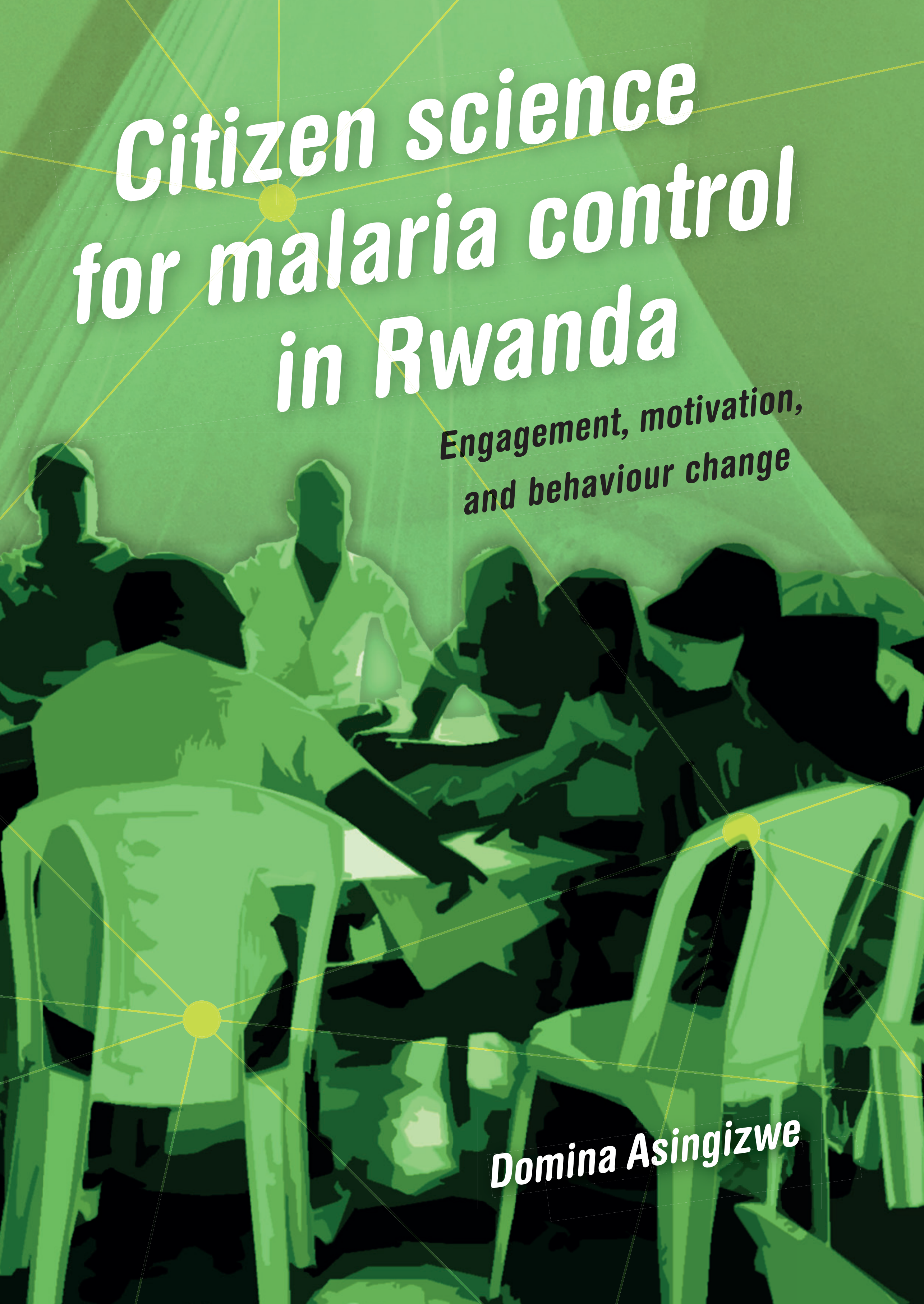
Citizen science for malaria control in Rwanda

Engagement, motivation, and behaviour change

Domina Asingizwe



Propositions

1. To address the malaria problem, interventions need to integrate individual and collective action approaches.

   (this thesis)

2. Motivation is the key element for the retention of volunteers in citizen science.

   (this thesis)

3. The potential of novel ICT for international development is overrated in science and policy.

4. Rejection of a manuscript is a stepping stone to career development.

5. Interdisciplinary research has a greater relevance to addressing wicked problems than multidisciplinary research

6. T shape skills are hard to get.

Propositions belonging to the thesis, entitled

Citizen Science for Malaria Control in Rwanda: Engagement, Motivation, and Behaviour change

Domina Asingizwe

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Citizen Science for Malaria Control in Rwanda:
Engagement, Motivation, and Behaviour Change

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Contents

List of Abbreviations

CHW: Community Health Worker

CMAT: Community Malaria Action Team

CSP: Citizen Science Program

FGD: Focus Group Discussion

HBM: Health Believe Model

IDI: In-Depth Interview

IRS: Indoor Residual Spraying

ITN: Insecticide-Treated bed Net

KII: Key Informant Interview

LLIN: Long-lasting insecticidal net

MEPR: Malaria Elimination Project in Ruhuha

NMCP: National Malaria Control Program

SDG: Sustainable Development Goal

SMS: Short Message Service

TPB: Theory of Planned Behaviour

UTAUT: Unified Theory of Acceptance and Use of Technology

Chapter 1

General introduction

Introduction

Vector-borne diseases are a major public health concern worldwide, and among them, malaria is the biggest threat, particularly in Africa where 93% of the world's malaria cases and 94% of malaria deaths occur (WHO, 2019). Despite the progress made to control the disease, resurgence of malaria was observed in malaria-endemic countries including Kenya, Senegal, and Rwanda (President's Malaria Initiative, 2016; Wotodjo et al., 2015; Zhou et al., 2011). Variability in human behaviour and failure to use control measures consistently and effectively are central to malaria resurgence and reintroduction (Gryseels, Durnez, et al., 2015).

The success of malaria control measures depends on the nature and scale of the behavioural response of the populations at risk either at the individual or at collective levels (Obala et al., 2015; Setbon & Raude, 2009). To increase and maintain high levels of malaria control, citizens need to have a level of awareness and understanding related to the disease and be engaged in finding possible malaria control solutions. Additionally, the recent world malaria report highlighted that tailored interventions that engage local citizens are needed for the achievement of malaria elimination, and SDGs in general (WHO, 2019).

The research reported in this thesis was carried out as part of a multidisciplinary project: "*Responsible Life-Science Innovations For Development In The Digital Age: Environmental Virtual Observatories for Connective Action (EVOCA)",* which aimed to develop virtual platforms and participatory monitoring systems towards inducing connective action for addressing development challenges in crops, water, health and wildlife management (Cieslik et al., 2018). Specifically, this research involved monitoring of mosquito populations to contribute to malaria prevention and control through designing and implementing a citizen science program in Ruhuha, Rwanda. This research was conducted in collaboration with an entomological component, and this social component aimed to explore the factors that influence the consistent use of malaria control measures. Through a co-designed citizen science program, it investigated the motivational factors, barriers, and effects of the program on the use of malaria control measures.

Malaria in Rwanda

Encouraged by the progress made in the reduction of malaria over the last decade, Rwanda planned to achieve the malaria pre-elimination phase by 2018 (President's Malaria Initiative, 2015). However, since 2012, Rwanda experienced a remarkable increase in malaria incidence that was reported across the country, especially in the eastern and southern regions, and this caused a great concern (MoH, 2017a; President's Malaria Initiative, 2016). A malariometric survey conducted in 2013 in the eastern part of Rwanda revealed a prevalence of malaria parasitemia of around 6% (Kateera, Mens, et al., 2015). Malaria prevalence continued to increase as time progressed. A Rwanda malaria indicator survey conducted in 2017 indicated that the prevalence of malaria in the general population was 7% and when provinces were compared, the prevalence is even higher (17%) in the Eastern province (MOH, 2017b). The same report revealed that the prevalence of malaria among children aged between five to fourteen years old was 11% and even 13% among children from rural areas. This indicates that malaria is still a burden in Rwanda especially in rural areas, and most dominantly in the Eastern province.

Many factors are associated with this increase in malaria prevalence over time. Human perceptions have played a role in the ineffective use of malaria control measures, and incorrect self-treatment (Ingabire et al., 2014; Ingabire et al., 2015). In addition, changes in mosquito biting behaviour, which contribute to residual transmission, have been reported (Hakizimana et al., 2018; Sherrard-Smith et al., 2019). Such residual transmission is further increased by human activities, especially when people spend more time outdoors in the evening, thus exposed to mosquito bites. Although a high proportion (around 80%) of bites from malaria vectors occurs when people are already in bed, outdoor transmission continues to have a high impact on the health of the population (Sherrard-Smith et al., 2019). This is because it can continue to increase malaria incidence even when universal coverage of malaria control measures has been achieved. In turn, outdoor transmission and its associated increase of malaria cases may cause people to question the effectiveness of the control measures, the efficacy of malaria medicines, and may even decrease the consistent use of these measures (Sherrard-Smith et al., 2019).

Malaria control measures

Long-Lasting Insecticidal Nets (LLINs), Indoor Residual Spraying (IRS), and control of mosquito breeding sites are the primary measures that have been used to control malaria in many malaria-endemic countries including Rwanda. Globally, 80% of insecticide-treated mosquito nets (ITNs) (the first generation mosquito nets) delivered by manufacturers, were distributed through mass distribution campaigns, and 87% of the total ITNs produced in 2018, were distributed to Sub-Saharan African countries (WHO, 2019). In 2006 Rwanda had the first mass campaign distribution of LLINs (the next generation mosquito nets) targeting pregnant women and children under five years of age (MoH & (NISR), 2009). Since then, the President's Malaria Initiative (PMI) has collaborated with the National Malaria Control Program (NMCP) and the Global Fund to continue the procurement and distribution of LLINs to achieve universal coverage as recommended by the World Health Organization (President's Malaria Initiative, 2017). The Rwanda Ministry of Health reported that between December 2016 and March 2017, more than 5 million LLINs were distributed countrywide (MoH, 2017a).

Generally, in 2019 only half (50%) of people at risk of malaria in Sub Saharan Africa slept under LLINs, and only 57% of the population had access to LLINs; this remains far from the target of universal coverage (WHO, 2019). In the same line, the recent Rwanda malaria indicator survey report indicated that 84% of households own at least one LLIN, and 72% have access to LLINs, meaning that 72% have enough LLINs (one for two people) (MOH, 2017b). However, 64% of the households visited slept under an LLIN the night before the survey, this indicates a gap between the accessibility and use; as well as between ownership and use of LLINs (MOH, 2017b).

Different authors have explored the factors associated with the use of LLINs. Babalola et al. (2018) reported factors including sociodemographic and household variables, and psychosocial variables to be associated with using a bed net every night rather than rarely or never using a bed net. Although the protective effect of LLINs against malaria has been widely accepted (Wangdi et al., 2018), some studies indicated a gap between ownership of LLINs and related consistent use (Ernst et al., 2017; Kateera et al., 2015). This indicates that availability and ownership of LLINs are not sufficient to ensure consistent and effective use.

Concerning the use and acceptance of the IRS, only a few people in malaria-endemic countries are protected by IRS (WHO, 2019). IRS coverage continues to drop as there was a shift from pyrethroids to more expensive insecticides, and hence fewer areas could be treated. The contribution of the IRS to malaria infection reduction largely depends on the scale of deployment and how early it was sprayed (Bhatt et al., 2015). In addition, the level of willingness to take up the IRS by the community members is still low (Wadunde et al., 2018), and some factors have been identified to influence IRS acceptance. Having enough information about IRS and trusting the sprayers have been associated with the willingness to take up the IRS (Wadunde et al., 2018).

Appropriate environmental management of mosquito breeding sites is one way to control malaria (Oladepo et al., 2010). Malaria control strategies by targeting its source have shown significant results in many settings (Castro et al., 2009; Ingabire et al., 2017). Following environmental management which involves community engagement, there is an increase in community awareness about mosquito ecology and mosquito breeding sites (Castro et al., 2009). Some strategies target the different stages of malaria vectors (for example larval source management) (Ingabire et al., 2017). This requires the involvement of local communities because some of the people’s activities, such as rice irrigation, result in more exposure to mosquito bites and hence increase their chance of getting a malaria infection (Janko et al., 2018).

Problem statement: a need for an integrated approach to control malaria

Combining environmental management and LLINs adherence significantly reduces the risk of getting malaria (Obala et al., 2015). In addition, engaging community members in environmental management reduces mosquito density, and, consequently, decreases malaria incidence (Castro et al., 2009; Obala et al., 2015). Like other endemic countries, Rwanda has also been making an effort to control malaria, and recent research has focused on larval source management (Ingabire et al., 2017). However, in most cases, these efforts work independently, and there is no integrated approach to control malaria. The World Health Organization calls for an investment in new approaches and tools to accelerate progress in controlling and eliminating malaria (WHO, 2019). This requires a complementary approach that integrates these control measures and engages community members in malaria control.

However, this raised the question of what could be the approach to engage community members in malaria control? In recent years several studies have suggested that citizen science can be a vital strategy for engaging communities (Church et al., 2019; Cieslik et al., 2018; Leeuwis et al., 2018). Therefore, this study investigates the co-design process and the impact of such a citizen science program.

Citizen science

Citizen engagement in scientific research has become increasingly popular in many parts of the world (Aristeidou et al., 2017; Jordan et al., 2017). Citizen science has been defined as the participation of members of the community in scientific work. This participation can vary and include involvement in defining research questions, collection of scientific data, analysis, and interpretation of these data. For a long time, citizen scientists have been involved mainly in the collection and reporting of scientific data. However, as the citizen science field expands, the collaboration of scientists and citizens has expanded as well and citizen science has been now focusing on environmental monitoring (Cieslik et al., 2018; Stevens et al., 2014).

Citizen science involves the general public in environmental monitoring through participating in collecting and submitting, and/or analyzing related data for further decision making (Bonney et al., 2016). Although citizen science can be designed and applied in all fields of research, it has been implemented in particular to address conservation and environmental problems (Pocock et al., 2017; Turrini et al., 2018). Citizen Science Projects (CSPs) have been conducted across a range of disciplines including biology, environment, astronomy, and medicine, with the latter occupying only 2% of these projects (Follett & Strezov, 2015).

Despite its potential to generate large amounts of citizen science data, the majority of studies evaluate the impact of citizen science focusing only on volunteers who are directly involved in the collection and report of citizen science data (Jordan et al., 2011; Toomey & Domroese, 2013), but not to the community at large. Only few studies extend the focus beyond volunteers to include other community members (Roetman et al., 2018). Furthermore, recently the United Nations have indicated that a citizen science approach can play a role in the achievement of SDGs (Pocock et al., 2018; Fritz et al., 2019; Quinlivan et al., 2020). For example, citizen engagement in water quality monitoring, which is comparable to the lab-based monitoring networks, may contribute to the achievement of SDG #6, clean water and sanitation (Quinlivan et al., 2020). However, despite its potential, citizen science typically has little priority and is often not visible among the tools that are used for achieving the SDGs in many developing countries particularly in Africa (Pocock et al., 2018).

Fostered by the current advances in technology, CSPs have the potential to not only provide reliable and localized information (Jordan et al., 2017), but also to connect people, and engage them in addressing environmental challenges (Cieslik et al., 2018). In citizen science, Information Communication and Technology (ICT) facilitates community outreach by using different communication channels, thereby broadening participation and exchange of large scale, real-time information (Sullivan et al., 2009). However, some CSPs have seen a high attrition rate and the reasons behind this are not fully clear (Jordan et al., 2017; Worthington et al., 2012). There is a need to explore the reasons for this high attrition rate, for future retention of the volunteers. One important way of exploring these reasons is to identify why citizens would decide to get and stay engaged in a citizen science project. These motivational factors may play a role in the participation and retention of volunteers in CSPs, thus, remain a central area to study. Additionally, when designing a CSP, one needs to plan about what outcomes to expect, and how they can be assessed. Consequently, the effect of the CSP is a key component to explore as well.

Theoretical framework

Overall, control of vector-borne diseases is influenced by different determinants, ranging from individual to collective levels. An integrated framework that can help to identify these determinants is still lacking. This thesis developed an integrated model of determinants of malaria prevention behaviour based on well-established models: Health Belief Model (HBM), Theory of Planned Behaviour (TPB), and Unified Theory of Acceptance and Use of Technology (UTAUT). This integrated model will guide the analysis across chapters of this thesis.

The *Health Belief Model (HBM)* explains the linkage between perceived threats, efficacy, and engaging in a certain behaviour (Olsen et al., 2008). It has been used to analyze the relationship between perceptions and use of LLINs (Abdullahi et al., 2013; Beer et al., 2012; Watanabe et al., 2014). This model is limited to individual perceptions and does not consider social factors as predictors of using malaria preventive measures (Beer et al., 2012; Watanabe et al., 2014).

On the other hand, the use of LLINs is considered more as an individual activity, thus the HBM would be appropriate when LLINs use is the only variable under study. These perceptions are considered to influence behaviour through intentions, however, HBM does not consider intention as one of the concepts (Conner, 2015).

The *Theory of Planned Behaviour (TPB)* is a theory explaining that the intention behind any behaviour is determined by an individual's attitude toward that behaviour, perceived behaviour control, and relevant subjective norms (Munro et al., 2007). However, for the behaviour to occur there should be an intention to perform that behaviour, and the intention is considered as a requirement for behaviour (Conner, 2015).

In this thesis, we initially envisioned to use a web-based platform for sharing and communicating malaria-related information as well as observations (mosquito nuisance and mosquito species) collected by the volunteers. For this reason, we also included part of the *Unified Theory of Acceptance and Use of Technology (UTAUT).* UTAUT is an expansion of the technology acceptance model which describes and predicts the usability and use of new information technology (Venkatesh et al., 2003). UTAUT considers social context and cultural trends as the main factors of technology acceptance.

Integrating these three models creates an innovative and comprehensive model that presents the determinants of the behaviour with regard to the use of malaria control tools in combination with factors that determine participation in a citizen science program. Beyond the integration of these models, some other collective factors including collective action and social capital have been added to the model. This model may be used either in other settings beyond the case study, in other vector-transmitted diseases, or other behavioural change projects.

Research objectives

The overall objective of this thesis is to understand the factors that influence the consistent use of malaria control measures and how a citizen science program may contribute to this use.

Specifically, the study designed and implemented a citizen science program and investigated the motivational factors and barriers to participate, as well as the effects of this program on the use of malaria control measures.

The thesis was guided by the following specific research questions:

1. What factors predict the consistent use of malaria control measures and participation in a citizen science program?

2. To what extent do individual perceptions influence the intentions to use malaria preventive measures, and what strategies stimulate the consistent use of these measures?

3. What preferences do community members present when co-designing a citizen science program for malaria control in Rwanda?

4. Why do people participate in a citizen science program for malaria control in Rwanda?

5. What benefits do community members get from a citizen science program for malaria control in Rwanda?

Methodology

This section describes the case setting, the overall study design, and the main data collection methods used.

Case setting

This study was conducted in the Ruhuha sector, in the Eastern province of Rwanda (Figure 1.1). This sector covers an area of 54 km^2 with 5,098 households and a population of approximately 24,000 (Kateera et al., 2015). It has 35 villages grouped in five cells (Kateera et al., 2015). The Ruhuha sector has one health center and around 140 CHWs. Ruhuha is bordered by Lake Cyohoha and has numerous marshlands and water streams draining into the Akagera River. This area was selected as it is among the high malaria-endemic areas in the country due to the presence of these marshlands and various rice farming activities in the area.

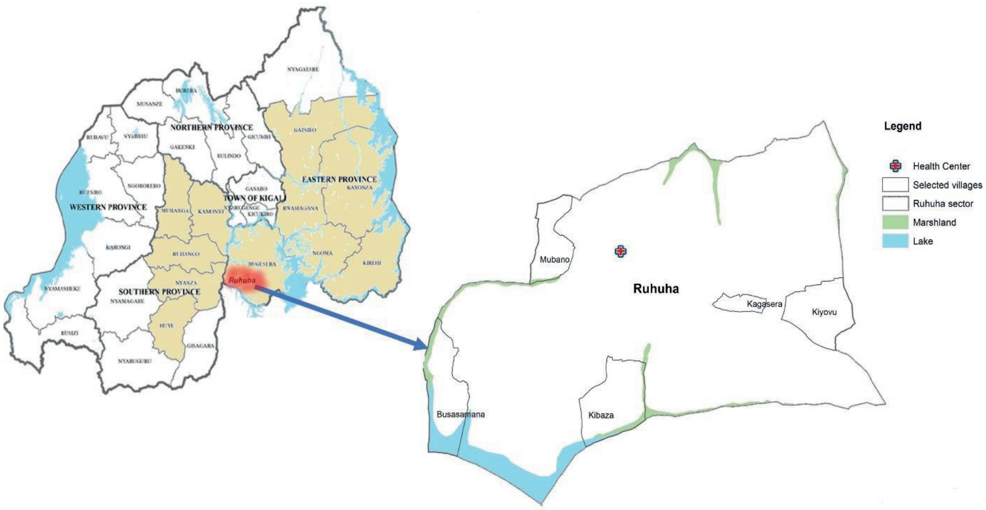

Figure 1.1: Map of Rwanda indicating Ruhuha sector as a study site and five villages where the citizen science program was implemented

Research design

Overall, a case study methodology was used. This is a valuable approach that allows for designing, implementing, and evaluating an intervention or a program (Baxter & Jack, 2008). It provides an in-depth understanding of a phenomenon and is most preferred when *why* and *how* questions are asked (Fridlund, 1997; Luck et al., 2006). Furthermore, a case study design allows for the use of mixed approaches, and multiple data sources for triangulation and generation of strong evidence (Yin, 1992, 1999). In this research, a non-ICT based citizen science program for malaria control was designed and implemented in Ruhuha, Rwanda. Prior to the design process, an exploration of malaria risks and the use of malaria control was made. This study was also partly participatory action research because it involved people in data collection and actions that aimed to improve their health (Baum et al., 2006). Both quantitative and qualitative approaches were used. The mixed approach was used to complement each other and to provide stronger, potentially valid and reliable results.

Methods used for data collection

Data were collected in four main phases (baseline, design, follow-up, and evaluation; Figure 1.2) and involved five different methods of data collections: surveys, interviews, focus group discussions, workshops, and meetings.

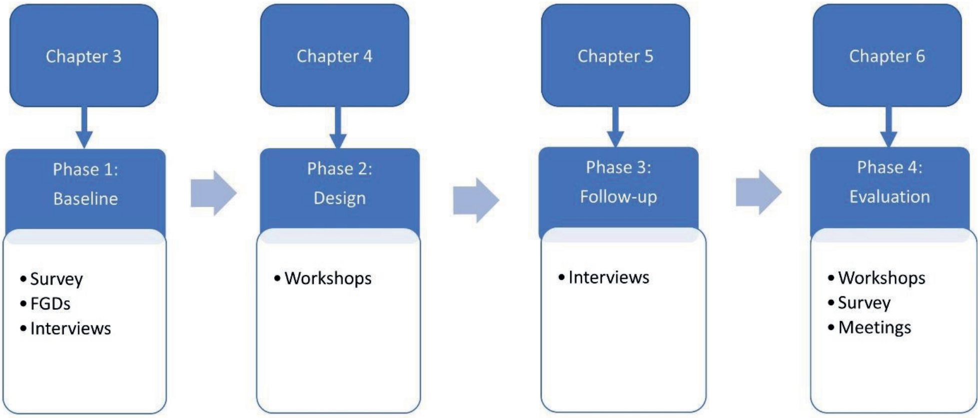

Figure 1.2: Research phases and methods of data collection for empirical chapters

Baseline and end-line surveys

Prior to the design of a citizen science program (CSP), a household survey was conducted in Ruhuha and Busoro sectors (phase 1). This survey was conducted to generate information related to perceptions about malaria, the use of malaria control measures, and barriers to their adoption. In addition, this was to analyze the knowledge gap and strategies that can be used to engage community members in malaria control. The end-line survey (phase 4) was conducted among those who were involved in the baseline to assess the change of individual perceptions and malaria-related behaviour over time, and compare these perceptions and behaviour among volunteers (those who were directly involved in the CSP) and non-volunteers (those who were not participating in collection and submission of citizen science data).

Interviews

In-depth interviews and key informant interviews were used in phases 1 and 3. Stuckey (2013) mentions that a well-conducted interview enables free expression and gets accurate answers.

In this regard, the interviews were preferred in this study because the use of malaria control measures specifically LLINs is considered an individual activity, and there are more chances of having a social desirability bias when one on one interview is not used in this case. Additionally, in phase 3, a follow-up study was conducted to explore the motivational factors to participate and the barriers to get and stay involved in a citizen science program. These interviews were conducted among volunteers (who actively participated in the program) and those who did not participate in the program but who attended participatory design workshops that were used to recruit the volunteers.

Focus Group Discussions (FGDs)

FGDs were conducted in phase 1 to (1) understand the perceptions related malaria and the effectiveness of current malaria preventive measures, and (2) explore possible strategies to promote their consistent use. To allow people to express themselves and maximize group interaction, homogenous groups were used (for example, a focus group of men).

Workshops

Participatory Design Workshops (PDWs) were used in phase 2 to engage community members in the co-design of a citizen science program. In addition, dissemination workshops were used in phase 4 to give feedback to the volunteers about what they are reporting, and discuss them about challenges encountered and how to overcome them.

Local meetings

Village meetings were conducted in phase 4 to discuss with the volunteers about collective actions that they may have done in their villages, and possible ways that they have used to disseminate the program's activities to non-volunteers in their respective village. The researcher visited the volunteers in their respective villages.

Further details on methods of data collection and data analysis are provided in the empirical chapters.

Outline of the thesis

This section highlights the content of each chapter of this thesis. The thesis is composed of seven chapters including this chapter, as illustrated in Figure 1.3.

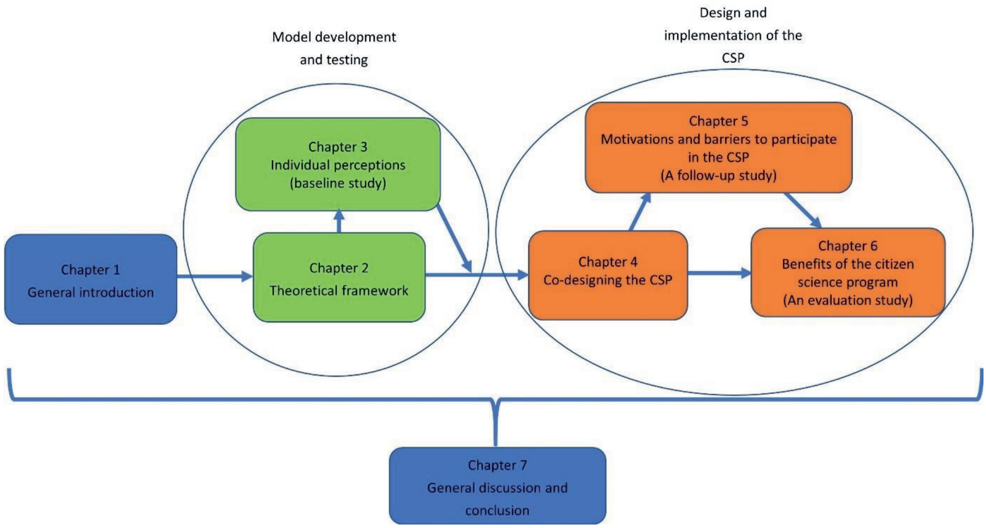

Figure 1.3: A logical flow of the chapters for this thesis; CSP= citizen science program

Chapter 2 presents an integrated conceptual model with both individual and collective factors to predict the use of malaria preventive and control measures and engagement in a citizen science program. In addition, it also hypothesizes the potential impact of a citizen science approach on malaria-related behaviour and key features of a citizen science program.

Chapter 3 tests the conceptual model by assessing to what extent individual perceptions influence the intentions to use malaria preventive measures, and explores strategies that may stimulate consistent use of malaria preventive and control measures.

Chapter 4 describes community preferences to consider during the co-design of a citizen science program for malaria control.

Chapter 5 investigates the motivational factors and barriers for participation in a citizen science program.

Chapter 6 evaluates the effect of a citizen science program for malaria control in Rwanda.

Chapter 7 synthesises the main findings, provides the general discussion of these findings by putting them in a broader context of citizen science, and malaria control in particular, and provides recommendations for policy, citizen science practice, and future research.

Chapter 2

Applying citizen science for malaria prevention in Rwanda: *An integrated conceptual framework*

This chapter is based on: Asingizwe, D., Poortvliet, P. M., Koenraadt, C. J. M., Van Vliet, A. J. H., Murindahabi, M. M., Ingabire, C. M., Mutesa, L., & Feindt, P. H. (2018). Applying citizen science for malaria prevention in Rwanda: An integrated conceptual framework.

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Abstract

Malaria remains a major threat to public health. Long-Lasting Insecticide-treated Nets (LLINs) and Indoor Residual Spraying (IRS) have been widely adopted as important malaria prevention and control interventions and have contributed to a significant reduction in malaria incidence. However, recently malaria resurgence has been reported in different countries, including Rwanda, indicating that current attempts to control and eliminate malaria may be failing due to environmental changes and changes in human behaviour. Engaging citizens in malaria prevention and control would help them to identify and prioritize their health concerns and be able to make appropriate decisions. A citizen science approach to monitor ecological changes by providing timely information is likely to support more effective and consistent use of malaria prevention and control interventions. However, the application of citizen science in malaria prevention and control has lagged behind when compared with areas of disease diagnosis and treatment. In addition, the determinants of participation in such a citizen science program have not been fully analyzed. This chapter presents a conceptual model of likely determinants of participation in connective action (collecting and reporting of malaria-related information), effective and consistent use of malaria preventive and control measures (LLINs and IRS) and collective action (participating in public goods for malaria prevention and control). The model will guide future research on behavioural and contextual factors and may enhance the effective and consistent use of malaria preventive and control interventions.

Introduction

According to the World Health Organization (WHO), malaria is one of the most important parasitic and infectious diseases worldwide (WHO, 2016) and contributes heavily to the global disease problem. The Sub-Saharan Africa region, including Rwanda, carries the heaviest malaria burden (WHO, 2016). While Rwanda's entire population is considered at risk of malaria, 19 of the 30 districts are classified as high malaria-endemic areas of which 11 account for more than 76% of the malaria cases (President's Malaria Initiative, 2017). During the last decade, much progress has been made in reducing malaria transmission in Rwanda. This has led the Ministry of Health to set a target of entering the pre-elimination phase (a phase between control and elimination) by 2018 (President's Malaria Initiative, 2015). The malaria reduction was associated with the deployment of malaria prevention and control strategies, early diagnosis, and treatment. Malaria prevention and control measures include the use of Long-Lasting Insecticide-treated Nets (LLINs) and Indoor Residual Spraying (IRS), destruction of breeding sites through environmental management, use of repellents and chemoprophylaxis (Atieli et al., 2011; Créach et al., 2016; Gimnig et al., 2016) as well as the use of intermittent preventive treatment among pregnant women (Tobin-West & Asuquo, 2013). However, on a large scale, malaria prevention depends most heavily on insecticide-based interventions (LLINs and IRS) (Okumu et al., 2013) to reduce human-vector contact.

Although there has been a significant global reduction in malaria prevalence, many developing countries have recently seen a resurgence in the number of malaria cases reported, including countries where malaria preventive measures (i.e., LLINs and IRS) were in place, such as Indonesia, Senegal, Kenya, and Rwanda (Murhandarwati et al., 2014; President's Malaria Initiative, 2016; Wotodjo et al., 2015; Zhou et al., 2011). This indicates that availability of these measures alone may not be sufficient for achieving continuous malaria reduction (Obala et al., 2015). Rwanda has seen an eleven-fold increase in reported malaria since 2011, leading the government of Rwanda to prioritize malaria to achieve the target of pre-elimination (President's Malaria Initiative, 2017).

Malaria prevention and control displays features of a 'wicked' public health problem. As first introduced by Rittel and Webber (1973), characteristics of a wicked problem are that it is difficult to define, is influenced by complex political and social factors, involves multiple stakeholders, and is managed but not solved. Similarly, as an infectious disease, malaria can be considered a multifactorial problem, involving multiple actors with various needs, and requires a holistic approach integrating many ecological and social factors (van Woezik et al., 2016). Ecological factors include the variation in space and time of the number of malaria mosquitoes as well as the malaria parasite. This variation is influenced by many environmental variables (e.g., weather, vegetation) (Cohen et al., 2012), societal activities (e.g., rice farming) and socio-economic factors (e.g., quality of housing). There is a need to have a coherent monitoring system for malaria vectors, parasites, malaria episodes in humans, and environmental factors. Ingabire et al. (2016) also revealed that as malaria transmission dynamics change, there is a need to establish and continue a regular monitoring of mosquitoes and malaria incidence to sustain the gains from previous malaria prevention interventions.

Although changes in ecological and environmental factors also contribute to malaria resurgence (Hay et al., 2002; Tong et al., 2017), changing behaviours of the human population at risk is often considered as one of the key factors (Dlamini et al., 2017; Hay et al., 2002; Setbon & Raude, 2009). The disuse of preventive measures is mainly influenced by people's beliefs about the seriousness of malaria (Dlamini et al., 2017), the perceptions about the protective benefits of malaria preventive measures (Galvin et al., 2011), and various other social and cultural factors. However, human behaviour and its determinants are often not considered in malaria control and prevention (Dlamini et al., 2017; Gryseels et al., 2015). Malaria preventive and control interventions will remain ineffective unless the same effort is put into understanding human behaviour and the contexts that influence these behaviours as in understanding malaria vectors (Dlamini et al., 2017; Mwenesi, 2005).

Several studies have indicated that engaging citizens in malaria prevention and control interventions can stimulate their consistent and effective application (Bamidele et al., 2012; Watanabe et al., 2015). Community engagement is key as the community members have the best understanding of their barriers to effective interventions and can propose related possible solutions. Engagement empowers citizens and may create ownership in preventive activities. Rickard et al. (2011) found that engaging individuals and the community in the creation and implementation of malaria prevention intervention helps in achieving and sustaining almost 100% of bed net usage rates. In their study in rural western Ghana, a community-based participatory approach was used through assistance in the hanging of bed nets and provision of related instructions, the creation of in-home small group education, and a regular home visit for follow-up by trained community members (Rickard et al., 2011). The community-based projects consist of involving people affected by a disease or a health event and include them as key partners in the discussion and development of strategies for their protection. However, there is no element of active engagement of citizens in collecting and/or analysis of observations under study.

A community-based project implemented in the eastern province of Rwanda with the involvement of Community Malaria Action Teams (CMATs) to distribute malaria messages in the community by home visit or through community meetings showed a successful contribution to health literacy to improve the use of preventive measures (Ingabire et al., 2016). These CMATs had received malaria-related trainings throughout the project and some of them especially community health workers had prior malaria-related knowledge. Engaging citizens creates a bidirectional communication flow and interaction within and between communities where individuals are invited to share their views and provide feedback on a particular matter of interest, malaria prevention in this case (Watanabe et al., 2015). In particular, Rwanda plans to support social and behavioural change communication strategies through the use of interpersonal communication, community radio with a focus on community mobilization and engagement in the use of LLINS and early diagnosis and treatment (President's Malaria Initiative, 2017). On this base, Rwanda would be a good place to test the application of a citizen science approach. In a citizen science approach, citizens are actively involved in the collection, and possibly interpretation and analysis of scientific data, in this case for example information about mosquito habitats, mosquito nuisance, and the history of specific malaria episodes. Such a citizen science approach may improve the perceptions related to malaria, malaria vectors, and malaria preventive measures, and thereby stimulate the effective and consistent use of these measures. In addition, Rwanda has implemented the RapidSMS initiative throughout the country, which shows that community health workers can already be actively involved in monitoring malaria incidence in children under the age of five.

Generally, most research projects and studies that are being conducted involve health workers in reporting of health-related events and do not involve the general public (Ingabire et al., 2016; Rickard et al., 2011). There is no system to which the health of the larger population can be monitored on a regular basis. Involving citizens in monitoring mosquito dynamics, mosquito habitats, mosquito nuisance, and malaria episodes, potentially creates more sustainable malaria interventions, promotes effective use of these interventions and thereby could decrease malaria incidence. However, thus far no studies have been published that evaluate how the involvement of citizens in the monitoring of mosquito dynamics and malaria episodes can be set up in an efficient way in rural areas of a country such as Rwanda. It is unclear what factors would determine the participation of people in such a citizen science program. It is also unclear how different levels of engagement or the accuracy and timing of information provided and the communication channels used will determine the number of people reached and influence the human behaviour regarding malaria prevention and control. Therefore, this chapter explores the potential determinants of two of the most important malaria preventive measures: the use of LLINs and acceptance of IRS. We then describe the potential impact of a citizen science approach to malaria-related behaviour. Afterwards, we present an integrated conceptual model with both individual and collective factors to predict the use of both malaria preventive measures and being actively involved in a citizen science platform which will be described later in the chapter and will guide future research. We finally present the key features of a citizen science platform that we aim to implement in Ruhuha, a malaria-endemic area in Rwanda.

Use and adoption barriers to malaria preventive and control measures

The WHO indicated that between 2010 and 2015, the proportion of people sleeping under bed nets has almost doubled in Sub-Saharan Africa (WHO, 2016). Eisele et al. (2010) estimated the protective efficacy of LLIN and IRS on the reduction of malaria-attributable mortality among children under the age of five at 55%. Therefore, the WHO Global Technical Strategy for malaria 2016-2030 (2016) stresses that these malaria prevention and control measures should be available and accessible to people at risk (WHO, 2016). Furthermore, these measures should be used effectively and consistently (Russell et al., 2015).

Consistent, effective use and non-use of Long Lasting Insecticide Treated Nets (LLINs)

LLIN provides individual protection by reducing the biting rate and thereby reducing both malaria incidence and malaria mortality (Rickard et al., 2011; Yasuoka et al., 2014). Together, the availability, acceptability, ownership, and the regular and effective use of LLIN are cardinal to malaria infection-prevention worldwide (Lindblade et al., 2015). However, consistent and effective use of LLIN faces major social, economic and cultural challenges (Ng'ang'a et al., 2009; Widmar et al., 2009). Many studies have shown a gap between ownership and actual use of LLIN (Atieli et al., 2011; Ernst et al., 2016; Kateera et al., 2015; Moon et al., 2016). For example, LLINs have been used for constructing chicken pens, fishing or agriculture (Honjo & Satake, 2014; Ingabire et al., 2015). Heat and discomfort were reported as barriers to effective use of bed nets (Ingabire et al., 2015; Rickard et al., 2011). Other studies, however, report low rates of misuse, e.g. only about 3% of study participants in Zambia (Macintyre et al., 2012) and less than 5% in Sierra Leone (Bennett et al., 2012). While these studies did not support the assumption that bed nets are diverted for alternative purposes, they confirmed a gap between bed net ownership and use.

These findings suggest that future empirical studies should aim to identify the determinants of effective use and of misuse of malaria preventive and control measures. Understanding the factors that shape behaviour will also help to design effective interventions to close the gap between bed net ownership and use.

To achieve malaria elimination, individual perception and behaviour related to malaria and malaria prevention are important factors that should be addressed in malaria prevention and control programs. Individual perceptions about the seriousness of malaria and related exposure encourage individuals to consistently and effectively use LLIN (Mukhopadhyay et al., 2016). In addition, Galvin et al. (2011), found that individuals' motivation to use LLINs depends on their perceptions related to bed nets' effect to reduce mosquito nuisance and other protective benefits. Those who use LLIN appear to perceive more malaria preventive benefits of LLIN than preventing mosquito nuisance (Berthe et al., 2014). Comfort (not being annoyed by mosquitoes) while sleeping under bed nets was also reported to encourage people to use LLIN.

The consistent use of LLIN is determined by behavioural factors such as diverting nets to other purposes, using LLIN only during the seasons with a higher risk of mosquito bites (rainy season) and sleeping outdoor (Birhanu et al., 2015; Ricotta et al., 2015). Sleeping location (bed versus floor), sleeping arrangements (the number of people sleeping in one bed) and availability of suitable locations for hanging the LLIN were reported to influence the use of LLIN (Ernst et al., 2016; Iwashita et al., 2010; Kateera et al., 2015). Sleeping on the floor mostly occurs in rural areas where beds are rarely available for all household members. The lack of a bed frame makes it difficult to hang the LLIN correctly, (Iwashita et al., 2010). Sometimes sleeping locations vary by night depending on weather or evening social activities such as alcohol consumption, particularly for men (Atkinson et al., 2009), and attending particular events like funerals (Dunn et al., 2011). Some people even prefer to take malaria preventive medicine because it is easier than sleeping under bed nets (Ernst et al., 2016).

