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“Fighting against malaria is everyone’s concern”: a randomized control trial assessing the role of incentives for encouraging local communities to record and upload mosquito sounds using the MozzWear application

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Abstract

Background Current malaria surveillance methods are considered too expensive to scale-up within limited-resource settings; hence, new technologies and approaches are necessary to maximize the collection of data and ultimately design new malaria control tools. Effective mosquito surveillance can be enhanced through the utilization of digital technologies and the engagement of citizens in real-time data collection. This study used the HumBug acoustic sensor with the MozzWear app to detect and identify host-seeking mosquitoes based on their flight sounds, with citizens receiving airtime incentives for recording and uploading sounds.

Methods A randomized controlled trial was used to assess the role of incentives to encourage the local community to record and upload mosquito sounds using the MozzWear application. Participants were randomized into two groups: (1) a control group, in which no incentive was provided; and (2) an incentive group, in which airtime credit was provided to participants. Both groups were provided with HumBug smartphones running the MozzWear app plus adapted mosquito bed nets ('HumBug Nets') to hold the phones during recording and were asked to record and upload mosquito flight tone data once per week for a period of four months. The intervention group was rewarded with an airtime incentive every week after the data were uploaded. At the end of the study, an experience survey was administered to participants in both groups to assess their experience participating in this study.

Results The overall results indicate that the control group performed well in terms of the number of nights spent recording and uploading data compared to the incentive group. The level of intrinsic and extrinsic motivation differs between demographic variables. Their feedback suggested that fighting against malaria was more important and was everyone's concern in rural Tanzania. In addition, the participants expressed their interest in being involved in future research related to mosquito surveillance and the fight against malaria.

Conclusion Citizens can play a valuable role in scientific research; even without giving them incentives, they can still participate in the study. By participating in mosquito surveillance and malaria prevention studies, community members can make significant contributions to addressing mosquito-borne diseases and improving health outcomes.

Keywords Mosquito surveillance, MozzWear application, Citizen science, Community, Randomized controlled trial

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Background

Mosquito-borne diseases continue to cause high human morbidity and mortality [1]. Studies estimate that more than 90% of the world's population is at risk of vector-borne diseases [2]. In 2021, the World Health Organization (WHO) estimated 247 million cases worldwide and 619,000 deaths caused by malaria alone [3]. In addition, other vector borne diseases (VBDs), such as dengue, Zika, and chikungunya, cause more than 700,000 yearly deaths and are responsible for 17% of all deaths from infectious diseases [2, 4]. The ability to estimate such evidence-based statistics requires ongoing entomological and epidemiological surveillance conducted over time [5].

The WHO's Global Malaria Technical Strategy for 2016–2030 emphasizes the critical role of entomological surveillance in achieving malaria elimination in Africa [6]. However, recent global analysis has revealed significant weaknesses in vector surveillance in many low-income countries, including those with the highest burden of vector-borne diseases [7]. Despite the importance of monitoring mosquito populations and their behaviour, many countries lack the resources and infrastructure to conduct robust surveillance programmes. As such, improving vector surveillance and addressing these weaknesses, which include considerable human labour and paperwork, are crucial. Recently, increasing numbers of digital-based surveillance platforms that use mobile phones, smartphones or tablets to collect data and integrate with community engagement have been developed. The use of mobile devices for public health surveillance has gained popularity due to their usability [8, 9]. For example, mobile phones have successfully been used to provide data for understanding human mobility and malaria transmission risks [10], acoustically mapping mosquito species [8], malaria-related text messaging surveillance for controlling malaria [11], estimating bed net coverage [12], and rabies surveillance [13]. Budget smartphones have been used to capture the flight tones of host-seeking mosquitoes, generating real-time data that can be used to identify mosquito species [8, 14–16].

The adaptation of citizen science for mosquito surveillance has also shown significant potential [17–19]. For example, Mwangungulu et al. [20] provided evidence that scientists can rely on community knowledge and experience to identify areas with high or low mosquito densities. Other studies have shown that the use of citizen scientists can help generate a large amount of data within a short period of time compared to other mosquito surveillance methods [21]. Additionally, previous studies revealed that citizen scientists can collect mosquito data from hard-to-reach locations [19], hence minimizing the data collection period. Public citizens have managed to

collect large quantities of scientific data that can help scientists and governments make evidence-based decisions [18, 19].

The provision of monetary incentives for citizens involved in research data collection has now gained popularity and has been proven to be effective [22]. Previous studies have used a range of incentives as a reward for data collection [22–24]. For example, Banka et al. [23] provided monetary incentives to patients in hospitals who participated in a study evaluating patient satisfaction. Additionally, in Malawi, a study provided monetary incentives to HIV patients who tested HIV positive to assess whether monetary incentives would motivate them to take the HIV test. The current study focused on assessing whether providing airtime incentives to study participants running the HumBug acoustic mosquito sensor [15] influences the number of successful recordings uploaded. Each month, participants in the 'incentive' treatment received 23,000/= Tshs as airtime credit (prepaid balance on a mobile phone account to allow users to make calls, send messages and use data services), while the control group received no incentive. In previous iterations examining the impact of incentives, the effect of text message reminders was also assessed. Here, the main objective was to assess whether providing airtime incentives alone would influence the community's participation, thereby increasing the number of nights of recording and uploading data. In addition, in the present study, the study conducted a more in-depth analysis of community demographic variables to determine whether these variables influenced the number of nights of recording and uploading data using the MozzWear app.

