention component and its implementation activities.

Qualitative data analysis

Data analysis will be ongoing and iterative throughout study. Each step of exploratory interviewing will shape the questions in the subsequent steps and guided by theoretical saturation of themes. The audios will be transcribed and coded according to the thematic content analysis, a rigorous procedure for identifying themes in text and for developing theoretical models of the relationships among themes. Quotes will be included in the qualitative report.

Insecticide susceptibility bioassay

The female adults from the three sources of mosquitoes will be tested for susceptibility to deltamethrin, using the standard WHO tube bioassay with 0.05% deltamethrin test papers [41, 47]. For each sample collection and preparation method, 140 to 240 female mosquitoes will be exposed to WHO papers impregnated with deltemethrin according to WHO protocol, with 20 to 25 mosquitoes per tube. For each sample collection and preparation method, 7–12 replicates will be used. Paraffin oil-treated papers without insecticide (control paper) will also be tested, and 20 to 25 mosquitoes were used. Mosquitoes will be exposed for 1 hour. The knockdown time of individual mosquitoes will be recorded every 10 minutes, and the time required for 50% knockdown of mosquitoes (KT50) will be determined by the Probit analysis using Stata software. After 1-hour exposure, mosquitoes will be transferred to recovery cups and maintained on 10% sucrose solution for 24 hours and the number of surviving mosquitoes recorded. All bioassay mosquitoes will be tested for metabolic detoxification enzyme activities and a subset of samples will tested for kdr gene mutations.

Scale-up of the project

We propose model replication to areas with similar malaria burden and those aiming to eliminate malaria. The model can potentially be integrated into the exiting malaria control programs for programmatic implementation and avoid effort and resources fragmentation.

Implication of the proposed malaria elimination model

The model when successfully implemented, it is believed to cause a paradigm shift from top-down, donor-led malaria control to community-owned malaria elimination approach, and further provide a testable model for multi-sectoral action, addressing the core social determinants of health including poverty, environment, and weak health services. The model can also serve as a global public good, demonstrating how to localize tropical disease elimination strategies in the African context.

Quality assurance

The following measures will be undertaken to ensure that the process of data management maintains the integrity and quality of the data:

- 1) All data collection tools will be pretested and adjusted accordingly to ensure validity and reliability, and to ensure questions are asked properly and understood by the study population.
- 2) Research assistants will be comprehensively trained before data collection, drawing special attention to demonstrating interviewing techniques, recording of responses, probing and ethics.
- 3) Data entry and analysis will be done by two people to check for accuracy. This will be overseen by the study lead biostatistician.
- 4) Meetings will be held after each field day to review the day's activities and plan for the following day.

Declarations

Ethical considerations and dissemination

Ethical approval was sought from the Uganda Christian University Research and Ethics Committee (UCUREC-2026-2087). In addition, permission will be obtained from the Ministry of Health, the District Health Officer of Iganga district, and from the in-charge of Nawanyingi HCIII. Written informed consent will be obtained from each of the participants in this study. Throughout the study, the need for privacy, confidentiality and security of data will be maintained.

Study findings will be disseminated through publication in peer-reviewed scientific journals, presentations at national and international scientific conferences, policy briefs, technical reports, and stakeholder dissemination meetings. Findings will also be shared with participating communities, Village Health Teams (VHTs), district and regional health authorities, the Ministry of Health, and implementing partners through community feedback sessions and stakeholder engagement forums. The dissemination process will ensure that evidence generated from the pilot informs malaria elimination policy, program implementation, and future scale-up of community-led malaria elimination interventions in Uganda and similar high-transmission settings.

Consent to publish

Not Applicable.

Competing interests

No conflict of interest.

Data availability statement

Not Applicable.

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Clinical trial number

Not applicable

Authors contributions

SWK, KMM, MK, PW, and BDT conceived and designed the study. SWK, KMM, MK, PW, and FGK developed the study methodology and implementation framework. KMM and NK coordinated the development of the protocol and drafted the manuscript. FGK, AM, IM, AW, NK, FM, SM, JN, DA, HN, JBL and PW contributed to the study design, technical review, and refinement of the intervention and implementation strategies. SWK, KMM, MK, and PW provided overall scientific and methodological supervision. All authors critically reviewed the manuscript for important intellectual content, approved the final version for publication, and agree to be accountable for all aspects of the work. KMM is the guarantor of the manuscript.

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