At the community level, social support, social pressure, and social norms can influence the consistent and effective use of LLINs by community members (Dunn et al., 2011; Graves et al., 2011; Rickard et al., 2011; Strachan et al., 2016). Studies have confirmed the importance of encouragement, interpersonal influences, and support from local leaders, village health teams, family members and neighbours to the consistent use of LLIN (Ernst et al., 2017; Ernst et al., 2016; Strachan et al., 2016). Encouragement and support may be provided through regular home visits for reminding people to use these measures or through direct assistance in case of need, for example by offering assistance in hanging bed nets (Strachan et al., 2016; Watanabe et al., 2015). Interpersonal influences were significantly associated with the use of LLIN in studies in Tanzania (Ricotta et al., 2015) and Ghana (Ernst et al., 2017). In addition, a study conducted in Nigeria found that individuals who receive information and assistance from their friends and family members were more likely to use bed nets (Russell et al., 2015).

Mosquito density varies over the seasons and this, in turn, affects the way people use LLIN depending on their perceptions of mosquito biting and nuisance. Although LLINs were generally perceived as having a protective effect against malaria, these perceptions differed between the rainy and dry seasons (Beer et al., 2012). During the rainy season, people perceived mosquito nuisance to be high, which increases the likelihood of using LLIN, whereas during the dry season mosquito nuisance is low and the consistent use of LLIN decreases (Beer et al., 2012; Mukhopadhyay et al., 2016). Apparently, the belief that bed nets should be used only during the rainy season is widespread (Ernst et al., 2016). Toé et al. (2009) showed that also in Burkina Faso people tend to use LLIN only when feeling disturbed by mosquitoes. When they are not bothered by mosquitoes, even during the rainy season when high transmission rates of malaria are expected, they do not use LLIN. In addition to mosquito nuisance, comfortability influences the use of LLIN.

Sleeping under bed nets during the dry season increases warmth and reduces comfortability. This issue is less prominent during the rainy season when temperatures are lower (Ernst et al., 2016; Ingabire et al., 2015). Watanabe et al. (2015) showed, however, that with greater perceived seriousness of malaria, people consistently use bed nets even in the dry season. These findings suggest a need to address cognitive perceptions that underestimate the risk of malaria transmission during all seasons as well as the seriousness of malaria infection (Toé et al., 2009).

Acceptance of Indoor Residual Spraying

In Africa, Indoor Residual Spraying is among the primary malaria vector control interventions (Pluess et al., 2010). Many studies have indicated the effectiveness of IRS in decreasing malaria vector densities and malaria transmission (Kleinschmidt et al., 2009; Pluess et al., 2010; Steinhardt et al., 2013). However, the share of the population at risk of malaria that is protected by IRS has declined globally from 5.7% in 2010 to 3.1% in 2015, and from 10.5% to 5.7% in Sub-Saharan Africa (WHO, 2016). The reduction in IRS coverage is mainly due to lack of financial means to sustain this effort over the long term. IRS is usually used only in particular areas where malaria is endemic and causing outbreaks. For example, in Rwanda, IRS is being executed in only five districts which have been classified as high malaria prevalence and high-risk districts (President's Malaria Initiative, 2017). The effectiveness of IRS decreases when not all rooms in a habitation are sprayed. Bedrooms and storerooms are usually not sprayed (Ingabire et al., 2015; Kaufman et al., 2012). The main challenge with the implementation of IRS is that in Rwanda it is broadly considered a government responsibility, which creates the perception that targeted individuals are not able to use it (Montgomery et al., 2010). Consequently, the attribution of IRS to the reduction of malaria is still limited and people associate IRS more with the reduction of insects rather than seeing it as a malaria control strategy (Munguambe et al., 2011).

The acceptance of IRS is positively associated with cognitive perceptions about its effectiveness in the reduction of insects, decrease of malaria incidence, past experience, and a reduction in the need for medical treatment (Kaufman et al., 2012; Munguambe et al., 2011). Atkinson et al. (2010) found that adherence involves a complex interaction between intervention acceptability, malaria risk perception, and socio-cultural factors.

Similarly, Montgomery et al. (2010) found that the acceptability of IRS is more influenced by the broader spectrum of the social-cultural and political context such as identity, citizenship, and rights, and is not limited to the physical effects of the spraying activities. For example, participants would criticize their neighbours if they refuse the spraying of insecticide in their house and these neighbours change their attitudes and accept the spraying activity (Montgomery et al., 2010). Interestingly, a citizen reported that he authorized the sprayers to go into their neighbours' house to spray when they are not around since he considered it his responsibility to support their neighbours in malaria control (Montgomery et al., 2010). Lack of acceptance to IRS due to a weak perception of both malaria risk and effectiveness of IRS was reported (Munguambe et al., 2011). In their study, Montgomery et al. (2010) found that regardless of having accepted the IRS and willingness to accept future spraying activities, many people don't believe that IRS is effective against the malaria vector. This is mainly the results of group-based citizenship, hence it becomes a passive form of acceptance through a sense of lack of empowerment to refuse it (Table 2.1). The reported factors that may hinder acceptance of IRS include ignorance of the measure, doubt about the effectiveness and the appearance of other insects such as mites, flies and bed bugs shortly after spraying (Ingabire et al., 2015; Kaufman et al., 2012; Munguambe et al., 2011).

Resistance against IRS is also motivated by cognitive believes about the presence of undesirable effects of spraying. These were for example expressed in a report about swelling of the face, itching, rash, asthma, and death of animals that are near the home (Ingabire et al., 2015; Kaufman et al., 2012). Similarly, the (expected) discomfort during the spraying process, including moving belongings, may reduce acceptance of IRS (Ingabire et al., 2015). While community leaders seem to be the most influential in relation to the acceptance of IRS, their eventual non-acceptance of IRS could also reduce the acceptance among community members (Munguambe et al., 2011). Socially shared beliefs about malaria risks may also affect people's ability to accept IRS. Lack of information and communication around spraying activity could lead to skepticism to the spraying procedures. For example absence of advance notification leads people to refuse spraying upon arrival of the sprayers at their homes (Ingabire et al., 2015; Munguambe et al., 2011). Sprayers' attitudes or conduct towards household members also may cause mistrust and affect the IRS acceptance (Ingabire et al., 2015). Generally, household members prefer sprayers whom they know in the community over newcomers, as the latter are considered strangers in their community.

Overall, the evidence suggests that acceptance and consistent use of malaria prevention and control measures are determined by a number of factors at both individual and collective levels. Therefore, if individuals are more engaged (example: through citizen science) in malaria prevention and control interventions, then the above-mentioned factors could be affected in a desirable manner.

Impact of a citizen science approach on malaria-related behaviours

According to Rickard et al. (2011), malaria interventions that are embedded in the community and that involve citizens allow more discussion and in-depth analysis on the benefits of those interventions hence may obtain a high level of acceptance and use. Not involving the general public/community members is a missed opportunity because, in the end, they are the receivers of public health programs. Citizen science refers to involving volunteers in observations, classification, and collection of data, which in turn are used by researchers (Cohn, 2008; Kullenberg & Kasperowski, 2016). Other authors consider citizen science as public engagement in scientific research with members of public joining scientists together to collect and analyze large quantities of data (Bonney et al., 2016). Citizen science comprises a wide range of projects involving citizens in the practice of science, varying from participatory action research to a large web-enabled effort that involves multiple fields around the world (Crain et al., 2014). Besides the collection of scientifically sound data, the goal of citizen science is also to engage citizens in conversation and decision making about environmental threats and related issues (Bonney et al., 2016) (Table 2.1).

Apart from increasing public awareness, citizen science reinforces people's intentions towards an intervention under study (Bonney et al., 2016; Crall et al., 2013). Examples, attending community events, removing local invasive species, and educating peers about invasive species (Crall et al., 2013). However, in some projects, there may not be a noticeable behaviour change mainly due to self-selection of the participants who may already have positive behaviour towards the intervention under study at the start of the project (Rick Bonney et al., 2016). Due to its ability to provide quality-controlled information (Aceves-Bueno et al., 2015), a well-designed citizen science program can enhance human-nature relationships

(Table 2.1) and provide feedback loops (Crain et al., 2014), which in turn contributes to the effective and consistent use of malaria prevention and control measures.

Citizen science projects such as Allergy Radar (de Weger et al., 2014), Tick Radar (Garcia-Martí et al., 2017) and Mosquito radar (Kampen et al., 2015) in the Netherlands show that thousands of people can be actively engaged in reporting a broad range of health-related and ecological observations over several years. Aceves-Bueno et al. (2015) argue that citizen science is an appropriate method to collect and monitor information and can also lead to a high level of community engagement. This engagement creates new social-ecological interactions (e.g. reflection on observed environmental changes and exposure to different social norms) (Crain et al., 2014). In turn, this exposure to different social norms may influence dynamic interactions, may develop new community norms and values, or change, reinforce and further develop the existing norms and values (Den Broeder et al., 2016; Den Broeder et al., 2017) (Table 2.1). Den Broeder et al. (2017) also argue that being a participant in citizen science extends one's social network, improves social cohesion, and increases participation in collective activities. Table 2.1 presents the link between the different dimensions of the malaria problem, different barriers to use malaria preventive measures, and the potential role of citizen science to overcome these barriers.

Table 2.1: Structured overview of links between malaria problem dimensions, potential causes, and proposed interventions

Problem	Problem dimension	Potential causes	Proposed intervention: Citizen science
Malaria	Biophysical /ecological	Lack of information	Apart from the provision of more localized information, citizen science also involves the citizens more deeply in decision making related to the environmental threat. Therefore, the citizens may be engaged in further action to decrease the public bad as well as to improve public health.
	Political/institutional	Lack of or limited resources to continue using malaria preventive measures specifically IRS	Citizen science may provide precise information on what location to target or where to start spraying (for example which village to start with, and not necessarily spray the whole district). This may also encourage different policymakers to look for more funding so that more affected areas can be sprayed. Through the engagement of local leaders, there may be an increase of commitment on the side of local government in order to address the citizens' concerns. In turn, this may decrease the passive form of compliance and promote perceived self-efficacy of malaria preventive measures on the side of citizens.
Malaria preventive measures adoption barriers	Social-cultural	Weak malaria risk perception	Citizen science offers an opportunity for a citizen to contribute to the collecting data about the malaria problem, and this, in turn, may make awareness regarding the risk of malaria more salient. Engaging citizens in collecting information enhances changes in perceptions, may promote a sense of community, develop new community norms and values, and change, reinforce and further develop the existing norms and values (e.g. about the environment, about science, and about institutions in charge of the problem) (Den Broeder et al., 2016; Den Broeder et al., 2017).
		Weak perceived efficacy of malaria preventive measures	Empowering participants through citizen science, increasing self-efficacy and response efficacy, and devise appropriate solutions to create better health (Den Broeder et al., 2016).
		Low connectivity (offline)	Citizen science strengthens connections between people, nature, and place (e.g. establishment of community monitoring networks or advocacy groups). It fosters community-building, increases social capital, and builds trust (e.g. promotes and increases participation in collective activities (Den Broeder et al., 2016; Haywood, 2013). Being a citizen scientist extends the own social network and social cohesion (Den Broeder et al., 2017).

The technological possibilities of engaging the public and specific stakeholders in scientific research are increasing because of the increased availability and adoption of mobile phone technology and the increasing access to the internet (Cole-Lewis & Kershaw, 2010).

Many studies involving mobile phone technology have been conducted in developed countries that have involved citizens in collecting and analyzing data. However, in the extant literature, only a few projects focus on African countries with much emphasis on HIV/AIDS and non-communicable diseases (Bloomfield et al., 2014; Forrest et al., 2015). Yet, Zurovac et al. (2012) identified several studies that used mobile phone text messaging in the areas of malaria surveillance (mainly case detection), management, and monitoring. For example, in Rwanda, mHealth (RapidSMS) has been used for early reporting of pregnancies, diagnosing, and treating diseases among children under the age of five (Ngabo et al., 2012). mSpray, a mobile phone-based project to increase malaria control through the use of IRS in South Africa showed the importance of timely and accurate data provision, monitoring of spray activities and improving opportunities for more location-targeted mosquito control (Eskenazi et al., 2014). Such projects provide real-time information to individuals and allow accurate and efficient disease monitoring, prevention and control (Hounmanou et al., 2016). Most of these projects used mobile phone SMS reminders to increase treatment adherence, but a few projects have also targeted the promotion of preventive health behaviours (Fjeldsoe et al., 2009), such as the anti-obesity behaviour modification project in Korea (Joo & Kim, 2007), and a college smoking cessation project in Washington DC (Obermayer et al., 2004). However, there is a little-published inquiry into the success factor of such projects.

Other studies have highlighted that implementation of digital technology-based projects in disease control and prevention would improve the care that the existing health system could not address, particularly for people at risk (Asiimwe-Kateera et al., 2015). According to Zurovac et al. (2012), health service delivery and health outcomes could be improved by the use of mobile phone applications or platforms. Cole-Lewis and Kershaw (2010) argued that digital technology-based projects provide an interactive two-way communication, which in turn stimulates information sharing. Meankaew et al. (2010) showed that the integration of mobile technology in malaria prevention and control programs can improve real-time malaria case investigation and active follow-up of those which may be positive. Another example comes from Ruhuha, Rwanda, where CMATs were formulated to identify malaria-related problems and find solutions to these problems. These teams facilitated both connection between the community malaria action teams and the community at large as well as knowledge exchange (Ingabire et al., 2016). This, in turn, increased the acceptance and the use of available malaria preventive measures as well as participation in community activities aimed at malaria elimination.

The spread and broad availability of new communication technologies such as mobile phones and the internet enable novel communication approaches to enhance the frequency, interactivity, and quality of citizen engagement and this may also be used to enhance malaria prevention strategies. However, the engagement of all actors in new communication technologies in malaria prevention requires that different domains should be interested and convinced about its usefulness. This engagement also needs a clear and explanatory model that looks at the various levels of malaria prevention. Such a model is currently still lacking. Having an explanatory model for malaria prevention and control remains crucial, as it would show factors that need to be considered when targeting malaria elimination. In the next section, we work out an integrated model of determinants of malaria prevention behaviour. The model proposes that by participation in a citizen science program through the collection and reporting of information related to ecological data and history of possible malaria episodes, there may be an increase of connective action (i.e. interaction, sharing and exchange of malaria-related information among the participants) and collective action.

A conceptual model to predict the use of malaria preventive measures and the citizen science program

We put forward the idea that both individual and socio-cultural factors need to be a central component of malaria prevention and control strategies. Therefore, our model shows clearly how these factors are connected to each other (Figure 2.1) and how leaving these factors out of the malaria control plan might affect the success of the implementation of the interventions.

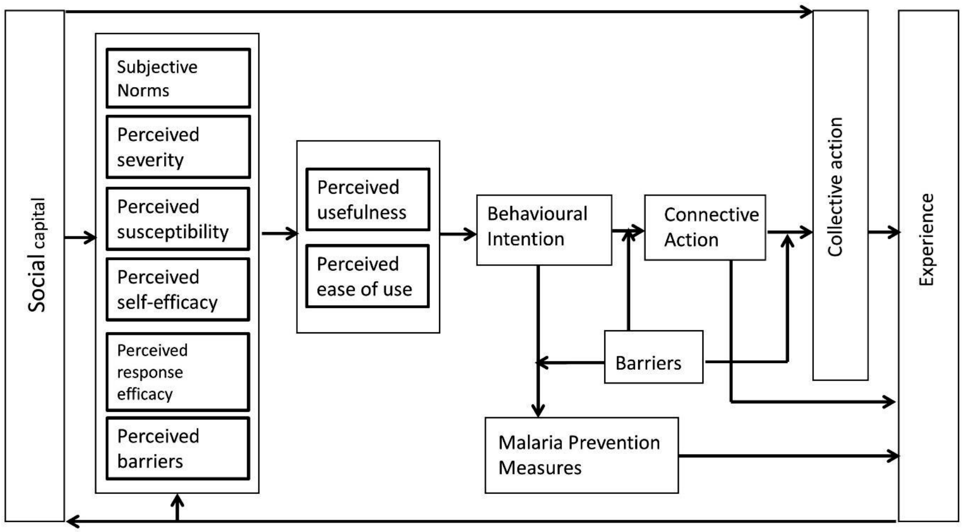


Figure 2.1: Integrated model of determinants of malaria prevention behaviour (Sources are the theories presented in Table 2.2, supplemented by other concepts by the researcher)

Underlying theories.

Given the complexity of behavioural research, no single theory exists that covers all important individual and social factors, and thoughtful selection and combination of theories may result in more robust interventions. Therefore, three well-established theories, the Health Belief Model (HBM), the Theory of Planned Behaviour (TPB), and the Unified Theory of Acceptance and Use of Technology (UTAUT) were selected from the field of social psychology and technology adoption. The HBM and the TPB were selected as they are among the first theories that focus on individual health behaviour and remain the most widely used nowadays especially in disease prevention and health promotion. The UTAUT was selected among other technology-related models as it is the predominant model deployed in predicting the use of information technology and related products and services. Importantly, it accounts for the influence of social factors on the adoption of technological services. All three theories aim to explain almost similar outcomes from different perspectives. That is, they use behavioural intention as the key predictor of the use of a new practice, product or behaviour and separately each has different determinants of behavioural intention.

As the concepts in different theories may be different but their conceptualization across theories may be similar, we considered the complementarity of these theories, independence, and relationships between concepts, as well as avoiding overlaps when selecting concepts. Therefore some of the concepts were omitted. At the end, we included those selected concepts together into an integrated model of determinants of malaria prevention behaviour that may be used in other behavioural research and other issues related to vector-borne or other infectious diseases. This proposed model is more than combining the selected concepts from three mentioned theories, as other concepts (not from the mentioned three theories) were added based on their theoretical relevance (Figure 2.1) which demonstrates the originality of this integrated model of determinants of malaria prevention behaviour. In the following section, we briefly explain the three theories used in our conceptual model.

Health Belief Model

The Health Belief Model (HBM) is one of the best-known social cognition models on individual health-related behaviour (Olsen et al., 2008). Our conceptual model used the following concepts: perceived severity, perceived susceptibility, perceived self-efficacy, and perceived barriers (Table 2.2).

Theory of Planned Behaviour

The Theory of Planned Behaviour (TPB) is an extension of the Theory of Reasoned Action and the most predictive persuasion theory (Munro et al., 2007). However, it does not account for factors that are beyond individual voluntary control. In our model, we included subjective norms and behaviour intention (Table 2.2).

Unified Theory of Acceptance and Use of Technology

The Unified Theory of Acceptance and Use of Technology (UTAUT) is an expansion of the Technology Acceptance Model and is used to describe and predict the acceptance of new information technology and ways of stimulating the use of technology (Venkatesh et al., 2003). In our model, we included perceived usefulness and perceived ease of use. Social influence was not included as it overlaps both with ‘social networks/interactions’ as one dimension of social capital and with ‘subjective norms’. In the following sections, we define each of these concepts and give a theoretical rationale for the relationships presented in the model.

Table 2.2: Source of the concepts presented in Figure 2.1

Constructs	HBM	TPB	UTAUT
Perceived severity	˅		
Perceived susceptibility	˅		
Perceived self-efficacy	˅		
Perceived barriers	˅		
Subjective norms		˅	
Perceived usefulness			˅ (termed “performance expectancy”)
Perceived ease of use			˅ (termed “effort expectancy”)
Behavioural intention		˅	

Note: HBM = Health Belief Model; TPB = Theory of Planned Behaviour; UTAUT = Unified Theory of Acceptance and Use of Technology.

Description of the concepts/determinants of behaviour

Social capital

Social capital is defined as forms of social organization such as social networks/interactions, norms of reciprocity and generalized trust that facilitate cooperation and coordination for common benefits (Putnam, 1995). Social capital has been described as rooted in social relationships and can serve as a resource that allows individuals to achieve objectives that they could not achieve otherwise (e.g., by people paying each other favours) (Coleman, 1988). With regard to malaria prevention, learning from other community members plays a big role in changing perceptions towards acceptance and use of malaria prevention measures. For example, in Rwanda, involving rice farmers in the planning of mosquito larval source management as a malaria control strategy contributed to the change of their perceptions related to the importance of larval source management in malaria control and increased their level of ownership of this action (Ingabire et al., 2016).

In addition, community health workers that are located in all villages of Rwanda play a major role in community mobilization towards malaria prevention. In Bangladesh, Ahmed et al., (2014) found this interpersonal communication (with relatives, friends, and neighbours) to be more effective in disseminating and acquiring malaria-related information and in changing perceptions compared to other forms of communication, including mass media and radio. However, in Rwanda, especially in rural areas, radio is among the most powerful sources of information for the citizens as most of the households have at least one radio. Use of social media is less common.

According to Panter-Brick et al. (2006), interventions seem to be most effective when they are linked to cultural narratives (which serve to discuss proper behaviour) and can be strengthened through community support, networks, and interactions. The increase of social interaction and trust can dispel negative perceptions that create individual and community resistance towards engagement in malaria prevention and control measures (Atkinson et al., 2010). Regarding trust in health-related matters, individuals seem to be influenced by those who are well known in the community including local leaders and health workers (Atkinson et al., 2010). Similarly, in Rwanda, Ingabire et al. (2016) found that interpersonal community meetings led by CMATs, CHWs, or village leaders helped to change negative perceptions towards the use of malaria preventive measures and to increase the use of these measures. Therefore, it is hypothesized that social capital influences individual perceptions (perceived severity, perceived susceptibility, perceived self-efficacy, perceived response efficacy, and perceived barriers) and subjective norms.

Several studies have indicated that elements of social capital can facilitate collective action, i.e. activities that individuals contribute together with the aim of realizing a public or common good, for example, the clearing of mosquito breeding sites (Fujiie et al., 2005; Ingabire et al., 2016; Ramos-Pinto, 2006). This is also applicable to Rwanda, as citizens engage in monthly community work at the village level (governed by the Rwandan Law) where they gather together in their villages, clean their environment and after that gather to discuss different topics including malaria. Therefore, it is clear that individuals who obtain information from their interpersonal networks would decide to participate in the creation of public goods if they trust the source of information. Thus, it is predicted that social capital has a positive influence on collective action.

Subjective norms

Subjective norms refer to the perceived social pressure to execute or not execute a behaviour (Ajzen, 1991). The theory of planned behaviour developed by Ajzen (1991) indicated that although subjective norms influence directly intention to perform behaviour it also importantly influence perceived behaviour control which is similar to perceived ease of use in our model. Munro et al. (2007) also defined subjective norms as a degree to which a person believes that other people in the community think that he/she should participate in certain behaviour. In their study testing a theoretical extension of the Technology Acceptance Model (TAM) using longitudinal data collected from four different systems at four organizations, Venkatesh and Davis (2000) found that subjective norms influenced perceived usefulness of information technology in the workplace. This indicates that people integrate social influences in their own usefulness perceptions. In the context of our research model, if a member within a personal environment suggests that a system or a platform might be useful and easy to use, then it is more likely that another person may come to believe the same. This was supported by Teo (2010) who studied the influence of subjective norms on the intention to use technology in education and found that subjective norms were direct predictors of perceived usefulness and ease of use. It was also in agreement with a study conducted in Korea by Kim and Park (2012) who indicated that the indirect effect of subjective norms on behavioural intention was mediated by perceived usefulness. In contrast, a study conducted among University students in Spain did not find the subjective norm to be a predictor of perceived usefulness (Agudo-Peregrina et al., 2014). This was probably because, in their study, perceived usefulness was used in two dimensions including performance and flexibility. Therefore, we predict that subjective norms positively influence perceived usefulness and perceived ease of use of a citizen science program.

Perceived severity

Perceived severity is defined as an individual's beliefs about how serious a disease and its related consequences are. These consequences may range from medical and clinical (disability, pain, death) to social and economic consequences (effect of the disease on family life, work, financial and social relations) (Champion & Skinner, 2008). If people think that malaria could harm them seriously, they are more likely to assign a high value to malaria prevention measures (Ankomah et al., 2012) or to adopt a technology related to malaria prevention and control. In their study conducted among female internet users in Malaysia investigating the influence of perceived health risk on health-related internet use, Ahadzadeh et al. (2015) found a positive relationship between perceived severity and perceived usefulness and the latter was a mediating variable toward the internet use. In Korea, Kim and Park (2012) developed and tested the extended TAM by analyzing health consumers' behavioural intention of using health information technology in healthcare. They found a significant effect of perceived severity on perceived usefulness of health information technology. This indicates that perceived severity is essential for people to see the usefulness and perceived ease of use for a particular intervention. Also in the Ruhuha sector in Rwanda, some citizens see the consequences of malaria and are likely to see the usefulness of a citizen science platform as long as it is clearly explained.

Our research model predicts that if an individual perceives the negative effects of malaria, then they will consequently perceive the usefulness of malaria preventive and control measures and that using them requires no efforts. Hence, it is hypothesized that perceived severity of malaria positively influences the perceived usefulness of malaria preventive and control measures and related perceived ease of use.

Perceived susceptibility

Perceived susceptibility refers to the beliefs about the likelihood of experiencing or getting a disease (Champion & Skinner, 2008). Individuals who perceive themselves to be at high risk of getting malaria, have higher malaria risk appraisal and are more likely to appreciate the usefulness of malaria prevention interventions. For example, a study done in Nigeria among pregnant women indicated that if pregnant women do not see themselves or their unborn babies at risk of getting malaria, then they are less likely to see the usefulness of malaria prevention and control interventions (Ankomah et al., 2012). The relationship between perceived susceptibility and perceived usefulness was also found in Malaysia (Ahadzadeh et al., 2015) and Korea (Kim & Park, 2012). If an individual perceives to be at risk of contracting malaria, this will lead to a positive perception of the usefulness of these interventions and that using them requires no or little effort. Thus, it is proposed that perceived susceptibility has a positive influence on both perceived usefulness and ease of use.

Perceived self-efficacy

Perceived self-efficacy refers to people's beliefs about their capability to use preventive measures. In this chapter, perceived self-efficacy is defined as the ability to participate in a citizen science platform and make use of malaria preventive measures through recognition of their usefulness and ease of use. Many technology acceptance related studies including Agudo-Peregrina et al. (2014) conducted in Spain, Wang et al. (2006) conducted in Taiwan, and Zhang et al. (2016) conducted in China revealed the effect of perceived self-efficacy on perceived ease of use. Others conducted in the US, Korea, and Australia found the effect of perceived self-efficacy on both perceived usefulness and ease of use (Lee & Mendlinger, 2011; Rose & Fogarty, 2006). Kim and Park (2012) also found that the greater the self-efficacy the higher the perceived usefulness and perceived ease of use of health information technology. This shows that if an individual perceives being able to use malaria interventions, then it is more likely that he/she will perceive the usefulness of these interventions and that using them requires little to no effort. It is proposed that perceived self-efficacy has a positive influence on perceived usefulness and perceived ease of use.

Perceived response efficacy

Perceived response efficacy is defined as individuals' beliefs about the effectiveness of recommended behaviour in preventing a threat (Witte, 1992). The association between response efficacy and perceived ease of use of mobile health services was revealed by Zhang et al. (2016). In this chapter, when individuals believe that a citizen science platform will contribute to the reduction of malaria through information provision, then they find it useful and easy to use. Therefore, the research model proposes that response efficacy is positively associated with the perceived usefulness and perceived ease of use.

Perceived barriers

Perceived barriers refer to people's evaluation of what would prevent them from using a certain measure while emphasizing on potential negative aspects of a particular health intervention (Champion & Skinner, 2008). If individuals perceive that use of malaria preventive measures has negative side effects, such as increased nuisance of bed bugs or that reporting through the citizen science platform is time-consuming, costly or difficult, then they are less likely to see the usefulness of those interventions. This is also a challenge in Rwanda because past studies indicated that citizens reported bed bugs and warmth to impede the use of bed nets (Ingabire et al., 2015). Consequently, we propose that perceived barriers have a negative influence on the perceived usefulness and perceived ease of use.

Perceived usefulness and perceived ease of use

Perceived usefulness is defined as the extent to which a person believes that using technology (for example, a citizen science platform) or other measures will improve his/her health outcome (Venkatesh & Bala, 2008). In a malaria prevention context, it may be defined as the extent to which an individual believes that malaria preventive measures may help to prevent getting malaria by reducing human-vector contact. Studies conducted in malaria-endemic areas of Nigeria and Burkina Faso indicated that perceived effectiveness and usefulness of LLINs influence the intention to use them (Ankomah et al., 2012; Toé et al., 2009). Other mHealth related studies conducted in Uganda (Campbell et al., 2017) and Bangladesh (Hoque, 2016) found a positive effect of perceived usefulness on behavioural intention. Therefore, perceived usefulness predicts behavioural intention to participate in a citizen science platform and also to use malaria preventive measures by community members.

Perceived ease of use refers to the degree to which a person believes that the use of a system (Davis, 1989) or a technology (Venkatesh & Bala, 2008), requires little effort. In their study, Agudo-Peregrina et al. (2014) found that a high level of system complexity and particularly in the case of users with low experience may reduce the intention to use the system. Other mHealth related studies found a positive association between perceived ease of use and behavioural intention (Campbell et al., 2017; Hoque, 2016). Thus, in our study, perceived ease of use positively influences the behavioural intention to participate in a citizen science platform and also to use malaria prevention measures by community members.

Behavioural intention

Behavioural intention is defined as the degree to which a person plans to perform a specific behaviour (Venkatesh & Bala, 2008). Behavioural intention is a key predictor of behaviour adoption, here referred to as malaria prevention measures and connective action – a technologically organized process that results in joint action within and between communities and stakeholder groups (Bennett & Segerberg, 2012).

Malaria preventive measures include those at the individual or community levels (use of the LLINs and cleaning of the home environment) as well as those performed by the government (use of IRS). People are likely to use malaria preventive measures and or share the information via a citizen science platform if they have the plan to do so. Following this rationale, our model proposes that behavioural intention has a positive influence on both connective action and the use of malaria preventive measures.

By using these malaria preventive measures, people gain experience, which, in turn, facilitates the regular and continued use of these measures. Therefore, using malaria preventive measures influences gaining of experience.

Connective action

Connective action is defined as a technologically organized process that may result in joint action (Bennett & Segerberg, 2012). Dessewffy and Nagy (2016) argued that the use of a digital platform has a potential role in spreading information and increasing communication. They added that the use of social media influences collective action. In Rwanda, especially in rural areas, the use of social media is less common. Additionally, DiMaggio et al. (2001) revealed that the use of the internet provides opportunities to share and exchange information as well as increases socialization. Though the internet is less common in rural areas of Rwanda, a citizen science platform can be a channel for building the organizational capacity of the community members to enhance the effectiveness of malaria preventive measures. Dessewffy and Nagy (2016) also revealed the effect of using social media on collective action and extending one's social network. Example: if a citizen sends information related to malaria and mosquitoes it is likely that first, his/her participation in malaria prevention may increase as a result of improved malaria-related perceptions. Secondly, he/she may increase her interaction with neighbours which in turn also increases the chance of this neighbour to participate in sending this type of information as well. Thirdly, the information shared, perceptions, and behaviour of people who participate in the platform may influence neighbours' behaviour (using preventive measures). By participating in the platform, there may be an increase in the cleaning of mosquito breeding sites. Consequently, we propose that connective action has a positive influence on collective action. By participating in the platform, there may be an increase in sharing and exchange of malaria-related information which leads to the rise of experience. Accordingly, the model proposes that connective action increases experience.

Barriers

Barriers such as lack of or inadequate malaria prevention measures, on one hand, lack of mobile phones or phone credits to report malaria-related observations on the other hand, as well as the lack of information on usability and productivity of a citizen science platform, may prevent the execution of intended behaviour. While developing an adoption readiness model, Weidman et al. (2015) also identified lack of information about available technology, its usability, productivity, and the associated cost to hinder innovation adoption. In rural areas of Rwanda, most citizens have simple mobile phones and sometimes with no credits and in turn, this may hinder their participation in the citizen science platform. Accordingly, our model proposes that these barriers moderate the effect of behavioural intention on both connective action and use of malaria preventive measures.

Other barriers like resistance to change, ignorance or lack of motivation may limit participation in public activities. These barriers may affect the distribution of the potential risks and benefits among community members following the introduction of a citizen science platform at both individual and collective levels. Consequently, we propose that these barriers moderate the effect of the connective action on collective action.

Collective action

Collective action is defined as activities that individuals contribute together with the aim of seeking the public good (Bennett & Segerberg, 2012). Participation in voluntary associations, groups or clubs is a universal action and members are attracted to join for the same purpose. People are motivated to provide collective good, simply because of the attractiveness of the collective good and common interests to the group members (Olson, 1971). Collective action does not mean the involvement of everybody in the community or benefit to everybody, rather of highly motivated and interested individuals who provide collective benefits for the community (Oliver & Marwell, 1985). A study conducted in a rural area of Kenya (Diiro et al. (2016) revealed that participation in community activities increases public health awareness and experience in performing related interventions. This may happen through public meetings and community work (Rickard et al., 2011). In Rwanda, there is also a community work every last Saturday of the month, and from there, citizens discuss some topics including disease prevention and receive some other important communication from the government.

In turn, citizens may improve their awareness on those discussed issues. Consequently, the model proposes that participation in collective action influences people to gain experience.

Experience gained from participation in a citizen science platform, involvement in collective action, and use of malaria preventive measures may lead to a change of perceptions which may turn into the rapid acceptance and consistent use of malaria preventive measures (Mozumder & Marathe, 2007; Rickard et al., 2011). This experience may also improve trust and social networks. Thus, the model proposes that having experience positively influences both individual perceptions and social capital.

The model's proposed relationships are to be tested through implementation of the project by using a citizen science approach, in two separate phases. Phase one will test the malaria risk perceptions and perceived efficacy of malaria preventive measures. This includes a baseline survey to determine malaria perceptions and malaria preventive measures in the local community. Phase two encompasses testing the entire model through a second household survey with the aim to evaluate the contribution of a citizen science approach to the consistent use and acceptance of malaria preventive measures. Both phases use a mixed-methods approach (quantitative and qualitative) with the aim to achieve triangulation of data.

Key features of a future citizen science platform in Rwanda

An integrated project called Environmental Virtual Observatories for Connective Action (EVOCA) is currently underway to design, implement and evaluate a citizen science approach that involves and evaluates the above-described research model. This interdisciplinary project with both social and ecological aspects presents added advantages as it considers all potential social and ecological data, hence prevent missing data in case these aspects are used independently (Crain et al., 2014). This citizen science platform is proposed to complement malaria prevention and control interventions that are currently implemented in Rwanda by the National Malaria Control Program (NMCP). The NMCP has various activities related to malaria prevention especially social and behavioural change communication strategies through the use of interpersonal communication, community radio with a focus on community mobilization and engagement in the use of LLINS and early diagnosis and treatment. The project may also play an important role in sustaining the gains from a community engagement project conducted in Ruhuha, Eastern region, Rwanda (Ingabire et al., 2016).

The EVOCA project planned in Ruhuha sector to involve the existing local infrastructure (CMATs) as useful and knowledgeable resources in the study area may improve their efficiency.

Similar to the other citizen science initiatives on mosquito ecology in Europe (Kampen et al., 2015), we envision the citizens to report information via either paper-based forms or via a web-based form. Via paper-based form, citizens are supposed to collect information about mosquito habitats, mosquito nuisance, and history of possible malaria episodes and this information will be digitalized. The paper-based form will be developed and distributed among those who are willing to participate in the project via monthly community work, evening parent meetings (so-called akagoroba k' ababyeyi), and other meetings that may be planned in the community. Those with smartphones may report through a web-based form.

To empower citizens to become active participants in the project and in the decision-making process regarding malaria, and its prevention, lay information needs to be provided. This may include information about malaria causes, malaria symptoms, malaria preventive and control measures, as well as early diagnosis and treatment.

Participation in citizen science requires community mobilization and motivation. Motivation to participate in a citizen science project includes personal interest in the topic, social interaction, and feedback as an external reward (Nov at al., 2011; Rotman et al., 2012). Olson also has argued that what motivates people to participate are not economic motives (money related), but rather other forms of motives, including friendship and respect, as well as other social and psychological motives (Olson, 1971). A survey conducted in the Ruhuha sector, after the establishment of CMATs in a community-based project, indicated an increase in personal acceptance and use of malaria preventive measures (Ingabire et al., 2016). This showed that the citizens gained more knowledge related to the burden of malaria, were interested in malaria prevention and were able to make personal decisions making on how to prevent it. Citizens are more likely to continue participation when their contributions are valued throughout the project, when involved in further data analysis and when they get the opportunity to have further training (Rotman et al., 2014). Though participation in citizen science is voluntary, it may also be driven by external parties or social norms (Nov et al., 2011). Rotman et al. (2014) also argued that the motivation of volunteers to participate in citizen science projects is affected by both personal and societal interests.

Nov et al. (2011) suggested that the design and implementation of a citizen science project should attempt to raise the volunteers' commitment to the project and related goals. To achieve this, communicating the project's goals and the intended outcome to the involved volunteers is key. Rotman et al. (2014) added that the provision of feedback helps the volunteers to understand what they have contributed. This, in turn, encourages them to do more and continue their participation in the long term. While preparing and discussing the implementation of a citizen science platform and motivation for participation, Bennett and Segerberg (2012) emphasized that scientists should know the great importance of community appreciation, respect and work/production recognition. Appreciation of volunteers is crucial as they are investing their time and even resources without expectation of a monetary reward. The form of feedback provision for our proposed citizen science platform will be discussed beforehand to ensure that it is integrated in the research process.

The inclusion of all stakeholders and their views on this new proposed platform is the first step before the actual design of the platform. Targeting all stakeholders does not automatically mean that they all participate or are willing to participate, as this involves a process of explaining the overall target and how everybody may benefit from that process. Discussing and agreeing on the processes and rules of engagement beforehand may help to create links and working lines among all stakeholders involved. Intensive and continuing interactions and discussion with various parties improves relationships among different stakeholders' groups and build up their confidence to become partners in the research process (Giller et al., 2008). This is planned to be done through stakeholder mapping and ensure that key stakeholders are aware of all processes that are expected to be conducted. A study conducted by Ingabire (2016) in Ruhuha, Rwanda did a stakeholder analysis and indicated three main categories of stakeholders including a primary category (lay community), a secondary category (administrative and health institutions), and a tertiary category who are key stakeholders (policymakers and funders). Thus, this may help to know whom to target, and which message to give to whom mainly at the initial stage.

Similar to other research projects, citizen science projects also encounter challenges and barriers. These include lack of resources for implementation and running the project, lack of or poorly designed technology, and lack of interest among decision-makers who are the potential stakeholders, especially when it comes to the sustainability of the project.

Rotman et al. (2014) argued that lack of time for participation, technological related problems, and local infrastructural barriers are the key factors to take into account when mobilizing communities. Considering the local context in which the implementation of the citizen science platform will occur, especially taking into account that the citizens are farmers, first of all, many of them may lack time for participation as most of the time they are working at their farms. The level of literacy may also be an issue that may limit them to participate. However, considering that at least one household member knows how to read and write, then this may be less of an issue as long as one can help others to answer any given question or provide any necessary information. Low socioeconomic status may prevent some of those interested in using mobile phones to send SMS as they may not have the credits. However, this may be less of an issue as an alternative paper-based form is planned.

Crain et al. (2014) revealed that mobilizing, attracting and retaining participants in citizen science projects is a complex process as it relies on numerous cognitive, behavioural and social characteristics. Therefore, there is a need to consider these barriers and characteristics from the start of the design and implementation of every citizen science project. Addressing these barriers and having decision-makers included and interested from the start of the design of the project may enable both short and long term participation of all stakeholders including volunteers. Therefore, these barriers and characteristics are considered in this integrated project in order to focus on the connection between heterogeneous human and vector behaviour. This chapter is focusing on human behaviour while a companion paper focuses on malaria vector surveillance and environmental conditions (Murindahabi et al., 2018).

Conclusion

By taking an integrative approach, our model of determinants of malaria prevention behaviour aims to enhance our understanding of the interrelationships between factors that influence individuals to participate in a citizen science platform and use malaria preventive measures. Our model of determinants of malaria prevention behaviour is the first to integrate the HBM, TPB, and UTAUT models into a synthesized research model for explaining behavioural intention to adopt a new innovation, in this case, malaria prevention measures and a citizen science platform. This model could be useful as a foundation for future interventions and research activities and will be tested in an application to support malaria prevention in

Rwanda. The proposed conceptual framework describes linkages in malaria prevention models and this has implications in both academic and societal settings in relation to malaria prevention and control. Most of the proposed linkages between the concepts (social capital and individual perceptions, social capital and collective action, connective action and collective action, experiences and social capital, as well as experience and individual perceptions to mention few) are new to malaria prevention context. Consequently, this proposed model could be valid for behaviour research and other issues related to vector-borne or other infectious diseases. This model may serve as an important step in this field of research, be empirically tested and provide useful information for further research and academic debates from different countries. As shown it is initially important to consider antecedents including social capital and individual perceptions when designing a citizen science platform. Community mobilization is a key to get people interested in a citizen science project. Features of a citizen science platform to be conducted as an interdisciplinary project involving the collection of socio-ecological data also present a promising tool to complement the existing malaria prevention and control interventions implemented by NMCP in Rwanda.

Chapter 3

Role of individual perceptions in the consistent use of malaria preventive measures: *Mixed methods evidence from rural Rwanda*

This chapter is based on: Asingizwe, D., Poortvliet, P. M., Koenraadt, C. J. M., Van Vliet, A. J. H., Ingabire, C. M., Mutesa, L., & Leeuwis, C. (2019). Role of individual perceptions in the consistent use of malaria preventive measures: Mixed methods evidence from rural Rwanda.