Methods

Study area

This study was conducted in four villages, Kivukoni (8.21°S and 36.68°E), Minepa (8.27°S and 36.67°E), Mavimba (8.31°S and 36.67°E) and Milola (8.36°S and 36.68°E), in the Ulanga district, south-eastern Tanzania between April and July 2022 (Fig. 1). These villages lie between 120 and 350 m above sea level, with annual rainfall and a temperature range of 1200–1800 mm and 20–38 °C, respectively. The main economic activity in this area is subsistence rice cultivation and fishing. These villages have two seasons for farming activities, a rainy season and an irrigation-based system during the dry season [25]. These farming practices provide mosquito breeding habitats that produce an abundance of different mosquito species throughout the year [26], including the dominant malaria vectors *Anopheles funestus* and *Anopheles arabiensis*. Most of the houses have structures that allow

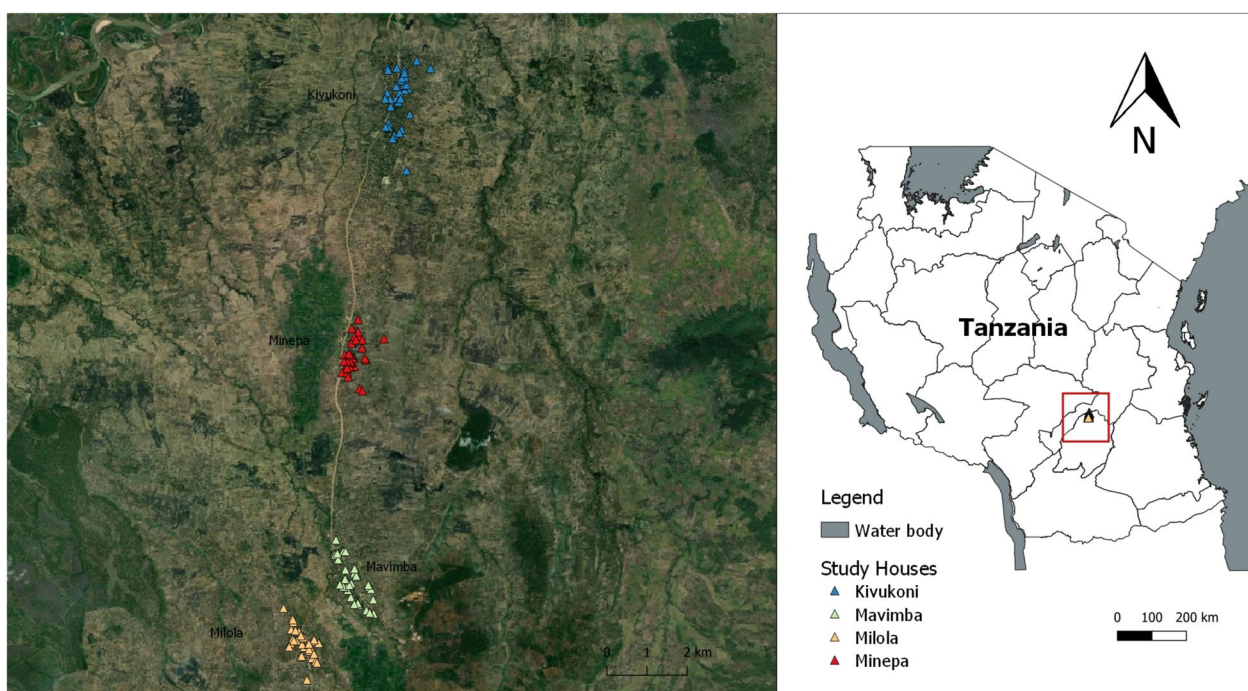


Fig. 1 Map showing the villages (in Ulanga districts) and households where the mosquito sound recording and uploading of data were conducted

mosquitoes to easily enter dwellings [27] and the primary vector control method used in this area are long-lasting insecticide-treated nets (LLINs). Due to the high mosquito densities in this area, epidemiological and entomological surveillance are among the most important methods for observing trends in malaria cases and mosquito species diversity. Thus, the study was conducted here due to the diversity of mosquito species and the high mosquito population throughout the year.

The vector surveillance systems in the area use traditional methods, including the Center for Disease Control (CDC) light trap, Miniaturized double-net trap (DN-mini), Resting bucket trap (RBu), Biogents BG sentinel traps, Gravid *Aedes* Trap (GAT), Biogents BG-Malaria trap, Suna trap, and Prokopack aspirators [28–33].

Study design

This study is a continuation of the work of Dam et al. [34]. Here, using the same process as that used by Dam et al. [34], a total of 144 participants from each village were re-enrolled to participate in this study. In the Dam et al. study, a total of 148 participants participated but after a one-year break, three participants were omitted from the final analysis due to death, and one participant moved to another village; thus, the final analysis was based on 144 participants. The study randomly

assigned participants from each village into one of two groups: the incentive group or the control group. In each village, 18 participants received airtime incentives, and 18 participants did not receive any incentive. All participation was fixed; there was no rotation throughout the experimental period. This study was conducted in three stages. The first stage involved a pretrial focus group discussion (FGD) session to inform the participants about the aim of the study and to ask for their willingness to participate. The second stage included a survey to assess demographic information about the participants plus investigate their reliability in uploading mosquito sound recordings to the HumBug server. The third stage was a post feedback survey where the study assessed the participants' experience in recording and uploading mosquito sounds. The study ran from April to August 2022.

Sample size and data analysis

The sample size for this study was calculated based on four factors: (1) significance level, (2) power, (3) differences between groups, and (4) standard deviation [35]. Considering that no previous studies had examined the parameters that were investigated in this area and that no pilot study had been conducted for this study, the values for the difference between groups and standard deviation remain unknown. However, many statisticians in social science research consider 30 to be the minimum

number of observations needed per intervention group to conduct a hypothesis test. This number is based on Student's *t* distribution and the normal distribution. To reduce the impact of attrition bias, this study used 148 smartphones and had at least 72 participants in each trial group (control and intervention arms). This study had four sites, with each site having a total of 36 participants (control = 18 and treatment = 18). The study aim was to recruit no more than 148 participants.

Study procedures

Recruitment

Participants were randomly selected during community meetings. Village leaders invited the study team to participate in their normal community meetings, where the aim of the study was explained. The community members were asked about their willingness to participate in the study; they were also assessed to ensure they met specific criteria, such as being older than 18 years old, owning a mobile phone (to receive airtime credit as an incentive), residing in a household with more than one person able to read Swahili, and having no plans to relocate during the study period. Thus, a total of 148 participants were selected based on their fulfilment of these criteria. In the present study, only 144 participants participated.