Malaria Journal, 18, 270.

Abstract

Malaria preventive measures, including long-lasting insecticide-treated bet nets (LLINs), indoor residual spraying (IRS), and controlling mosquito breeding sites, are key measures to achieve malaria elimination. Still, compliance with these recommended measures remains a major challenge. By applying a novel and comprehensive model for determinants of malaria prevention behaviour, this study tests how individual perceptions influence the intentions to use malaria preventive measures and explores strategies that stimulate their consistent use. The study was carried out in the sectors of Ruhuha and Busoro, Rwanda during October and November 2017, and these were conducted into two phases. Phase one involved a questionnaire survey (N=742), whereas Phase two employed a qualitative approach that included nine focus group discussions, seven key informant interviews, and three in-depth interviews. The findings of the quantitative study showed that participants very often use LLINs (66.6%), accept IRS (73.9%), and drain stagnant water in case of presence (62%). The intentions to use malaria preventive measures were consistently driven by perceived severity, perceived self-efficacy, perceived response efficacy, and subjective norms, and hindered by perceived barriers. The intentions were also positively associated with the actual use of LLINs, acceptance of IRS, and drainage of stagnant water. The is no evidence that either not having enough LLINs (ownership of at least one bed net in the household, here referred to as availability) or having sufficient LLINs (having one LLIN per two people in the household, here referred to as accessibility) moderated the relationship between behavioural intentions and actual use of LLINs. The qualitative study indicated that participants believed malaria risk to be high and perceived a high mosquito density. They also believed that repetitive malaria episodes are caused by the perceived low effectiveness of anti-malaria medications. Lack of LLINs increased the perceived added value of LLINs, and together with the increased malaria burden increased the perceived response efficacy. Participants highlighted the need to continuously mobilize and engage community members especially those who do not use LLINs when having one, and those who do not accept the spraying activities. Malaria prevention interventions should target individual perceptions to enhance the consistent use of malaria preventive measures. Three strategies to improve consistent use and acceptance of these measures are highlighted: (1) access to LLINs and regular spraying activities, (2) community mobilization, and (3) citizen engagement in malaria prevention and control activities.

Background

Malaria, a vector-borne disease, is a serious threat worldwide (WHO, 2017b). From 2010, a reduction in malaria incidence was observed, but around 2014 the rate of decrease halted and even reversed in some countries (WHO, 2017b). One of these countries is Rwanda where since 2011 a significant increase in malaria incidence was observed (President's Malaria Initiative, 2017). Despite this resurgence, significant progress in scaling up of malaria preventive measures is currently taking place (MoH, 2017a). These measures include long-lasting insecticide-treated bet nets (LLINs), indoor residual spraying (IRS), and the control of mosquito breeding sites. The World Health Organization (WHO) recommends using LLINs for all people who are at risk of getting malaria (MoH, 2017a). According to the Rwanda malaria contingency plan 2016-2020, by 2020, 90% of the population at risk should be protected by the following locally appropriate malaria preventive measures (use LLINs, accept IRS, and control all mosquito breeding sites), and 75% should use LLINs consistently (MoH, 2017a).

Despite this ambition to increase the consistent use of preventive measures, the latest Rwanda Demographic and Health Survey conducted in 2014-2015 indicated that 81% of households own at least one LLIN and that only 43% of households have at least one LLIN for every two people (RDHS, 2015). This indicates that the proportion of households with sufficient LLINs (one LLIN for every two people) remains inadequate. The same report indicated that 62% of the visited household members slept under LLINs the night before the survey (RDHS, 2015). Apart from the use of LLINs, the implementation of IRS even dropped in Rwanda due to limited resources (MoH, 2017a).

Whether people use LLINs consistently, accept IRS, and control mosquito breeding sites depends on many factors including the accessibility to LLINs, and IRS, but also importantly on people's perception of malaria risk and of the effectiveness of malaria preventive measures (Babalola et al., 2018). Hence, there is a need to understand people's perceptions and determine to what extent they predict the intentions towards the actual and consistent use of malaria preventive measures.

Although limited availability of LLINs (not having one LLIN per two people) is a critical factor of non-use (Hetzel et al., 2012; Ricotta et al., 2015), several studies indicate that around 20%

of the people who own LLINs still do not use them (Ernst et al., 2017; Gonahasa et al., 2018; Kateera et al., 2015; Ntuku et al., 2017; Samadoulougou et al., 2017). This calculation of use gap was mainly based on two indicators: ownership of at least one LLIN, and population use of LLIN, and this calculation may be misleading since the consideration of ownership of at least one LLIN may leave out those with insufficient LLINs (availability) (Koenker & Kilian, 2014). However, the extent to which both ownership of at least one LLIN and accessibility (having one bed net per two people in the household) affect the consistent use of LLINs is still unclear. Other studies reported IRS refusal and failing to remove stagnant water bodies (Ingabire et al., 2015; Kaufman et al., 2012; Munguambe et al., 2011). From these studies, there are indications that the use of malaria preventive measures is partly determined by the perception of the risk of malaria infection and the effectiveness of these measures, by the increased prevalence of insects in the house after spraying, and by throwing LLINs away once they become dirty or torn out (Babalola et al., 2018; Birhanu et al., 2015; Hung et al., 2014; Ingabire et al., 2015; Kaufman et al., 2012; Munguambe et al., 2011; Watanabe et al., 2014).

Only few studies assessed the determinants of consistent bed net use (Babalola et al., 2018; Koenker et al., 2013), and as of yet, there is no evidence of the extent to which the identified determinants affect the intentions to use malaria preventive measures consistently, how important they are and how they can be influenced. In addition, a study using an integrated model of determinants of malaria preventive behaviour (Asingizwe et al., 2018) that maps the association between these perceptions and intentions to use these preventive measures is lacking. The current study aims to assess how individual perceptions influence the intentions to use malaria preventive measures and to explore strategies that may stimulate consistent use of malaria preventive measures. Therefore, the study addressed the following research questions: (1) how do community members perceive the risk of malaria? (2) how do community members perceive the effectiveness of malaria preventive measures? (3) to what extent do individual perceptions influence the intentions to use malaria preventive measures? and (4) what strategies can, according to community members, be used to stimulate consistent use of malaria preventive measures? In this chapter, “availability is defined as having at least one LLIN and this is considered as not having enough LLINs” as most of households have more than two people. In addition, “accessibility is defined as having one LLIN per two people and this means having sufficient LLINs in the household”.

Both variables (availability and accessibility) were included in the conceptual framework and statistical models as moderators between behaviour intentions and consistent use of LLINs.

Conceptual framework

In order to understand how individual perceptions influence behavioural intentions to use malaria preventive measures, the study uses an integrated model of determinants of malaria prevention behaviour (Asingizwe et al., 2018). The model categorizes individual perceptions into perceived severity, perceived susceptibility, perceived self-efficacy, perceived response efficacy, subjective norms, and perceived barriers (Asingizwe et al., 2018). Below, the rationale behind the different determinants in the model (Figure 3.1), and how the model's determinants positively or negatively predict intentions to consistently use malaria preventive measures are described.

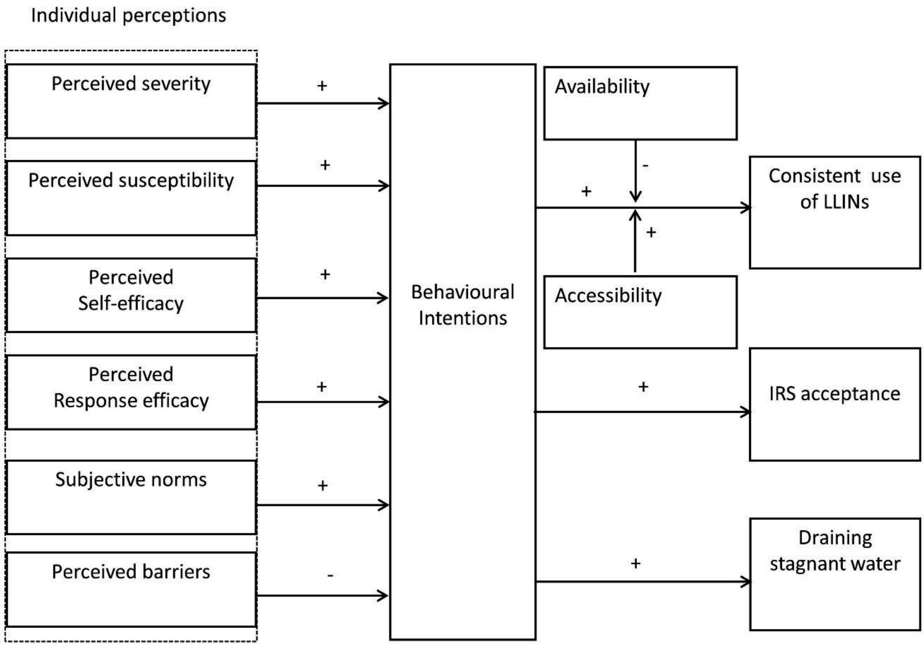


Figure 3.1: Overview of how determinants influence the use of malaria preventive measures (Asingizwe et al., 2018)

Malaria risk perceptions have been reported to predict the consistent use of LLINs (Koenker et al., 2013; Watanabe et al., 2014). If people intend to use malaria preventive measures because of associated high perceived risk of malaria, then it is likely that once the malaria prevalence reduces, the adoption rate of these measures also decreases (Koenker et al., 2013). Some people plan to use the LLINs because they have noted how they prevent malaria and think that consistently using them is better to remain free from malaria even if the prevalence of malaria reduces. However, for other people, the usage of LLINs drops because people think that malaria is no longer a problem (Koenker et al., 2013). Thus, perceived severity of malaria positively influences intentions to use and accept malaria preventive measures. People who do not perceive themselves to be at risk of having malaria are less likely to adopt these measures even if they own them (Ankomah et al., 2012). Consequently, the perceived susceptibility is positively associated with the behavioural intentions to use malaria preventive measures (Figure 3.1).

Some studies documented that the perceived self-efficacy (belief in one's ability to use malaria preventive measures), and the perceived response efficacy (people's beliefs about the effectiveness of malaria preventive measures) influence the consistent use of these measures (Babalola et al., 2018; Hung et al., 2014). Similarly, Beer et al. (2012) indicated that perceived response efficacy of LLINs remains an important reason for using them in case of a reduction in malaria incidence and associated low malaria risk perception. Accordingly, both perceived self-efficacy and response efficacy will positively influence the intentions for the consistent use of malaria preventive measures (Figure 3.1). Among other factors that influence intentions to use LLINs consistently, Koenker et al. (2013) presents the role of subjective norms. If a high proportion of people in the community sleep under LLINs, accept IRS, and drain stagnant water, then many people in that community may intend to follow the apparent social norm and may plan to consistently do the same (Babalola et al., 2018). Thus, subjective norms and behavioural intentions are expected to have a positive relationship (Figure 3.1). However, when people believe that the chemicals in LLINs are no longer effective in killing mosquitoes, they are more likely to use them for other purposes (Birhanu et al., 2015).

Perceived barriers to use LLINs and accept IRS, including feeling too hot when sleeping under the LLINs (especially in the dry season), discomfort, irritability, and presence of bed bugs or other insects after spraying, were reported in previous studies (Hetzel et al., 2012; Ingabire et al., 2015). These factors were reported to hinder the use and acceptance of malaria preventive measures (Hetzel et al., 2012; Ingabire et al., 2015). Consequently, perceived barriers will negatively influence behavioural intentions (Figure 3.1). Previous studies indicated that both ownership of at least one LLIN and access (having sufficient LLINs) are strong determinants for its use (Hetzel et al., 2012; Ricotta et al., 2015). Therefore, not having enough LLINs (having at least one LLIN) and access (having enough LLINs: one per two people) will moderate the effect of intentions on use of LLINs (Figure 3.1).

Quantitative and qualitative approaches to study individual perceptions

The research consisted of two phases (Figure 3.2) and these were driven by the research questions which were informed by the conceptual framework. Phase one involved a quantitative study to map and assess the strength and direction of the relationships between the model variables. Phase two involved a qualitative study and was added to enable more comprehensive explanations for why participants have certain perceptions related to malaria and malaria preventive measures, and to identify strategies to enhance the consistent use of these measures. Additionally, the qualitative approach tried to better understand the relationships that were identified in the quantitative phase. Given an equal emphasis among the two phases, the data were collected close together in time. The two phases are linked in that all stages (that is, design, data collection, analysis, results interpretation, and integration) (Figure 3.2) are developed based on the concepts of the research model (conceptual framework). Thus, the research model (called “Model” in Figure 3.2), informed all stages of the research process. Consequently, quantitative and qualitative phases complement each other, with the ultimate aim of enabling drawing a robust conclusion. As such, this mixed methods design provides more insights related to the directions and strengths of the relationships indicated in the model and offers the underlying explanations to why people have these perceptions.

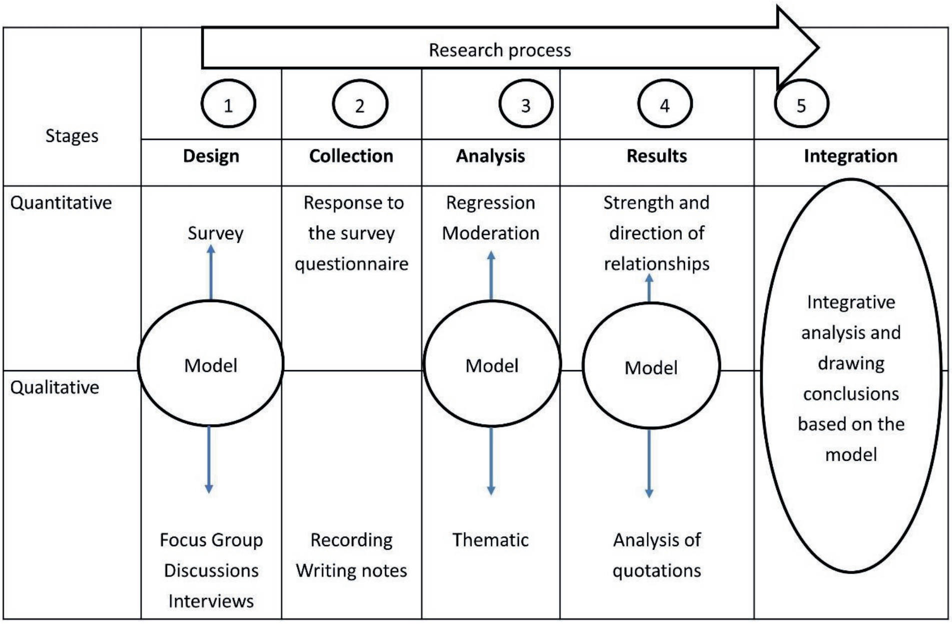


Figure 3.2: Flow and exchange between the two research phases (quantitative and qualitative)

Quantitative phase

Methods

Study setting

The relationships between individual perceptions and behavioural intentions, and the possible moderating role of both not having enough LLINs and having sufficient LLINs on intentions and LLINs use were tested in Ruhuha, a sector in Rwanda's Eastern province, and Busoro, a neighbouring sector, but in Rwanda's Southern province. Ruhuha has around 35 villages grouped in five cells, and approximately 5,000 households (Kateera et al., 2015), while Busoro has around 40 villages grouped in six cells, and approximately 8,000 households. Both sectors have numerous marshlands and water streams draining into the Akagera River, and were selected as they are among the highest malaria-endemic areas in the country due to the presence of these marshlands and various rice farming activities that are a source for malaria vectors (Kateera et al., 2015).

Study population and sample size

The study population included all households in Ruhuha and Busoro sectors. A sample of 742 households with equal numbers from each sector was selected. To choose this sample, a multistage sampling method was used, including stratified random sampling. Each cell within each sector was considered as a stratum, giving a total of 11 strata. Cells have a range of five to nine villages. At the cell level, two villages were selected by simple random sampling. At the village level, lists of households were provided by the village leaders, and systematic random sampling was used to draw a sample of households to be visited. The n^{th} household was determined based on the size of the village, and a starting number was chosen randomly.

Data collection

At the start, an initial meeting with the village leaders of selected villages was conducted. The selected households were notified ahead of time by the respective village leaders. A team of six research assistants conducted the survey. The team was fluent in the local language (Kinyarwanda) and the research assistants received a one-day training session to interview the respondents. The questionnaire was installed on Samsung Galaxy 2 Tablets using Open Data Kit (ODK) software. Written informed consent was signed by the head of a household prior to initiation of the data collection. Whenever possible and with participants' agreement, direct observations were made to minimize self-reported biases, mostly in the case of LLIN use. Participants did not receive any form of compensation or reimbursement.

Variables

The questionnaire was first developed in English, translated in Kinyarwanda, back-translated into English, and then pre-tested in a pilot study of 10 households selected randomly in the Mareba sector, Eastern Province, Rwanda. All translations were made by professional translators including members of the project team and cross-checked by native speakers. The translators were asked to review and cross-check the items and identify any problems in language, terminology, understandability, and relevance.

All independent variables were measured on five-point Likert scales (from 1 - strongly disagree to 5 - strongly agree). These included perceived severity, perceived susceptibility, perceived self-efficacy, perceived response efficacy, subjective norms, and perceived barriers. The latter was assessed into two categories: perceived discomfort and perceived lack of information. Except behavioural intentions, which was measured on five-point Likert scales (from 1 - strongly disagree to 5 - strongly agree), other dependent variables including consistent use of LLINs, acceptance of IRS, and draining stagnant water were measured on five-point Likert scales (from 1 almost never to 5-very often).

Data analysis

SPSS version 21 was used to test the relationships between the model variables. Descriptive statistics using frequencies, percentages, means and standard deviations were used to summarize the data. Cronbach's alpha values were calculated to determine the internal reliability of the variables of interest. Correlation coefficients were computed to explore the relationships between the predictor variables. The mean item scores were obtained by dividing the sum scores by the number of items for each subscale. To determine the independent predictors of the behavioural intentions and malaria preventive measures, a hierarchical linear regression analysis was conducted consisting of two steps. In the first step, demographic characteristics (age, gender, and education) were included as control variables. In step 2, the predictor variables perceived severity, perceived susceptibility, perceived self-efficacy, perceived response efficacy, subjective norms, perceived discomfort, and perceived lack of information were added. To investigate whether the strength and direction of the relationship between behavioural intentions and use of LLINs could be changed by the two moderators availability and accessiblity of LLINs , a moderation analysis was conducted. This was done through assessing the statistical significance of interaction terms from: (1) availability (not having enough LLINs and defined as having at least one LLINs), and (2) accessibility (defined as having sufficient LLINs: one per two people) and behavioural intentions in the regression model. The two moderators were included to explore whether: (1) having at least one LLIN will improve their consistent use by buying others in case of need, and (2) having sufficient LLINs will motivate people to increase their consistent use. As used in other studies, the access (having one LLIN per two people) was calculated by dividing the number of LLINs owned by each household by the number of household members [who slept in that household the previous night preceding the survey] (Koenker & Kilian, 2014; MEASURE Evaluation et al., 2013).

Ethics approval and consent to participate

The ethical approval was guaranteed to the study (Approval Notice: No 405/CMHS/IRB/2016) by the Institutional Review Board of the College of Medicine and Health Sciences, University of Rwanda. In addition, Rwanda Biomedical Center and Bugesera district approved this study.

Results

Participants characteristics

Of the 742 study participants, 59% were female, more than half had either no formal education or incomplete primary school, and most of them were farmers (78.6%) (Table 3.1). The average age of the respondents was 43.3 years (SD = 14.8), and the majority (69.4%) owned a bed net.

Table 3.1: Characteristics of the study participants

Variables	Variable categories	n (%)
Gender	Male	304 (41)
	Female	438 (59)
Education	None	247 (33.3)
	Incomplete primary	248 (33.4)
	Complete primary	183 (24.7)
	Incomplete secondary	32 (4.3)
	Complete secondary	28 (3.8)
	Tertiary	4 (0.5)
Occupation	Farmer	583 (78.6)
	Public servant	5 (0.7)
	Self-employed	40 (5.4)
	Private servant	15 (2)
	Student	5 (0.7)
	Unemployed	94 (12.7)
Age	Mean (SD)	43.3 (14.8)
N of HH members	Mean (SD)	4.9 (2.2)
N of sleeping rooms	Mean (SD)	2.5 (1.1)
N of beds	Mean (SD)	2.2 (1.0)
LLIN ownership	No	227 (30.6)
	Yes	515 (69.4)
LLIN used last night (among those who own them)	No	63 (12.2)
	Yes	452 (87.8)
Household members that use bed net last night	Every household member	310 (68.6)
	Only adults	70 (15.5)
	Only few people (mixture group)	42 (9.3)
	Only children	30 (6.6)
N LLINs owned	Mean (SD)	2.01 (1.13)
Access (one LLIN per two people)	Mean (SD)	0.47 (0.34)
Ever heard about IRS	No	56 (7.5)
	Yes	686 (92.5)
Presence of stagnant water	No	585 (78.8)
	Yes	157 (21.2)
Presence of bed bugs	No	297 (40)
	Yes	445 (60)

Internal reliability and correlations between predictor variables

As shown in Table 3.2, the Cronbach's alpha values for eight constructs ranged from .64 to .90 indicating that the scales used had adequate reliability. The behavioural intentions as the main predictor variable was significantly positively associated with perceived self-efficacy and response efficacy, and negatively associated with perceived discomfort and lack of information. All relationships will be fully explored in the following analysis.

Table 3.2: Bi-variate correlations between study variables

Subscales	**N of items**	**Cronbach's alpha**	***M (SD)***	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Perceived severity	8	.76	4.38 (0.51)							
2. Perceived susceptibility	8	.71	3.44 (0.68)	.24**						
3. Perceived self-efficacy	7	.77	4.37 (0.50)	.42**	.11*					
4. Perceived response efficacy	6	.64	3.92 (0.63)	.35**	.06	.52**				
5. Subjective norms	9	.86	2.99 (0.74)	-.03	-.03	.04	.01			
6. Perceived discomfort	5	.69	1.74 (0.66)	-.27**	-.05	-.49**	-.35**	-.02		
7. Perceived lack of information	2	.76	2.13 (1.01)	-.31**	-.13**	-.49**	-.35**	-.13**	.38**	
8. Behavioural intentions	7	.90	4.53 (0.47)	.38**	.11*	.62**	.45**	.15**	-.49**	-.52**

Note: * $p < 0.01$; ** $p < 0.001$. *M* = mean; *SD* = standard deviation.

Malaria preventive measures

Respondents were asked to rate the frequency of performing three different malaria preventive measures. The results revealed that 66.6% of the participants very often (consistently) uses an LLIN, 73.9% accepts IRS to be done in their house, and 62.0% drains stagnant water in case it is present. No apparent substantial differences across the three malaria preventive measures studied was found (Figure 3.3).

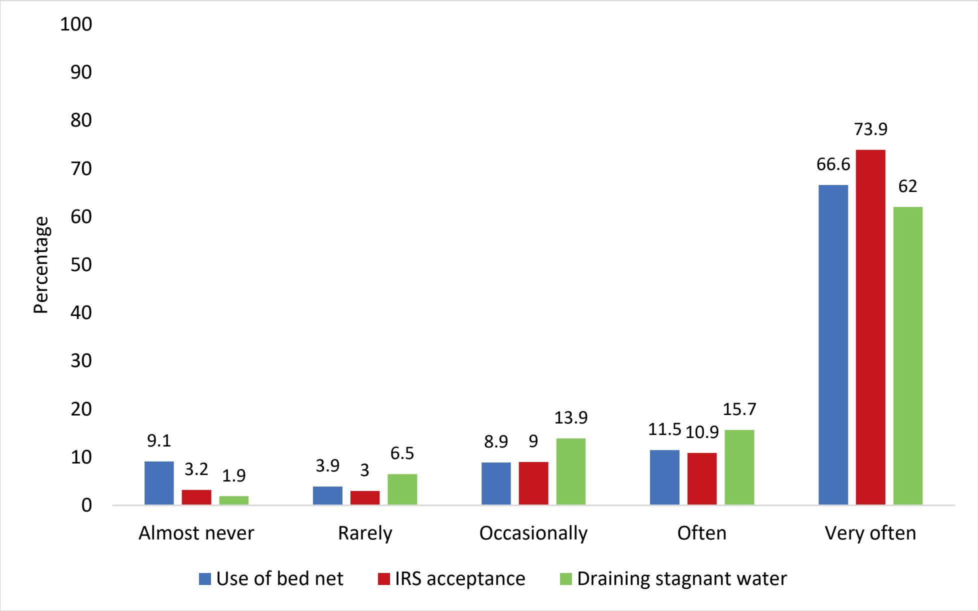


Figure 3.3: Use and acceptance of malaria preventive measures

Predictors of behavioural intentions to use malaria preventive measures

The results show that perceived severity, perceived self-efficacy, perceived response efficacy, and subjective norms were positively related to behavioural intentions, while perceived discomfort and lack of information were negatively related. The full model explained 50% of variance of behavioural intentions (Table 3.3). Looking at the control variables, there was no significant difference in behavioural intentions between male and female, and between older and younger participants. However, there is a slight significant positive relationship between behavioural intentions and education.

Table 3.3: Regression analysis of predictors of behavioural intentions to use the malaria preventive measures

Steps	Variables	Behavioural intentions	
		1	2
1	Age	.03	.00
	Gender	.02	.00
	Education	.08*	.01
2	Perceived severity		.09**
	Perceived susceptibility		.01
	Perceived self-efficacy		.31***
	Perceived response efficacy		.11***
	Subjective norms		.11***
	Perceived discomfort		-.19***
	Perceived lack of information		-.20***
	R^2 Change		.50***
	Adjusted R^2	.00	.50***

Note: Standardized regression coefficients are reported. *$p < .05$; **$p < .01$; ***$p < .001$.

Moderation analysis of behavioural intentions and use of malaria preventive measures

Interaction terms were computed from the availability and accessibility of LLINs and behavioural intentions. The results showed that behavioural intentions were positively related to LLINs use, IRS acceptance, and draining stagnant water in case present. However, no evidence supported the hypotheses that either availability or accessibility of LLINs moderated the relationship between behavioural intentions and actual use of LLINs (Table 3.4). Looking at the control variables, slight significant associations between gender, education and use of LLINs, and a significant positive relationship between age and draining stagnant water were observed.

Table 3.4: Moderation analysis on behavioural intentions and use of malaria preventive measures

Steps	Variables	LLINs			IRS		Stagnant water	
		1	**2**	**3**	**1**	**2**	**1**	**2**
1	Age	-.02	-.05	-.04	-.00	-.01	.26*	.22*
	Gender	-.08	-.08	-.08*	.04	.03	-.02	-.04
	Education	.09*	.06	.06	.01	-.00	.05	.04
2	Behavioural intentions		.10*	.10*		.22***		.21*
	Availability		-.02	-.01				
	Accessibility		.08	.07				
3	Interaction term 1 (behavioural intentions and availability)			-.05				
	Interaction term 2 (behavioural intentions and accessibility)			.07				
	Adjusted R^2	.01*	.02*	.02	-.00	.04***	.03	.07*

Note: Standardized regression coefficients are reported. *p < .05; ***p < .001.

In summary, intentions to use malaria preventive measures were positively influenced by perceived severity of malaria, perceived self-efficacy, perceived effectiveness of malaria preventive measures, and subjective norms, and negatively associated with perceived barriers (perceived discomfort and lack of information). There was no significant evidence supporting the moderation between either availability or accessibility of LLINs to behavioural intentions and use of LLINs (Figure 3.4). Standardized coefficients are reported.

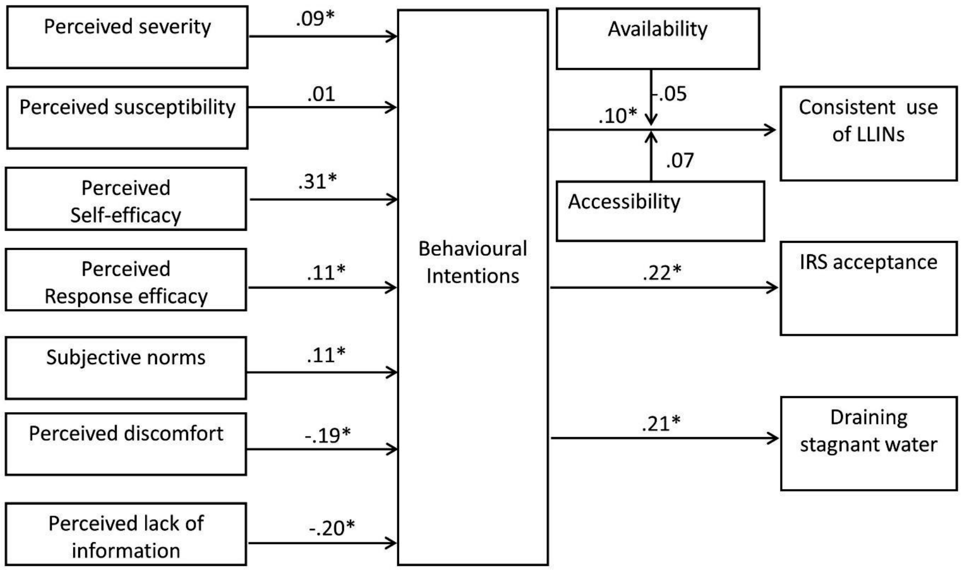


Figure 3.4: Results of the integrated model showing the relationships (* indicates a significant relationship)

Qualitative phase

Based on the relationships that were found in the quantitative survey, a more in-depth understanding of the mechanisms that explain these relationships was obtained. This was done by exploring different perceptions related to malaria and malaria preventive measures, and identifying strategies to enhance the consistent use of these measures. Therefore, phase two employed focus group discussions and interviews to gain this in-depth understanding.

Methods

Selection of participants

A total of 76 residents of the Ruhuha sector took part in nine Focus Group Discussions (FGDs), seven Key Informant Interviews (KIIs) and three In-Depth Interviews (IDIs). A homogenous purposive sampling method was used to select the community members to participate in three FGDs of male, female, and youth respectively. The selection of participants with similar characteristics (age and gender) in FGDs was performed to ensure that all participants had equal opportunities to share their views. Consequently, male, female, and youth groups were selected. Other groups were identified based on a stakeholder analysis described in a previous study (Ingabire et al., 2016). The FGDs were composed of (1) one group of Community Health Workers (CHWs), (2) one group of members of Community Malaria Action Teams (CMATs), (3) one group of female community members, (4) one group of male community members, (5) one group of youth community members, (6) three groups of cooperative members, and (7) one group of religious leaders. Initially, the target was to have eight participants per group discussion, however, on the scheduled day, some participants were unable to attend the discussion due to different personal reasons. Consequently, the youth and male groups had seven participants each and the religious group had five participants. Initially, ten FGDs, ten KIIs, and three IDIs were scheduled to start with. Following the review and assessment of the transcripts and notes taken, after conducting nine FGDs, seven KIIs, and three IDIs, saturation had been achieved as no new data was appearing and all concepts in the conceptual framework were fully developed.

At the start, contact details of suitable CHWs and CMATs that could be contacted for FGDs and interviews were obtained from the local health centre. Male, female and youth community members' participants were identified by the CHWs and CMATs. Cooperative members and church leaders were selected with the help of Ruhuha sector staff. In addition, the interviews with sector level staff and policymakers were scheduled by the researcher. Participants from KII included the representative of CHWs at cell and sector level, in charge of cooperative's union, one participant at the sector level, and one participant at the national level. The participants of IDI involved three community members (a male, female, and a young person, aged around 20 years).

Data collection

A focus group guide and interview guide (one for IDI and another for KII) were developed based on concepts from the conceptual framework (Figure 3.1) and the research questions. Minor adjustments and few probes were added throughout the data collection based on preceding FGDs, and interviews. Data were collected by one PhD researcher trained in qualitative data collection. A digital voice recorder was used alongside with taking notes. Verbal consent for participation and recording was obtained prior to the start of each FGD and interview. Only one interview participant refused to be recorded. In that case, the researcher only took notes. The FGD lasted between 70 and 90 minutes, while both IDI and KII lasted approximately the same time and took between 40 and 60 minutes. The interviews with sector level staff and policymakers were conducted in their offices or at another suitable location. The remaining interviews were conducted at the health centre. The language used during all discussions and interviews was Kinyarwanda as all participants were proficient in this language.

Data analysis

Thematic analysis followed by mainly a deductive method was employed to analyse the data (Braun & Clarke, 2006; Elo & Kyngas, 2008). Data were evaluated following the consolidated criteria for reporting qualitative research (COREQ) guidelines (Tong et al., 2007). The integrated model of determinants of malaria preventive behaviour guided the analysis and its concepts served as the main themes. However, in case additional themes emerged, then those were added. Voice recorded interviews and FGDs were transcribed and translated into English. Transcripts were verified for completeness and checked to ensure that personal identifiers were deleted. The research team conducted an iterative revision and discussion about verbatim texts. Analysis of the text resulted in an initial set of categories that were independently developed by the first author. This was done following the deductive nature of content analysis, which was driven by a predefined conceptual framework and related concepts which were considered the main themes. Other members of the research team (2nd, 3rd and 4th authors) further independently reviewed this initial set of coding and suggested additional categories to increase the readability of the findings. These categories were further matched with the list of corresponding themes. No much discrepancy was observed, and in case discrepancy in the categories was found, then this was resolved before they were applied to quotes. Hence, inter-rater agreement and kappa were not calculated as was not deemed necessary. In presenting the results, the headings reflect the main themes used for the analysis and subheadings reflect the categories that emerged during the discussion and the process of reading and coding the transcripts.

Results

In this section, the results are reported based on the seven themes of discussion: (1) perceived severity of malaria, (2) perceived susceptibility to malaria, (3) perceived self-efficacy to use bed nets, (4) perceived response efficacy of bed nets, (5) perceived barriers to use bed nets, (6) IRS acceptance, and (7) strategies to enhance the consistent use of malaria preventive measures. As shown in the sections below, some of these themes indicated more variation among participants compared to others, hence these are reported using different categories that emerged during the discussion.

Perceived severity of malaria

Participants indicated that the incidence of malaria clearly increased in 2017 relative to 2016. Malaria severity and an increase in the number of malaria cases was discussed and four categories emerged: (1) malaria is perceived as an epidemic, (2) a high number of malaria cases in relation to high mosquito density, (3) increased malaria cases in relation to weather as well as (4) repetitive episodes of malaria in relation to low perceived effectiveness of Coartem® (brand name of artemether-lumefantrine, one of the medicines recommended for artemisinin-based combination therapy).

Malaria is perceived as an epidemic

Malaria was widely believed to be a serious disease and more severe than it used to be in the past (in 2017 compared to 2016). With no exception, participants perceived that malaria posed a very real threat. They expressed worry as most of the household members suffer from malaria from time to time and it is hard to find a family without a malaria case:
"*In the past, malaria was not considered as a severe disease, however nowadays it has become an epidemic. When you visit one household, you find that, for example, five members suffer from malaria. For this reason, people are even telling us to ask the health professionals on their behalf whether this is malaria as it used to be or whether it is an epidemic." (CHWs FGD)*

"Nowadays people are asking themselves what kind of disease is this? 2017 came with a difference in relation to malaria, compared to 2016. Even people are calling each other to go to the health centre together as if they are going to pray together!." (Male FGD)

A high number of malaria cases in relation to high mosquito density

Some participants indicated that there is a high mosquito density and mosquito nuisance. The participants also reported an increase in perceived severity of malaria. Mosquitoes were reported to be everywhere in or outside the house and they can bite anytime especially during the night when sleeping:

"*These days in the evening, you hear a lot of mosquito noises like bee buzzing. There are a lot of mosquitoes these days, and this makes me think that even if you are protected under the bed net at night you can even get a mosquito bite outside the house, and get malaria." (Female FGD)*

Increased malaria cases in relation to weather

Few participants associated the malaria burden with seasonality. In this line, it was perceived that malaria cases increase when it starts raining (in September) as a result of rapid mosquito reproduction, and malaria cases decrease during the dry season (in July):

"Because of change in weather many people are being affected. Nowadays, we are in a short rainy season (locally termed Umuhindo*), and we know that there is a lot of multiplication of mosquitoes in this period. Although mosquitoes multiply throughout all seasons, this can be one of the reasons for this increase in malaria cases. " (Cooperative FGD)*

Repetitive episodes of malaria in relation to the low perceived effectiveness of Coartem®

By having repetitive malaria episodes without cure, respondents reported that these episodes may be due to low effectiveness of the malaria medicine, and reported a need to either replace the current medicines and bring ones with high effectiveness or find out a malaria vaccine. Participants believed that normally when you have malaria and get treated, one cure of Coartem® is enough for the sick person to get better. However, their experience is that this is no longer the case. Some of the participants reported to prefer buying some medicines in private pharmacies and perceived that they have a higher quality than those found at the health centre:

"*Malaria has increased this year (2017), there are many malaria cases. We have observed that the medicines that used to cure malaria patients, now it seems like they are not curing. These days a person completes the cure without getting better, and after some days a person falls sick again. Thus, personally, I see that the current medicines may no longer have a strong capacity to cure malaria."(KII Female participant)*

"When you discuss with people, they tell you that when they go to the health centre and get medication, they don't get cured, but when they go to the private pharmacy and buy medications [there are some medications for 3500 Rwf, approximately 4 US dollars] they get cured. Why this, they asked? Do the medicines from the health centre have the same capacity to treat malaria as those at the pharmacy?" (Youth FGD)

Perceived susceptibility to malaria

There was a general agreement about susceptibility to malaria among the participants and there was not much variation in the responses indicated. Everybody was considered at risk of getting malaria, and this was mainly due to the observed increase in malaria prevalence. Participants reported that there are many people who are going for treatment and that during the last years they did not suffer from malaria, but now they got it. There is a diversity in those people affected and you can not say that it is only one group of people or certain age group, rather all people, men, women, and children:

"This year was so special to me. I have never suffered from malaria before, but some months ago I got it and it was serious. I went to the CHW and had it diagnosed. After a few days, my wife and children also had it. Now, being either a child, young adult, or old person does not matter. Everybody is getting malaria." (Male FGD)

"Last time I treated an old woman (81 years) and she told me that it was her first time to suffer from malaria in her life. She told me that it is an epidemic and not malaria as such. She was advising me to go and ask the health professionals about this epidemic in [cell name was removed] this cell."(CHWs FGD)

Perceived self-efficacy to use a bed net

There was not much variation in the reported self-efficacy to use a bed net. All participants agreed that community members are confident in their ability to use a bed net when available. They reported that sleeping under a bed net is an activity that they are confident to perform. In addition, they also mentioned that it is their responsibility to monitor their children (mostly children under five years of age, as these cannot put the bed net on the bed themselves) so that they are sure that they sleep under the bed net once they own it:

"Sleeping under a bed net does not cost anything and I believe that even for those who don't have a bed frame it is not a problem, they hang the bed net on the wall and it looks fine." (CHWs FGD).

Perceived response efficacy of LLINs

Many participants believed LLIN to be an effective measure to prevent malaria. Although this was reported, many participants indicated the observed high perceived effectiveness of LLINs to be related to the increase of malaria incidence (reported as an increased number of malaria cases), and the reduction of the number of bed nets owned. This reported effectiveness of LLINs was extended beyond malaria prevention as some participants highlighted the non-malaria benefits of the LLINs. However, few participants noted that the observed increase of malaria incidence is beyond the capacity of LLINs protection. The reported perceived effectiveness of LLINs could be split into three categories: (i) increase of malaria incidence in relation to the decrease in the number of LLINs owned; (ii) non-malaria benefits of LLINs; and (iii) perceived absence of insecticide and type of LLINs owned.

The increase of malaria incidence in relation to the decrease in the number of LLINs owned

It was clear that the increase of malaria cases and associated consequences is related to the reported high perceived effectiveness of bed nets. Given the high malaria incidence, participants reported that even when it is too hot to use bed nets, the nets are an important tool in preventing being bitten by mosquitoes including those causing malaria.

The reported effectiveness is also linked to the decrease of LLINs ownership as many participants reported planning to use them, and, unfortunately, they do not own them anymore as some of the participants noted that the LLINs received from last distribution were used for other unintended purposes:

"Since malaria severity has gone up people started appreciating the importance of the bed nets. Unfortunately, some of them don't have the bed nets as from the last distribution some people received the bed nets but they used them for other purposes." (KII Male participant)

"During the previous years, people did not value the bed nets and there weren't many malaria cases. However, nowadays as malaria cases have increased, they started giving them value when they don't have them. It is similar to the other proverb "utaribwa ntakinga" meaning that you increase awareness when you lose." (FGD CHWs)

Non-malaria benefits of LLINs

Apart from being a malaria preventive measure, protection against other insects or reptiles that may fall from the roof while sleeping were reported as non malaria related benefits of LLINs. Some of the participants highlighted that sleeping under a LLINs has become a common practice. They are considering bed nets as something that protects them without thinking necessarily about mosquitoes. Even if it can be hot, they prefer to sleep under the bed net and leave aside the bed sheets:

"I have never slept without a bed net because it can even protect me from other insects or reptiles like lizards that may fall over. For example, I was sleeping one day and I started feeling sand/pebble falling from the roof. When I looked, it was a snake climbing the wall. Therefore, if I had not slept under the bed net, it would have bitten me. Thus, sleeping under the bed net and making sure you insert it properly under the mattress protects you from so many things." (CHWs FGD)

Perceived absence of insecticide and type of LLINs owned

Due to high perceived severity of malaria, some community members believe that this severity of malaria exceeds the capacity of the LLINs. People believe that the LLINs do not have the proper insecticidal protection, or the insecticides are not effective anymore and the LLINs are no longer able to keep the mosquitoes away. Participants indicated that normally mosquitoes would die immediately when they get into contact with the LLINs, however, that is not the case, rather mosquitoes just remain alive on LLINs. Few participants reported also the large mesh size of some type of LLINs and perceived that they can allow mosquitoes to enter and bite the person while sleeping:

"A few months ago, I got a new bed net from the health centre, and I currently sleep under it, but my child gets sick very often and sometimes everybody at home is sick, then I am wondering why? I think the bed nets are not effective anymore." (Male FGD)

"I think the main reason why many people are affected by malaria is that these bed nets do not have the insecticide for protection, therefore the mosquitoes can bite anytime. I have also seen that the current bed nets have big mesh and I believe that they can even allow mosquitoes to enter and bite the person sleeping under it. Truly they are not protecting us." (Female FGD)

Perceived barriers to use LLINs

Participants indicated three types of barriers that affect the use of LLINs. This can be thematically grouped under: (i) lack of or limited availability of LLINs; (ii) discomfort due to hotness, irritation, and bed bugs; as well as (iii) weak malaria risk perception.

Lack of or limited availability of LLINs

Lack of bed nets was mentioned by most of the participants to be the first barrier to use them and automatically put them at risk of getting malaria. Even for LLINs that are still intact, participants mentioned that they no longer contain insecticidal effects which underscore the need for replacement or retreatment (a procedure that was done by using "*Karishya*" kits that could be found in different shops, but they are no longer available). However, with the LLINs, retreatment is no longer necessary as they are treated with insecticides in the factory and this eliminates the needs for retreatment. Participants highlighted that the LLINs are only available for those attending antenatal consultation or vaccination:

"These days, people don't have bed nets. Most of the households do not have bed nets. It is even clear because once an infected malaria mosquito bites somebody in the family, you will see that after some time all family members are sick because of lack of preventive measures. This means that the same malaria mosquito stays in the house and bites all of them." (CHWs FGD)

"These days people get bed nets at the health centre from antenatal consultation or child vaccination at 9 months. Those who don't attend consultation or vaccination services have a problem of getting bed nets." (Male FGD)

Discomfort due to hotness, irritation, and bed bugs

Discomfort while sleeping under LLINs in the dry season, irritation (especially for those using the bed net with a strong texture or getting in contact with LLINs when using it for the first time), and presence of bed bugs while sleeping under the bed net were reported as hindrances to use bed nets. Many participants noted that the discomfort used to be the main hindrance. However, it was reported by few participants only, as perceived malaria risk exceeds the reported discomfort and many people have changed their opinion/perception:

"There is a time you go around mobilizing people to sleep under the bed net, but some, honestly tell you that if they use a bed net, they get irritated. And these days many people have bed bugs in their beds which prevent people to use bed nets even if they own the nets." (KII Female participant)

"In my house, I have not moved from my sleeping room because of a mosquito, but I have moved because of bed bugs. It is really annoying. Therefore I pay much attention to the bed bugs more than I do for the mosquitoes and I can not sleep in a bed net when bed bugs are there." (Male FGD)

"Due to the hotness that is here in Bugesera, sleeping under the bed net sometimes is like a punishment. And you may say that "even if I get a mosquito bite and get malaria, I will get treated instead of sleeping the whole week in this condition, it is really very hot."(KII Male participant)

Weak malaria risk perception

Although some respondents mentioned bed bugs as a barrier to sleep under a bed net, others believe that more attention should be on mosquitoes rather than bed bugs. This was explained in relation to the consequences of malaria where also the cost of treatment is involved once the person gets sick. Participants added that when a person is sick, his/her routine activities are disrupted, hence his/her economy is affected. Hence, the perceived malaria risk outweighs the perceived beg bugs' bites:

"If there is a room in my house that I can move in and not get into contact with the bed bugs, but no room I can go in and say that I am safe from the mosquitoes, then I should be worried. I know bed bugs are bad and when they bite they cause itching, but after all, I get up in the morning and go to my farms without any problem. In contrast, when an infected mosquito bites me, and I get malaria, in the morning I have to look for somebody to take me to the health centre as I cannot reach there alone. Consequently, this affects my economy "(Male FGD).

IRS acceptance

Many of the participants reported the effectiveness of IRS to be good. Participants generally agreed that, after spraying, a person could observe that mosquitoes and other insects were dead. At that time, one could enter in the house without fear as there is no way to get into contact with mosquitoes. However, changing the spraying company was reported to be a problem by the participants. The last spraying activity was done by the Inkeragutabara group (*members of the District Administration Security Support)*, whereas the CHWs used to be responsible for spraying. Therefore, this new group was seen as an outsider in the community and participants highlighted that they did not spray properly. Participants believed that the sprayers had diluted the insecticide, or they are simply not well trained and qualified for the spraying activity. Thus, people were reluctant to accept IRS in their houses:

"CHWs used to be the one spraying, and to be honest the community members have very much trust in CHWs. But last time the people called "Inkeragutabara" were selected to do the spraying activities. Even some households were not sprayed. We don't know whether they were entering the house and remain there until getting out without spraying." (CMATs FGD)

"People are willing to receive the sprayers, but the main problem is those sprayers who don't spray properly. The last team came to spray, but really, they were not spraying, because even at the end of the day (after spraying) you could see the mosquitoes flying. Therefore, some people were hesitant to stay at home and wait for the sprayers as people think that they are wasting their time, waiting for those people for nothing, and they close and go in their farms." (Female FGD)

Strategies to enhance the consistent use and acceptance of malaria preventive measures

A number of strategies to enhance the consistent use and acceptance of malaria preventive measures were mentioned by the participants. These were classified into three categories: (i) availability of LLINs and regular spraying of insecticide; (ii) community mobilization; and (iii) citizen engagement in malaria preventive activities.

Accessibility of LLINs and regular spraying of insecticide

Making LLINs available, and regular spraying of insecticides both in houses and in marshlands were reported to be strategies to increase consistent use and acceptance of these measures. For LLINs, participants reported that if they were available in local shops for a cheaper price, then they would buy them. However, others indicated that there are those who cannot buy them either because they cannot afford them or simply because they used to get them from the government for free and believe that they cannot spend money buying the LLINs:
"Even if the bed net cannot be freely distributed, at least they can be put in local shops and at cheap prices for us to be able to buy them. But you need to have a place where you can buy it. For example in my family, I only have two bed nets and I need three more, therefore, if there is a place to buy, definitely I will buy them unless they are too expensive." (KII Male participant)

Community mobilization

Community mobilization was generally highlighted as a strategy to promote the consistent use of malaria preventive measures. The focus should be more on those who do not use or accept the malaria preventive measures. Mobilization can be done through monthly community

work, *akagoroba k' ababyeyi* (parents' evening meeting), and *isibo* meetings (roughly 15 households neighbouring each other), and home visits. Mobilization should be the responsibility of every community member in collaboration with CHWs:
"We need to continue community mobilization. I know people hear mosquitoes when they make much noise, especially in the rainy season. So, we need to tell them that even in the dry season mosquitoes are there and they have to use the preventive measures consistently even when having bed bugs." (IDI Youth participant)

"Community mobilization related to malaria severity, its consequences, and benefits of bed net use is still lacking. This can be done in a formal and informal meeting at the amasibo, village, and cell levels. Community work and parents' evening meetings also are good opportunities to share this type of information and mobilize people to remove all kinds of mosquito breeding sites that can be around their homes. Those who never attend the meetings can be visited at their home." (Youth FGD)

Citizen engagement

As everybody is at risk of getting malaria, participants noted that every citizen should be actively involved in malaria prevention activities. When everybody feels responsible and actively contributes to malaria prevention through using LLINs consistently, controlling mosquito breeding sites, and accepting IRS, then mobilization could be easier. Thus, proactive mechanisms, discussions, and interactions between community members can be enhanced:
"Every community member should feel it [malaria prevention and control] as a personal responsibility, because even if you can mobilize, but people don't feel responsible, then nothing can be changed. But if everybody engages in malaria prevention, I believe that perceptions can be improved." (Youth FGD)

"Even if you distribute the bed nets today, tomorrow you will not find them as long as the perceived discomfort and bed bugs are still there. Do you know what they are saying? They are saying that the bed bugs go to the bed net in the night. In their feeling, they say that bed nets bring bed bugs. They remove them and burn them. Consequently, even if you distribute bed

nets today, you will not solve the problem. First of all, let's target the issue of bed bugs and related perceptions, and then we distribute the bed nets later." (KII female participant)

Discussion

This study used a mixed-methods approach to assess the relationship between individual perceptions and intentions to use malaria preventive measures, to explore why people have certain perceptions, and to identify strategies that stimulate consistent use of malaria preventive measures.

Perceived severity and susceptibility

A high perceived severity of malaria among the study participants was reported and this was found to have a significant positive association with intentions to use malaria preventive measures. High-perceived malaria risk in relation to mosquito density was also reported elsewhere (Beer et al., 2012; Msellemu et al., 2017). Watanabe et al. (2014) found a weak malaria risk perception to be associated with a reduction in malaria incidence and disappearance of mosquitoes in the dry season. Thus, a high-perceived severity of malaria reported in the present study could be attributed to the time of the study (short rainy season) in which mosquito density is expected to be high, consequently people intend to use LLINs to prevent mosquito nuisance.

Regarding susceptibility, Beer et al. (2012) reported children to have a greater chance of contracting malaria than any other group of the population. The reported high-perceived susceptibility among the majority of the study participants in the current study was due to high perceived severity of malaria and to repetitive malaria episodes among the majority of the community members. The perceived low effectiveness of Coartem® also increases the perceived severity of malaria as well as susceptibility. Artemisinin-based combination therapy is considered the first line treatment and the most effective anti-malarial drug (MoH, 2017a; WHO, 2017b). The perceived low effectiveness of Coartem® is challenging as it may lead to possible incorrect self-treatment through buying medicines in the pharmacy without a diagnosis, hence drug resistance in the longer term. While the reasons for lack of a significant relationship between perceived susceptibility and intentions to use malaria preventive measures are not fully clear, however, this may be due to the fact that people who live in malaria-endemic areas are familiar with the malaria risk, hence become more accustomed to it.

Perceived self-efficacy and response efficacy

The finding that the perceived response efficacy is related to the observed increase of malaria cases is consistent with previous studies (Beer et al., 2012; Dye et al., 2010; Koenker et al., 2013; Msellemu et al., 2017). This indicates that participants are worried about malaria consequences and tend to think about the benefits of malaria preventive measures, hence this may increase their use. In addition, this study revealed a positive association between both perceived self-efficacy and response efficacy, and intentions to use malaria preventive measures. (Birhanu et al., 2015) showed that in the dry season, when perceived mosquito nuisance decreases, use of LLINs also decreases. It is often an issue in the dry season as people are less concerned about malaria and mosquito nuisance, thus, intentions to consistently use LLINs also decreases. The non-malaria related benefits of LLINs, including avoiding biting insects and a good night sleep were also reported as factors that influence people to sleep under LLINs in Kenya (Dye et al., 2010), Zanzibar and Tanzania (Koenker et al., 2013; Msellemu et al., 2017), and Vanuatu Islands (Watanabe et al., 2014). Comfortability and provision of warmth during cold weather were also reported in previous studies (Koenker et al., 2013; Msellemu et al., 2017). This shows that the non-malaria related benefits of LLINs exist and may also be promoted in malaria-related messages, especially in a dry season when the use of LLINs reduces due to the decrease of malaria incidence and mosquito density.

While some criticized the type of the bed nets (strong texture and large mesh size of the net), Beer et al. (2012) found that some people prefer them as they do not tear easily and they also allow ventilation. The dissatisfaction about the type and size of bed nets was also reported in a study conducted in Tanzania (Msellemu et al., 2017). If people believe that they can get mosquito bites through the LLINs and get repeated malaria episodes, then they may doubt the effectiveness of LLINs, hence intend not to use them (Msellemu et al., 2017). The perceived lower effectiveness of LLINs was also reported in Ethiopia where participants indicated that the LLINs' insecticide was unable to kill mosquitoes and other insects, therefore people throw them away or use them for other purposes (Birhanu et al., 2015). Regarding IRS, a high perceived effectiveness of IRS was reported and behavioural intentions have a positive relationship with IRS acceptance. In contrast, some previous studies have found that IRS acceptability may be more related to the perceived obligation to accept government initiatives rather than based on its effectiveness (Kaufman et al., 2012). The reported high perceived effectiveness of IRS in this study may be due to the campaigns that have been conducted at the start of spraying activities. Equally, the fact that CHWs also participated in the previous spraying activities may also be an added advantage as they could provide more explanations to some of the households when they refuse to get their houses sprayed.

Subjective norms and perceived barriers

The result indicates that subjective norms were positively related to behavioural intentions. If many people in the community use and accept malaria preventive measures (LLINs, IRS, and draining stagnant water), then it is more likely that most of the people in the same community will intend to consistently use those measures (Babalola et al., 2018). However, lack of collective awareness about collective management of, for example, mosquito breeding sites may hinder the plan to consistently use malaria preventive measures (Leeuwis et al., 2018). In the same way, collective action that supports the community members to think about malaria preventive measures and related benefits may influence people to use these measures.

Lack of LLINs was reported to impede the consistent use of LLINs. Other studies also revealed a lack of access to LLINs to be the reason associated with non-use (Koenker et al., 2013; Msellemu et al., 2017). However, no significant evidence supports that availability or accessibility moderate the relation between intentions and consistent use of LLINs. Thus, regardless of how both availability and accessibility of LLINs are potential factors of LLINs use, we did not find evidence that they are statistically significant moderators in the relation between intentions and consistent use of LLINs. This strongly indicates that when people plan to use LLINs, having them or not may not be an issue. These results are in line with those found by Msellemu et al. (2017) who reported that when participants were reminded that they should still be having the LLINs that were distributed freely, accessibility was not an issue anymore, and other measures including closing doors in the evening and use of mosquito sprays were then reported to be preferred over the sleeping under LLINs and participants emphasized the protective value of these measures. The same authors reported that people may spend own money buying LLINs, but still do not use them, and keep them for either visitors or children only (Msellemu et al., 2017). This provides evidence that individual perceptions play a large role in the decisions to use or not use malaria preventive measures and should be addressed prior to or parallel to LLINs distribution and spraying campaigns.

Discomfort, irritability, and bed bugs were reported in previous studies to hinder the consistent use of LLINs (Ingabire et al., 2015; Koenker et al., 2013; Pulford et al., 2011). Fear of chemicals in the LLINs that may cause irritation and itching were also cited as reasons for not using LLINs in an Ethiopian study (Birhanu et al., 2015). While reasons for non-use of ITNs were widely reported, it was highlighted in this study that the discomfort of mosquitoes outweighs the discomfort of feeling hot while sleeping under the LLINs or the presence of bed bugs. In the same line with the current study, distrust of household members in sprayers was also reported in other studies to decrease acceptance of IRS (Ingabire et al., 2015; Kaufman et al., 2012; Munguambe et al., 2011). In some circumstances, sprayers are recruited exclusively based on where they live, or their religion (Kaufman et al., 2012). Refusal of IRS can be addressed by community mobilization.

Strategies to enhance the consistent use of malaria preventive measures

It is clear that when a person intends to use the LLINs, then the person can buy them. However, even if the person owns LLINs, and does not see the associated effectiveness, then the person will not use them. In that regard, community mobilization and citizen engagement in the development of malaria prevention strategies is crucial as it promotes acceptability, adherence, and sustainability of those strategies (Kajeechiwa et al., 2017; Sahan et al., 2017). Community mobilization in form of health education campaigns focusing on the importance of consistent use of LLINs and consequences of not using them was also reported in Tanzania as one of the strategies to increase their consistent use (Msellemu et al., 2017). Considering LLINs as an essential part of life, and becoming accustomed to it, is an important factor and first step of engagement towards maintaining and sustaining the consistent use of them despite fluctuations in perceived malaria risk and malaria incidence (Koenker et al., 2013). However, mobilization and engagement alone without LLINs distribution in a place where LLINs are limited and even not accessible cannot achieve tangible results (Hetzel et al., 2012). Still, in a place where perceived discomfort can explain non-use of LLINs (e.g. if bed bugs are present), there is no guarantee that the combination of community mobilization and distribution of LLINs would enhance the use of LLINs, rather the engagement and feeling of ownership of these measures should be the first step as it may target and remove or modify the perceived barriers.

Given the public health burden caused by malaria, the following are three important policy and program implications of the findings reported: (1) individual perceptions play a large role in the decisions to use or not use malaria preventive measures and should be addressed prior to or parallel to LLINs distribution and spraying campaigns. This can be done by enhancing and encouraging the feeling of ownership of these measures through community mobilization and citizen engagement in malaria prevention and control activities. In turn, this may promote acceptability, adherence, and sustainability of those strategies. (2) Especially in a dry season when the use of LLINs reduces due to the decrease of malaria incidence and mosquito density, non-malaria related benefits of LLINs should be promoted in malaria-related messages organized at a national level. Since malaria prevention may not be enough reason for people to consistently use LLINs in dry seasons, other benefits of LLINs should be included in malaria-related messages. For example protection against other insects, and provision of a good night sleep should be incorporated in malaria-related messages so that sleeping under LLINs consistently becomes a common practice. And (3) for IRS, hiring of sprayers should consider those who are trusted and preferred by the household members (example: CHWs).

Strengths and limitations

A mixed-methods design allowed us to explore the individual perceptions and quantify the effects of different individual perceptions on the intentions to use malaria preventive measures. This is essential as it offers new insights into the field of vector-borne disease risk and malaria prevention in particular. For example, the fact that individual perceptions explain 50% of variance in intentions to use malaria preventive measures suggests that interventions to promote the consistent use of malaria preventive measures should consider adopting an approach based on an integrated model of determinants of malaria preventive behaviour (Asingizwe et al., 2018). The use of this model provides a comprehensive understanding of this key area of self-protective behaviour in relation to vector-borne diseases. Future research could test this model in other (geographic) settings, in the context of other vector-transmitted diseases, or other behaviour change projects.

The documented reasons of why people have certain perceptions may explain the gap between the ownership and use of LLINs reported in previous studies (Babalola et al., 2018; Ernst et al., 2017; Gonahasa et al., 2018; Kateera et al., 2015; Ntuku et al., 2017; Samadoulougou et al., 2017). In addition, the reported lack of significant evidence supporting the moderation effect of availability of LLINs to intentions and use of LLINs shows that availability and accessibility of LLINs are not enough when people do not have intentions to use them.

While this study provides several useful insights that can be considered when implementing malaria prevention interventions, there may be other factors beyond the individual perceptions that may also play a large role in the consistent use of malaria preventive measures. However, focusing on individual perceptions allows for quantifying how important these perceptions are, and indicates how they should be taken into consideration when designing malaria prevention interventions. Future research should take into account other factors beyond individual perceptions in order to give insights on how they also influence intentions to use malaria preventive measures. These factors include issues pertaining to collective action.

The study was conducted during the short rainy season (October and November) which is one of the peaks for malaria transmission and, therefore, this could have affected the perceived severity and perceived effectiveness of LLINs. Thus, future studies that explore the variation of individual perceptions across different seasons are warranted.

Conclusion

This mixed-methods study aimed to assess the relationships between individual perceptions and the intentions to use malaria preventive measures by applying an integrated model for determinants of malaria preventive behaviour. In addition, the study also explored the viability of strategies that stimulate the consistent use of malaria preventive measures. Perceived severity of malaria, self-efficacy and response efficacy of malaria preventive measures, and subjective norms were reported to influence intentions to use malaria preventive measures consistently. Irritation, increase of warmth, and bed bugs were frequently cited as the main reasons for not using LLINs. Although IRS was perceived to be effective, distrust in sprayers affected the acceptance of IRS. While not having LLINs was frequently reported by most of the participants as impediment of consistent use of LLINs, statistical analyses did not support this as the sole factor explaining non-use when have intention. The study also explored whether accessibility can moderate the effect of intentions to the consistent use, and the results did not show any significant moderation effect. The full conceptual model that included individual perceptions explained 50% of variance of behavioural intentions among the participants, and the intentions were significantly associated with the consistent use of LLINs, IRS acceptance, and draining of stagnant water. Thus, future malaria prevention interventions to consistently use malaria preventive measures should consider individual perceptions by taking into account that the intentions are driven by multiple factors at different levels. This can be done by enhancing the feeling of ownership of these measures through community mobilization and citizen engagement in malaria prevention and control activities.

Chapter 4

Co-designing a citizen science program for malaria control in Rwanda

This chapter is based on: Asingizwe, D., Murindahabi, M. M., Koenraadt, C. J. M., Poortvliet, P. M., Van Vliet, A. J. H., Ingabire, C. M., Hakizimana, E., Mutesa, L., Takken, W., & Leeuwis, C. (2019). Co-Designing a Citizen Science Program for Malaria Control in Rwanda.

*Sustainability, 11,*7012,

Abstract

Good health and human wellbeing is one of the sustainable development goals. To achieve this goal, many efforts are required to control infectious diseases including malaria which remains a major public health concern in Rwanda. Surveillance of mosquitoes is critical to control the disease, but surveillance rarely includes the participation of citizens. A citizen science approach (CSA) has been applied for mosquito surveillance in developed countries, but it is unknown whether it is feasible in rural African contexts. In this chapter, the technical and social components of such a program are described. Participatory design workshops were conducted in Ruhuha, Rwanda. Community members can decide on the technical tools for collecting and reporting mosquito species, mosquito nuisance, and confirmed malaria cases. Community members set up a social structure to gather observations by nominating representatives to collect the reports and send them to the researchers. These results demonstrate that co-designing a citizen science program (CSP) with citizens allows for decisions on what to use in reporting observations. The decisions that the citizens took demonstrated that they have context-specific knowledge and skills, and showed that implementing a CSP in a rural area is feasible.

Introduction

Malaria remains a major public health concern in many sub-Saharan African countries, including Rwanda (President's Malaria Initiative., 2018; Karema et al., 2012). In Rwanda, a significant reduction in malaria has been achieved through the use of control measures including long-lasting insecticidal nets (LLINs), indoor residual spraying (IRS), and artemisinin-based combination therapy (ACT) (Karema et al., 2012). However, from 2012 to 2016, Rwanda experienced an upsurge of malaria cases that was reported across the country, especially in the eastern and southern regions. This increase put the entire population at risk and children under five years old and pregnant women were the most exposed to malaria infection (MoH, 2017a, 2017b).

The increase of malaria in Sub-Saharan African countries urged the global community to improve the disease and vector control response because human wellbeing is one of the United Nations' sustainable development goals (WHO, 2017a). Since the level of investment in malaria control across the world remains inadequate (WHO, 2017a, 2018), the World Health Organization supports the development of effective, locally adapted and sustainable vector control (WHO, 2017a). The latter includes mosquito surveillance, which consists of regular reporting of the density and the pathogen prevalence rate of vectors in a specific region. This helps to identify how vectors spread the infections to hosts and to determine appropriate interventions to reduce the risk of infection (Wu et al., 2016). In Rwanda, in addition to active surveillance of malaria cases, mosquito surveillance is carried out in 12 sentinel sites established across the country (President's Malaria Initiative, 2019). Trained entomology technicians and officers, and some trained local community members are employed on a monthly basis to undertake mosquito surveillance in their assigned areas. Hence, this requires stable financial resources for staff payment. In addition, mosquito surveillance is based on the systematic reporting of the distribution, diversity, and density of malaria vectors using pyrethrum spray and human landing catches (HLC) as mosquito collection methods. Another indicator that is being reported is the entomological inoculation rate (EIR), expressed as the number of infectious bites per person per year (Hakizimana et al., 2018). The entomologists submit a compiled monthly report with entomological indicators mentioned above to the person in charge of the vector control unit of Rwanda Biomedical Center for compilation, and further analysis (Murindahabi et al., 2018) to guide the planning of interventions.

Despite this program, there are several gaps in the surveillance system. For example, beyond the 12 sentinel sites, there are still many regions where mosquito surveillance is not established because of limited funds or lack of trained entomologists. Consequently, it hinders the progress in malaria reduction and limits community awareness on malaria vectors. A possible solution to complement the current malaria mosquito surveillance is to involve the public via a citizen science-based program (CSP). Citizen science as a tool for mosquito surveillance requires an understanding of who is going to collect or report what, how, and when. This chapter outlines how such a surveillance program could be designed, put in place, and what preferences exist in local communities with regard to the technical and social components of such a program. A description of what activities are required to implement such a program are also described. We focus on several aspects including (1) the process of recruiting volunteers, (2) technical tools for collecting and reporting observations, (3) frequency of collection and reporting observations, and (4) feedback generation. The following section provides the conceptual background which elaborates on existing CSPs in mosquito surveillance and explains how the co-design concept was used to develop the CSP.

Conceptual background

Citizen science as a tool for mosquito surveillance

Citizen science can be described as a collaboration between scientists and volunteers, particularly to expand opportunities for scientific data collection and to provide access to scientific information for society (Bonney et al., 2009; Shirk et al., 2012). With the acknowledgement of participatory action research (PAR) and other community-based interventions (CBI) that have been conducted in the last decades to improve health literacy and ability to make decisions related to malaria prevention and control (Ingabire et al., 2016; Rickard et al., 2011), citizen science has been used to actively engage people in the collection, and/or in the analysis and the interpretation of data. This approach has been explored for monitoring invasive and endemic mosquito species in developed countries (Kampen et al., 2015; Vogels et al., 2015). In these countries, citizen science has provided large amounts of relevant mosquito data, hence, citizen science proved its potential in the monitoring of (invasive and endemic) mosquito species (Kampen et al., 2015; Vogels et al., 2015).

These projects involved volunteers that participated in different ways such as collecting and mapping *Culex pipiens* biotypes or assessing mosquito nuisance experienced by citizens in the Netherlands (e.g., Muggenradar) (Vogels et al., 2015). Additionally, volunteers also participate in detecting country-wide changes in mosquito fauna (e.g., Mückenatlas in Germany), and adding real-time information for daily mosquito management such as the Asian tiger mosquito (*Aedes albopictus*) (e.g., Mosquito Alert in Spain) (Hecker et al., 2018; Palmer et al., 2017; Walther & Kampen, 2017). In most cases, these CSPs were designed to allow the volunteers to report by sharing pictures and observations online when a specific event occurred in their regions (Hecker et al., 2018; Palmer et al., 2017; Walther & Kampen, 2017).

CSPs have become more interactive because of the availability of the internet, and most of the projects are now online-based. However, in absence of the internet and with limited access to electricity, for example in rural areas of Rwanda (NISR, 2017), traditional methods and strategies of reporting mosquito observations can be used instead (e.g., paper forms) (Chaki et al., 2011; Kiware et al., 2016). In addition to providing a valuable extension of the professional surveillance networks, CSPs can have other important functions in the strategies to reduce malaria. These include the increase of public awareness and engagement in the topic (for example about mosquito-borne diseases) (Eritja et al., 2019). In addition, participation in citizen science creates new opportunities for connections between various stakeholders such as researchers, citizens, policymakers, funding agencies, and decision-makers, thereby extending their own social network (Asingizwe et al., 2018), and it can strengthen community-based management of residual foci of malaria transmission (Ingabire et al., 2016).

CSPs consists of technical and social components. The technical component defines the citizen science infrastructure like the physical kit and the technology assets. The physical kit may consist of various equipment that could be for example mosquito traps, microscopes, and buildings. The technology assets are the information technology-based platforms/tools and services used to collect, store, manage, process, share, visualize, and analyze information (data and metadata) which is produced by citizen science (Hecker et al., 2018). However, the technology asset is not a required component for running a CSP (Jordan et al., 2017). The social component includes the organizers of the projects or researchers, the citizens, and the social networks of connected individuals (Hecker et al., 2018).

Co-designing a CSP

The development of a robust and context-specific CSP for mosquito surveillance requires the inclusion of people in the design process and integration of a diverse range of experiences, interests, and knowledge (Bartumeus et al., 2019; Bonney et al., 2009; de Campos et al., 2017). Co-designing a malaria mosquito surveillance system includes defining the social structure of the program, and defining the infrastructures and the tools, sampling and feedback strategies to be used (Figure 4.1.).

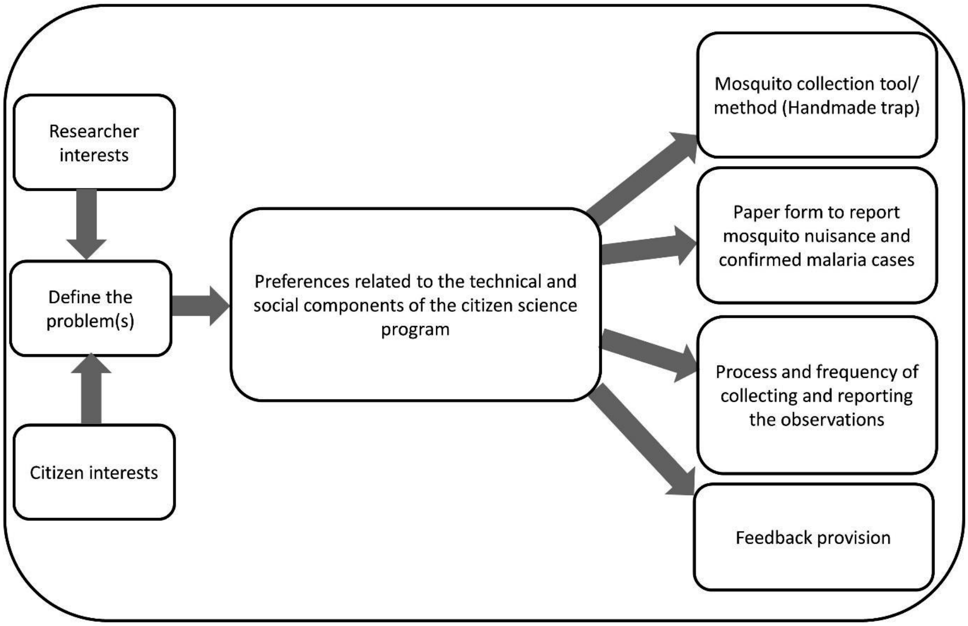


Figure 4.1. The framework indicating the co-designing process of the citizen science program for malaria control

Participation in the design of the technical and social components of a citizen science program provides opportunities for the citizens to express their preferences with regard to relevant design choices, and give feedback on proposed design components. As a result, this may foster ownership of the program (Hecker et al., 2018). Additionally, citizen participation and engagement in citizen science projects increases resource capacity for mosquito surveillance, and also promotes the acceptability of, and adherence to malaria control strategies among the community members (Asingizwe et al., 2019).

Strong partnerships with communities in vector control are required for sustainable innovation such as through citizen science. The success also involves the provision of feedback that is essential in every CSP to keep people engaged in the research (Jordan et al., 2016; de Campos et al., 2017).

Methods

Study area

The study was carried out in the Ruhuha sector of Bugesera district, located in the eastern province of Rwanda. Ruhuha covers an area of 54 square kilometers with a population of more than 24,000 (over 5,500 households; 2017 data). The Ruhuha sector encompasses five cells with 35 villages. Ruhuha is bordered by Lake Cyohoha in the south and is characterized by its many water streams and marshlands classifying the region as a historical malaria endemic zone. Rice cultivation and wetland agriculture are the main economic activities. The Ruhuha sector was selected because of the high number of malaria cases reported since 2012. One village per cell was randomly selected for inclusion in the study. These five villages were Busasamana, Kagasera, Kibaza, Kiyovu, and Mubano.

Study design, population, and sampling

Six workshops (including one for the pilot) were carried out in 2018 prior to the implementation of a CSP for malaria mosquito surveillance in selected villages in the Ruhuha sector. Participatory design workshops (PDWs) were used. A PDW is defined as a workshop through which all stakeholders including users (citizens in this case) that are affected by the upsurge of malaria in their environment, are invited to collectively define the problem that affects them and to set up mechanisms to solve the problem while anticipating their needs (Sanoff, 2007). It is, therefore, a user-centered design method in which the focus is on the active role of the users.

The first workshop was a pilot conducted in March 2018 and aimed to discuss the malaria upsurge and to explore whether participants were willing to participate in malaria control by being enrolled in the CSP and how they could participate in such a program. In addition, the pilot workshop aimed to inform the process of the main PDWs through testing the content and steps of the PDW. The pilot study was conducted in one of the ten villages in which a baseline study was conducted (Asingizwe et al., 2019) and was randomly selected. With the results from this pilot workshop, five follow-up workshops were organized and conducted in August 2018. Each workshop lasted around 6 hours and aimed to establish a citizen network that was willing to actively participate in the CSP.

Recruitment process

Based on ten villages selected in the baseline survey (Asingizwe et al., 2019), six of these (one for pilot and five for the main PDWs) were selected for the implementation of the CSP. Generally, each village has approximately 150 households and we targeted a third (45 community members) of the total number of households. In each village, the households are grouped in *isibo* (cluster of 15 neighbouring households) thus each village has approximately 10 *isibos*. Therefore, three community members in each *isibo* and the *isibo* leaders were targeted to participate which results in a total of 40 participants per village. In addition, each village has three community health workers (CHWs) and one village leader. Consequently, these were also added to the 40 selected community members. Lastly, an executive of the respective cell was also expected to attend the workshop. Hence, in each of the five selected villages for the PDWs, a total of 45 people were supposed to attend. This number was the same in the pilot workshop. The village leaders selected the community members and we were careful that these community members were neither from the same household nor relatives.

To ensure this, the village leader announced this workshop during a village meeting and those who showed interest were invited to participate. At the beginning of each workshop, the researchers (two first authors) verified whether the criteria had been fulfilled through requesting people from each *isibo* to stand up, and asking them whether they are from different households. Although this verification was done, people were not informed whether researchers were cross-checking. In some few cases, it was obvious that a husband and wife could attend when one of them was a village leader and another was a CHW; this was inevitable. As shown in Table 4.1, in some villages, community members did not attend in a sufficient numbers. The main reason for this low turn up in some villages was that these villages (Busasamana and Kibaza) are located further away from the health center where the workshops were conducted.

In addition, the day we conducted a workshop for Busasamana it was raining, and some community members decided to go to their farms for field work instead of attending the workshop.

Co-design processes

Pilot workshop

During the pilot workshop, the following guiding question was asked to the participants: “As a community member, how are you going to be engaged in malaria control?” The main reason of this question was that “citizen engagement in malaria prevention and control activities” was one of the three strategies to improve consistent use and acceptance of malaria control measures mentioned by the participants from the baseline survey in the study area (Asingizwe et al., 2019). This clearly indicated that the community members were willing to participate. After the guiding question, each participant was requested to write (maximum) three ways of engagement in malaria control. These notes were then collected by the researchers, who in turn grouped those which were similar to the themes. Among the themes listed, control of mosquito breeding sites stood out. Furthermore, participation in community mobilization was also listed. Participants were divided into small groups to discuss the themes, and after discussion, participants presented the outcomes of the discussions. In addition, participants were requested to fill out a small questionnaire to indicate whether (1) they have ever experienced mosquito nuisance, (2) they were willing to participate in the collection of mosquitoes, and if so, (3) to describe how they think they can collect mosquitoes.

Five participatory design workshops

The PDWs were structured in three main steps (Figure 4.2). As informed by the pilot workshop, the guiding questions had to be modified based on the outstanding theme. The first two authors facilitated all PDWs and the sixth co-author also joined one of the PDW.

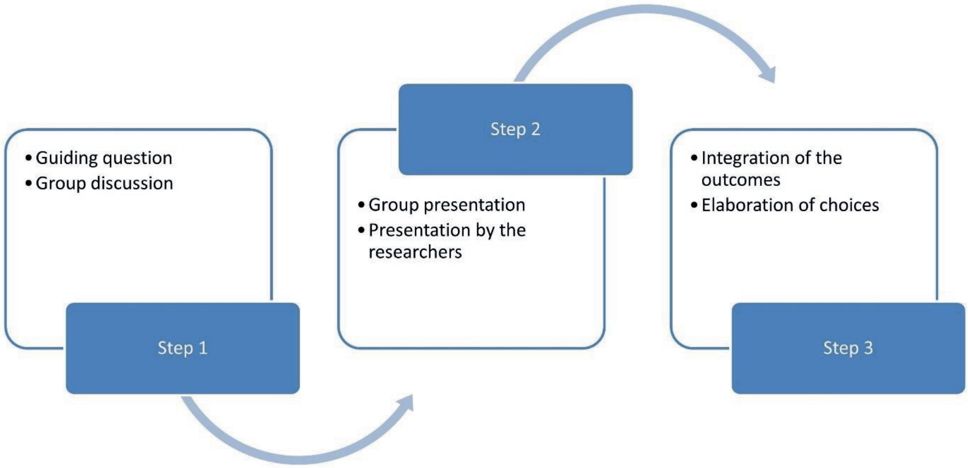


Figure 4.2. Steps followed during the participatory design workshops

Step 1: Part 1. Guiding questions

At the beginning of each PDW, guiding questions were announced. The first set of guiding questions focused on the understanding of mosquito nuisance, as well as reporting of mosquito nuisance and collecting mosquito specimens: “How do you interpret the term mosquito nuisance? If you are asked to provide observations such as mosquito nuisance experienced and mosquitoes (mosquito species), how can you report it and /or collect it? Do you think it is feasible? Why would you (not) do that? How frequently can you do that”? The second guiding question focused on ways or means for providing feedback: “If you report observations, what and how would you like to get feedback”? A handout of the guiding questions was given to the groups to facilitate the discussion. It was observed that providing these guiding questions could help the participants to reflect more on their ways of engagement in malaria control rather than giving them one broad guiding question as was done during the pilot workshop.

Step 1: Part 2. Group discussion

Following the guiding questions, three different homogeneous groups were formed including only men, only women, and only youth (between 18–25 years).

These homogenous groups were created to ensure that all participants had equal opportunities to share their views. This was also a result of the pilot workshop, in which we observed that some participants could not express themselves in heterogeneous groups.
During the focus group discussion, which lasted for 1 hour, members of the group elected a group leader and a reporter who presented the outcomes of the discussions. The different groups were requested to write down the answers of all the guiding questions on flip charts which further helped them during the presentation of the outcomes of the discussion.

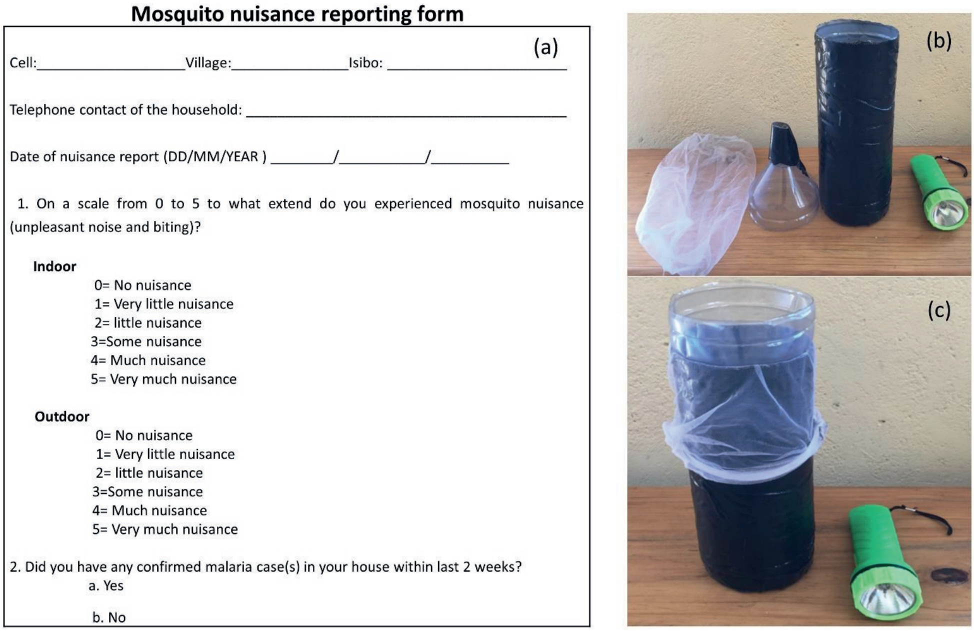
Step 2: Part 1: Group presentation

After group discussions on the guiding questions, a representative from each group shared their outcomes of the discussion and participants from other groups were allowed to ask questions or provide comments. After the group presentation by the different focus groups, a summary of the outcomes of each group was presented by the researchers and all participants were able to add inputs into the summary. This was done to ensure the harmonization of ideas and to facilitate the integration session (Step 3).

Step 2: Part 2. Presentation from the researchers

The researchers' presentation explained how to report mosquito nuisance and malaria cases by filling out a paper-based form (Figure 4.3a) and on how to catch and report mosquitoes (Figures 4.3b and 4.3c). The reporting form included two questions: (1) To what extent do you experience mosquito nuisance (unpleasant noise and biting; to be assessed on a scale from zero (no nuisance) to five (very much nuisance))? and (2) did you have any confirmed malaria case(s) within the last two weeks in your household?
Additionally, participants also gave feedback on the perceived efficacy of a carbon dioxide-baited trap in collecting mosquitoes following the results presented by the researchers. This trap was prototyped and tested in the laboratory and in the field. The trap was proposed as recommended by the participants of the pilot workshop, as the majority requested tools to collect mosquitoes. Thus, researchers followed up on this by validating a low-cost, easy to use "handmade carbon dioxide-baited trap" (Figure 4.3c).