Group assignment and training

In order to reiterate the purpose of the study and confirm participants' continued willingness to engage, the study held small group discussions. These were not formal FGDs but participatory information sessions, which also served as initial co-design forums for the implementation process. To avoid peer pressure, additionally the study provided private opportunities for participants to affirm their consent individually. Thereafter, groups were assigned to each village. The process of assigning participants to the intervention and control groups involved writing the words "intervention" and "control" on 36 separate pieces of paper, with an equal number of papers for each group. A random selection process was then conducted, whereby each participant was asked to pick one piece of paper, unfold it, and read the word written on that particular piece of paper. As a result of this process, 18 participants were assigned to the control group, while the remaining 18 participants received an airtime incentive. After assigning participants to their respective groups, training was conducted to explain how to record mosquito sounds using the MozzWear application, including how to upload the recordings to a server. Participants were also educated on how to protect themselves from mosquito bites and informed about mosquito behaviour to enhance health awareness during their participation. Participants were provided with a new sim

card android smartphone (IteL A-16 Plus) loaded with the MozzWear app, 500Tsh cost for charging their phones and a HumBug Net (Fig. 2) (see Sinka et al. [15] for full details of the set-up). The HumBug Net were family sized bed nets. Finally, each participant received an application manual, which provided guidance on how to use the MozzWear app.

Experimental groups

All participants from both groups were asked to record and upload data once each week using the Mozzwear app. The intervention group was provided with an airtime incentive each month after recording and uploading the data once each week within that month. The airtime was sent directly to the participants' own mobile phones by Beem Africa, a company that had been consulted to send the airtime on a monthly basis. The control group did not receive any incentive.

Experimental set up

Participants were instructed to hang the HumBug net (Fig. 2) over the bed where they regularly slept each night. The HumBug net consists of two mosquito nets, with an insecticide-treated net over the bed, tucked in to prevent any mosquitoes from accessing the person sleeping under it. A second, larger, untreated bed net is then hung over the inner net, so there is a gap of approximately 20 cm between the outer and the inner net. The outer net is raised from the ground by 1 m, allowing mosquitoes to access the space between the two nets [15] and within this space, and above the end of the net where the sleeper's head is located, a pocket is attached, allowing the user to hang a mobile phone running the MozzWear application. The mosquito will be attracted to the CO₂ from the breath of the person sleeping under the bed net and as it tries to access the sleeper, the MozzWear application will be able to record its flight tone. Using these sound data, the HumBug system can passively detect and identify host-seeking mosquitoes in the community.

Each participant turned on the smartphone and the MozzWear app when they were ready to sleep, placed the smartphone in the pocket, and recorded mosquitoes that visited the net throughout the night until the participant woke up in the morning. Once the participant woke up, they turned off the recording function and used the MozzWear app to upload the acoustic data that had been recorded. This process was performed to ensure that there was no additional effort or disruption to their routine (Fig. 3).

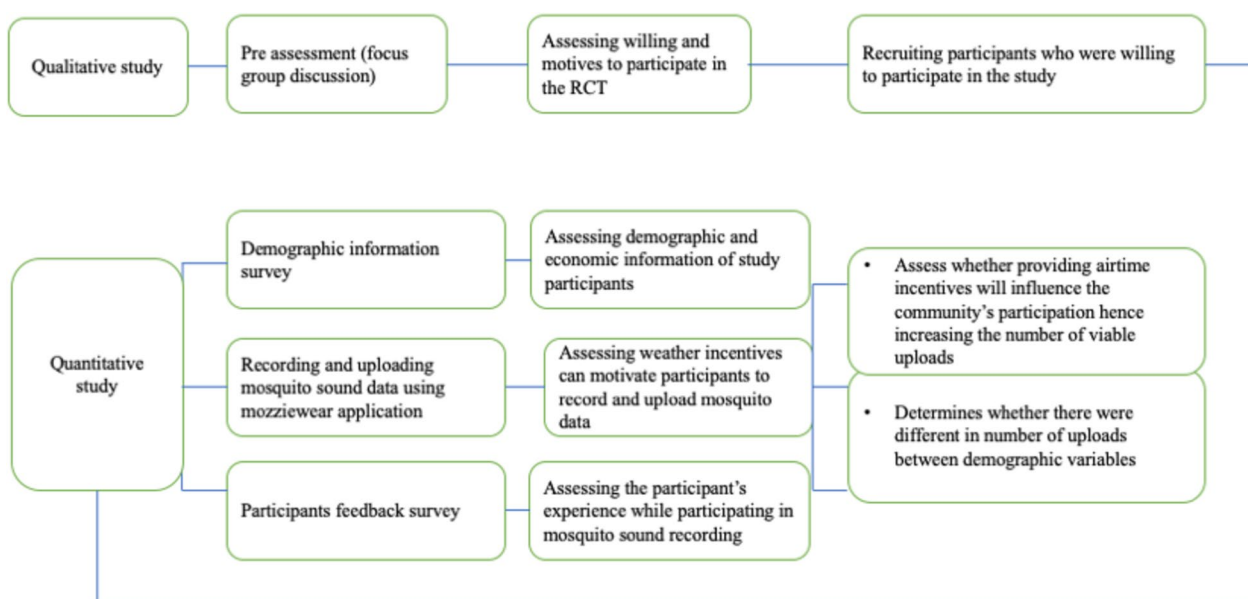


Fig. 2 Illustration of the study design for assessing the role of incentives in increasing the likelihood of recording and uploading mosquito sounds using the MozzWear application

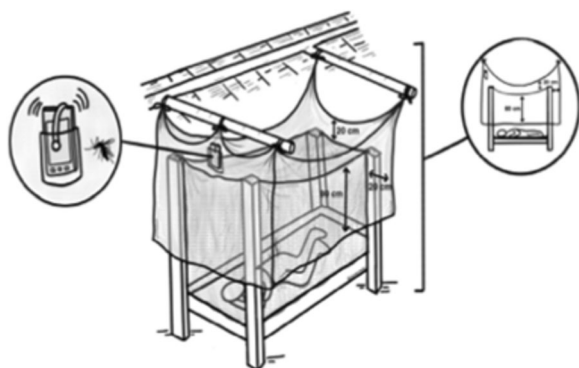


Fig. 3 Humbug bed net showing one additional outer net with a small pocket holding a smartphone placed above the occupant's head. The occupant inside the net produces CO₂ that attracts mosquitoes to the smartphone. Sinka et al. [16]

Data collection

Stage one: qualitative study

The Focus Group Discussion (FGD) included all of the participants in the study. The ages of the participants ranged from 18 to 69 years; most of them were farmers, business owners, employees, or village officers. Male and female participants were separated into groups because, the experience shows, when discussion groups are mixed, men tend to dominate the discussions. The discussion had four groups each with nine participants for a total of 36 participants in each village. The FGD study guide was developed and piloted with a few participants to

evaluate how well the questions flowed and if they lead to meaningful discussion. The time taken for each section was monitored to ensure that the discussion was within the allotted time. The discussion was audio recorded and conducted in Swahili, the local language. These sessions refer to the same group discussions held at the onset of the study, which served to confirm consent and co-develop study procedures. The discussion was facilitated by two research officers, one of whom took notes as the other conversed with the participants. For Minepa, Mavimba and Milola, the discussions were held at local ward offices, while for Kivukoni, they were held at the local primary school class.