This trap uses carbon dioxide as a stimulus which is produced by mixing yeast, sugar and water (Smallegange et al., 2010) and light. The trap was designed taking into account the cost and the practicability of the existing mosquito collection method in rural Rwanda. Prior to its application for the CSP, different trap designs were evaluated under laboratory conditions at Wageningen University & Research, and afterward in the field in Kibaza village (Murindahabi et al. in preparation). During the workshops, researchers presented the results from the lab and field evaluations. Furthermore, researchers presented different means of feedback provision after collecting and reporting data by the volunteers.


Mosquito nuisance reporting form

(a)

Cell:__________ Village:__________ Isibo: __________

Telephone contact of the household: __________

Date of nuisance report (DD/MM/YEAR) ______/______/______

1. On a scale from 0 to 5 to what extend do you experienced mosquito nuisance (unpleasant noise and biting)?

Indoor
- 0= No nuisance
- 1= Very little nuisance
- 2= little nuisance
- 3=Some nuisance
- 4= Much nuisance
- 5= Very much nuisance

Outdoor
- 0= No nuisance
- 1= Very little nuisance
- 2= little nuisance
- 3=Some nuisance
- 4= Much nuisance
- 5= Very much nuisance

2. Did you have any confirmed malaria case(s) in your house within last 2 weeks?
   a. Yes
   b. No

Figure 4.3.(a) The paper-based form for reporting observations, (b) the handmade carbon dioxide-baited trap showing the different elements that are part of the trap, and (c) the trap after assembly. The torch was suggested by volunteers and added afterwards.

Step 3: Part 1. Integration of outcomes

After a presentation by the researchers on the proposed tools, participants returned to their groups to discuss which proposed tools were preferred and why.

Additionally, participants indicated the reporting scheme of the observations, process of reporting, preferred frequency of reporting, and ways to provide feedback.
A handout of the proposed methods together with flip charts were given to the participants to facilitate the discussion and help them write down the answers for further presentation. This integration part was added to explore the different reasons to why some methods were preferred over the others and observe whether participants could be able to compare and criticize different methods including those listed by other groups. All flip charts were kept for further transcription and analysis.

Step 3: Part 2. Elaboration of choices

All results from the group discussions were presented and discussed among all participants to ensure the validity of the information provided during the focus group discussions. Hence, the researchers made a summary of the choices presented by each group and then shared it with the participants for final agreement and approval.

Data analysis

The results from flip charts were transcribed and analyzed. The summaries from the large group discussion taken by the researchers were also used to facilitate and inform the transcription process in case some hand writings were not readable, and complement the transcripts in case the flip charts did not include the details because some questions for clarifications were asked during the group presentations. All transcripts were classified under different categories that emerged from the guiding questions and each group was coded independently to avoid duplication of the results. In reference to the guiding questions, different categories that included reporting mosquito nuisance, collecting mosquito specimens, recruitment of volunteers to be enrolled in citizen science, the process of collecting and reporting the information, the frequency of reporting observations, and feedback generation were defined. Finally, after the completion of the data analysis, the categories were divided into two themes (technical and social) according to the co-design framework of CSP (Figure 4.1). The presentation of the results followed this framework as well.

Ethical approval

Ethical approval was granted to the study (Approval Notice: No 414/CMHS/IRB/2017) by the Institutional Review Board of the College of Medicine and Health Sciences, University of Rwanda.

Results

The results are organized in two main sections. The first section presents the outcomes of the pilot workshop which indicate the responses about mosquito nuisance experienced and willingness to collect mosquitoes. The second section elaborates the results of the five PDWs which are divided into two main themes: (a) The technical component that includes tools to collect and report the observations, and (b) a social component that consists of (1) recruitment of volunteers, and collection of information, (2) strategies for collecting and or reporting the observations, and (3) mechanisms of feedback to the community members about the outcomes of the shared observations.

Pilot workshop

Forty-four participants attended the pilot workshop. These included 29 community members, ten *isibo* leaders, three CHWs, one village leader, and one Kindama cell representative.

Mosquito nuisance experienced

All participants (100%) answered that they had experienced different levels of mosquito nuisance. Locations reported where participants experienced more mosquito nuisance are in the bush (22 times; 61%), the rice field (24 times; 69%), and near the pond (21 times; 72%).

Willingness to participate in mosquito collections

Among the participants, 11(26%) reported willingness to collect the mosquitoes. Among these, four (36%) answered the question related to which tool/materials to be used and three (27%) were not able to mention any method. In relation to the materials to be used, one participant indicated catching mosquitoes by hand, two reported that they would need materials from researchers, and one reported using light from a torch to “hypnotize” the mosquito and catch it afterward.

The participatory design workshops

Characteristics of the participants who attended the five PDWs

One hundred and eighty-five participants (82%) out of 225 that were expected, attended the workshops (57% women; Table 4.1).

Table 4.1. Characteristics of the participants attended the Participatory design workshops (PDWs)

Village	Expected Participants	No. of Participants Attended PDWs	Male	Female
		Frequency (%)	Frequency (%)	Frequency (%)
Busasamana	45	17 (38%)	10 (59%)	7 (41%)
Kagasera	45	45 (100%)	12 (27%)	33 (73%)
Kibaza	45	33 (73%)	17 (51%)	16 (49%)
Kiyovu	45	43 (95%)	17 (40%)	26 (60%)
Mubano	45	47 (104%)	24 (51%)	23 (49%)
Total	225	185 (82%)	80 (43%)	105 (57%)

Technical component of the CSP

In general, not many changes were made to the technical components (tools to be used to collect and report the observations) of the design as the participants already expressed that they could not report the information if the materials are not given. Below these technical tools are presented in detail.

Technical tool to report mosquito nuisance and confirmed malaria cases

All groups indicated that it was feasible to estimate and report the level of mosquito nuisance experienced as well as reporting confirmed malaria cases.

Participants described mosquito nuisance as the biting and the sound that the mosquito produces when flying. They all highlighted that nuisance does not necessarily relate to number of mosquitoes, because even one mosquito can bite or make noise. Among the different ways proposed by the participants to communicate the results on mosquito nuisance and confirmed malaria cases, phone calls, Short Message Service (SMS) text, and *isibo* or village meetings were mentioned. Both paper forms and SMS were viewed as a possible means to report mosquito nuisance and confirmed malaria cases. However, weighing the constraints that these two methods pose, some participants indicated that using a paper form is more preferable because it does not require much costs, while airtime credits may hinder the usage of SMS text. Therefore, the paper form was opted for to report mosquito nuisance and confirmed malaria case instead of an SMS text.

Another group of participants reported potential delays in reporting and loss of paper forms as a drawback of using paper forms. Therefore, these participants proposed to use both paper forms and SMS text or mobile phone calls as a means for reporting mosquito nuisance to the researchers. When discussing the advantages and disadvantages of using the two proposed methods, the majority of participants eventually preferred the paper form as it is less costly.

Technical tool for collecting mosquitoes

Participants indicated that it was feasible to collect mosquitoes if proper mosquito sampling tools were provided. To anticipate on this and based on the results from a pilot workshop conducted in March 2018 during which the majority of the participants reported not to be able to collect mosquitoes, the researchers proposed a handmade carbon dioxide-baited trap (Figure 4.3c). Based on the results presented from the trap test trial (conducted in the lab), participants indicated that using the carbon-dioxide-baited trap was feasible. However, some constraints with regard to the trap's practicability were mentioned. These included the difficulty to find the different components used to assemble the trap, such as the net and the 1.5 litres plastic bottle.

Other constraints mentioned by the participants were related to the costs (in case the volunteers have to buy these themselves) of the ingredients such as the yeast and the sugar used for the production of carbon dioxide to attract the mosquitoes in the trap. Participants indicated another constraint in relation to a new law that will ban the use of plastic bottles. The government of Rwanda is planning to remove plastic bottles from the market. The law on banning single-use plastics is still under evaluation in the Rwandan parliament. From the group discussions, one of the male groups indicated that catching mosquitoes using hands was also a possible option, as it does not require money.

In terms of quantity, the buckets or bottles proposed were preferred as means for collecting mosquitoes, as they seem to catch more mosquitoes than using hands and are also less sensitive to collector bias. Some of the participants reported that a bucket is easy to find, and it does not require sugar or yeast such as when using a bottle. On the other hand, if the proposed handmade carbon dioxide-baited trap and the ingredients used as odour attractant are provided, the proposed handmade trap using a plastic bottle was the preferred tool to use by the participants to collect mosquitoes.

Social component

Initially, the research team assumed that the data could be collected by the CHWs, or the *isibo* leaders and can be reported on biweekly basis. Additionally, CHWs would submit the collected data to the researchers at the health center on biweekly basis as well. Alternatively, the researchers could gather the collected data at the household level in the studied villages. As indicated below, most of these initial design options changed after the discussion with the community members.

Recruitment of volunteers for the CSP and the collection of the observations

There were no predefined rules on how to select volunteers and who should collect what information as all participants were eligible to participate in the program. However, as participation was voluntary, participants were invited to write their names and their telephone contacts on a list if they were willing to participate in the proposed CSP. It was made clear that they could either report mosquito nuisance and confirmed malaria cases only using the paper form, collect mosquitoes only using the proposed carbon dioxide-baited trap, or do both. It was also explained that there would be no monetary incentives for participation. Among 185 community members who attended the workshops, 116 volunteers (63%) wrote their names on the list as potential participants. Of these 116, 19 were willing to report mosquito nuisance only, 42 were willing to collect mosquitoes only, and 55 were willing to participate in both.

There was a general agreement among the participants on why it would be useful to participate in the collection and reporting of the observations such as mosquito nuisance, confirmed malaria cases, and mosquitoes. All groups highlighted that collecting mosquitoes was a way of contributing to malaria control as malaria affects many people.

Participants believed that through collecting and reporting of observations, their awareness related to mosquitoes and malaria can be enhanced. Consequently, the increased awareness may play a role in reducing malaria incidence. In addition, one of the male groups indicated that collecting mosquitoes could improve their knowledge of different mosquitoes' parts and species. However, collecting mosquitoes requires some skills and appropriate tools to do so. For this reason, one of the female groups voiced that they may not be able to collect mosquitoes because of the lack of knowledge and appropriate materials. The same concern was also reported in another mixed-gender group.

Strategies for collecting and reporting the observations

The initial idea to use the CHWs, *isibo* leaders, or collecting the observation at the household level by the research team was changed because of (1) a high number of *isibo* leaders (approximately 50 for the five selected villages), (2) high workload attributed for the CHWs in the community, and (3) logistic issues in case the researcher collects the data at the household level. Hence, each group of volunteers in five selected villages nominated an *isibo* representative. The organizational stucture of the reporting and collecting system was defined (Figure 4.4).

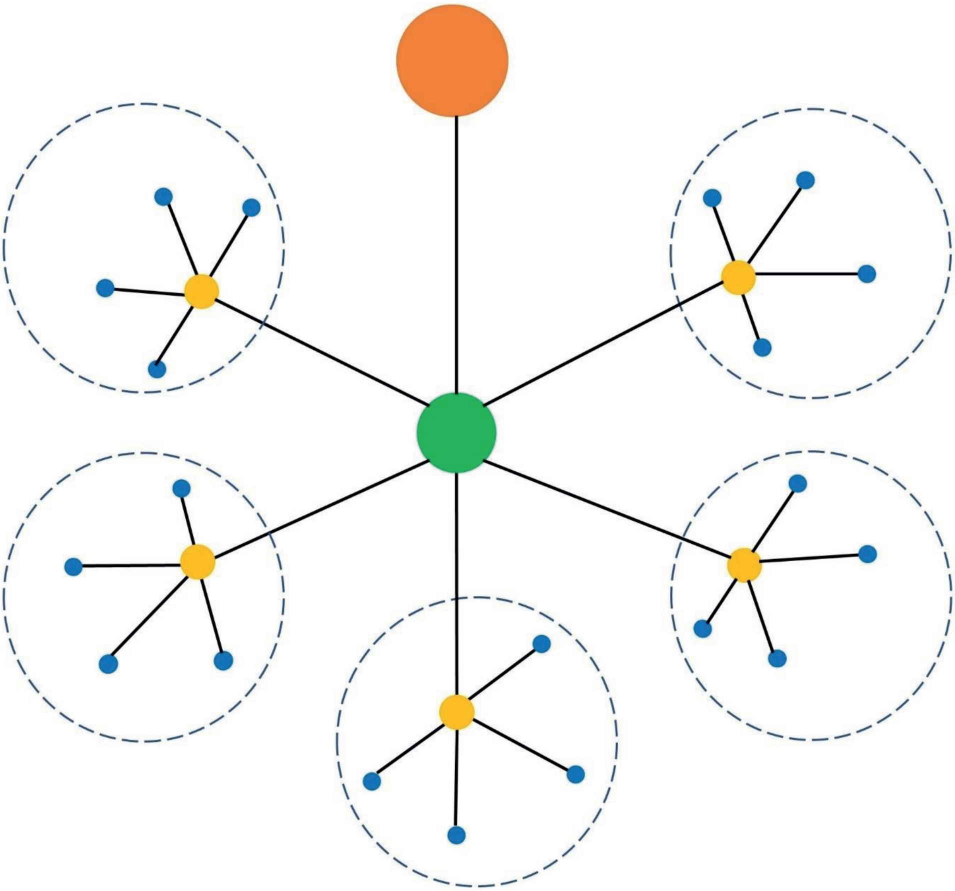


Figure 4.4. Fundamental architecture of the citizen science program (CSP) for malaria control. The blue dots represent the volunteers; the yellow dots represent the *isibo* representatives; the blue dashed circles represent villages, the green dot represents the researchers, the orange dot is the vector unit of the Malaria and Other Parasitic Disease Division (MOPDD). The lines represent the two-way communication between the different stakeholders involved in the CSP for malaria control. Specifically, the black lines show that these *isibo* representatives are directly connected to researchers and to the volunteers because (1) they are the ones submitting the observations every last Friday of the month, and (2) they collect the reports from volunteers, receive the feedback and share it with the volunteers in their respective villages.

These *isibo* representatives were tasked to distribute the tools (paper form and mosquito collection traps) and to gather and report the data on a monthly basis. They were also tasked to inform and remind the volunteers about when to fill out the forms and set up the traps. In addition, volunteers who indicated the preferred period for them to collect and report the observation in collaboration with the researchers shared a proposed schedule. The schedule indicated when to submit the collected data at the Ruhuha health center where the research team for this study was located. Hence, *isibo* representatives gathered the observations from all volunteers in their respective villages and submitted the observations to the researchers every last Friday of the month. *Isibo* representatives received feedback sent by the researchers, which in turn they shared and discussed with the volunteers among the five selected villages. The process of reporting observations starts with distributing the tools/materials for collecting the citizen science data to *isibo* representatives and ends when volunteers meet and discussed the feedback from the data reported the previous month. In addition, they also discussed the actions or measures to be taken.

Frequency of collecting and reporting observations

Initially, the researchers expected that volunteers could report observations on a bi-weekly basis. However, there was an extensive discussion on the frequency of collecting and reporting the observations because some participants assumed that collection and reporting of observations would take much time (Table 4.2). Hence, the consensus was to report the observations once a month. They decided on this based on the fact that *isibo* members meet once a month.

Table 4.2. Frequency of reporting and collecting mosquitoes suggested by the different discussion groups during the workshops

Village	Groups		
	Men	**Women**	**Youth**
Busasamana village	Once a month		
Kagasera village	Once a month	Once in two weeks	Once a week
Kibaza village	Once a month	Once a month	
Kiyovu village	Once a month	Once a month	Once a month
Mubano village	Once a month	Once a month	Once in two weeks

Note: Because of a limited number of participants for Busasamana, one mixed group was made.

Feedback generation from the reported observations

Participants mentioned that getting feedback on their submitted observations was a precondition for knowing what to improve. In relation to why that feedback should be generated, participants indicated that by getting the results from what was reported, participants could be motivated to consistently use malaria preventive measures. Participants mentioned that this feedback could be given in various ways such as flyers, public talks, workshops, home visits, and SMS text messages. Participants highlighted that once submitting the mosquitoes to the researchers, they will need to know whether the collected mosquitoes were malaria vectors or not. As chosen by the participants, SMS texts could be sent to the *isibo* and the results could be shared during the *isibo* meetings with the volunteers and during the workshop every three or four months, and via the flyers. Flyers could be distributed during the quarterly workshop as proposed by the participants.

The technical and social choices made based on the citizens' preferences are summarized in Table 4.3.

Table 4.3. Key technical and social choices made based on citizens' preferences

Components	Preferences/Choices
Technical Design Component	
Reporting mosquito nuisance	-Write down the mosquito nuisance level indoor, outdoor, and in general on paper forms and this is done every last Wednesday of the month by the volunteer. -Weighing the costs of using a paper-based form and mobile phone, paper-based form does not cost much. Hence it was preferred for reporting mosquito nuisance.
Collecting mosquitoes	-Mosquitoes are caught with a handmade trap that consists of a plastic bottle filled with yeast and sugar, a torch, and this is done every last Wednesday of the month. -Provision of materials to collect mosquitoes (yeast, sugar, torch, and the trap).
Social component	
Volunteer recruitment	-Everybody that attended the participatory workshop was eligible to be a volunteer. Those who were willing to participate were invited to write their names on the provided sheet.
Who should collect what?	-Volunteers could choose whether to report mosquito nuisance only, collect mosquitoes only, or do both.
Reporting the information	-Volunteers selected the *isibo* representatives who are responsible for gathering the collected information and submit them to the research team. -Volunteers hand in the forms indicating the mosquito nuisance experienced and the mosquitoes caught to the *isibo* representatives during the monthly meeting that takes place in the last week of the month. The *isibo* representatives then have to submit the observations to the researchers at the health center where the researchers are based every last Friday of the month.
Frequency of collecting and reporting the information	-Once a month during the *isibo* meeting.
Feedback generation	-Once a month, researchers provide feedback to the *isibo* representative via SMS. He/she then communicates the feedback to the volunteers when volunteers collect the materials for the next round. Volunteers discuss the feedback and may take measures based on it. For example, if some malaria cases were reported, they discuss why those cases appeared and aimed to reduce the number of cases reported in the next round of reporting by more consistent use of malaria control measures.

Discussion

Our results indicate that a CSP for malaria control in a rural context in Rwanda is likely to work best if the inputs and insights from citizens are included in the selection of the technical and social components. By using PDWs, this study presents the design process to follow for implementation of a CSP with much attention to co-design principles as key for better implementation of such a program.

Involving citizens in the co-design process

Involving citizens in the design process of a CSP is of particular importance as it may stimulate other beneficial effects (for example new knowledge) (Mahajan et al., 2019). This involvement helps participants in deciding whether to participate or not. Some CSPs that do not engage citizens in the co-design process, have to incentivize participants once they submit the data (Jordan et al., 2017), and these incentives (money in most of the cases) can be a key motivation for them to participate.

The co-design process that was employed in our program provided added advantages beyond normal trainings, because apart from acquiring new knowledge, the participants felt part of the design and were motivated to contribute to both scientific research as well as malaria control with no monetary incentives. The engagement of citizens in the design process may influence the recruitment rate and level of participation in CSPs (Jordan et al., 2017; Worthington et al., 2012). Hence the participatory design workshops proved an important step for the community members to be able to decide whether to participate in a CSP.

When the research team started, it was optimistic about the use of mobile phones as one of the communication channels and for reporting observations. It was clear that the participants did not prefer it as this option presented more challenges than solutions to the problem. Similarly, Beza et al. (2018) also revealed that the price of sending SMS can affect the decision to participate in a project that requires the use of mobile phones. Consequently, the mobile phones were only used in this study to provide feedback to volunteers via SMS on a monthly basis and this has no cost implications for the receiver of this SMS.

It was clear that when volunteers have different options (for example different mosquito collection tools), they can critically reflect, discuss, and decide what works better for them.

Including citizens in the design process promotes critical discussion which may foster further community actions to tackle the problem under study (Mahajan et al., 2019). Communities are different, have different backgrounds, ideas, and they may learn from each other. While some groups indicated that catching mosquitoes is not possible unless collection tools are provided, others proposed some materials including buckets and the use of hands to catch and submit mosquitoes to the research team. This created a new learning synergy needed to implement a CSP.

Why providing feedback to volunteers?

Communicating the key messages that result from what people report is crucial in any CSPs (West & Pateman, 2016). Keeping volunteers updated about the progress of the project is an important aspect as it increases the interaction between volunteers and researchers, and volunteers can provide feedback on how to improve the project (West & Pateman, 2016). In turn, this feedback can retain participants, and hence sustain the project (Rambonnet et al., 2019). As volunteers contribute their time without financial or any other direct benefits, giving feedback is one of the non-monetary incentives that motivate participants (West & Pateman, 2016). Different forms of feedback, including automated SMS text to individual volunteers, newsletters and websites, have been used in CSPs (Nov et al., 2014; van der Wal et al., 2016; West & Pateman, 2016). When regular feedback is provided, it enhances opportunities for learning and development for the participants. This, in turn, may strengthen the network among participants and may improve collective practices (Ryan et al., 2018). As reported in this study, feedback provision was also considered during the design process. Participants indicated a wish to have monthly feedback from the reports in a form of SMS text. Additionally, quarterly workshops in order to meet with other volunteers and learn from others, as well as develop leaflets indicating and comparing reports from different villages were also added.

Study limitations and future research

We realize that additional components may be needed, such as well-documented rules and regulations for guiding volunteers and preventing them from using other than agreed tools. However, if tight rules are put in place, the withdrawal rate may be higher as volunteers may think that it is too difficult for them if they have to obey too many rules for voluntary work.

On the other hand, not putting these rules and regulations in place may lead to misuse or non-use of the agreed trap. Future research will explore the use of the trap, by assessing the quality of the reports that the citizens are submitting.

At the start, the research team was interested in the collection of mosquitoes and reporting of mosquito nuisance, and this limited the generation of information about community preferences regarding what should be observed in the first place. However, researcher motivation is in most cases an important reason to start a CSP (Rambonnet et al., 2019). Still, in our case there was also a clear societal reason for why to start this CSP, i.e., addressing the burden of malaria. The selection of gathering observations of nuisance and mosquitoes was based on the best available knowledge and successful experiences elsewhere (Ingabire et al., 2016; Kampen et al., 2015). In addition, the research team wanted to see whether participants would come up with their own mosquito collection methods. Unfortunately, this was not the case. Therefore, the team designed and proposed a trap that could be easily used in low resource settings. The paper-based form also was designed and proposed based on the results of the baseline survey in 2017. In this survey, only 45% of the people in the study area owned a mobile phone, and among these only a small proportion (18%) mentioned that they also use their mobile phone for SMS activities (sending and/or receiving any message). To this end, proposing a paper-based form was a way to overcome this technology-related barrier.

Besides the information gathered by the current CSP, the program may provide other information that may help to design more targeted interventions such as spraying and larval source management. Follow-up studies will determine the Spatio-temporal distribution and population dynamics of the collected malaria mosquitoes in relation to malaria transmission risk, and assess how this will support the current government-led mosquito surveillance program.

The perceived initial motivations to participate in citizen science may be subject to change over time, and participants presented different motivational factors including a desire to contribute to malaria control, and to gain knowledge and awareness about mosquito species. Thus, future studies should remain exploring ongoing motivations as this is a key determinant for the retention of the participants and thus the sustainability of the program. Although in this study volunteers indicated interest to acquire new knowledge and skills, for further collective decision making it is important to evaluate the CSP by assessing throughout the participation process what people gain while participating, and whether there are some individual and collective actions (for example collective management of mosquito breeding sites that may result (Asingizwe et al., 2018; Leeuwis et al., 2018).

Conclusion

Considering the possibilities and preferences of citizens prior to the implementation of a CSP for mosquito surveillance is essential for its success. Some technical as well as social changes were made together with volunteers following their preferences and choices. Following the involvement of citizens in a co-design process, we arrived at different decisions that we did not always foresee beforehand. For example, involving volunteers in organizing the process of collecting and reporting observations facilitated the decision about how and who should gather the observations, and submit them to the research team. Deciding on the tools to use while reporting data is of importance because participants know what works for them. Furthermore, this may positively influence the level of participation. The findings also revealed that providing feedback from what people report is crucial in a CSP. Thus, this study revealed a number of technical and social components that are relevant to making a CSP applicable and feasible in rural areas and/or in locations where internet connectivity is limited. Additionally, a CSP can build capacity and increase knowledge, which in turn, may lead to further individual and collective actions for malaria prevention and control.

Chapter 5

Why (not) participate in citizen science? *Motivational factors and barriers to participate in a citizen science program for malaria control in Rwanda*

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Abstract

The field of citizen science is currently growing and this stimulates its application in various disciplines. However, the underlying motivational drivers to participate or not in citizen science is rarely studied in different stages of participation. Using a citizen science program for malaria control implemented in Rwanda as a case study, this study explores the motivational factors and barriers to participate in citizen science. It also assesses the changes in motivational factors over time and compares these factors among age and gender groups. Using a qualitative approach, this study involved 44 participants of whom 30 were volunteers of the citizen science program, and 14 were non-volunteers but who attended participatory design workshops used to recruit the volunteers, but who decided not to join the present project. Results indicated that at the initial stage, people participated in the project because of curiosity, desire to learn new things, helping others, and willingness to contribute to malaria control. As the engagement continued, other factors including ease of use of materials to report observations, the usefulness of the project, and recognition also played a crucial role in the retention of volunteers. Lack of time and information about the recruitment process, perceived low efficacy of the mosquito trap, difficulties in collecting observations, and challenges related to changing the batteries of the torches during the night were reported as barriers to get and stay involved. Some variations in the motivational factors were observed among age and gender groups. Generally, desire to learn new things and curiosity were more prominent among young people and women while contributing to malaria control were dominant among adults and men. A framework including motivational factors and barriers at each stage of participation is presented. This framework may be used to explore motivations and barriers in future citizen science projects. The motivational factors and barriers reported in this study should be considered to know whom to target, by which message, and at what stage of participation to recruit and retain volunteers in citizen science projects.

Introduction

The involvement of the public in citizen science projects (CSPs) is currently growing significantly (Jordan et al., 2017; Kampen et al., 2015; Theobald et al., 2015). The present contribution reports on a CSP focusing on malaria control in Rwanda referred to as “a CSP for malaria control”(Asingizwe et al., 2019) and this CSP aims to provide insights in mosquito nuisance, confirmed malaria cases, and mosquito populations in a rural setting where this type of information is readily available. An important challenge with the design and implementation of CSPs is how to involve people and retain them. In this regard, motivational factors seem to be important, but information on these motivations and barriers is limited especially for non-ICT-based CSPs. Sometimes CSPs may turn out to be unsuccessful because they do not consider these motivational factors, thus there is a waste of resources if people start participating and then drop out afterwards (Cunha et al., 2017; Druschke & Seltzer, 2012). Therefore, to establish an effective and sustainable CSP, this study explored the motivational factors and barriers to participate in the CSP for malaria control.

Some studies that explore volunteer motivations to participate in “Information Communication and Technology (ICT)” based CSPs have been conducted in fields as diverse as agriculture (Beza et al., 2017), biodiversity and conservation (Domroese & Johnson, 2017), astronomy (Raddick et al., 2013), environment (Land-Zandstra et al., 2016), and health (Land-Zandstra et al., 2016). There is a large variation in motivational factors reported in these studies. For example, the motivational factors differ by country and discipline (Beza et al., 2017). Currently, there is still a knowledge gap regarding the array of these factors in non ICT-based CSPs. Addressing this gap is important for the improvement of recruitment procedures and, as such, may contribute to the retention of volunteers.

People’s motivations to participate in CSPs include a desire to learn new things, to help others, to establish a social network, to contribute to scientific research, to help the environment, to obtain a good reputation in the community, and to further one’s career (Nov et al., 2011; Rotman et al., 2012; West & Pateman, 2016; Wehn & Almomani, 2019). While motivational factors may change over time, many studies have examined these factors at a single point in time (Hobbs & White, 2012; Martin et al., 2016; Marti et al., 2016; Raddick et al., 2013). Only a small portion has explicitly discussed these motivational factors at different points in time, either as initial and/or as retaining motivational factors (Carballo-Cárdenas & Tobi, 2016; Rotman et al., 2014; Rotman et al., 2012). Given that many CSPs experience a high attrition rate across different stages of participation (Jordan et al., 2017; Worthington et al., 2012), there is a need to explore motivational factors and barriers at different points in time to understand what to focus on at which point of participation to retain volunteers in CSPs.

The motivational factors for participation in CSPs may differ among different groups of people and some studies indicated associations between motivational factors and demographic factors (Raddick et al., 2013; Wu & Tsai, 2017). For example, Raddick et al. (2013) compared the motivational factors among men and women and found that men were more likely to participate in a CSP because they wanted to contribute to scientific research, while women were more likely to join because of personal enjoyment associated with the project. Land-Zandstra et al. (2016) revealed contribution to science and concern for health to be more salient motivational factors to join CSP among adult people than in young people. The reasons for participating in citizen science were also compared with the volunteers' level of education (Tinati et al., 2017). Although the contribution to science was the most prominent motivational factor across all levels of education, curiosity to engage in science, fun, and relaxation were frequent among participants who reported being at high school (Tinati et al., 2017).

While there are many motivations to participate in CSPs, volunteers may also encounter barriers or challenges that limit their participation. A marine-related project, by Martin et al. (2016) revealed that the most important barrier to participate was people's belief about limited knowledge of species that they aim to collect. Lack of time and poor or inadequate technological infrastructure were also reported to discourage volunteers to participate in CSPs (Rotman et al., 2014; Wehn & Almomani, 2019). When volunteers encounter challenges that interfere too much with their daily activities throughout the participation, they are more likely to cease their participation at any time and any stage of participation.

This study aimed to explore the factors that determine participation and continued participation in a CSP for malaria control. The following research questions were answered: (1) What are the motivational factors to participate in a CSP for malaria control? (2) What are barriers for getting and staying involved in a CSP for malaria control? and (3) How do motivational factors change over time and vary among age and gender?

Age and gender were chosen as key demographic characteristics of interest, also because in the study area the majority of the volunteers of the CSP for malaria control have comparable low levels of education and all of them are farmers, effectively precluding these factors to use for comparative purposes.

In the next section, a conceptual framework is presented that describes the different stages of volunteers' participation in a CSP at different points in time, and different motivational factors and barriers to participation (Figure 5.1). This is followed by a description of the methodology of our study with a description of the CSP for malaria control. Then the results regarding the initial and ongoing participation are presented together with changes in motivational factors over time and variations among age and gender. Finally, the results are discussed in a broader context of the citizen science field.

Conceptual framework

Volunteers' participation in CSPs involves various stages at different points in time and these include the decision to participate or not, initial participation, ongoing participation, and future or sustained participation (Figure 5.1). In most of CSPs, not all those invited are willing to join. Furthermore, not all people who decide to take part in the program by registration do move to the initial participation, submit or report the first observations, and stay involved (West & Pateman, 2016).

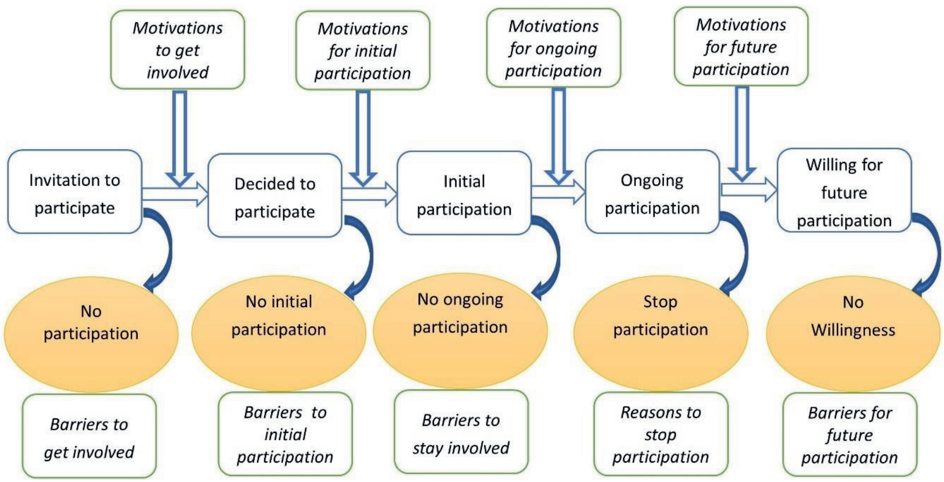

Figure 5.1: Different stages of volunteers' participation (active collection and reporting/submission of citizen science data) in a citizen science program

Different ways have been used in the literature to categorize motivational factors (Clary et al., 1998; Finkelstien, 2009). The categorization used most in citizen science literature is by Clary et al. (1998) and includes six motivational functions for volunteerism: *values* (desire to help others and contribution to health and or environment), *social* (want to meet new people, socialize), *understanding* (interest in learning opportunities), *protective* (desire to address own problems), *enhancement* (want personal improvement), and *career* (interest in gaining experience) (Clary et al., 1998; West & Pateman, 2016). These functions serve as motivation to start and continue participation in CSPs (Cox et al., 2018; Peachey et al., 2014; West & Pateman, 2016). Another categorization of motivational factors is from Batson et al. (2002) who classified motivational factors in four categories: *egoism* (self-related motivations or increasing one's welfare), *altruism* (helping others), *collectivism* (contributing to general health and environment or contributing to the overall project's goals), and *principlism* (moral principles).

Although these authors have classified the motivational factors using different categories, it is clear that some of the categories are similar or somehow related. For example, the values function in the first categorization is related to altruism and collectivism in the second category, and different studies have used these classifications in different ways (Beza et al., 2017; Domroese & Johnson, 2017; Raddick et al., 2013). It is apparent that these factors may change at different stages of participation (Figure 5.1), and many factors may operate at one single point in time. For example, the motivations at the initial stage are subjected to change over time as citizens deepen their engagement in the project, and knowledge increases (Batson et al., 2002; Raddick et al., 2013).

In the current literature, few studies have used the four categories of motivations of Batson et al., (2002) to indicate motivational factors in different stages of participation in CSPs. For example, some studies indicated egoism (for example learning about bees in the Pollinator project) to be a primary motive for initial participation, while altruism and collectivism (for example, contributing to both research and environment) were associated with long term participation (Domroese & Johnson, 2017; Rotman et al., 2012). In contrast, Land-Zandstra et al. (2016) found contribution to research, health, and environment to be the most dominant factors that motivated people to join the Dutch iSPEX CSP, a project on measuring air quality. These differences indicate that a common framework to present these motivational factors and barriers in the different stages of participation is needed. Exploring the motivational factors and barriers in these stages provides evidence that may better inform future CSPs on what to do at each stage to encourage people to get and stay involved.

Materials and Methods

Overview of a citizen science program for malaria control in Rwanda

The study was carried out as part of a project that is being implemented in five villages of the Ruhuha sector in the Bugesera District in the Eastern province of Rwanda. Ruhuha was selected because it is a malaria-endemic area, with no current active vector surveillance. The sector is divided in five cells, and the cells are further divided in different villages. One village was randomly selected in each cell for the implementation of this CSP. On average, each village has 150 households and 45 households were invited to attend the participatory workshops where volunteers were later selected and this project was launched in 2018 (Asingizwe et al., 2019). Of the 185 people who attended the recruitment workshops, a total of 116 (63%) volunteers accepted to participate in the project and 69 (37%) decided not to participate.

Through co-designing, the goal of the project was to engage citizens in malaria control through the collection and reporting of mosquito species, mosquito nuisance experienced and confirmed malaria cases that occurred two weeks prior to reporting. When collecting mosquitoes, volunteers use a handmade trap and have to change batteries of the torches during the night. The details of the co-design and the handmade trap are in Chapter 4 (Asingizwe et al., 2019). Volunteers reported data on a monthly basis (collected the data every last Wednesday of the month) and the researchers provided monthly feedback. The researchers also organized dissemination workshops every four months to provide updates about the observations reported in the previous four months, offer additional knowledge on the mosquito species, as well as discuss challenges and ways forward (Asingizwe et al., 2019).

Study design and participants

An exploratory descriptive design with a qualitative approach was used. This study involved both volunteers and non-volunteers. Volunteers were defined as those who participated in the CSP on malaria control which consisted of reporting mosquito nuisance experienced or the number of confirmed malaria cases in the family, and/or participated in mosquito collection. Non-volunteers were people who only attended the participatory design workshops that were used to recruit volunteers but decided not to join the project (Asingizwe et al., 2019). In total, 30 volunteers across all five villages who reported mosquito nuisance and or collected mosquitoes were purposively selected to participate in this study of citizen science implementation; that is, six volunteers per village. These included both men and women of all ages (young adult: aged 23 to 35; adult: aged above 35). In addition, 14 participants who attended the participatory design workshops but did not join the project were also selected purposively. Table 1 provides an overview and details of the study participants.

Data collection instrument

A semi-structured interview guide was developed based on the research questions. Open-ended questions and probing were used to get an in-depth understanding of motivations and barriers. The guide was flexible to allow exploration of new ideas presented by the interviewees and to enable the addition of questions and probing as the data collection progressed. The guide had two versions: one for volunteers and another for non-volunteers. The volunteer version was used to explore the motivational factors for making decisions to participate and submit initial citizen science data, for continued participation, as well as for willingness for future participation. It also included questions related to barriers for staying involved, perceived reasons to stop, and perceived barriers for future participation. The non-volunteer version included the questions related to barriers to get involved in the CSP and willingness to get involved.

Data collection procedure

Overall, 44 individual in-depth interviews were conducted to capture participants' reflections on motivational factors to participate and barriers to get and stay involved in the CSP on malaria control. A list of participants drawn during the participatory design workshops (Asingizwe et al., 2019) as well as monthly reports from volunteers were used to select the participants to be interviewed. Data were collected in March 2019 (this means after four rounds of monthly citizen science data collection as reporting started in November 2018). A digital voice recorder was used together with taking notes for each interview. All interviews were conducted at the Ruhuha health center, a central and convenient location for all study participants. The duration of the interviews ranged from 25 to 50 minutes.

Data analysis

Each interview was recorded and later transcribed. A qualitative content analysis was used (Hsieh & Shannon, 2005). This approach allows for obtaining direct information (categories) from the data analysis without having or imposing predetermined categories (Hsieh & Shannon, 2005), hence getting a deeper and richer understanding of the phenomenon under study. After transcription, the demographic data were extracted from Word to an Excel sheet and for reasons of confidentiality, each participant was given a code that was then used in the presentation of the results. For the first round of reading, open coding was performed for ten interviews to become familiar with the data and preliminary codes were identified.

After that, all interview documents were transferred to ATLAS.ti, and open coding was performed to all documents using the identified codes. As indicated by Elo and Kyngas (2008), open coding involves writing notes and headings in the text while reading the transcripts. Through coding, verification was also done to check whether there is data that may not fit the identified codes, hence adding new codes; or whether there are codes that may be overlapping or similar in which case they could be merged. From there, the related codes were grouped into categories. The categories were revised and checked to ensure that they were mutually exclusive, thus a final list of categories was made. These categories were then grouped into subthemes.

To explore changes in motivational factors over time (initial and ongoing motivational factors), a network view between categories and related subthemes was created in ATLAS.ti. This was done to visualize linkages between categories and the initial or ongoing phases of participation. For comparing the motivational factors among age and gender groups, the code-document table was used by matching the motivational factors with age and with gender groups. To equalize the coding density of all selected groups, normalization was done in ATLAS.ti. The code-document tables were then exported directly to excel to create figures.

Results

We first present the demographic background of the participants, followed by the results pertaining to the three research questions of this study. The presentation of the results follows the structure of Figure 5.1. We show the results by stages of participation in the CSP for malaria control and for each stage, we indicate the corresponding motivational factors and barriers. In addition, the change of motivational factors over time and comparison among age and gender groups are also presented.

Demographic characteristics of the participants

Overall, forty-four participants were involved in this study. More than half (57%) of volunteers were aged above 35 years and (57%) of non-volunteers were aged 35 years and below. There was an equal number of female (50%) and male (50%) volunteers. Among non-volunteers more than half (57%) were female. Regarding the education level, the majority had partial or complete primary school in volunteer (63%) and non-volunteer groups (57%).

Table 5.1: Demographic characteristics of the study participants

Variables	Categories	Volunteers n (%)	Non Volunteers n (%)
Age	Young adult (35 years and below)	13 (43)	8 (57)
	Adult (above 35 years)	17 (57)	6 (43)
	Total	30 (100)	14 (100)
Gender	Male	15 (50)	6 (43)
	Female	15 (50)	8 (57)
	Total	30 (100)	14 (100)
Education	None	3 (10)	1 (7)
	Primary (partial or completed)	21 (70)	8 (57)
	Secondary (partial or completed) and above	6 (20)	5 (36)
	Total	30 (100)	14 (100)

Motivational factors

The motivational factors were divided in three main categories including (i) factors that influence the decision to participate and initial participation, (ii) factors that influence retention or continued participating, and (iii) factors that may determine participation for the long run of the reporting activities even beyond the completion of the research project. The decision to participate and initial participation were combined because there was a high level of participation since the project started. All participants that decided to participate submitted the first observations as part of the CSP for malaria control. In addition, almost all continued in the first year of the project.

The decision to participate and initial participation

It was clear that people had more than one motivational factor when they decided to participate. Four main factors emerged: (i) curiosity, (ii) desire to learn new things, (iii) helping others, and (iv) contributing to malaria control.

Curiosity

Generally, many people decided to participate because they were curious to catch mosquitoes and were interested to use the handmade trap as one mentioned: *"when started I had the curiosity to collect mosquitoes. I could not imagine the water bottle catching mosquitoes! Until when we started and I was able to collect mosquitoes that is when I believed that it is possible."* (KRPV_AF1). Surprisingly, many people reported that they did not sleep when they first set the trap (for the first month) because they wanted to observe how the mosquitoes are caught by the trap: *"When I started, the first month I did not collect mosquitoes and I reported no mosquitoes caught. I was very angry and disappointed. [....] for the following month, I was awake the whole night."(YRPV_YF1).*

Desire to learn new things

Some participants saw this project as an opportunity to expand their knowledge about malaria and its control: *"The main reason I decided to participate in this project is what I learned when I came for the first workshop. [....] when I attend a workshop, there are always important things that I gain which in turn may help me to control malaria." (BRPV_YF4).* Participants were interested to see the malaria mosquitoes and thought that through providing feedback and dissemination workshops they will acquire the knowledge and skills about mosquito identification. Some of them were even ambitious that after gaining knowledge on different mosquito species they can easily identify them whenever they see them: *"[....]. I would not know how a female mosquito looks like. Therefore, after some months, if you will bring these mosquitoes and show us those species, I am sure I will gain some knowledge in that. [....] if I will go in the bushes and see a mosquito, I will be able to confidently [....] identify the name." (MRPV_YM5)*

Helping others

Some participants expressed that they were willing to help researchers at the beginning of the program and they wanted to collaborate by collecting and reporting observations as one expressed: *"After the workshop [....] I thought that I do not have to look at my interest only and think that there is no payment. [....] I thought that if researchers are requesting for help to* *collect and report information without any payment, then it would not be right if there is nobody to help them." (BRPV_AF6).* In addition, one participant already saw the researcher collecting mosquitoes in an area close to his home, and thought the work was tiresome. Consequently, he thought that participation would make the work easier: *"You see that your colleague used to come down there to collect mosquitoes in our village, it was tiresome for her. Thus, after the participatory workshop, I immediately thought that I have to participate and make her work easier. I wanted to help her so that she will not be tired." (ZRPV_YM2)* Some participants thought that after attending the workshop and gaining knowledge, they would be able to confidently advice their neighbours about the use of malaria control measures: *"[....] I can explain and share knowledge with others, I mean those who did not have the opportunity to attend the workshop." (MRPV_YF7)*

Contribute to malaria control

The majority of the interviewees indicated a desire to contribute to malaria control through collecting mosquitoes as they disturb them while sleeping as one stated: "*Right after mentioning that you wanted the volunteers to collect mosquitoes, I immediately said that I am going to write my name on the list of mosquito collectors so that I can really catch them during the night because they bite me a lot [....]." (MRPV_AF4).* Other study participants expressed their interest to participate in malaria reduction as they indicated the severity of the disease and its associated consequences. One participant said: *"I always have one goal in my life [....] to improve the wellbeing of every Rwandan. Normally, there are some values that everybody should follow [....]. I feel that whichever way can be used to control malaria, I am willing to go for that and do it. I am committed to help the country to eliminate malaria in any way. That is the main reason that I did not hesitate to write my name on the list of volunteers [....] malaria is a very serious disease that has many consequences to all Rwandan population [....]." (BRPV_AM3)*. In addition, some volunteers consider participation as a social responsibility to improve the wellbeing of people around them: *" [....] I felt that participation will benefit the country, and I also benefit when I live with people who have a better health. [....] thus, I always feel responsible to play a role in others' development, better health, and better surrounding environment." (KRPV_AM2)*

Ongoing participation

After deciding to participate, all volunteers collected and submitted the first data and continued to report for the period of the project (one year). Six factors were reported (i) opportunity for learning, (ii) helping others, (iii) malaria control, (iv) ease of use of the tools, (v) usefulness of the project, and (vi) recognition.

<u>*Opportunity for learning*</u>

As the program continued, participants expressed their interest to learn new things, and this motivated them to continue reporting. This learning process mainly happens during workshops: *"Nothing pushed me to continue except [....] gaining knowledge. I think if I continue participating, obviously I will learn a lot of things [....]." (BRPV_YM2).* Another participant expressed: *"The reason I continued is that although you have explained many things to us, for example, different measures to be used for malaria control, there is still more that we do not know yet. I can not specify exactly what it is, but I believe there is more to come and I have to make sure that I participate [....]." (MRPV_YF7).*

<u>*Helping researchers*</u>

Some interviewees reported being motived to continue because the researchers still need them in the program and they already agreed to provide support. Therefore, they feel obliged to continue in a team of volunteers: *"When you start something, you need to continue until the end. [....] that is the main reason I would put much effort to continue. I have to be on the same page as others and continue until the research will end. So that by the time it ends, I will be confident that I have contributed from the start to the end." (MRPV_YM5).* Furthermore, respondents mentioned that the research was still ongoing, and believed that the results are not obtained: *"The reason I have to continue collecting and reporting the observations is that there is no way the research can continue if we do not submit the observations. You cannot say that you are doing malaria-related research with a focus on mosquitoes when you do not have those mosquitoes. [....] thus, the research can only achieve its objectives, when you have those mosquitoes, and we are the one to collect and submit them." (MRPV_YF7)*

Malaria control

Some respondents indicated that they were interested to continue because the research was related to malaria. By submitting the observations, the results can show a picture on the mosquito density in their villages, and this can indicate a correlation with malaria risk as well: *"I continued reporting the observations because there is a time you can collect one mosquito this month, and probably next month you see an increase in number of mosquitoes caught. When increased, that will indicate that there is also an increase in malaria risk." (MRPV_AM8).* Furthermore, participants indicated that it is the responsibility of every citizen to play a role to control mosquitoes and malaria in general. In this regard, researchers were seen as stakeholders in this control action: *"I always believe that our government is doing a lot in terms of mobilizing people to control mosquitoes. In this regard, researchers came also as important stakeholders so that we can play a large role in fighting against mosquitoes." (ZRPV_YM6)*

Ease of use of reporting materials

The majority of the respondents indicated that participation (collecting mosquitoes through setting up a handmade trap) did not require effort and this, in turn, had an effect on the retention of the participants. Some expressed that waking up during the night to change the batteries of the torches is not a problem as they also generally wake up at night and move around the compound for the security of their domestic animals: *"Personally, that time of setting up the trap and follow it up to change the batteries of the torches during night is not a problem. Furthermore, in a normal circumstance, as a man in the house, I usually wake up during the night and go out to see what is happening in the compound especially when you have cows or other domestic animals." (MRPV_AM1)*

The perceived usefulness of the program

The usefulness of the program was key in maintaining volunteers' interest to continue participating. Some respondents indicated an increase in using malaria control measures and being able to mobilize their neighbours about malaria control. As a result, some interviewees reported a perceived decrease in malaria cases in their families and getting positive feedback from their neighbours: *" The most important reason that motivated me to continue is the effect* *of these activities in my family. Since I started participation, I am using malaria control measures, and consequently, I have observed a reduction in malaria cases [....], I always mobilize my neighbours, and they have been telling me that the advice given was helpful [....]." (ZRPV_YM5).* Other participants continued participating because they expect more benefits in the future. Some participants believed that once researchers get the results, they will provide the information back to them, and try to solve the problem in collaboration with the policymakers: *"After reporting the observations and having the information about the results, you will give us advices, or do something to resolve the problem. [....] if I do not participate and provide the report, there is no way that the researchers or policymakers can be able to know the target location [....]." (BRPV_YM2)*

Recognition, attribution, and expectations

Some interviewees expressed that they do not expect anything in return as a payment (monetary incentives). However, most of them indicated a need for recognition. Participants reported a range of minimal recognition that could motivate them to continue reporting and facilitate long-term participation. These include (i) feedback provision, (ii) visits, (iii) more workshops, and (iv) ticket reimbursement for attending a workshop. In relation to the feedback, participants stated: *"When we receive that Short Message Service (SMS), we see that you always think about us and our effort. Because giving feedback means that we are still together in the program [....] and you value the work that we are doing. This is encouraging." (BRPV_YM2)*

Some interviewees indicated a need for more interaction with researchers during village visits, home visits, or phone calls: *"Village visits and interaction with researchers would motivate people to continue reporting. Because if you visit people in their villages, they, in turn, think that you care about them and value what they are doing. For example, yesterday when you called me for this interview, I really felt very happy because you still remember me. Thus, you can plan village visits, or phone calls because it is also an interaction. You can even plan some home visits, or visit us in our isibo meetings." (KRPV_AM2)*

Furthermore, some participants expressed a need for more workshops and expressed ticket reimbursement as one of the motivating factors. This was expressed thinking that when they attend a workshop they usually spend the whole day without doing any other activities: *"You may observe that it has been a long time without having a workshop for all volunteers, and you may invite all of them together. After the workshop, you may say that as a reimbursement of the day (because they may not have worked for that entire day) I am giving you this ticket. I believe this can motivate us." (MRPV_AM8).* Some participants also voiced that it would be good for the volunteers to have a common distinctive symbol for their identification: *"I think you can give us a distinctive symbol so that when somebody comes in the meeting or workshop, others may know who he/she is and where the person is going, they will say that "this person belongs to that group of volunteers". For example, you can give us T-shirts with a logo of the project." (MRPV_AF2)*

Future participation

<u>Among volunteers</u>

All volunteers indicated a willingness to continue to participate even after the completion of this PhD project. Participants indicated that they would like to continue participating so that they will know how (to what extent) mosquitoes are in their home environment given that participation does not require many resources and effort: *"Completing the research project does not mean eliminating malaria. Therefore, if there is somewhere to submit the report, then I can continue [....]." (MRPV_AM8)*

<u>Among non-volunteers [interest to get engaged]</u>

When we asked non-volunteers if they have thought about the project afterwards and may be willing to participate and change their decision, all of them indicated their desire to do so. Some of them felt that it was a failure not to be among volunteers and felt they could have taken a different decision. In addition, some visited the volunteers to see how they have been collecting mosquitoes: *"When others started collecting data, and I was not among them, I thought it was a failure as I took a wrong decision [....]. I even went to one of the volunteers to see how he collects mosquitoes [....]. Thus, in case there is another opportunity to include other people, I am willing to participate." (KRPNV_YM3).*

Although many non-volunteers indicated their willingness to participate, the volunteers indicated that some non-volunteers think that they are getting paid, and that could be one of the reasons why they also want to be involved: *"There are several people who are willing to participate in my village, but some of these think that we are getting paid. However, there is another category of people who want to know anything that can eliminate malaria in their families. Consequently, they are willing to do anything possible that can eliminate mosquitoes in their homes." (KRPV_AF1)*

Barriers to participate in the malaria-related CSP

Several factors were identified that can impede people to get or stay involved in the malaria-related CSP. These barriers were grouped into four: (i) barriers to get involved, (ii) barriers to stay involved, (iii) perceived reasons to stop, and (iv) anticipated barriers for future participation.

Barriers to get involved

Most of the interviewees (non-volunteers) indicated that they were not well informed about the recruitment process that was used. In addition, since they have participated in the participatory design workshops, they thought that this would put them automatically in volunteer groups. Thus, they thought that they would be called back to pick up the materials to be used for reporting the observations: *"I do not know how it happened. I remember writing my name on one sheet of paper, so I did not follow what was happening on the other sheet. For the second time, when you distributed the materials and I was not invited, that is when I realized that I was not included on the second list of volunteers." (MRPNV_YM1)*

Although the majority stated that they were not well-informed, a small number of participants indicated lack of time as a primary reason for lack of participation, and one participant stated that she would not be available by the time of collecting observations because she was planning to be out of the study area for quite some time: *"I was doing some school training in Kigali, and I thought if I write my names on the list, you may call and find that I am not there. Or it would be difficult if I have to travel all the way every month. Thus, I just took a decision not to participate." (BRPNV_YF2).* In addition, another indicated that he was too old and thinks that those are the activities for women and youth. Because to him, those are the people that are available most of the time and can closely follow up on those activities: *“I am an old man (68 years old), and I remember I did not write my name on the list of volunteers because I thought the youth will do it. I could not imagine at my age collecting mosquitoes [....] I have a lot of work to do at home [....] and I do not think I can have time to do that. There is some work [....] for young people, those who still have a lot of energy and time[....].” (KRPNV_AM1)*

Barriers to stay involved

The majority of volunteers mentioned that they have not encountered any barrier since they started participating. Others mentioned some barriers related to (1) perceived low efficacy of the trap, (2) pressure to collect more mosquitoes, and (3) difficulties related to changing batteries at night.

Perceived low efficacy of the trap

The majority of volunteers reported a perceived low efficacy of the trap that was made available. Some participants were wondering whether the trap has been tested before taking it to the field: *“The challenge is the trap we use while collecting mosquitoes. It has been so difficult for me. [....] mosquitoes are not going inside the trap. I sometimes wonder whether you have tested these materials before bringing them to be used in the field.” (KRPV_AF5)*

Pressure to collect more mosquitoes

Relatedly, as a result of perceived low efficacy of the trap, some reported pressure to catch mosquitoes, and submitting a report with no mosquitoes was considered as a shame to some of the participants. In this regard, some participants preferred to use other methods (for example catching mosquitoes by only using a net and hands) in case the trap did not catch the mosquitoes: *“I have been considering a report without mosquitoes to be a bad report. It does not really look good. It would be a problem to submit a report saying that you did not find mosquitoes while they are there [you can hear them making noise]. In addition, there are many strategies to collect them. I do not like to give a bad impression, neither I like to withdraw my commitment. Thus, I preferred to continue and use hands to collect them.” (BRPV_AF6)*

Furthermore, instead of using a trap for one day (for one round of collection per month) as indicated, some people preferred to set the trap twice (two days) so that they try their luck and see whether they can collect mosquitoes. For this, some people use the same mixture (sugar, yeast, and water) for two days, or buy other ingredients and make another mixture again: *"For the first time I submitted a report with no mosquitoes, but I was really disappointed. Then after that, I started using two days to see whether I can collect at least a few. I could use the same mixture (sugar, yeast, and water). I had to make sure in the following morning if no mosquito caught, I could cover the mixture carefully and use it again in the evening. [....] I always wish to submit a report with mosquitoes as recommended." (YRPV_YF1)*

However, some respondents think they have to report whatever caught by the trap. Thus, they do not feel ashamed when they do not collect mosquitoes as long as they set the trap as recommended. In addition, using other methods to collect mosquitoes was considered by some of the participants to be against the rules of the research: *"[....] I think that would be against the rules given from the researchers. I always think that there is a reason why you gave us those tools and definitely those are the ones to be used." (KRPV_YF6). "When I do not collect mosquitoes, I do not feel ashamed [....]. What I have to make sure is that I set the trap as recommended, that's it. Otherwise, if no mosquito caught, then it is ok. I have just to submit the report." (YRPV_AM2)*

<u>*Difficulties related to changing batteries at night*</u>

A final barrier that was perceived was related to changing the batteries of the torches. Participants reported that sometimes it is difficult to know when the torch gets off, thus a close follow-up should be made: *"These days collecting mosquitoes was a challenge, due to these tools that we are using. It requires a close follow-up during the night so that you know when to change the batteries of the torches." (ZRPV_AF4)*. Along the same line, another participant stated: "*Sometimes I wake up at midnight going to change the battery of the torch, but I found the torch is already off, so in that regard, you don't know exactly when it turns off." (KRPV_AF1)*

Perceived reasons to stop (leave the project)

All participants believed that there was no reason to stop participating unless they move to another location, get a disease that cannot allow them to continue or is a decision from the researchers: *"I do not think there is a reason why I should stop this activity.*

However, today's world is full of problems and challenges. Sometimes you may move to another location to look for other ways of living, and these are inevitable. Thus, if those inevitable reasons may happen, I may decide to stop." (BRPV_AM3). In the same line, another respondent mentioned*: "As long as I am still alive, I will not stop, unless I have a chronic disease that may make me a bedridden patient, because in this case, I would not be able to do it." (KRPV_YF3)*

Anticipated barriers for future participation

Many participants indicated that there will be no challenge to continue reporting observations after the completion of the research project, as participation does not require effort. However, a majority indicated anticipated barriers including the inability to find materials (when they will no longer be offered by the project): *"The main challenge that may even prevent further reporting of observations is lack of materials. You see that we use sugar and yeast, and not every volunteer may be able to buy them. Finding a person willing to buy sugar and yeast for collecting mosquitoes, when he/she does not have even a matchbox or soap, will be difficult." (ZRPV_YM6)*

Change in motivational factors

The motivational factors were compared over time (initial vs ongoing), and variations between age and gender were explored.

Change of motivation over time

A network view (Figure 5.2) showed that, when volunteers decided to participate in the malaria-related CSP, they were curious about collecting mosquitoes, wanted to learn new things, and contribute to malaria control. As they started submitting the observations, some motivational factors continued to be present and encouraged them to continue reporting. These included the opportunity for learning, helping researchers, as well as contributing to malaria control. In addition, other factors like ease of use, usefulness, as well as recognition came into play as participation progressed.

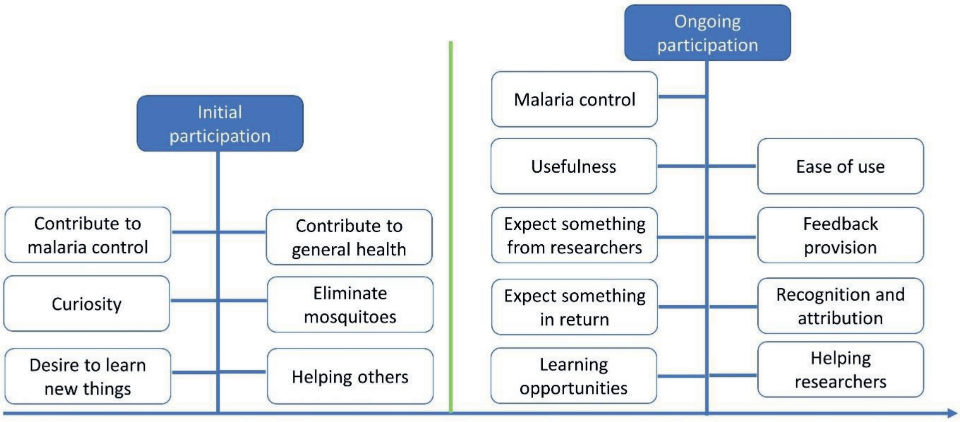

Figure 5.2: A network view indicating linkages between motivational factors over time (initial vs ongoing participation)

Comparison of motivational factors by age categories

The motivational factors (both initial and ongoing) were compared between young adults and adults (Figures 5.3 and 5.4). For initial motivation, desire to learn new things and curiosity were more prominent among young people while helping others and mosquito elimination were dominant among adults (Figure 5.3). These two groups were almost equally motivated by contribution to malaria control. For ongoing participation, still, the opportunity for learning came at the first place among young adults, while ease of use of the materials and usefulness of the program were central for adults (Figure 5.4). Also, the two groups were almost equally motivated by the recognition of their effort.

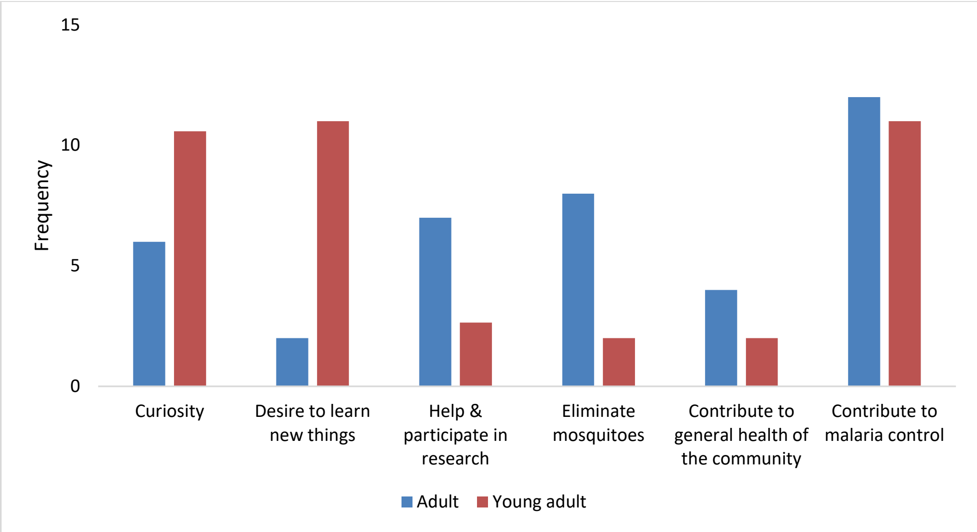

Figure 5.3: Initial motivational factors according to age

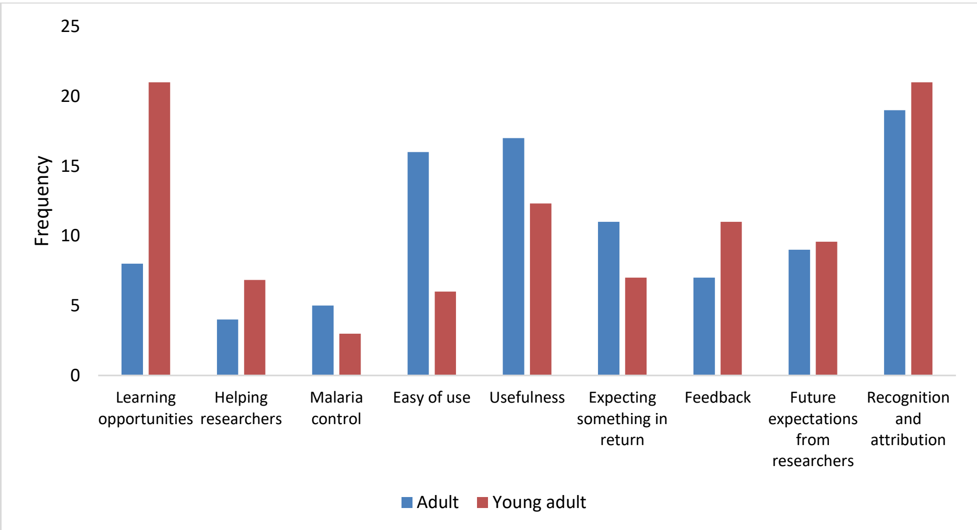

Figure 5.4: Ongoing motivational factors according to age

Comparison of motivational factors by gender

The motivational factors (both initial and ongoing) were also compared between men and women (Figures 5.5 and 5.6). Generally, not many differences were observed between the motivational factors reported by both men and women, especially at the initial stage (Figure 5.5). However, Figure 5.5 shows that women reported personal interest (curiosity and desire to learn new things) more frequently while men were more motivated to contribute to malaria control. This is also clear from the motivations reported for retention, where women indicated that they were more motivated by the usefulness of the project, ease of use of materials, and learning opportunities while men reported recognition as primary motivation for them to continue reporting observations (Figure 5.6).

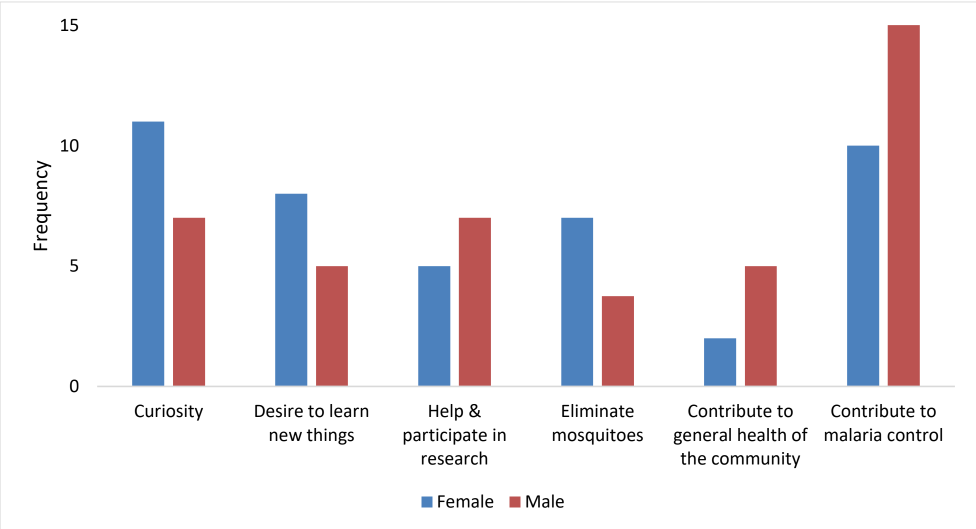

Figure 5.5: Initial motivational factors according to gender

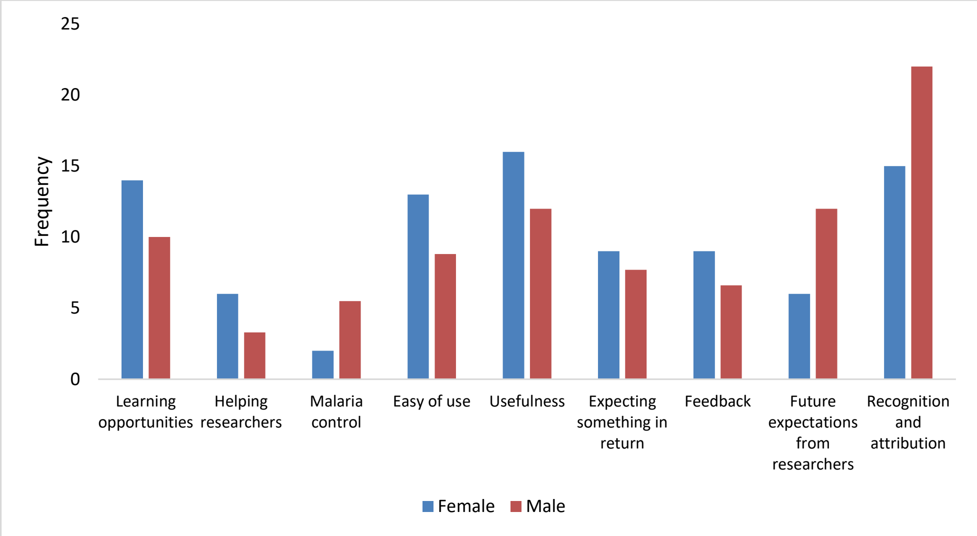

Figure 5.6: Ongoing motivational factors according to gender

Discussion

This study explored the motivational factors and barriers to participate in the CSP for malaria control, assessed changes in motivational factors over time, and compared these factors among age and gender groups. The first part of this section discusses the findings (motivational factors, barriers to get and stay involved, and the changes in motivational factors) (Figure 5.7). The second part presents the implications of the results in a broader context of citizen science. Finally, it presents the strengths, limitations, and avenues for future studies.

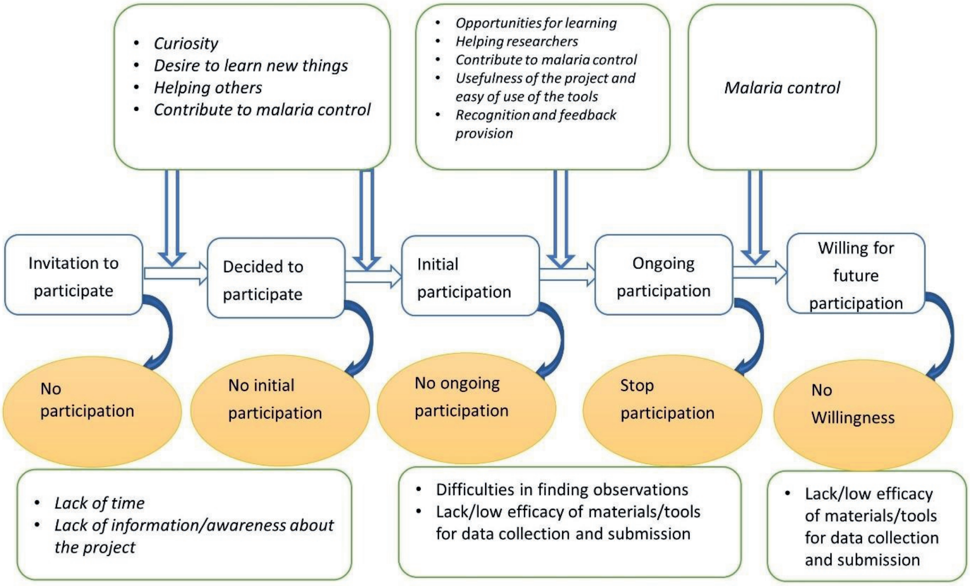

Figure 5.7: Motivations and barriers to engage in different stages of participation in a citizen science program

Discussion of the findings

Motivational factors to participate in the citizen science program

The findings of this study revealed that at the initial stage, people had different motivational factors including curiosity, desire to learn new things, and contributing to malaria control. Similarly, some other CSPs also revealed the presence of both personal interest and collective motives at the initial stage like in the Great Pollinator Project (Domroese & Johnson, 2017) and Seeds for Needs project (Beza et al., 2017). In contrast with these results, at the initial stage, some other CSPs revealed either the presence of personal factors (egoism) alone, for example in ecological base CSPs (Rotman et al., 2012), or collective factors (value: contribute to health, scientific research, and environment) alone, for example in the iSPEX CSP project (Land-Zandstra et al., 2016), the Great influenza project (Land-Zandstra et al., 2016), astronomy research (Raddick et al., 2010; Raddick et al., 2013), and a marine-related project (Carballo-Cárdenas & Tobi, 2016).

The presence of both personal and collective factors in the current study may be attributed to the interest in the topic (malaria control) and interest in collecting mosquitoes as citizen science is a new approach in the study setting. In addition, the data collection tools may have made volunteers curious to explore how mosquitoes can be caught by the handmade trap. Equally, the co-design approach that was used may have triggered both motives (Asingizwe et al., 2019). The fact that people started participating in the current citizen science program because they wanted to contribute to malaria control is promising. In turn, this may have played a big role in their ongoing participation because they considered malaria as a threat that requires a joint effort for better control.

Opportunities for learning, helping researchers, contributing to malaria control, the usefulness of the project, ease of use of the tools, and recognition were identified as motivational factors for retention. The desire to help researchers to accomplish their tasks has also been reported in the Seeds for Needs project (Beza et al., 2017). Sometimes, volunteers help researchers to reach their goals knowing that they will also get something in return (Beza et al., 2017). The presence of collective motives in this ongoing stage also corroborates with earlier citizen science studies. For example, a marine-related project, by Carballo-Cárdenas and Tobi (2016) found that participants were still concerned about the environment in the later stage of the project, and also other factors including learning, self-enhancement, and socializing came into play. While participating, volunteers have some expectations related to the future use of citizen science data, and this may motivate them to stay in the project. For example, in the present study, volunteers reported that once observations are submitted, the data can be used for further planning about malaria control interventions, hence they were motivated to continue participating. In a similar way, in the iSPEX project, which involves measurements of air quality, volunteers expected that after submitting the measurements, the data can give a clear picture about aerosols in The Netherlands, hence the data can have an impact on both health and environmental policies (Land-Zandstra et al., 2016). These expectations show how people are concerned about health, issues related to living places and environment, and how these collective motives play an important role in the retention of volunteers (Land-Zandstra et al., 2016).

Recognition was mentioned as an important factor that motivated volunteers to continue reporting the observations in the current study.

Appreciation of volunteers' contributions and acknowledgment have been also reported in ecological CSPs to influence the ongoing participation in CSPs (Rotman et al., 2014; Rotman et al., 2012). While the majority of volunteers in citizen science do not expect anything in return after sharing the citizen science data, some of these volunteers expect some rewards including information about the topic under study and sometimes monetary incentives (Beza et al., 2017). Feedback was considered as one form of recognition. Receiving feedback implies that the work of volunteers is being used for the project's purpose (Rotman et al., 2014; Rotman et al., 2012). The feedback also helps the volunteers to feel part of the project which in turn, affects the engagement in the long term (Tinati et al., 2017).

Willingness to participate in future CSP activities

All volunteers were willing to continue participating even after the completion of the research. Previous studies have reported some conditions for future participation in CSPs (Land-Zandstra et al., 2016). These conditions include reminders to report and feedback about the value of volunteers' contributions. The willingness to participate in future activities depends on the previous fulfillment of individual motivations (Clary et al., 1998). As in this study, in the Great Pollinator project, by Domroese and Johnson (2017), the appreciation of the project's activities and willingness to participate among non-volunteers have been reported. This indicates that the feedback provision or sharing project's activities is an important factor for (1) engagement over a prolonged period and (2) willingness for future participation. When people consider the goals of the project to be a priority in their daily lives, then the willingness to participate or continue participation will increase (Fienieg et al., 2012).

The consideration of malaria as a burden in the community where this study has been conducted could have influenced the willingness to participate in the future because through the submission of observations, other malaria control interventions can be implemented in the area.

Barriers to get and stay involved in the citizen science program

Lack of time and lack of clear information about the recruitment process were the two most salient barriers among those who did not participate in the citizen science program.

Unlike to this study, the time constraint was a barrier among those who ever participated but later dropped in marine-related projects (Carballo-Cárdenas & Tobi, 2016; Martin et al., 2016), and the Great Pollinator Project (Domroese & Johnson, 2017). On the other hand, the barriers among those who never participated in a marine-related project included low perceived threat of lionfish, thus collection of related data was perceived to not have value (Carballo-Cárdenas & Tobi, 2016). In the same way, Rotman et al. (2012) reported (perceived) power relations between scientists and citizens to be a barrier for initial contact and the decision to participate. Considering researchers as trained professionals with power and that they are conducting research for their purposes sometimes hinder the initial collaboration between researchers and volunteers and negatively affect the initial decision to participate (Rotman et al., 2012). These reported factors among non-volunteers are mainly due to the lack of project related information. The relatively long duration (six hours) of the participatory design workshops used to recruit the volunteers in the current study (Asingizwe et al., 2019), might have affected the participants' concentration level. Hence, some of them missed out the information about the recruitment process.

Similar to the current study, difficulties in identifying observations, for example, flowers and or bees were reported as barriers for continuing participation in the Great Pollinator Project (Domroese & Johnson, 2017). Comparing with ICT-based CSPs, some technology-related barriers were reported as challenges to stay engaged and influenced people to leave the project (Carballo-Cárdenas & Tobi, 2016; Martin et al., 2016). For example, Martin et al. (2016) revealed that technological design-related problems (systems which are not user-friendly and which have limited internet connection) can be barriers for volunteers to collect and submit citizen science data.

Additionally, failure to recognize and take into account the interest of volunteers may make them think that their motivations are downplayed and can result in leaving the project (Rotman et al., 2012). Contrary, when the voice of the volunteers is heard, then it is more likely that they can stay involved. For example, in this study waking up at midnight to change the battery of the torches was reported as a barrier. When this was raised, the volunteers alternatively suggested to buy other types of torches with batteries which can last for the whole night. Consequently, this suggestion was considered by the researchers, and new torches were bought.

Thus, without discussion, the researchers would not have known whether the torches needed to be replaced. In turn, this could have affected the collection of citizen science data.

Comparing motivational factors to participate in a citizen science program across age and gender

Similarly to this study, Land-Zandstra et al. (2016) found adult volunteers to be motivated by their contribution to a CSP. While young adults were motivated by learning opportunities in the current study, in a water quality monitoring project, Alender (2016) also revealed the need for career development to be higher among young people than older volunteers. Besides age, the variations in motivational factors were also observed among women and men where curiosity and desire to learn new things were more prominent among women while contribute to malaria control were dominant among men. These findings largely corroborate with the results of a Galaxy Zoo project, by Raddick et al. (2013), however interest to learn new things was also higher in men than in women. Contrary, Land-Zandstra et al. (2016) found the opposite where women were more motivated to participate because they were concerned about health, while men were more interested in science and the fun part of the project.

Implications of the current results in the field of citizen science

Based on the results of this study, the following implications were formulated:

The present results on motivational factors and barriers largely agree with the findings of ICT-based CSPs (Carballo-Cárdenas & Tobi, 2016; Domroese & Johnson, 2017; Rotman et al., 2012). This shows that when volunteers are committed to collect and submit citizen science data, the nature of the project (whether ICT or non ICT-based) does not play a large role. What should be considered is how the citizens are recruited, how they are engaged in the design process, what benefits they are receiving, and how their contributions are acknowledged. The motivational factors should be considered because highly motivated volunteers can collect and submit high-quality citizen science data (Dem et al., 2018). This indicates that in the absence of technology-related tools, a CSP can be implemented as long as the citizens are motivated to do so.

Nevertheless, two important factors, feedback provision and recognition, need further emphasis in citizen science. In citizen science, volunteers may not directly or explicitly ask for payment or monetary incentives (for example because of shyness), and in turn, they can ask some valuable objects (for example ticket reimbursement in this case). While monetary compensation can be motivating on the one hand, on the other it can also be a barrier for the CSPs with a low budget and may affect their willingness to learn and the quality of data. This is mainly due to that volunteers may be focusing on getting compensation, and consider it as paid work, rather than as a voluntary contribution with commitment. Therefore, scientists in citizen science have to provide clear information about whether there is any form of compensation and recognition planned in the project right at the start of the project. Equally, other benefits (for example opportunity for learning) should be well articulated at the start of a project.

We did not find "social" (socializing, social network, or social interaction) emerging as a prominent motivational factor, a common factor reported in ICT-based CSPs (Carballo-Cárdenas & Tobi, 2016; Peachey et al., 2014). In CSPs, the interaction happens either physically (mostly in non ICT-based CSPs) through workshops and meetings, or virtually (in ICT-based CSPs) through forums, blogs, and chats' groups. Although "social" motivation is salient, however, some ICT-based CSPs also reported this to be the least motivational factor (Cox et al., 2018; Domroese & Johnson, 2017; Land-Zandstra et al., 2016). This may be due to that in some CSPs, volunteers do not meet or interact very often, and they are interested in understanding (learning new things) and value (contribution to health and environment).

The variations observed in motivational factors over time, among age and among gender groups, deserve further consideration in CSPs. Some CSPs are conducted for a certain period of time or target a particular group of people, for example, a FeederWatch project by Martin and Greig (2019) only target young adults. Other CSPs experience a high attrition rate throughout different stages of participation (Jordan et al., 2017; Worthington et al., 2012). Equally, Brouwer and Hessels (2019) also revealed a high dropout among younger volunteers, and these had a lower willingness to participate in future related projects. In the current project, drop-out was rarely observed, as there was a high participation rate throughout the study period, and only perceived reasons to stop could be explored.

The high participation rate observed in this study may be the result of the co-design process used prior to the implementation of the program, and monthly feedback provided (Asingizwe, et al., 2019). These findings indicate that special attention should be given to the motivational factors for each group to prevent loss of interest, keep all motivated, and retain them in the project. Thus, it is important for other CSPs especially those that experienced a high dropout rate or used different design approaches, to assess the relationship between these motivational factors and dropout.

Strengths, limitations, and future research

This study explored the motivational factors at different stages of participation and provided explanations for the increase or attrition of participation in a CSP over time. These results may inform future CSPs on what to focus on at each stage of participation which may, in turn, increase the retention of volunteers on the one hand, and increase the quality and quantity of citizen science data on the other. Therefore, these findings merit consideration during the design and implementation processes of CSPs. The comparisons of motivational factors made among age and gender groups inform future CSPs on which group of people to reach out and how to motivate them at different points in time. The variations reported among age and gender groups can be further tested through quantitative surveys with volunteers in the citizen science program.

Although a small number of volunteers also belong to other groups that are well known in the community (for example community health workers), having this project in the area with some previous research projects brought some ideas that may be different when a similar project is implemented in a different setting. For example in this study, volunteers indicated a need for T-shirts. This idea could have been the result of observing other groups in the community (for example community malaria action teams) wearing T-shirts of that particular project.

The reported barriers to get and stay involved indicate that information about a citizen science opportunity, a detailed description of the recruitment process, as well as the requirements to participate should be clearly communicated before the recruitment of volunteers. In addition, as people reported the trap to catch less or not be able to catch mosquitoes at all, further studies may explore possibilities to compare the collection of mosquitoes using different types of traps versus using eyes and hands; and determine volunteers' preferences and acceptance of these methods. This is mostly because some volunteers reported that they no longer mixed the ingredients (water, sugar, and yeast) rather they prefer to use hands. This means that some resources (sugar and yeast) may be wasted when the volunteers may take them but never use them, or use them for other purposes.