Stage two: quantitative study

Demographic survey questionnaire

A structured questionnaire was developed to capture the demographic characteristics of the study participants, and the questionnaire was tested and revised accordingly before being administered during the first week of the study. The questionnaire captured the age, sex, education, occupation, and economic status of the study participants. Additionally, the questionnaire captured the number of household members and the socioeconomic information of the participants.

Recording and uploading data

The participants were recording the mosquito sound using the MozzWear app at night while they slept and the

next day, the data were uploaded. The study compared the differences in terms of the number of nights with successful data uploads between the control and incentive conditions in terms of age group, gender, income, occupation, and education level.

Stage three: quantitative and qualitative study

Feedback survey questionnaire

Upon completion of the study, a second questionnaire was administered to assess the participants' experiences while taking part in this study. This questionnaire aimed to capture information specific to the study, including the duration of time required to complete the recording and uploading exercise, the effectiveness of the training provided, the sufficiency of the incentive amount, the ease of use of the HumBug sensor, and the ease of uploading data.

Data analysis

Qualitative study analysis

For qualitative analyses, audio data from the FGDs were transcribed, translated, and checked for data processing and analysis. Thematic analysis was conducted by ordering, structuring, and interpreting the collected data. During data analysis two qualitative research scientist conducted qualitative coding independently and there were no different in terms of emerged themes. Themes identified included the motives for participating in the study, the support needed for the study to be successful, the challenges participants might face during the study and receiving feedback after the end of the study. The qualitative data were analysed using Nvivo software version 13.

Quantitative study analysis

The data were analysed using R open-source statistical software version 4.2.1[36]. Descriptive statistics were used to show the number of participants according to their corresponding demographic characteristics and the mean number of nights of successful data upload between the control group and the treatment group. A Poisson generalized linear model (GLM) with a log Link function was used to estimate the mean number of nights of successful data upload between the control and treatment groups. The estimated means and their 95% confidence intervals were subsequently used to plot bar charts to show the significance of the differences between the control and treatment groups. In those models, the number of successful nights was used as a dependent or response variable, while intervention (control and treatment) was used as an independent or predictor variable under different demographic characteristics, such as age, sex, occupation, education level, monthly income, and

village. Models for each predictor variable were fitted separately. All plots were generated using the ggplot2 package.

Ethical consideration

Ethical approval was provided by the medical research coordinating committee of the National Institute for Medical Research of Tanzania (approval number NIMR/HQ/R.8a/Vol.IX/3352). Additionally, the study was approved by the institutional review board (IRB) of the Ifakara Health Institute under approval number IHI/IRB/NO:22–2019. Consent to conduct the study was sought at both the communal and individual levels. Informed consent was obtained by discussing the study with local leaders and requesting to conduct it in their villages. Individual consent, including the request to participate, was obtained by discussing the study with each participant, including details about the procedure and its implications for the future control of mosquito-borne diseases. Those who agreed to participate in the study were given written consent forms to fill out before the randomized controlled trial began. Permission to publish this study was granted by the director general of the National Institute of Medical Research in Tanzania, Ref no: BD.242/437/OIA/38.

Results

Stage one: assessing willingness to participate

Pretrial focus group discussion

A focus group discussion was conducted prior to study with 144 participants. During the discussion, four key themes were identified and analysed using thematic analysis. These included the following: (1) Motives for participating in this study; (2) support needed for the study to be successful; (3) anticipated challenges; and (4) receiving feedback on the study.

Motive for participating in this study

The majority of respondents agreed to participate in this study due to their strong desire to understand how to identify mosquito species and to contribute to malaria control efforts in their community. For example, their responses include the following:

"... Malaria is a very dangerous disease that can cause harm. I would be happy to participate in the study because I will be one of those people who will be responsible for fighting malaria." (Male 30 years)
"...What will be interesting for me is to identify the mosquito species that spread malaria and, second, after identifying them, how we fight them..." (female, 55 years).

Support for the study to be successful

In response to the support needed for the study to be successful, the majority of the respondents had varying views on the support they needed. Some respondents highlighted that they did not have access to electricity at their homes and needed funds to cover the cost of charging their mobile phones, while others needed power banks or solar chargers for charging phones. In addition, some participants emphasized the need for training and guidance to help them during the study.

"...A challenge that I can foresee is power cuts. Electricity can be cut off for three or four days. Therefore, if our phones are not charged, we will not be able to record the mosquito sound data or send you this information. For this reason, I would like to be given something extra like power a bank or solar chargers..." (Female, 25 years).

"...I think the biggest help most of us would need is electricity because these devices need to be charged all the time. I think most of us charge a phone at the homes of people with electricity for a small amount of money. If researchers will provide us with little amount of money so that we are able to charge the phone..." (Male, 36 years).

Anticipated challenges

The majority of respondents suggested the challenges that they may face during the implementation of the study. These challenges include travelling away from the study area, unreliable electricity supply, knowing how to use smartphones, forgetting to record data, having a shortage of bed nets and possibly theft.

"... What would happen if you needed to travel outside my village for three or four days? Can you leave the device at home or do you travel with it to your destination?" (Male, 35 years).

"...A challenge I can see is that the phones can be stolen..." (female, 21 years).

Receiving feedback of the study

The majority of respondents emphasized the importance of receiving feedback on their progress during and after the study. It was proposed that monthly feedback would be helpful in identifying and correcting mistakes. Furthermore, some participants suggested that end-of-the-study feedback would be very important in identifying communal problems and finding solutions.

"...I would like to know the results from this study because it is very important for us citizens to under-

stand how we can fight mosquitoes and solve the challenge of malaria..." (female, 36 years).