Conclusion

This study explored the motivational factors and barriers at different points in the lifetime of a citizen science program on malaria control. At the initial stage, people participated in the CSP because of curiosity, interest to learn new things, helping researchers, and willingness to contribute to malaria control. After the volunteers submitted observations, other motivational factors came into play for maintaining their participation and these include ease of use of materials to report observations, the usefulness of the project, and recognition. Lack of time and information about the recruitment process were reported as barriers to getting involved. Volunteers reported some challenges while participating in the CSP and these included perceived low efficacy of the trap, difficulties in collecting observations which put pressure on them, and challenges related to changing the batteries of the torches during the night. The findings revealed that curiosity and desire to learn new things were more prominent among young people and women, while contributing to malaria control were dominant among adults and men. This implies that in a CSP, target groups require different recruitment and retention strategies. Thus, future CSPs should consider using different communication channels and strategies at different stages of participation to maximize the recruitment, participation, and retention of volunteers. The desire to contribute to malaria control, both in initial and later stages, is promising. Therefore, as participants were willing to participate for a long period of time, the reported motivational factors need to be considered to retain volunteers in CSPs.

The presented motivational framework may be used to explore motivations and barriers in other CSPs.

Chapter 6

What benefits do community members get from citizen science? *Evidence from a Rwandan citizen science program on malaria control*

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Abstract

Malaria control remains a challenge globally and in malaria-endemic countries in particular. In Rwanda, a citizen science program has been set up to improve malaria control. Citizens are involved in collecting mosquito species and reporting mosquito nuisance. This study assessed what community members benefit from such a citizen science program. We analysed how the citizen science program influenced perceptions and behaviour related to malaria control. This study employed a mixed-methods approach using dissemination workshops, a survey, and village meetings as the main data collection methods. Dissemination workshops and village meetings involved 112 volunteers of the citizen science program and were conducted to explore: 1) the benefits of being involved in the program and 2) different ways used to share malaria-related information to non-volunteers. The survey involved 328 people (110 volunteers and 218 non-volunteers) and was used to compare differences in malaria-related perceptions and behaviour over time (between 2017 and 2019), as well as between volunteers and non-volunteers. Malaria-related perceptions and behaviour changed significantly over time (between 2017 and 2019) and became favourable to malaria control. When the findings were compared between volunteers and non-volunteers, for perceptions, only perceived self-efficacy showed a significant difference between these two groups. However, volunteers showed significantly more social interaction, participation in malaria-related activities at the community level, and Indoor Residual Spraying (IRS) acceptance. In addition, both volunteers and non-volunteers reported to have gained knowledge and skills about the use of malaria control measures in general, and mosquito species in particular among volunteers. The reported knowledge and skills gained among non-volunteers indicate a diffusion of the citizen science program-related information in the community. Thus, the citizen science program has the potential to provide individual and collective benefits to volunteers and society at large.

Introduction

Despite major efforts to control the disease, malaria is still a severe health concern worldwide and particularly in Africa (WHO, 2018). In Rwanda, malaria remains a burden where its prevalence is 7% in the general population and even higher (11%) among children aged between five to fourteen years (MOH, 2017b). Furthermore, this prevalence rises to 17% in the general population in the Eastern province which is considered a malaria-endemic area (MOH, 2017b). Stalling malaria reduction and the reported malaria resurgence in some African countries, including Rwanda, hinder the progress towards malaria elimination.

The levels of investment in malaria control, access to, and acceptance of malaria control measures are still inadequate (WHO, 2018). For example, a malaria indicator report conducted in Rwanda revealed that 72% of the visited households had access to Long-Lasting Insecticidal Nets (LLINs), and only 64% slept under LLINs the night before the survey (MOH, 2017b). To improve the uptake of malaria control measures, a comprehensive approach that operates at local levels, and that engages affected community members is encouraged by the World Health Organization (WHO, 2018, 2019). Furthermore, citizens' engagement in malaria prevention activities has been proposed to improve the consistent use of malaria control measures (Asingizwe et al., 2019). However, how and to what extent such engagement may affect malaria-related perception and behaviour is still underexplored.

Citizen science, defined here as the engagement of citizens in scientific research, has been implemented in different disciplines (Beza et al., 2017; Jordan et al., 2017; Kampen et al., 2015; Worthington et al., 2012). Especially in the field of biology, many citizen science projects have been established (Follett & Strezov, 2015). In the context of the research program Environmental Virtual Observatories for Connective Action (EVOCA) (Cieslik et al., 2018), with the ultimate goal of malaria control through improving the consistent use of malaria control measures, a Citizen Science Program (CSP) for malaria control in Rwanda's Ruhuha sector was set up (Asingizwe et al., 2019). This CSP for malaria control sought to increase insight into the spatial and temporal variation in (malaria) mosquito populations, mosquito nuisance, and confirmed malaria cases, in a rural area where this type of information was not readily available. Volunteers were asked to report these variables. This CSP was co-designed with citizens through participatory design workshops conducted in August 2018 (Asingizwe et al., 2019). Throughout reporting of citizen science data, monthly feedback through Short Message Service (SMS) and quarterly dissemination workshops were provided to the volunteers (Asingizwe et al., 2019).

Citizen science has the potential to generate large quantities of data and engage citizens to better address and respond to complex environmental and societal issues, thereby enhancing the health and wellbeing of the population (Den Broeder et al., 2017; Van Brussel & Huyse, 2019). This engagement improves citizens' knowledge, as well as perceptions and behaviour (Den Broeder et al., 2017). As volunteers continue their participation in citizen science, they may expand their social networks (Bremer et al., 2019; Jordan et al., 2012). The network can either be within the volunteer group or beyond and thus may involve non-volunteers (those who do not submit citizen science data). Through the interaction between volunteers and non-volunteers, the impact of a citizen science project can be transferred and diffuse to other community members (Haywood et al., 2016; Roetman et al., 2018). The non-volunteers can be influenced by activities of the project (including the feedback or results provided by scientists) (Hollow et al., 2015; Roetman et al., 2018), or by the discussion and interaction initiated by the volunteers (Roetman et al., 2018). Interaction and sharing of experiences from participation can increase social capital (here referred to as fostering the network of community members to improve malaria control) (Bremer et al., 2019). Meeting and interacting with other community members can increase openness and trust as well (Bremer et al., 2019; Den Broeder et al., 2017).

Despite its potential, there is a lack of evidence for the impact of engaging community members in a citizen science program on both volunteers and non-volunteers, and to what extent and how it stimulates the consistent use of malaria control measures and participation in malaria control activities. Particularly, it is unclear to what extent malaria-related perceptions and behaviour change over time, and how they differ between those who directly contribute to the citizen science data and those who do not. To address this gap, this chapter intends to explore the effect of the CSP for malaria control in Rwanda as a case study. The following three research questions were investigated: (1) What factors could explain the changes in individual perceptions and malaria-related behaviour over time? (2) What factors could explain the differences and similarities in perceptions and malaria-related behaviour between volunteers and non-volunteers? (3) How do volunteers and non-volunteers benefit from a citizen science program? The answers to these questions are important to guide the design and implementation of future CSPs and inform policymakers why citizens' engagement in malaria control activities is vital for malaria elimination.

An integrated model of determinants of malaria preventive behaviour was used (Asingizwe et al., 2018). This model proposes that engagement in CSPs influences individual perceptions, social capital, and both individual and collective action (Figure 6.1). Volunteers interact and share malaria-related information to non-volunteers, in turn, the impact diffuses to non-volunteers as well. Social capital here refers to interaction and discussion between volunteers and non-volunteers in the neighbourhood or the community, and collective action refers to participation in malaria control activities at the community level.

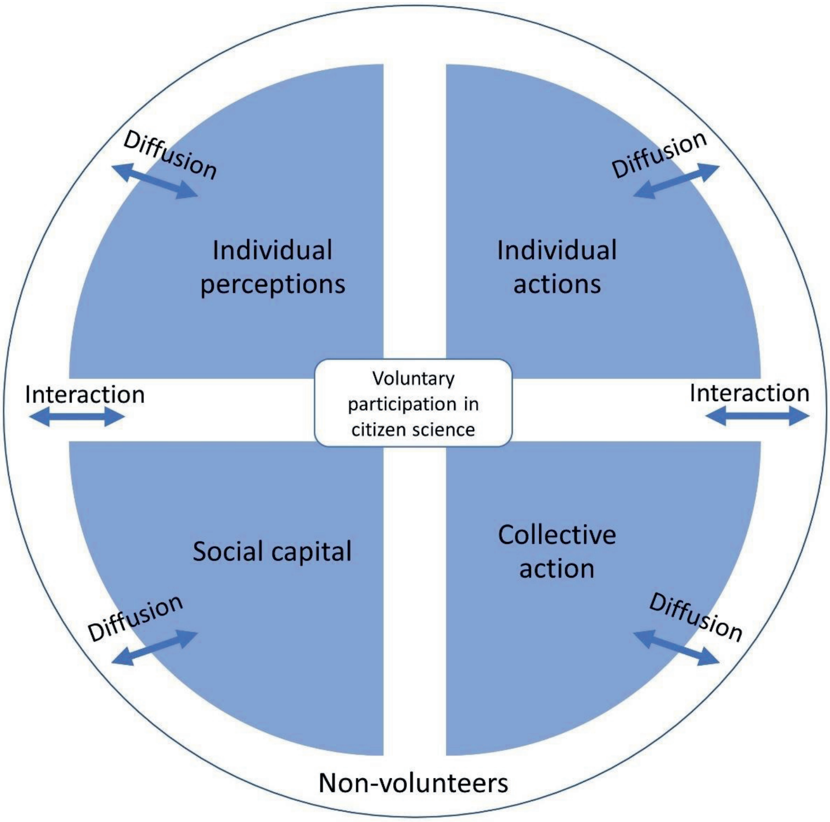

Figure 6.1: Effect of a citizen science program among volunteers and non-volunteers at both individual and community levels. Interaction refers to sharing information between volunteers and non-volunteers, while diffusion indicates the spreading of individual and collections actions.

Methodology

Study setting and project description

This study was situated in the Ruhuha sector of the Bugesera district in the eastern province of Rwanda as this region carries a high malaria prevalence relative to other provinces. Ruhuha was also selected for the implementation of this CSP because it is a location that does not have a sentinel malaria mosquito surveillance site implemented by the National Malaria Control Program (NMCP) of Rwanda. The details of the recruitment and design of the program are included in chapter 4. The CSP was implemented to provide data on mosquito density, mosquito nuisance, and malaria cases, to complement the ongoing active surveillance in 12 sentinel sites in the country, and may help NMCP to plan and implement targeted malaria control interventions.

Study design and population

In this study, a pre- and post-intervention design with mixed methods was used. All volunteers (112) (see reference in chapter 4 on how these were selected) (Asingizwe et al., 2019) that participated in the citizen science program were invited to attend two dissemination workshops. Almost all (108 in the first, and 112 in the second workshop) attended. Five village meetings were scheduled and were attended by the respective volunteers. These meetings were held in the villages where volunteers usually meet in case they have a meeting.

Two comparisons were made (Figure 6.2). The first comparison involved changes in malaria-related perceptions and behaviour over time (between 2017 and 2019). A list of people included in the baseline survey conducted in 2017 (Asingizwe et al., 2019) was used to select the respondents in the end-line survey. Among 150 participants that were involved in the baseline survey in the study area (Asingizwe et al., 2019), 97 were also available during the end-line data collection, hence they were included. In addition, a comparable group (double of volunteers) of non-volunteers was randomly selected to reach the sample size of 328. The second comparison was done between volunteers and non-volunteers and involved 328 randomly selected participants. These included 110 volunteers and 218 non-volunteers so that we could assess the benefits of the CSP among volunteers and non-volunteers.

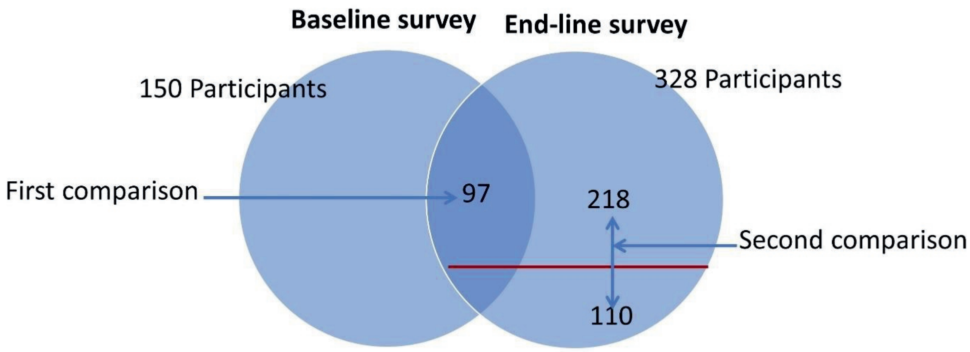

Figure 6.2: Study population and comparisons that were conducted. The first comparison indicates a pre-post, while the second one is between volunteers and non-volunteers

Data collection and study instruments

The data were collected with different methods (dissemination workshops, a survey, and village meetings) in three main steps (Figure 6.3).

Step 1: first dissemination workshop

Four months after the start of the CSP, a first dissemination workshop was conducted to share the information about what volunteers reported. Four months were chosen based on the agreement and the decision taken during the design phase (see chapter 4) (Asingizwe, et al., 2019). Group discussions were held to indicate the benefits of being involved in the program, what volunteers have learned, and what they have gained through the participation process. To collect this information, a group discussion guide was used.

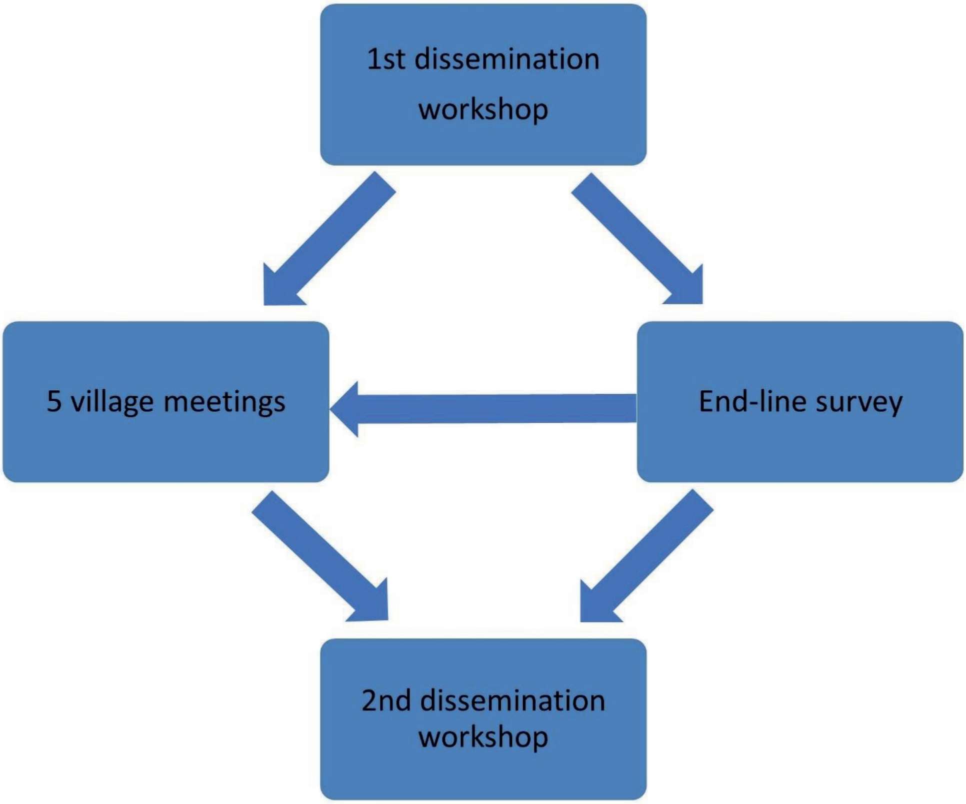

Figure 6.3: Different data collection methods used and how they follow each other

Step 2: end-line survey and village meetings

The second step involved both a survey and five village meetings. The end-line survey was used to compare with the baseline survey (Asingizwe, et al., 2019) and to get information about the benefits of participating in the program. For case-matched pre- and post-intervention comparison, the same questions that were asked in the baseline survey (Asingizwe, et al., 2019) were repeated in the end-line survey. The main variables included individual perceptions which were measured using a 5 point Likert scale. Individual perceptions included perceived severity (measured with eight statements), perceived susceptibility (measured with seven statements), perceived self-efficacy (measured with seven statements), perceived response efficacy (measured with six statements), perceived barriers (measured with eight statements), norms (measured with nine statements), and behavioural intentions (measured with seven statements). Furthermore, malaria-related behaviour (use of LLINs, Indoor Residual Spraying (IRS), social interaction, and collective action) were measured by one statement each. Based on the outcomes of the first dissemination workshop, closed-ended questions related to the benefits of the CSP were added to the survey questionnaire as well.

Five village meetings were held with volunteers in their villages to discuss the collective action that they may have started and to explore how volunteers share the malaria-related information with non-volunteers. Two main questions guided the meetings: one about the collective action, and another one about sharing malaria information with non-volunteers. They were conducted on the last day of the visit for survey data collection in each village. The main reason to conduct these meetings on the last day was to get insights on the awareness of the program among non-volunteers. This was received through debriefing sessions with the research assistants at the end of each day.

Step 3: second dissemination workshop

The third step involved a second dissemination workshop. It aimed to complement the information about the benefits of being involved in the program. These included what they have learned, and what they have gained through participation. In addition, the main questions about how volunteers share the malaria-related information to non-volunteers, and what collective action they have initiated as a group, were again discussed in the workshop for validation and sharing of information among all volunteers. The structure of the second workshop was a bit different from the first dissemination workshop in such a way that the discussion groups were mixed (volunteers from different villages). Researchers had to make sure that each village was represented in each group. This was done to ensure that participants could share information with others from different villages. Indeed, this helped the researchers to compare and validate the information shared during village meetings.

Data analysis

The quantitative data were analysed using SPSS version 25. Composite scores were computed for each variable by calculating the average score for each variable per individual. Non-parametric tests were used for comparisons because the data were not normally distributed.

Wilcoxon (matched-pair) signed-rank test was performed to examine the changes in individual perceptions between paired observations (between 2017 and 2019). Furthermore, as the use of malaria-related measures (LLINs and IRS) was measured with one statement each, these were considered as ordinal variables, hence marginal homogeneity tests were used to compare the matched observations (between 2017 and 2019) for these variables.

Further, the Mann Whitney U test was performed to assess the differences in individual perceptions between volunteers and non-volunteers. In addition, behaviour-related variables were compared using a chi-square test because they were measured with one statement each. Qualitative data were analysed manually to support the quantitative data by providing insight into the underlying reasons for the differences and similarities observed for both individual perceptions and malaria-related behaviour.

Results

The results are presented in three sections. The first presents the demographic characteristics of the study participants. The second section reports on the changes in malaria-related perceptions and behaviour between 2017 and 2019. In addition, it includes factors that may explain the observed changes. Finally, the third section presents information about the differences and similarities between volunteers and non-volunteers. It also elaborates on the benefits of the CSP for malaria control.

Participants' characteristics

Table 6.1 shows that of the 328 study participants 56.4% were female. Half of the participants had either no education or partial primary school. 57% of the participants were married and most of the participants were farmers (82.3%). The average age of the respondents was 44.1 years (*SD* = 13.6).

Table: 6.1: Demographic characteristics of the study participants

Variable	Categories	Frequency	Percentage
Gender	Male	143	43.6
	Female	185	56.4
Education level	None	78	23.8
	Partial primary	97	29.6
	Primary	99	30.2
	Partial secondary	29	8.8
	Secondary	20	6.1
	University	5	1.5
Marital status	Single	16	4.9
	Married	187	57.0
	Cohabited	56	17.1
	Divorced	18	5.5
	Widow	51	15.5
Main occupation	Farmer	270	82.3
	Public servant	7	2.1
	Self-employed	27	8.2
	Private Officer	4	1.2
	Student	1	0.3
	Unemployed	19	5.8
Age	Mean (±SD)	44.1	(±13.6)

Change in malaria-related perceptions and behaviour between 2017 and 2019

The results presented in Table 6.2 indicated that there were statistically significant changes in perceived susceptibility, perceived self-efficacy, perceived response efficacy, norms, behavioural intentions, and malaria-related behaviour (use of LLINs and IRS acceptance) between 2017 and 2019. There was also a significant decrease in perceived barriers. Perceived severity did not change.

Table 6.2: Changes in malaria-related perceptions and behaviour between 2017 and 2019 (97 paired observations). Wilcoxon (matched-pair) signed-rank test was used for others while marginal homogeneity tests were performed for Bed net use and IRS acceptance).

Variables	Mean		P-value
	2017	2019	
Perceived severity	4.3	4.4	0.609
Perceived susceptibility	3.0	3.5	<0.001
Perceived self-efficacy	4.3	4.6	<0.001
Perceived response efficacy	3.3	4.4	<0.001
Norms	2.9	3.7	<0.001
Perceived barriers	2.4	1.5	<0.001
Behavioural intentions	4.5	4.7	0.001
LLINs use	4.0	4.8	0.017
IRS acceptance	4.6	4.9	0.005

We asked the participants whether they noticed any change in their use and acceptance of malaria control measures between 2017 and 2019. In line with the results presented in Table 2, 22% of the participants indicated that they changed the frequency of using bed nets and 51% reported change in IRS acceptance. Regarding the direction of change, among those who reported a change in bed net use and IRS acceptance, 56%, and 95% indicated that the use and acceptance of bed nets and IRS acceptance had increased, respectively (Table 6.3).

Table 6.3: Change in bed net usage and IRS acceptance

Variables	Categories	Frequency	Percentage
Change in frequency of bed net use	Yes	50	22
	No	173	78
	Total	223	100
	Increased	28	56
	Decreased	22	44
	Total	50	100
Change in IRS acceptance	Yes	166	51
	No	161	49
	Total	327	100
	Increased	158	95
	Decreased	8	5
	Total	166	100

Factors explaining the differences observed over time

To interpret the quantitative results presented in Tables 6.2 and 6.3, some additional qualitative analyses were conducted. Participants who increased the frequency of bed net use reported to do so because of increased knowledge and awareness about malaria-related benefits of using bed nets, as it prevents people to be in contact with mosquitoes which cause malaria. This indicates the improvement in perceived response efficacy. One participant mentioned: *"I have increased the frequency of sleeping under a bed net because the bed net prevents me to get into contact with mosquitoes which can cause malaria."* Another participant stated: *"Because of the workshops and information about malaria that I received, I am now using the bed net every night".*

For those who mentioned that they have decreased the frequency of sleeping under a bed net, the main reasons highlighted were the perceived decrease of mosquito density, being in a dry season (at the time of data collection), and discomfort (feeling too hot) when sleeping under a bed net. Some respondents said: "*I have decreased the frequency of sleeping under a bed net because the mosquitoes also have reduced these days.*" Another indicated: "*I have decreased the frequency because now we are in a dry season*." In relation to discomfort, one mentioned: *"I have decreased the frequency because sometimes it makes me feel too hot."*

For those who reported no change in frequency of bed net use, most of them indicated that they have been sleeping under a bed net consistently because they want to prevent malaria, or they fear to get malaria, therefore the frequency of using bed nets remained the same. One participant said: "*To me, the frequency of sleeping under a bed net was not changed because I have been using it every night so as to prevent malaria."* Another mentioned, *"I have been sleeping under the bed net every night because I am afraid of getting malaria."*

Regarding IRS, most of the respondents indicated an increase in acceptance because they became aware and realized that the current insecticide is more effective than what they used to spray. One mentioned: *"the current insecticide is more powerful than the previous one that they used to spray in our houses".*

Individual perceptions and behaviour between volunteers and non-volunteers

A comparison of individual perceptions and malaria-related behaviour between volunteers and non-volunteers was conducted. Table 6.4 indicates that except for perceived self-efficacy, no statistically significant differences in other individual perceptions could be found between these two groups. However, significant differences were observed in social interaction (discussion about malaria in the community, talking to neighbours about malaria and its control), collective action (participating in malaria-related activities at the community level) the use of LLINs, and IRS acceptance.

Table 6.4: Differences in individual perceptions and malaria-related behaviour between 110 volunteers and 218 non-volunteers. Mann Whitney U test for individual perceptions (first seven variables) and chi-square test for behaviour (last five variables). The mean reported is a mean score at a 5-point Likert Scale based on six-nine statements.

Variables	Volunteers	Non Volunteers	*P* value
	Mean		
Perceived severity	4.4	4.4	0.779
Perceived susceptibility	3.4	3.5	0.302
Perceived self-efficacy	4.7	4.6	0.028
Perceived response efficacy	4.4	4.4	0.960
Norms	3.8	3.7	0.152
Perceived barriers	1.5	1.5	0.114
Behavioural intentions	4.8	4.8	0.364
Discussing about malaria in the community	2.9	2.3	<0.001
Talking to neighbours about malaria and its control	2.9	2.3	<0.001
Participating in malaria related activities (social/community work)	3.1	2.0	<0.001
Frequency of using LLINs	4.5	4.7	<0.001
IRS acceptance	4.9	4.7	<0 .001

Benefits of the citizen science program among volunteers and non-volunteers

The quantitative results presented in Table 6.4 are supported by the qualitative data collected among volunteers. These data were collected during village meetings and the second dissemination workshop with volunteers. During village meetings, information about how they share malaria-related information with non-volunteers was discussed.

In some villages, volunteers started some actions that made the project's activities visible. For example, in the village of Busasamana, volunteers decided to divide themselves into small groups to conduct visits to the homes of non-volunteers to explain what activities they were doing and to mobilize them for malaria preventive measures. In one village meeting, one volunteer said: *"We have formed small groups and went into households of non-volunteers to show them how they can control malaria. After that, we had a meeting with the whole village, and we demonstrated what we do as volunteers, what they can do to control mosquitoes, and we mobilized them to use malaria control measures in general".*

The active sharing of information with non-volunteers was also mentioned in the second dissemination workshop, in relation to the question asked during group discussions "How do you share/communicate malaria-related information among non-volunteers in the village"? In response to this question, one group mentioned: *"When there is a village meeting, we take some time and talk about malaria to inform those who are not volunteers; we occasionally go in their households and mobilize them about malaria prevention. In addition, we sometimes collect mosquitoes in their homes so that they can be aware of what we are doing because some of them ask us to set the trap in their houses".*

Apart from what volunteers mentioned about sharing the information with non-volunteers, the latter also confirmed this in the end-line survey as reported in the following section. This reports the source of information about the program, what they learned and gained, as well as indicating their willingness to participate in the program.

Perceptions related to the presence of the citizen science program in the community

Table 6.5 shows that 88% of non-volunteers already knew this program by the time the survey was conducted, and 45% had at least some information about the program. Among those who had information about the program, a substantial proportion (73%) received this information from the volunteers. Generally, the majority of both volunteers and non-volunteers judged the program as very good (68% vs 33%) or good (32% vs 52%) respectively.

Table 6.5: Perception of citizen science program among 110 volunteers and 218 non-volunteers

Variables	Categories	Frequency	Percentage
Heard about the citizen science initiative in this area	No	27	12
	Yes	191	88
	Total	218	100
Informed about the citizen science program	Not informed at all	120	55
	Not informed	37	17
	Somewhat informed	44	20
	Well informed	15	7
	Very well informed	2	1
	Total	218	100
Source of information	Workshop	5	5
	Volunteer	72	73
	Collected mosquitoes in my house	21	21
	Total	98	100
Having a citizen science program in the area near your home (volunteers)	Good	35	32
	Very good	75	68
	Total	110	100
Having a citizen science program in the area near your home (non-volunteers)	Bad	5	2
	Not good and not bad	28	13
	Good	113	52
	Very good	72	33
	Total	218	100
The extent of learning from this citizen science program (volunteers)	Moderate	13	12
	Much	61	55
	Very much	36	33
	Total	110	100
The extent of learning from this citizen science program (non-volunteers)	Nothing	133	61
	Little	54	25
	Moderate	22	10
	Much	8	3.5
	Very much	1	0.5
	Total	218	100

Learning and gaining from the citizen science program

The analysis of what learned and gained was limited to those who heard about the initiative and at least have learned something (from little to very much, i.e. 110 volunteers and 85 non-volunteers see Table 6.5). Figure 6.4 indicates that both volunteers and non-volunteers learned some topics from the citizen science program. Volunteers learned more about collecting mosquitoes (92%) and different mosquito species (64%), while non-volunteers learned more about the use of malaria preventive and control measures (44%).

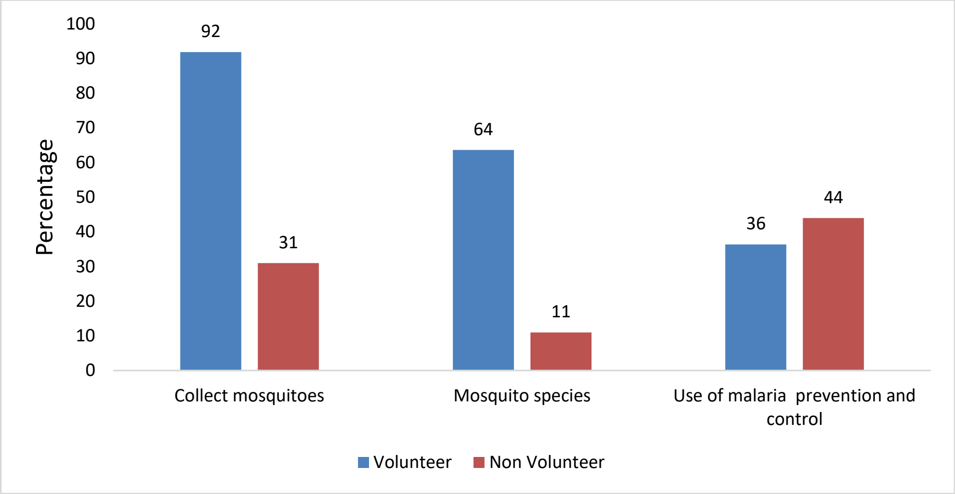

Figure 6.4: Proportions of volunteers and non-volunteers reporting about what they learned since they had the CSP in the area near their homes ($N_{volunteers} = 110$; $N_{non\text{-}volunteers} = 85$).

As indicated by Figure 6.5, both volunteers and non-volunteers gained knowledge and skills. Additionally, volunteers expanded their social network and gained opportunities for collaboration with peers and researchers.

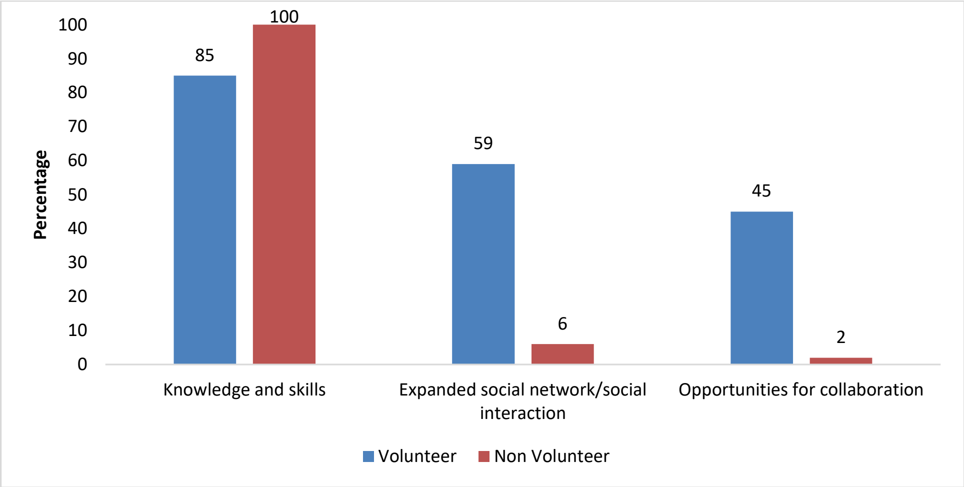

Figure 6.5: Proportions of volunteers and non-volunteers reporting on what people gained as a result of the CSP ($N_{volunteers} = 110$; $N_{non\text{-}volunteers} = 85$).

Willingness to join/continue participate in the citizen science program

Figure 6.6 indicates that all volunteers were willing to continue participate in the project even after the completion of the research, and a large proportion (75%) of non-volunteers wished to join the project as well.

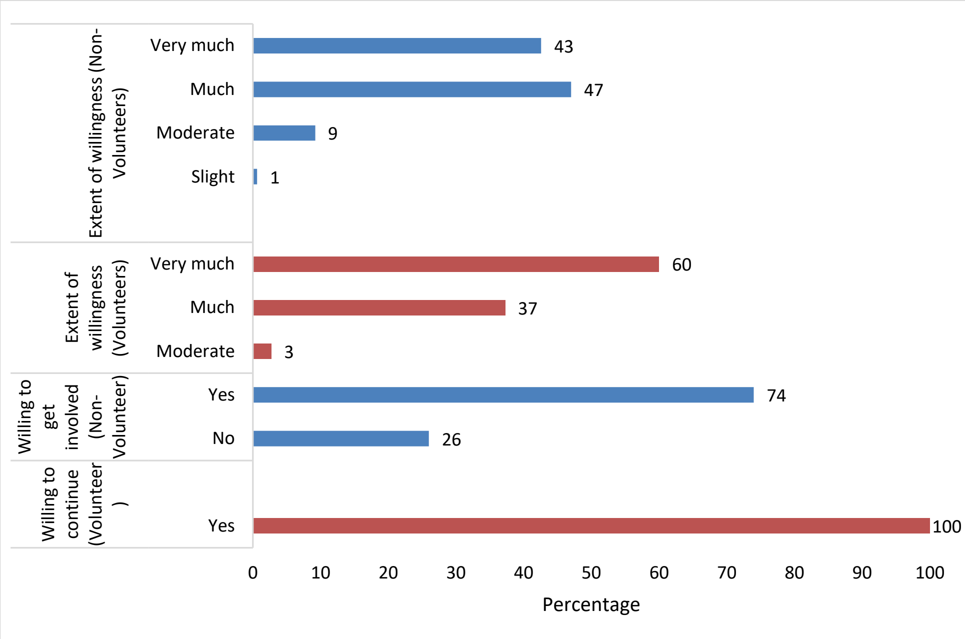

Figure 6.6: Proportions of volunteers and non-volunteers reporting their willingness to participate in the CSP

Discussion

This study provided quantitative and qualitative insight in the impact of the CSP for malaria control that was conducted in Rwanda. Specifically, it determined the changes in individual perceptions and malaria-related behaviour over time, identified the differences and similarities in perceptions and malaria-related behaviour between volunteers and non-volunteers of a CSP, and explored the reported benefits of the program.

Change in perceptions and behaviour

Generally, the research findings indicate that participation in the CSP for malaria control influenced both individual perceptions and malaria-related behaviour among volunteers and non-volunteers. Malaria related perceptions and behaviour increased significantly over time (between 2017 and 2019). When the results were compared between volunteers and non-volunteers, no significant differences in individual perceptions between these two groups could be found. However, significant differences were observed in social interaction, participation in malaria-related activities and IRS acceptance. Significant increases in malaria-related behaviour observed among volunteers in this study corroborate with the literature that indicates that the more people engage in citizen science, the greater the impact on their behaviour (Hollow et al., 2015; Roetman et al., 2018). For example, Roetman et al. (2018) found that through participation in a pets' related CSP, volunteers who were engaged in the management of their cats reported to change their behaviour and kept their cats indoors more often. Equally, a health promotion related to CSP conducted in The Netherlands also reported intentions and actual changes in lifestyle behaviour among citizen scientists (Den Broeder et al., 2017).

As a result of participation in CSP, the volunteers have played a large role in the transfer of the malaria-related information to non-volunteers, and this resulted in similarities in individual perceptions reported in this study. The non-volunteers could learn from and be influenced by citizen science projects in many ways (Hollow et al., 2015; Roetman et al., 2018). For example, the non-volunteers in the Cat Tracker citizen science project reported changes in attitudes (Roetman et al., 2018). These changes may be a result of following the project as observers, or interest the non-volunteers may have had in the feedback provided to volunteers by scientists (Roetman et al., 2018). This sharing of information is analogous to what Rogers (1983) coined "diffusion", a process by which an innovation (for example CSP for malaria control) is communicated among members of a social system over time using different channels to reach a common understanding (Rogers, 1983).

As reported in this study, some volunteers planned home visits and meetings at the village level with non-volunteers and explained the project's activities. In turn, this might have influenced the changes in perceptions and behaviour reported in this study.

In line with this, sharing generally positive feedback about the goals and benefits of the project to the wider community by the citizen scientists, and direct discussion about the project with non-volunteers have been reported in citizen science literature (Haywood et al., 2016; Jordan et al., 2011; Roetman et al., 2018). In line with sharing what volunteers learned from citizen science, Bremer et al. (2019) found that some volunteers reported sharing what they learned in the project with students and colleagues (Bremer et al., 2019). In turn, this may play a large role in the change of attitudes among non-volunteers, and stimulate willingness to participate in other citizen science projects' activities, or even in other projects (Roetman et al., 2018). Through discussion and interaction in the community, collective efforts can be made to solve common problems (malaria burden in this case), hence improve the health and wellbeing of the community. In this study, by initiating the discussion about malaria and related control measures, volunteers felt concerned about malaria and felt that the discussion can be the first step towards collective efforts in controlling malaria.

Apart from the discussion about malaria-related activities with neighbours, or with community members in general, other organizational activities have been observed. For example, in this project, volunteers in one village decided to form a cooperative which would facilitate them to meet more often and discuss about malaria and its control. To encourage this, in the cooperative, they decided to contribute a monthly fee and they could rotate among themselves by either buying a domestic animal for each member on a monthly basis or in case a person is not interested in buying domestic animals, then, they could give him/her money to accommodate the needs. In the latter, other members could make sure that the money will not be misused. This indicated that participation in this CSP for malaria control may not only be related to malaria control but may also induce other financial gains. When time continues, there is no hesitation that this may also be open to non-volunteers who might be interested. Similarly, in other CSPs, some additional activities, and interesting cases were reported. For example in a cat tracker CSP conducted in South Australia (Roetman et al., 2018), one volunteer engaged neighbours to volunteer their pets for tracking and organized different meetings to discuss the results. Beyond the discussion, the same author added that the volunteer had more curiosity related to animal behaviour and returned to school to study the related subject (Roetman et al., 2018).

Participation in malaria-related activities, social and community work (for example to clear mosquito breeding sites) was higher among volunteers. In the same way, an increase of participation in conservation activities, more engagement in CSP-related activities, as well as joining other projects at national and regional levels have been reported in a CSP on coastal observation and seabird survey conducted in South Australia (Haywood et al., 2016). Joining other invasive plant removal projects and changes in planting habits have been also reported by volunteers in a CSP related to the ecology of invasive plants (Jordan et al., 2011).

Learning in a citizen science program

In the present study, both volunteers and non-volunteers reported that they have learned about how to collect mosquitoes, identify different mosquito species, and use malaria control measures. Consistently, learning new things and awareness raising especially about the object of study has been reported by many researchers in CSPs (Brouwer & Hessels, 2019; Dem et al., 2018; Haywood et al., 2016; Hollow et al., 2015; Toomey & Domroese, 2013). For example, a CSP conducted in the north of the Philippines about ecosystem functions reported an increase in awareness about different species that they were collecting (Dem et al., 2018). Likewise, Den Broeder et al. (2017) also reported an increase in social skills and self-confidence in talking and discussing with non-volunteers about health-related topics such as healthy lifestyle and health promotion activities. The reported knowledge and skills gained in the current study may be helpful as the citizens reported the lack of information about mosquitoes during the design phase of the project (Asingizwe et al., 2019), and were interested in discussing control of mosquito breeding sites (Asingizwe et al., 2019). Thus, the knowledge and skills gained may help them in the control of mosquito breeding sites in the area.

Apart from the knowledge and skills gained among both groups, volunteers also reported having expanded their social network, and opportunities for collaboration. By participating in citizen science, volunteers meet new people, interact with them and become friends with several people in volunteers' groups, neighbourhood, and beyond (Bremer et al., 2019; Den Broeder et al., 2017). For example, in a CSP on climate adaptation conducted in Bangladesh volunteers created a network (which they referred to as a family) that helped them to interact regularly outside of the project's meetings (Bremer et al., 2019).

These social networks and interactions often enhance trust and social cohesion among people in the community (Bremer et al., 2019; Den Broeder et al., 2017).

Willingness to become involved or continue participating in the citizen science program

Willingness to become involved, or continue participating in the program was assessed and the majority (100% of volunteers and 75% of non-volunteers) indicated that they were. In the evaluation of citizen science projects, other researchers also assessed the willingness to participate in a new project. For example, in their study about koala management, Hollow et al. (2015) revealed that 91% of the volunteers, 54% of those who heard about the project, and 29% of those who are not informed about the project were willing to participate in another koala related project. In the same line, in a water quality citizen science project, Brouwer and Hessels (2019) also revealed a high level (90%) of willingness to participate in future studies related to water quality measurements. The high level of willingness reported in the present study may reveal the concern of the citizens about the malaria burden, and probably their interest for participation in related scientific research.

Implications of the findings to the citizen science practice

When implemented, CSPs may have different objectives (Brouwer & Hessels, 2019). Most of the co-designed CSPs target scientific, societal, and political impacts. In this regard, an integration of these elements at the start of the project, and establishing how they will be assessed and achieved is key to realize the full potential of CSPs. Following the findings reported in this study, some key elements related to societal impact merit attention and inclusion in the citizen science evaluation framework. These include the nature of learning and learning arrangements. The latter may be thoroughly planned before the implementation of CSPs. This is because in most cases, CSPs are mainly considered as a tool to facilitate collection of environmental data, and most scientists give priority to the quality and quantity of citizen science data, but not to the educational part of the initiative. However, the educational aspect of citizen science may influence the quantity and quality of data. Therefore, pairing ecological data (scientific impact) and social data (societal impact) may provide tangible evidence to policymakers for political impact.