"... I would like to know about the progress of the study, and at the end of the study, I would like to know whether the study was successful or not..." (Male, 28 years).

Stage two: Demographic survey and mosquito data recording and uploading

Socioeconomic and demographic characteristics of the study participants

Of the 144 community members who participated in this study, 49% were male and 51% were female. The ages of the participants were grouped, and the majority (34%) were aged between 30 and 39 years. Most of the participants (69%) had a primary-level education, and 69% were farmers. The majority of them (67%) had an income ranging from 100,000 to 300,000 Tshs monthly (Table 1).

The trend of recording and uploading mosquito sound data

The graph (Fig. 4a) below shows the mean number of nights with successful uploads during the 16 weeks of collection. There were no significant differences between those who received incentives and those who received control in weeks 5, 6, 7, 12 and 15. However, there were significant differences between those who received incentives and those who received controls in weeks 1, 2, 8, 9 and 16, where those receiving incentives uploaded data more often than did the control group. Although there was no significant difference between the incentive group and the control group in weeks 3, 6, 10, 11, 13 and 14, there was a trend for the incentive group to upload more often than the control group did (Fig. 4a). Overall, study findings showed that participants in the control group recorded and uploaded data more often during the night than did those in the incentive group (Fig. 4b).

Differences in the mean number of nights of recording between demographic variables

According to the village data, there were significant differences between those who received incentives and the control group in all villages (Minepa, Milola, Kivukoni, and Mavimba) (Fig. 5a). In Minepa and Kivukoni, those who received incentives recorded and uploaded data for more nights than did those in the control group. Conversely, in Mavimba and Milola, the control group performed well compared to those who received incentives. In terms of education level, those with higher education levels in the incentive group recorded and uploaded data on more nights than did those in the control group, whereas at the primary and secondary education levels,

Table 1 Demographic information of the study participants (N = 144)

Variable	N (%)
Gender	
Male	71(49.3)
Female	73 (50.7)
Age group	
Under 30 years	35 (24.3)
30–39 years	49 (34.0)
40–49 years	34 (23.6)
Above 50 years	26(18.1)
Educational status	
Primary	99(68.8)
Secondary	33(22.9)
Higher Education	12(8.3)
Main occupation	
Employed	16(11.1)
Business	29(20.1)
Farmer	99(68.8)
Household income (Tshs)	
Less than 100,000	22(15.3)
100,000–300,000	97(67.4)
300,000–500,000	10(6.9)
Above 500,000	15(10.4)
Number of children	
No children	20 (13.9)
1–5	118(81.9)
6–10	6(4.1)
Owning mobile phone	
Yes	144(100)
No	–

Values are reported as N (%)

the control group performed better than did the incentive group. (Fig. 5b).

The age of the participants also appeared to influence the results, with significant differences found between incentive and control groups. For example, age groups ‘under 30’ and ‘40–49’ in the control group recorded and uploaded data for more nights compared to the incentive group, and the age group ‘30–39’ and above ‘50’, the incentive group recorded and uploaded data for more nights than the control group (Fig. 5c).

In terms of gender, female participants with no incentives recorded and uploaded data for more nights than to female participants with incentives. However, for male participants, those with incentives recorded and uploaded data for more nights than did male participants in control group. (Fig. 5d).

However, in terms of income level, the participants with income ranging from 100,000/= Tshs to 300,000/= Tshs

and above 300,000/= Tshs in the control group recorded and uploaded data on more nights than participants with incentives. For those with an income level less than 100,000/= Tshs the incentive group recorded and uploaded more data for more nights than did the control group. (Fig. 5e).

Additionally, in terms of occupation, the farmers, tailors, fishermen, health worker and teachers, who received incentives recorded and uploaded more data than did those in the control group. However, business participants with no incentives recorded and uploaded data for more nights than the business participants with incentives (Fig. 5f).

Stage three: participants feedback on the use of the MozzWear application

In terms of their experience in participating in this study, 98% of participants strongly agreed that the information provided helped them to perform the activities in the study effectively, and 85% strongly agreed they were updated about the study. Additionally, 87% expressed that they felt valued for their participation in this study. Regarding the MozzWear app, 64% agreed that it was easy to record and send the data, but 36% disagreed. Ninety-two per cent agreed they were treated with courtesy and for those who received incentives, 57% agreed that the airtime credit incentives provided were sufficient, while 43% disagreed with this. In addition, 79% agreed that a fully charged mobile phone managed to record the mosquito sound overnight. Also, 69% agreed to upload the MozzWear application on their personal mobile phones and 60% agreed that they would Like to get feedback at the end of the study. Finally, 79% strongly agreed to consider taking part in future studies (Fig. 6).

Discussion

The aim of this study was to explore the impact of incentives on citizen scientists involved using the HumBug mosquito detection tool, specifically to assess whether airtime incentives motivate participants to record and upload mosquito data. The study hypothesized that the provision of airtime incentives would increase the motivation for their participation, resulting in an increased number of nights of successful recording and uploading acoustic data. Overall, study results suggest that the participants in the control group recorded and uploaded data for more nights than did those in the incentive group. A previous study conducted in Malawi assessed whether providing incentives would motivate participants to take their HIV tests. This study showed that giving participants incentives increased their desire to seek HIV results [37]. However, a previous study conducted in Peru assessed whether providing incentives for

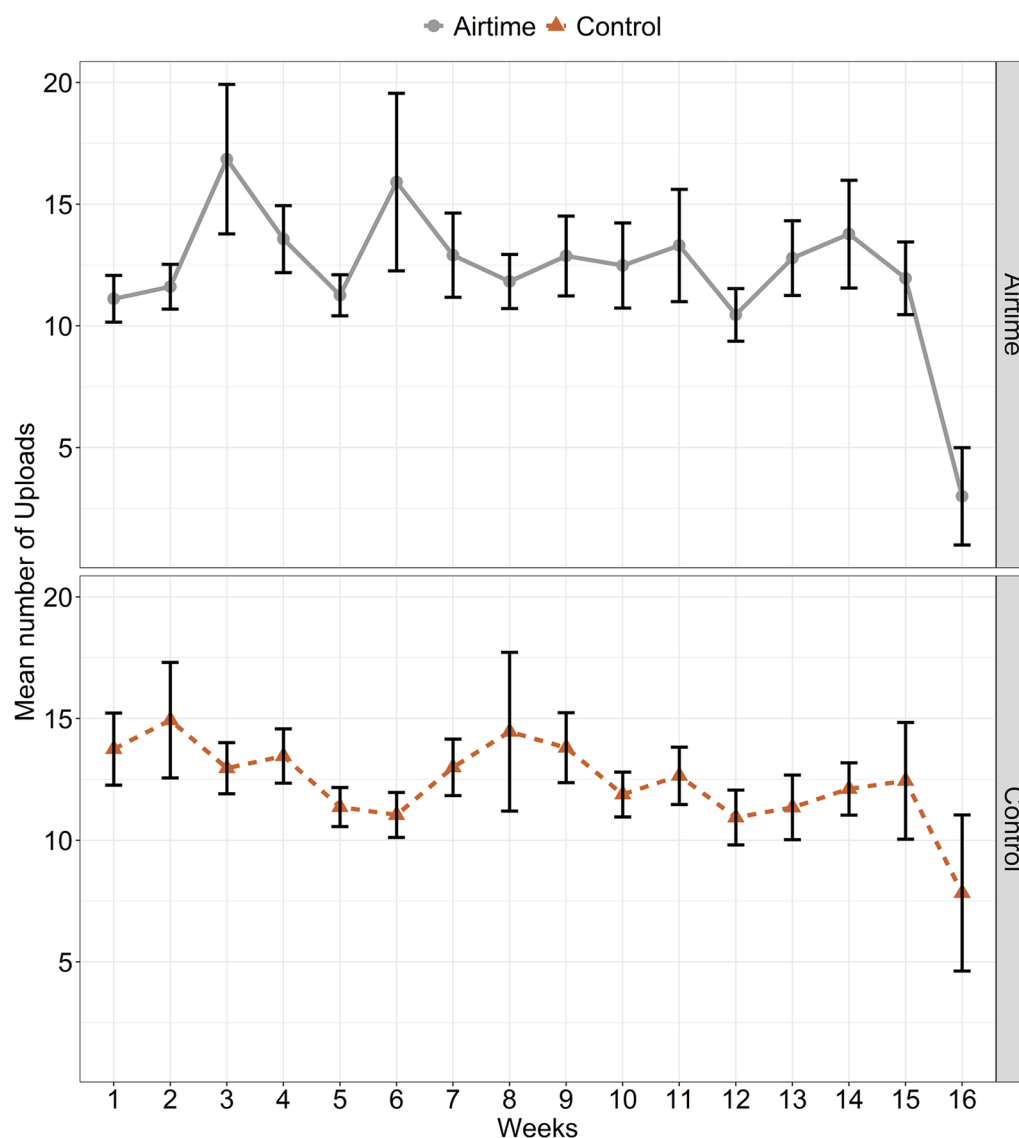


Fig. 4 **a** The graph showing the trend of the mean number of nights with successful uploads in 16 weeks of data collection between the incentive and control groups. **b** Overall mean number of nights with successful uploads of mosquito sound data between the incentive and control conditions

participation in a vector-control campaign undermines the natural desire of community members to participate. The study showed that providing incentives did not affect the natural desire for participation; nevertheless, it was found that incentivized participants were actually more likely to continue participating in the campaign after the incentives were removed. The authors suggest that incentivizing participation in public health campaigns can be an effective way to increase engagement without undermining intrinsic motivation [24].

This study also demonstrated the relationship between different demographic variables and the number of nights

of data recording and uploads. The study revealed differences in performance in terms of recording and uploading data in the different villages. In Mavimba and Milola, participants in the control group recorded and uploaded data more often during the night than did those with incentives. However, in Minepa and Kivukoni, participants who received incentives performed better than did those in the control group. Additionally, for the participants' age, this study found that the control group in the age groups 'younger than 30' and '40–49 years' recorded and uploaded data on more nights than did the incentive group. Younger participants were more likely to have

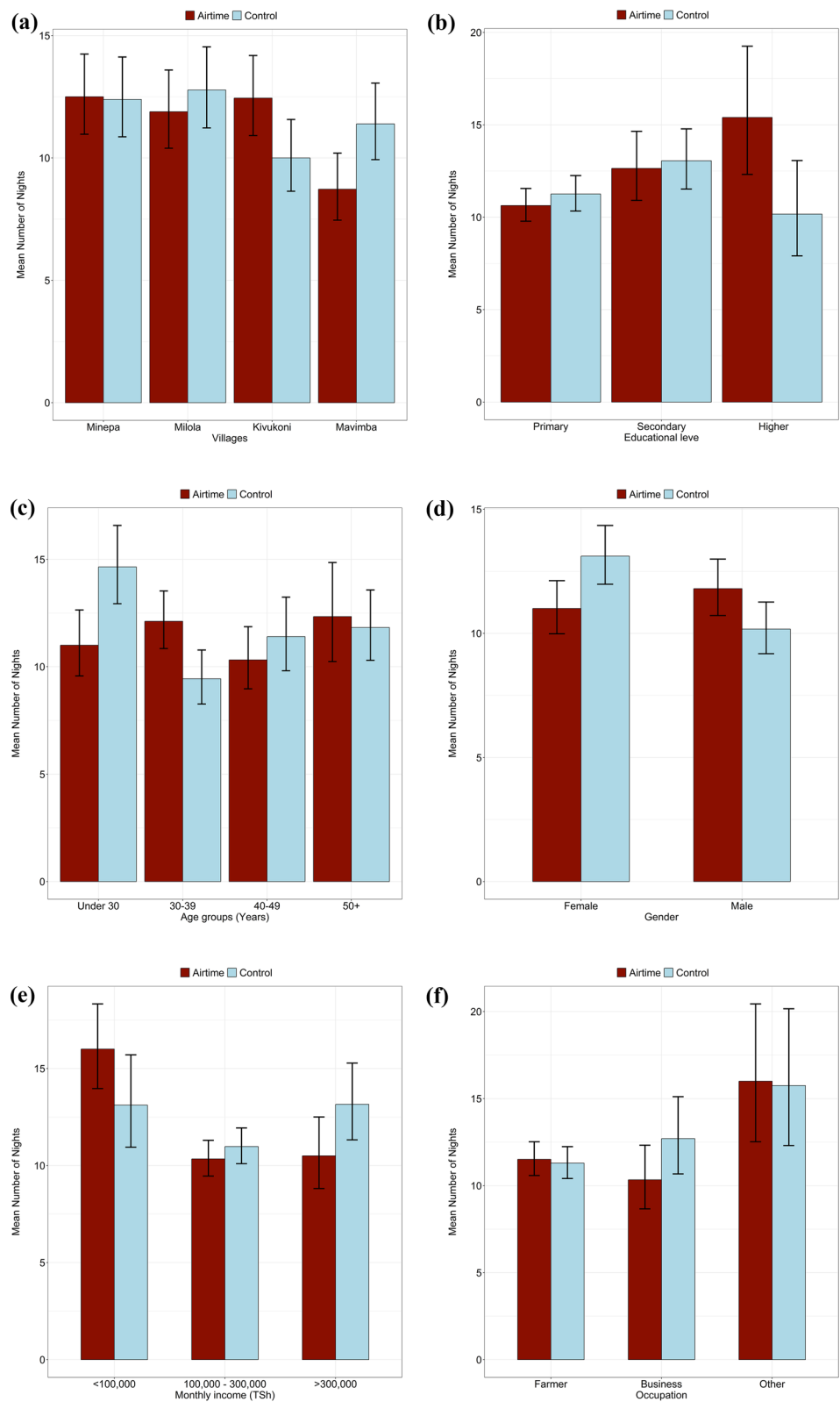


Fig. 5 Graphs showing the effect of receiving an incentive to record and upload mosquito sound data. The study compared **a** villages, **b** education levels, **c** age groups, **d** gender, **e** income, and **f** occupation in terms of the number of nights of recording and uploading data

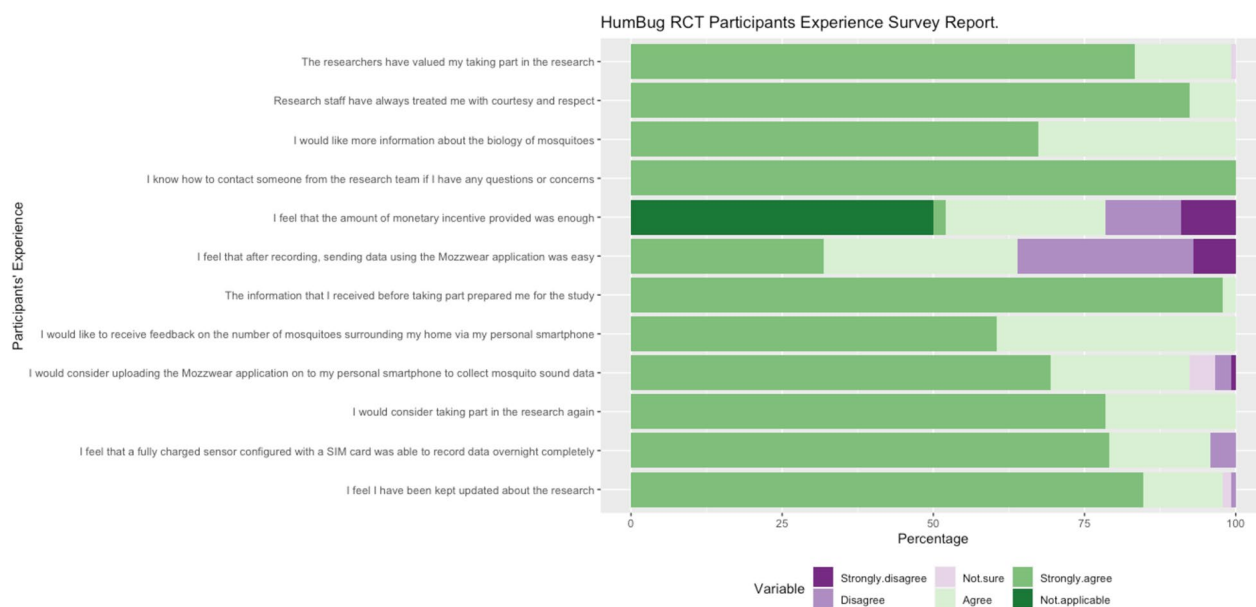


Fig. 6 Likert scale plot showing participants' experience during the study

knowledge of using smartphones than older participants were. This could explain why the younger 30 participants performed even without incentives compared to the older 50 years old participants. The farmers were highly motivated by incentives; this group tends to migrate to their farms for a couple of days [26], and these villages also have two seasons of farming (the rainy season and dry season using irrigation systems), which might hinder their performance. However, compared with the incentive group, the control group in the business category recorded and uploaded data on more nights. The contrasting results between the two groups could be related to the fact that the farmers' incomes are seasonal, so any incentive could help them improve their Life. Nevertheless, businesspeople accumulate income on a daily basis, so such incentives might not affect their intrinsic motivations as much as they do for farmers. This study also revealed differences in performance in terms of gender. The findings showed that female participants in the control group recorded and uploaded data more often than male participants, whereas the males in the incentive group performed better. In this study area, the culture forces women to be responsible for all household activities, while men are responsible for providing for all family needs. This might also explain why women performed better without incentives than men did. Additionally, in terms of income levels, those with incomes higher than 100,000/= Tshs in the control group performed better than did those with incomes Lower than 100,000/= Tshs. This is also an indication that those with earnings are more likely to work even without considering any

incentives. However, for education level, compared with participants with higher education levels, those with primary and secondary education in the control group recorded and uploaded data more nights.

The importance of using citizen science in mosquito surveillance and control programmes has been demonstrated in several previous studies [17–19, 21, 38, 39]. For example, Low et al. [17] highlighted the benefits of using citizen science in vector control efforts to increase participation in hard-to-reach locations, improve data collection and analysis, and minimize the time frame for data collection [18]. This present study, citizen scientists were involved in recording and uploading the flight tones of mosquitoes using the MozzWear smartphone app. During the FGD, the study showed that the participants were willing to participate in the study, as they desired to be part of the study on malaria elimination and wanted to gain knowledge on mosquito identification by the end of the study. This was also observed, for example, as female participants with no incentives recorded and uploaded data for more nights than did those who received incentives. These reasons are consistent with those mentioned by other citizen participants in previous studies involving addressing issues that hinder their community's health and wellbeing [40–42]. Participants were willing to take part in the study even without receiving incentives. Previous studies have also indicated that citizens are willing to take social responsibility for addressing concerns, especially when solving problems that result in a loss of life, such as disease [40, 42]. In this study, the participants expressed that they needed support to make the trial

successful. They mentioned that solar chargers or power banks are needed for charging phones, especially during the rainy season, since power cuts are frequent and could hinder the recording and uploading of data.

Before commencing the study, participants anticipated some of the challenges that they may face during the study, including lack of electricity in their household for charging their phones, seasonal migration to farms during the rainy season, phones being stolen, lack of knowledge about using smartphones to record mosquito sounds. They also requested being given feedback about the findings of the research by the research team [34]. Therefore, in the present study, participants were provided with a weekly mobile phone charging cost of 500/= Tsh to enable them to record and upload the data successfully. Participants were asked not to travel with the smartphones provided by the study since they were only allowed to record at the consented household and villages; hence, a requirement to take part in the study was that each participatory household should have at least two adults so that one of them is absent and the other person can record and upload the data. This was done accordingly by the participants, and there was no problem with this. Additionally, three phones were stolen, as highlighted by participants at the beginning of the study, and the research team immediately replaced the phone to avoid delays in recording and uploading the data. Regarding the participants' familiarity with smartphone usage, the study revealed that after providing them with training and user manuals, they were able to record with minimal errors. To provide feedback, after completing the study, the research team returned to the villages and conducted feedback sessions where they reported the results, encouraged discussions and provided information on how the community could reduce mosquito biting and hence malaria transmission. However, no report of gender-based violence were received in relation to the incentives given to female participants.

An important finding from this study is that citizens wanted to remain informed about the study's progress and receive feedback at the end. In the past, the researchers collected data from their villages and never returned to explain what was found during the study. As such, participants expressed a desire to learn about their achievements and any significant problems that were discovered so that they could take appropriate action. Moreover, the participants highlighted the need to be treated with courtesy and respect, which they confirmed was achieved during this study. The participants also emphasized the need for cooperation between researchers and citizens to address serious mosquito-related problems. Previous studies have also indicated the importance of providing feedback to communities after they accomplish their

objectives [42]; this process builds trust and strong relationships among researchers and communities.

The study also confirmed that airtime incentives can be sent directly to participants via companies that provide this service. Each participant in the incentive group received 23,000/= Tshs every four weeks (4 days of recording and uploading data). This airtime was sent directly to participants' personal mobile phones. This service was provided by Beem Africa, and there were no complaints from participants about the services. This service also minimized the cost of operation, such as hiring a car to travel to the villages to distribute airtime. This approach was also used since the study relied on leaving the participants to monitor mosquitoes on their own and recording and uploading the data without assistance during the length of the study. Thus, paying the incentive via Beem Africa helped to minimize study team presence in the villages.

Recognizing the potential of the citizen participants, this study evaluated their experience taking part in mosquito sound recording and uploading the data. The study showed that the information provided to citizen participants helped them to easily record and upload the data. Most participants in the incentive group indicated that they had received a suitable amount of airtime credit, although a few suggested that the incentive should be increased in the future and that they would prefer cash more than airtime. Participants across both trial groups reported that it was easy to record and send the data using the MozzWear app, although some reported problems with uploading the data. Since uploading mosquito data depends on a viable internet connection, villages that were further away from the internet tower, such as Kivukoni, Mavimba and Milola, had more problems in uploading the data, and they had to move to places where they could obtain better connections. Many participants reported that they would like to upload the MozzWear app to their personal mobile phones in the future, and all the participants of the study were ready to take part in future studies.

This study has several limitations. While citizen participants were recording and uploading mosquito flight tone data, some of the participants were using their mobile phones for personal reasons despite being asked not to do so. Indeed, some of the participants uninstalled the MozzWear application (although the phones were locked), assuming that at some point, the participants could use the smartphone for personal use, hence destroying the whole system of recording mosquito sounds. The study also showed that some participants installed new applications that were not on the phones when they were deployed. Some of the smartphones ended with broken screens, while others had issues with the charging

system, causing a factory reset. Finally, as noted by some participants in the initial interviews, three phones were stolen. However, the main issue encountered was Internet connectivity, especially for villages far from the Internet Tower. This issue was raised during the participants' experience survey conducted at the end of the study. This study also did not include special groups, such as participants with disabilities; therefore, future studies should consider including these important groups.

Conclusions

This study demonstrated that incentives strongly motivated how well the community participated in the study. The study gained evidence that, without incentives, citizens uploaded data on more nights than did those with incentives. The level of motivation varies between demographic variables. Citizens with high incomes and those with businesses are more likely to upload data more quickly without any incentives because individuals with more resources and greater financial stability are less dependent. The participants' level of motivation was driven by intrinsic motivation. This study also highlighted that younger citizens were more willing to participate even without incentives because younger people are often interested in following technology; hence, providing them with smartphones could be the reason for better performance. Participants were willing to use their personal mobile phones to record and upload mosquito sound data in the future because of their ability to fight mosquito-borne diseases. However, some participants did not use the MozzWear recording app because they made some changes to those smartphones by changing some features and adding new applications to the phone despite restrictions. Thus, future studies should consider assessing human behavior when providing tools or technologies to study participants to understand how the participants behave, what motivates them, and what perceptions of value, trust usability and challenges may encounter.

Abbreviations

RCT	Randomized control trial
VBD	Vector borne diseases
LLINs	Long lasting insecticidal nets
WHO	World Health Organization
FGD	Focus group discussions
GAT	Gravid Aedes Trap
CDC	Centre for diseases control
RBu	Resting bucket trap
BG	Biogent
GLM	Generalized linear model
IRB	Institution review board
Tshs	Tanzanian shillings
HIV	Human Immunodeficiency virus

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Author contributions

KW, RD and WPM designed the study, WPM implemented the study, analysed the data and drafted manuscript. YM analysed the data and reviewing manuscript, DM, MS, IK, EH, SR, and EK were involved in implementation of the study and reviewing the manuscript. All author read and approved the manuscript.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare no competing interests.

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