While the effect of citizen science extends beyond those who are actively participating, many CSPs only assess learning and consider this as the main outcome in citizen science (Crain et al., 2014). This is mainly because of a lack of pre-determined criteria to be assessed throughout the project's period. This study provides evidence that CSPs offer other benefits including environmental management at the community level. Therefore, researchers in citizen science should explore the benefits of citizen science beyond volunteers at both individual and collective levels.

In citizen science, long term engagement may be more influenced by the societal impact (Cunha et al., 2017). This is to say that co-designed CSPs that are based on existing societal problems (for example malaria in this case) or build upon a joint interest between researchers and citizen scientists may lead to successful participation and achieve the educational goal (Crain et al., 2014). This implies that the evaluation of CSPs should take into consideration the nature of the project and the design used.

Strength, limitation and further research

Overall, the findings reported in this study merit consideration in future CSPs, as they contribute to the design and implementation, as well as the sustainability of CSPs. For example, the comparison made between volunteers and non-volunteers provides useful information related to the educational and citizen engagement goals of the project.

Most of the respondents who reported change in perceptions and behaviour reported doing so because they have acquired information related to the use of malaria control measures, and this information may be partially attributed to the CSP for malaria control. The change of perceptions and behaviour over time cannot be associated completely with the program because quantification of the effect of the CSP on volunteers (pre-post interventions for the volunteers only) was not done. However, given that there was no other malaria initiative in the area during the study period, the substantial impact may be attributed to this CSP. Further studies quantifying the impact of this program with a comparison of some community members away from the study site (for example Busoro sector which was involved in the baseline study (Asingizwe et al., 2019)) as a control group is desired.

Finally, some studies have demonstrated that CSPs play a large role in the policy arena (Hollow et al., 2015). This societal impact of the CSP for malaria control presented in this study provides evidence that it is useful for decision-makers and policy development for malaria elimination. Further studies that involve policy-makers are needed to determine their perceptions of the program, and how it can complement the active surveillance of the national malaria control program.

Conclusion

This study assessed the quantitative and qualitative impact of a CSP for malaria control. The study offers empirical evidence of the extent to which and how a CSP changes perceptions and improves the use of malaria control measures. From the research findings, we observed that the individual perceptions in general and malaria-related behaviour changed significantly over time (between 2017 and 2019), thereby becoming more favourable to malaria control. When the results were compared between volunteers and non-volunteers, a significant difference was observed only for the perceived self-efficacy. However, it was apparent that in general, volunteers perform malaria-related behaviour more than non-volunteers. Volunteers and non-volunteers reported gaining knowledge and skills about the use of malaria control measures in general, and mosquito species in particular among volunteers. In fact, the use of LLINs was more among non-volunteers than volunteers. Indeed this shows the diffusion of CSP-related information in the community and gives promise that the non-volunteers may also adopt other malaria-related behaviour similar to the volunteers. Thus, a CSP has potential not only as a means of collecting a large amount of citizen science data, but also equally important, as a means of engaging citizens in decision making and solving environmental and public health problems.

Chapter 7

General discussion

Introduction

This thesis investigated the factors that influence the consistent use of malaria control measures. Through the design and implementation of a citizen science program, it also explored the motivations and barriers to participate in the program. Finally, it evaluated the effects of this program on malaria-related behaviour among volunteers and non-volunteers. In this thesis, malaria prevention and control measures refer to three of the most important control measures that are being used in Rwanda: long-lasting insecticidal nets (LLINs), indoor residual spraying (IRS), and environmental management (i.e. control of mosquito breeding sites).

This chapter aims to discuss the findings of the previous chapters of this thesis. It starts with a summary of the findings to the specific research questions presented in the introduction chapter of this thesis. After that, the main findings are discussed in relation to the overall insights they bring to the field of citizen science and malaria control in particular. Key themes include factors that influence malaria control, participation and retention of volunteers in citizen science, benefits of a citizen science program, the role of information communication and technology (ICT), the importance of including a social component in the design and implementation of citizen science projects, and how to deal with social differences in citizen science. Further, recommendations for improvement in malaria control, and better designing and implementing citizen science projects are presented. Lastly, further research avenues in the fields of citizen science and malaria control are proposed.

Summary of the main findings

Developing and testing an integrated model of determinants of malaria preventive and control behaviour

To understand the determinants of malaria prevention and control behaviour, an important component was to develop an integrated model to explain and relate different factors that play a role in malaria control. These factors may also influence participation in a citizen science program (Chapter 2). This model was based on an exploration of literature and integration of three well-established theories, the Health Belief Model (HBM), the Theory of Planned

Behaviour (TPB), and part of the Unified Theory of Acceptance and Use of Technology (UTAUT). Chapter 2 indicated how malaria control is complex as it involves different dimensions (ecological, institutional, and social-cultural). To tackle these dimensions and have a successful malaria control program, an integrated model that includes both individual and collective factors is presented (Figure 7.1.).

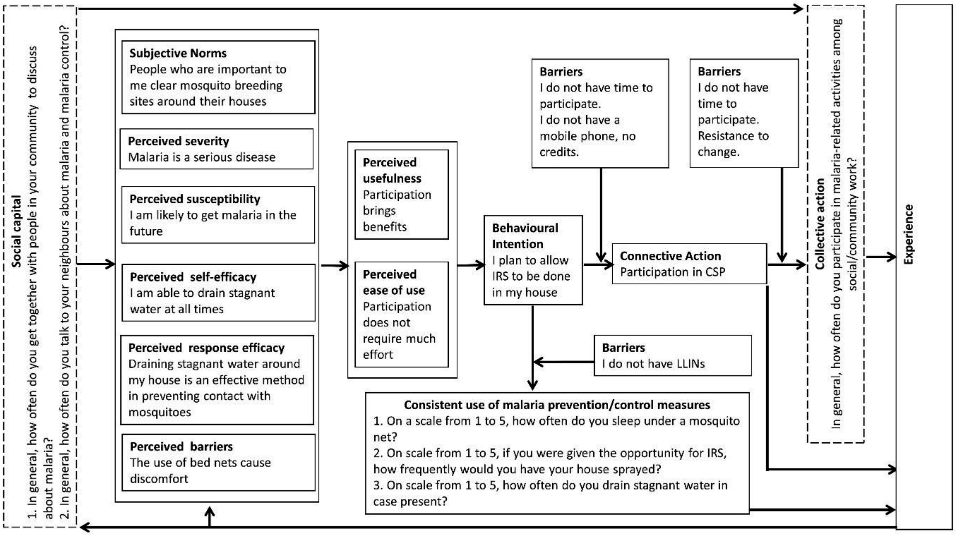

Figure 7.1: Overview of the integrated model used in this study and examples indicating how concepts were operationalized. Boxes with solid lines represent individual factors while boxes with dotted lines represent collective factors.

Using the integrated model of determinants of malaria prevention behaviour, Chapter 3 determined how community members perceive the risk of malaria and the effectiveness of malaria preventive measures. It also tested to what extent individual perceptions influence the intentions to use malaria preventive measures (LLINs, IRS, and control of mosquito breeding sites). Finally, it explored strategies that stimulate the consistent use of these measures. Individual perceptions refer to: perceived severity, perceived susceptibility, perceived self-efficacy, perceived response efficacy, subjective norms, and perceived barriers.

High perceived severity of, and perceived susceptibility to malaria was reported. This was mainly explained in terms of repetitive malaria episodes among the majority of the community members and the perceived low effectiveness of malaria medication. Perceived response efficacy and self-efficacy were also reported to be high due to the observed increase of malaria cases in the study area. This indicates that when malaria incidence increases, people get worried about the consequences of malaria, and in turn, will think about the benefits of using preventive measures and their ability to do so. Consequently, people may increase the use of these measures. Although people were motivated to use LLINs, accept IRS, and participate in the control of mosquito breeding sites, some barriers were reported that hinder the consistent use of LLINs. These include lack of LLINs, discomfort, irritability, and presence of bed bugs. Although a lack of LLINs was reported to impede the consistent use of LLINs, and availability and accessibility of LLINs are potential factors of LLINs use, no significant evidence was found that they alter the effect between intentions and consistent use of LLINs. This suggests that the higher the intentions, the higher the consistent use of LLINs, while the number of LLINs owned (whether enough or not) does not change this relationship.

Except for perceived susceptibility, other variables that include perceived severity, self-efficacy, response efficacy, norms, and barriers were statistically related to behavioural intentions, and together these explained 50% of the variance in behavioural intentions towards the consistent use of control measures. This indicates that there are other factors that may explain parts of the remaining half. These include collective factors for example, the organizational and leadership capacities needed to form groups or associations that encourage malaria control activities, and/or engage in collective control of mosquito breeding sites at the community level. Finally, access to LLINs and regular spraying activities, community mobilization, and citizen engagement in malaria control activities were highlighted as strategies to improve consistent use and acceptance of preventive and control measures.

Designing a citizen science program for malaria control in Rwanda

After exploring the need for citizen engagement, Chapter 4 focused on how citizens can be engaged in the design of a citizen science program for malaria control (here referred to as CSP for malaria control). The co-design of such a program involved both technical and social components. The technical component included tools to collect and report the observations (mosquito species, mosquito nuisance, and confirmed malaria cases). The social component included recruitment of volunteers, strategies for collecting and/or reporting the observations, and mechanisms for providing feedback.

The findings revealed that among the tools (paper form, phone calls, and SMS text) to report mosquito nuisance and confirmed malaria cases, participants preferred the paper form for being less costly. For the collection of mosquitoes, they discussed the use of hands, buckets, and a handmade trap. Participants preferred the handmade trap over the others in case the ingredients (sugar and yeast) used as odour attractant are provided.

Chapter 4 showed that the participants decided on the organizational structure to report observations by selecting their representatives, and indicated how feedback provision is important in improving the quality of citizen science data, and their consistent use of malaria preventive measures. Overall, this co-design process helped participants to decide whether to participate or not. The decisions made by the participants demonstrated that they have context-specific knowledge and skills, and showed that implementing a CSP in a rural area and with limited technology is feasible. Finally, the chapter reported a high willingness to join the program. This indicates that a CSP for malaria control is likely to work best if the inputs and insights from citizens are included in the design process.

Implementation of a citizen science program for malaria control in Rwanda

Chapter 5 explored the motivational factors and barriers to participate in the CSP for malaria control through different stages of participation and different categories of people (young adults vs adults; men vs women). The results indicated how motivations changed over time (initial vs ongoing participation) as volunteers increased their skills and understanding related to the program. For example, curiosity and a desire to learn new things were frequently reported at the initial stage, whereas the usefulness of the program and recognition played a role in the retention of volunteers. It was clear that a lack of information about the recruitment process was the main barrier for getting involved, while the perceived low efficacy of the mosquito trap was reported as a barrier for staying involved in the program. Comparing motivational factors among age and gender groups gave a clear picture of how different groups for example young adults vs adults and men vs women join a citizen science program with different interests. An example of this difference is how young adults were more motivated to join the project because of a desire to learn new things, while adults were more motivated to participate in malaria control.

Considering these motivational factors, especially how they change over time and how they differ among involved groups, is important to retain volunteers and optimize the full potential of the program.

Chapter 6 investigated the changes in individual perceptions and malaria-related behaviours over time (between 2017 and 2019), explored differences and similarities in perceptions and malaria-related behaviour (both at the individual and collective levels) between volunteers and non-volunteers, and identified what volunteers and non-volunteers benefit from a citizen science program. The findings showed that individual perceptions in general and on malaria-related behaviour changed significantly over a two-year period. When the results about individual perceptions were compared between volunteers and non-volunteers, except for perceived self-efficacy, no other significant differences in individual perceptions between these two groups were found. This showed the diffusion of information related to the program among non-volunteers through horizontal networks, and this resulted in similarities in individual perceptions. Statistically significant differences were observed among collective factors (social interaction and participation in malaria-related activities) and IRS acceptance. As both volunteers and non-volunteers reported gaining knowledge and skills about the use of malaria control measures in general, and mosquito species in particular among volunteers, this showed that the collective actions (for example increased participation in the clearing of mosquito breeding sites at community level) may also be adopted by non-volunteers.

Discussion of the main findings

The discussion of the results focuses on cross-cutting issues that contribute to theoretical debates towards an integrated approach to control malaria, and to the general literature about citizen science practices. I start by elaborating on malaria control and how a balance between factors at both individual and collective levels is essential to address the malaria problem. Next, I focus on what this thesis contributes to the design and implementation of citizen science projects by discussing the participation and retention of volunteers and the social impact of a citizen science program. Then, I reflect on the role of ICT and the importance of social processes in the design and implementation of citizen science programs. Lastly, I discuss the social differences such as differences in preferences, understanding, and motivations that can be observed in citizen science and how they may influence either the level of participation and/or the quality of citizen science data. Finally, possibilities for the scalability of the citizen science program are also discussed.

A balance between individual and collective factors in malaria control

A large amount of literature has studied malaria control at the individual level and revealed that individual factors (individual perceptions and behaviour) have played an important role in malaria control (Babalola et al., 2018; Iyer et al., 2019). This is true because most of the studies looked at one of the primary preventive measures, using LLINs, and taking this measure is mostly considered an individual activity (Iyer et al., 2019). However, successful malaria control requires a combination of different measures, and this involves an integrated approach that goes beyond the individual level. Globally, the World Health Organization has encouraged malaria control interventions that are designed and implemented at the community level (WHO, 2019). By using an integrated model of determinants of malaria preventive and control behaviour, this thesis presented both individual and collective level factors that influence malaria prevention and control (Chapter 2). By presenting this model, this thesis concludes that both factors should be integrated in malaria control interventions.

Chapter 3 revealed that individual perceptions partially explain behavioural intentions towards the consistent use of malaria prevention and control measures. This shows that individual perceptions alone are not enough to target efforts to optimize malaria control. Other factors need to be considered as well. Although participants indicated the non-use of LLINs to be mainly associated with lack of access to LLINs, and earlier work also showed similar results (Birhanu et al., 2015; Koenker et al., 2013), the quantitative findings indicated that having enough LLINs or not does not affect the relationship between intentions and use of LLINs (Chapter 3). These results add to earlier studies which showed that the consistent use of LLINs is hindered more by behaviour failure than by inaccessibility (Birhanu et al., 2015; Hetzel et al., 2012). Similarly, a study conducted by Obala et al. (2015) revealed that ownership and accessibility of ITNs in a given household do not lower the odds of malaria unless they are consistently used, and nearby breeding sites are cleared. The latter suggests that community-level interventions that focus on environmental management need to be implemented before or together with the distribution of LLINs.

This implies strengthening the required capacities of communities to form groups or clubs that focus on mobilizing community members about malaria control activities (Ingabire et al., 2016).

The high levels of perceived severity reported in Chapter 3 suggest that people are concerned about malaria and may be willing to participate in the effort towards malaria control. In fact, highlighting citizen engagement and community mobilization as strategies to enhance the consistent use of malaria control measures supports the integrated model presented in Chapter 2. Indeed, if citizens are involved in malaria control activities (for example clearing of mosquito breeding sites), this increases awareness about malaria. Those who are engaged can mobilize others, and in turn, this can improve the use of LLINs and acceptance of IRS. This is in line with earlier work by Obala et al. (2015) who revealed that adherence to environmental management of mosquito breeding sites may optimize the efficacy of ITNs.

Environmental management of mosquito breeding sites is particularly important because it reduces mosquito density, hence prevents new cases of malaria. The reduction in mosquitoes and mosquito larvae is key especially given the reported change in mosquito biting time, which increases residual transmission (Sherrard-Smith et al., 2019). This change in biting time hinders the protective efficacy of LLINs, because people may stay out until late in the night or wake up early in the morning (Iyer et al., 2019). Furthermore, some activities including agriculture practices around homes may also increase the abundance of larval sites (Janko et al., 2018; Obala et al., 2015). Therefore, if individuals are engaged in community actions, there is a higher chance that breeding sites may be controlled.

The need for participation and retention of volunteers in citizen science

In citizen science, retention of volunteers is often identified as a critical issue (Crall et al., 2017; Jordan et al., 2017; Worthington et al., 2012). However, in our case, we did not experience problems with retention. Rather, we observed a high participation and retention rate. The level of participation and retention highly depends on how volunteers are attracted to join the project, and how their interests and motivations are considered and maintained throughout the participation cycle. The reported high retention rate in our study may be attributed to five main features: (1) the co-design used during the recruitment process, (2) the motivations to contribute to malaria control, (3) the feedback provided to the volunteers, (4) the study area

(Ruhuha) as a malaria research hub, and (5) the Rwandan context. These elements are discussed in the next paragraphs.

The recruitment strategy is an important element in the decision to participate, as well as in initial participation and retention of volunteers. Chapter 4 showed how the co-design approach used in the recruitment of volunteers resulted in a high level of participation throughout the period of the program. The results indicated that a co-design process is crucial when addressing a societal problem. Community members have their own preferences, and they are the ones to make decisions when their engagement in a certain program is needed (Chapter 4). Contrary to this study, other recruitment strategies such as online campaigns used in the Zooniverse project (Crall et al., 2017), a combination of active and passive strategies (emails, press releases, face to face presentations, and social media) used in the WamSAT project (Skelton et al., 2019) resulted in high initial participation but low retention rates, because volunteers tend to participate in one round of collection after sensitization, after which they do not return. Some earlier work indicated that high recruitment rates should be considered in case of high dropout to replace those leaving the project (Crall et al., 2017). However, recruitment requires resources, and replacing those who leave a project should not be a target in CSPs to achieve projects' goals, rather the priority should be to retain those who are recruited.

Apart from a recruitment strategy, the motivation to participate also plays a key role in the retention of volunteers and achievement of a CSP's objectives (both collection of citizen science data, and the educational goal). We found that consideration of the motivational factors and barriers at each stage of participation is necessary to retain volunteers throughout the period of the project (Chapter 5). Unlike other studies that explored motivations at one single point in time (Domroese & Johnson, 2017; Raddick et al., 2013), Chapter 5 explored the changes in motivational factors over time (initial vs ongoing phases of participation). The results showed that curiosity, desire to learn new things, helping researchers, as well as contributing to malaria control and general health motivated people to join the project and to report the citizen science data. These findings largely agree with earlier work conducted in ICT-based CSPs (Carballo-Cárdenas & Tobi, 2016; Cox et al., 2018), and contradict some others which positioned egoism as a leading motivation for initial participation (Rotman et al., 2012).

Generally, learning and contributing to a better health and a better environment were factors that played a leading role in initial and ongoing phases of participation. These factors have been also reported by Church et al. (2019). As a result of the perceived severity of malaria, people believed that participation in citizen science could decrease their chance of getting malaria by increasing the knowledge about control measures, and in turn, improving the control of mosquito breeding sites in their home environment. Other program-related factors, including ease of use of materials to report observations, the usefulness of the program, and recognition, also played a role in the retention of volunteers (Chapter 5). This supports earlier studies on the adoption of innovation which revealed that innovation is likely to be adopted and implemented when it is easy to use and when people see the benefits associated with participation as higher than those who are not participating (Panzano & Roth, 2006; Wisdom et al., 2014). In our program, some volunteers believed that participation brings benefits including an increase in using malaria control measures and being able to mobilize other community members in their neighbourhood about malaria control.

The findings that feedback provision is one of the motivational factors to retain participants in CSPs support earlier results by others (Crall et al., 2017, Wehn & Almomani, 2019). Regular feedback and acknowledgment of volunteers' contribution are necessary for retention, and different forms of recognition have been reported in the current study including learning opportunities and feedback provision (Chapters 4 and 5). In this regard, different communication channels have been used in this study to give feedback (for example SMS text and dissemination workshops) or interact with volunteers (for example meetings). This is contrary to most online (ICT-based) CSPs which use blogs, group chats, and discussion forums to communicate with volunteers. Although these ICT based communication channels are better to reach many people within a short period of time, our citizen science program was not suitable for these channels because of the limited usage of ICT based tools (for example mobile phone) (Chapter 4). Therefore, the use of face to face workshops was preferred as a channel to disseminate the citizen science data in addition to monthly feedback via SMS with no cost implications for the receiver (volunteers' representatives) of this SMS.

Channels of communication and messages to be shared are important and need to be structured in different ways based on motivational factors among different groups of volunteers (Chapter 5). CSPs need to develop a clear plan of communication strategies prior to the launch of a project, and these should be modified or updated based on motivational factors at different stages of participation. This thesis indicates that the effort should be put in retaining volunteers rather than regular recruitments, because highly motivated volunteers also interact more with non-volunteers to communicate projects' goals, and may also recruit other participants. Once the project's goals are diffused in the community, there is a high chance of organizing and uptake of related community action.

In citizen science, some settings may not have a history of research and/or participants who have some knowledge about scientific research. Chapters 4, 5, and 6 present the CSP on malaria control, and how both volunteers and non-volunteers were willing to continue participating or join the program. This is in accordance with the findings of Lee et al. (2018) who revealed that within a community, when people observe that other people are participating in some activities, they consider it as a social norm, and this, in turn, motivate them to join as well. Implementing this project in Ruhuha, which can be considered a malaria research hub with some previous research projects, such as the Malaria Elimination Project in Ruhuha (MEPR) (Ingabire et al., 2016), may have influenced the level of participation in the current study. This is to say that Ruhuha may not be the most representative environment to understand the complexity of a citizen science program. However, given that the majority of volunteers were not participants of MEPR, the current findings may be broadly compared with other CSPs conducted in settings with no access to previous groups of volunteers. Further, this shows that in citizen science, a recruitment strategy (for example a co-design process in this case), and addressing motivational factors may be more effective than a study setting.

Lastly, the socio-organizational structure of Rwanda and the socio-cultural dynamics of the Rwandan population may have played a role in participation and retention. Strong social commitment (for example how community members participate every last Saturday of the month in community work called *umuganda*) and cultural values foster active participation in community activities. This supports earlier work in innovation adoption which revealed that socio-cultural factors can influence the adoption and implementation of innovation (Wisdom et al., 2014). In Rwanda, the health system is structured in such a way that every village has Community Health Workers (CHWs), who are volunteers and responsible for diagnosis and treatment of several health issues at the community level (Condo et al., 2014; Ngabo et al., 2012). The CHWs were put in place throughout the country in 2009 to reduce the gap in human resources for health, and since they are closely involved in community activities, they are generally respected (Condo et al., 2014). Based on this respect and appreciation of their work by their peers in the community, this can also stimulate and motivate other community members to join other groups of volunteers.

Impact of the citizen science program

Citizen science projects result in three distinct outcomes: (1) generation of citizen science data (scientific impact), (2) education of citizens about the subject under study to enhance learning, behaviour change, and actions among volunteers and their broader network (societal impact), and (3) transfer of the results into policy (political impact) (Van Brussel & Huyse, 2019). Generally, all of these impacts have to be considered in the design phase because they influence each other. Although the educational aspect of citizen science may play a vital role in the quality and quantity of citizen science data, and in turn, these results can be considered by policymakers (Van Brussel & Huyse, 2019), often, researchers ignore this aspect. Van Brussel and Huyse (2019) consider scientific and political impacts to be the external value of the citizen science as they deal with data generation and use of data for decision making, while the societal impact is considered as the internal value as it improves literacy and perceptions, builds social capital, and enhances behaviour change in the community. The internal value will likely have much influence on the external value, and if the former is achieved, then, there is also a high chance to achieve the latter as well.

Chapter 6 indicated that the benefits of the CSP expand beyond active participants (volunteers) and impact the community at large through the diffusion of information to non-volunteers. This diffusion happens when volunteers interact with other people (here called non-volunteers) in the community, and share their experience related to participation in citizen science, and mobilize them about malaria control measures. As a result, non-volunteers also improved knowledge and skills, which in turn, will foster the adoption of malaria control measures. These results support earlier citizen science studies which also revealed a diffusion of knowledge in volunteers' social networks (Bremer et al., 2019; Church et al., 2019). When non-volunteers are aware of the program, there is a high chance of people willing to join the project. Importantly, Chapter 6 showed that no differences in perceptions between volunteers and non-volunteers, whereas changes in perceptions over time (between 2017 and 2019) were observed. This may explain how the diffusion of project-related information influenced non-volunteers' perceptions.

Through sharing of information, people's social networks also expand. Depending on the diversity of volunteers, social networks can vary and include a variety of people like neighbours, colleagues, friends, workmates, customers, students, and others (Bremer et al., 2019). This social network indicates how information sharing in citizen science promotes behaviour change and enhances collective actions (Church et al., 2019; Overdevest et al., 2004).

Through the strengthening of personal skills and social networks, a citizen science approach can play a role in promoting health and human wellbeing (SDG 3) (Den Broeder et al., 2017). Given the benefits of the CSP on malaria control, one could argue that the initiative may also have a positive impact on other diseases (for example other infectious diseases), hence enhancing health and wellbeing in a broader sense (SDG 3). These results are consistent with other findings from CSPs which indicated the impact of citizen science on the achievement of SDGs (Quinlivan et al., 2020). A recent world malaria report indicated that malaria reduction contributes to SDG #3, which is central to the achievement of other SDGs (WHO, 2019). Consequently, maximizing the societal impact of a citizen science program on malaria may result in promoting the general health of the population.

Apart from the societal impact of the program, the current program also revealed a scientific impact (Murindahabi et al., in preparation). Volunteers collected and reported citizen science data (mosquitoes species, mosquito nuisance, and confirmed malaria cases) on a monthly basis for one year. The results revealed a correlation between mosquito nuisance and mosquito density. This was also reported in Chapter 5 where volunteers indicated that by submitting the citizen science data in their villages, these data can offer information about malaria risks (malaria hotspots). The current citizen science program can serve as means to assess the distribution (when and where) of malaria transmission, hence it can complement the current active surveillance that is being implemented by the National Malaria Control Program (Hakizimana et al., 2018). Consequently, this complementarity may strengthen health systems.

The role of Information and Communication Technologies (ICT) in citizen science projects

In areas with internet connections, ICT has played a role in the diffusion of CSPs by recruiting a high number of volunteers. Some assumptions have been made by earlier work that ICT is a solution to issues related to data quality and participants' engagement in environmental management (Cieslik et al., 2018). At the start of the current project, it was proposed to design an ICT based CSP, and part of the UTAUT model was used in designing the integrated conceptual model (Chapter 2). However, limited technology access in the study area in Rwanda hindered the development and use of an ICT-based CSP, because mobile phone ownership and use among participants was relatively low (Chapter 4). This also partially explains the underrepresentation of citizen science programs in many parts of developing countries (Pocock et al., 2018). However, Chapter 4 showed how this technology barrier was overcome by designing and implementing a non-ICT-based CSP. SMSs that were used as feedback involved no cost to the receivers of the SMS.

We decided to design a non ICT-based CSP to allow everybody to join and participate in the project. At the design phase, participants preferred a paper-based form over the use of mobile phones for reporting data, simply because the use of a mobile phone is associated with some costs (Chapter 4). These findings support earlier work which revealed that, in practice, the use of ICT tools in recruitment does not necessarily make the process easy. Besides, some studies have used direct contact for recruitment of participants as well, and direct contact was identified as most effective over other strategies even in ICT-based CSPs (Wiggins, 2013). This is to say that, when ICT tools are used to recruit the participants, this may enhance the visibility of the project to a wider audience, but does not necessarily lead to participation and retention.

While ICT has contributed a lot in the recent increase of CSPs through data generation, the reality is, however, that ICT does not optimize the full potential of a CSP, rather it also provides its own challenges (Wiggins, 2013). Besides the relatively limited availability of ICT in developing countries (Pocock et al., 2018), sometimes it is not affordable for everyone and, consequently, becomes a barrier for citizen scientists (Beza et al., 2018; Quinlivan et al., 2020).

The collection and reporting of citizen science data should be simple and easy to navigate, otherwise, if it is frustrating, some participants may not complete the given tasks (Skelton et al., 2019). This can, in turn, affect the retention of volunteers unless they have strong motivations that drive their contribution to the project. Difficulties in accessibility and usability of platforms in online CSPs have been reported to hinder the retention of volunteers. Earlier work conducted on ICT-based CSPs reported some barriers including time, effort, costs, lack of internet and mobile phone, as well as unfavourable technology to collect and submit citizen science data (Carballo-Cárdenas & Tobi, 2016; Martin et al., 2016; Skelton et al., 2019).

In Chapter 5, volunteers reported ease of use of tools to collect and report citizen science data to play a role in their retention. Further, our findings show how a lack of internet coverage or unavailable technology, in general, should not be a barrier when engaging citizens in citizen science projects (Chapters 4 and 5). Therefore, when selecting and designing ICT to use in citizen science, a first and essential step is to assess the project's goals and participants' characteristics as they are indispensable for participation and retention (Wiggins, 2013). Besides, when conducting an ICT-based CSP, challenges related to ICT should also be identified and possible strategies should be addressed at the early stage (Wiggins, 2013). Avoiding complex and sophisticated ICT systems would be a better strategy when an ICT-based CSP is desired (Wiggins, 2013). The present study showed an alternative CSP which relied less on ICT, but which optimized the level of participation and retention through putting much effort in the social organizational component of the program during the design and maintenance phases (Chapters 4, 5 and 6).

Unlike other ICT-based CSPs that indicated social networking capacities of ICT to play a vital role, the present study did not identify it as an important motivational factor for people to participate in the program (Chapter 5). This could indicate that people were more interested to participate because malaria is a serious issue in their households as well as in the community in general. Indeed, apart from monthly meetings, and quarterly workshops, volunteers did not have other platforms to meet and chat, and this could have been the reason why this was not a significant factor to them. Although it was not their primary motive, volunteers reported expanding their social networks and reported sharing malaria-related information with non-volunteers (Chapter 6). This indicates that non-ICT-based citizen science can also foster social networks.

The importance of social processes in citizen science

In citizen science, social processes play a role in the design and maintenance of projects. In the design phase, both technical and social components were considered and citizens were involved in the design process as the community members have the best understanding of their context (Chapter 4).

In this regard, Houghton et al. (2019) indicated that creating a technical tool is not enough as it is expected to interact with or used by people. In addition, conscious decisions about how these people will shape the developed tools should be taken. Earlier work by Rogers (1983) on the diffusion of innovation, reported that sometimes the social component of the technology is most of the time forgotten or not visible, and people often concentrate on the technical component. In the health care setting, WHO/EXPANDNET (2009) reported that a technical solution alone cannot be considered as a health intervention unless it is combined with the socio-organizational structure that maintains implementation capacities.

In the current study, the engagement of community members in the design may have also influenced the level of participation and retention (Chapters 4, 5 and 6). It was recognized that it was important for the community members to select the structure to follow when collecting and submitting the citizen science data. Community members had to choose the *isibo* representatives who were tasked to distribute materials for data collection, as well as assemble and submit citizen science data to researchers (Chapter 4). This selection of social structure made the social component unique and showed how it played a key role in the participation and retention of volunteers.

The interaction between community members and researchers in the design and implementation helped to build trust, and volunteers could express themselves and share reflections about the implementation of the program. In this case, misunderstanding between volunteers and researchers could be addressed because sometimes volunteers may deviate from the usual protocol (for example the way they use a tool to collect mosquitoes).

A close follow-up was made to enable a smooth implementation of the project and enhance the retention of volunteers (Chapters 5 and 6). By conducting a study on motivation and barriers to participate in the program, the project was able to find out how to retain volunteers, and some deviations from the objective of the program were discovered. For example, while people had a trap to use for collecting mosquitoes, some felt the pressure to collect more mosquitoes. They believed that a trap only collects few mosquitoes. This made them use other methods, for example, collecting mosquitoes by hand instead of using a trap as indicated (Chapter 5). Without a follow-up study on motivational factors and barriers, this would not have been noticed.

The motivations reported by the volunteers were continuously incorporated whenever possible to retain the volunteers and optimize the impact of the program (Chapter 5). These findings corroborate with previous studies which showed that responding to volunteers demands may enhance retention (Sullivan et al., 2009; Wiggins, 2013). This indicated that social and technical components should go hand in hand in the co-design process to optimize the adoption and retention rates (Allotey et al., 2008; Oria et al., 2014).

Dealing with social differences in citizen science

In citizen science, social differences can be observed in the design and implementation of a CSP, and they can influence the level of participation. During the design of the CSP, Chapter 4 indicated how community preferences (for example frequency of reporting observations and different opinions about data collection tools) differed among groups of people (for example men vs women) and different villages. These differences triggered discussions, and decisions could be taken with consensus.

During implementation, differences in motivations may also influence the level of engagement. Chapter 5 indicated how motivational factors to participate in the CSP for malaria control varied between men and women, and between young adults and adults. These differences reported in the current study corroborate with other studies in citizen science (Alender, 2016; Land-Zandstra et al., 2016; Raddick et al., 2013). Exploring these differences during the implementation of a CSP is an important step because the strategies that scientists use to recruit and retain volunteers should reflect on these motivations (Lee et al., 2018). For example in our study, providing feedback either via SMS or through dissemination workshops made volunteers stay engaged because 1) they knew that their reported data are being used for scientific purposes, 2) they believed that by attending a workshop, they learn something new (for example mosquito species), and 3) they also believed that they will get advice related to malaria prevention and control. Consequently, by addressing these motivations people think that they are part of the project, and stayed in the program.

Apart from motivations, differences in understanding can also happen during the implementation of a CSP which may affect the quality of the citizen science data. Chapter 5 showed how differences in understanding among volunteers may influence the use of data collection tools. While some volunteers mentioned that using other methods would be a deviation from the research, others thought of competing with other villages (e.g. when it comes to comparing the number of mosquitoes caught per villages). This raised pressure to catch more mosquitoes and triggered the use of other methods (for example using eyes and hands), or setting the trap two days to be able to collect more mosquitoes. One may think that this is a lack of clear information about the project's objectives. However, it may not be true. Those who used other methods were hardly discussing this with peers, because they think that they are not allowed to use these other methods. This shows that when implementing citizen science projects, there may be tension between societal objectives and scientific objectives. Consequently, a close follow-up during the implementation of a citizen science project is necessary to be able to detect this kind of tension and to determine strategies to manage this tension. For example, one strategy would be to have regular field visits and one on one discussions to be able to discover the tension, and together as a team discuss possible solutions.

Can a citizen science program for malaria control be scaled up and sustained?

There is a growing body of literature about scaling up public health interventions or innovations to improve health outcomes (Bulthuis et al., 2019; WHO/EXPANDNET, 2011; Yamey, 2012). Scaling up is a process that involves multiple stakeholders, groups, and organizations. WHO/EXPANDNET (2009) defined scaling up as a system which consists of five interacting elements: an intervention, an environment (social, economic, political, and cultural contexts that may affect the process of scaling up), a resource team (individuals or a group of people that provides guidelines or technical support to facilitate wider use of an intervention), a user organization (seek or expected to use, adopt, and implement the innovation; for example, a non-governmental organization, or a public sector), and a scaling-up strategy (plans and actions required to include an intervention into policy).

Developing a scaling-up strategy should be the first step, the resource team and user organization provide support and guidance in the design of this scaling-up strategy (Bulthuis et al., 2019; WHO/EXPANDNET, 2009). The design and implementation of this scaling-up strategy is influenced by the environment. Therefore, critical decisions and choices about the type and process of scaling up, ways of assessing and mobilizing resources, as well as the process of monitoring, evaluation, and dissemination of information should be made (WHO/EXPANDNET, 2009).

In the current program, the scalability and sustainability of the CSP for malaria control rely first on the societal, scientific, and political impacts of the program, and the availability of resources to scale up. Our findings revealed societal impact (Chapter 6) which partially provides evidence and helps to foster scalability locally. However, the scientific impact requires a full realization of the potential of the program to generate the citizen science data (Murindahabi, et al. in preparation). Then, the policy implications of the program rely on both societal and scientific impacts. Volunteers reported the citizen science data (mosquito density, mosquito nuisance, and confirmed malaria cases) for one year and these data indicated temporal and spatial variations of mosquito density (Murindahabi, et al. in preparation). Besides, it was clear that mosquito nuisance can be used as an indicator of mosquito density. Therefore, these results can serve as evidence to know when and where to implement a malaria control intervention. For example, the results can show which month and which villages to target for IRS.

In the design of our program, the concept of scalability and sustainability was considered by designing a handmade trap that can be locally available and easy to use (Chapter 4). Also, a close follow-up to maintain the program was done with consideration of volunteers' motivations and addressing the challenges they encountered. For example, when volunteers reported low perceived efficacy of the trap as an issue, we agreed as a team (i.e. volunteers and researchers) that they can use other methods to collect mosquitoes with the condition that they have to specify the method used on the paper form which was used to report mosquitoes. Besides, the majority of volunteers indicated a willingness to continue participating even when the ingredients are not given (Chapter 5). This supports a report published by WHO/EXPANDNET (2009) which indicated that taking into account the implications of scaling up intervention during the design and implementation phases, yields better results than thinking about scaling up after the completion of a pilot study.

Another factor that may foster the scaling up of the current program is the willingness of the participants. Volunteers indicated a willingness to continue participating even after the end of the current research, and besides that non-volunteers showed an interest to join the project (Chapters 5 and 6). Generally, the volunteers expressed that as long as there is a location (for example at the health center) where to submit citizen science data, collecting and reporting would not be an issue.

Given the observed value of the feedback provided in the retention of the volunteers, probably if not provided, this may, in turn, affect the collection and reporting of citizen science data once the program is scaled up. Earlier work has reported the barriers to scale up a health intervention and these include limited capacity of implementers, lack of community engagement, and contextual factors (social, political, and cultural) (Yamey, 2012). Thus, the simpler the innovation, the more easily it can be adopted and scaled up (WHO/EXPANDNET, 2011).

Finally, effective and sustainable scaling up involves many factors that support the expansion of an intervention (WHO/EXPANDNET, 2009). Attention should be paid to all elements of the system because none of them can succeed alone and these factors are not mutually exclusive, therefore, they influence each other (Bulthuis et al., 2019). However, the societal impact of a proposed intervention may be the first step that determines further pursuit of the intervention (WHO/EXPANDNET, 2011). In this regard, the benefits of the citizen science program presented in this thesis may serve as an initial stage for further discussion, assessment, and planning about the scaling up of the program.

Recommendations for policy, practices, and future research

The findings of this thesis offer a basis for rethinking the process of malaria control. Designing and implementing the citizen science program for malaria control provided evidence of how to engage citizens in malaria control. The thesis suggests that this current citizen science program may complement the existing active mosquito surveillance.

Therefore, several recommendations for policy, practices, and future research derived from the above cross-cutting issues merit discussion.

Recommendations for policy

Given the complexity of the malaria problem, integration of factors at both individual and collective levels is required to achieve malaria elimination. This thesis has shown how community members need to be engaged in malaria control interventions, and how they are motivated to contribute to malaria control. This calls malaria control programs to consider involving community members in malaria control interventions and integrate their preferences in decision making. For example, current results provide an example of how community members can be engaged in malaria control through a citizen science program.

Given the benefits of the CSP for malaria control, and the willingness of the volunteers and non-volunteers to continue participating and join the program, the program can be sustained over time in collaboration between the National Malaria Control Program, researchers, and community members. This collaboration needs to look at how citizens can be facilitated to submit the data, which resources are required, and what could be the source of funding.

Looking at how information is spreading, and how non-volunteers are benefiting from having this initiative in the study setting, it is possible to scale up the initiative in other areas, but it should be noticed that Ruhuha has been a research hub in the past years. Therefore, recruitment and retention rates may differ when this program is implemented in other settings. The scale up needs to take into account the technical and social features of the program as a whole and not just one component, because scientific and societal impacts of the citizen science program interact. Houghton et al. (2019) also revealed that a system (both technical and social elements) should be adopted as a whole because it is not only the app or a platform that works alone, but also organizational and social elements that maintain and foster its function. Some social elements to consider while scaling-up include the recruitment strategy (co-design), communication channel, and volunteers' satisfaction by addressing their motivations. The process and requirements to scale up and sustain this program need further exploration.

Recommendations for citizen science practice

Investing in a citizen science program does not only enhance knowledge and skills but also individual and collective actions. Equally important, the volunteers are not the only ones to benefit, but also non-volunteers and the wider community. Monitoring and evaluating CSPs require a common framework. This framework may target outcomes at both individual and community levels involving those who are directly engaged in the collection of citizen science data and those who are not directly involved. At the individual level, outcomes to be measured include an increase in awareness and understanding of nature, environment, and the scientific process. At the community level, the outcomes include community leadership, organizational capacity to address collective problems and improve community well-being, and social capital. In addition, what to evaluate should be thought of right at the beginning of the project, and the educational goal of the program should be clear before the implementation starts so that those who are motivated by learning opportunities may join the program. To reinforce this, motivational factors should be regularly identified at different stages of participation and should be addressed where possible.

Differences in motivations, understanding, and level of engagement have been observed among people who participate in the program. Therefore, more investment in the design and regular follow-up are needed to successfully achieve the program's goals. Scientists could consider addressing these differences by encouraging more discussions with volunteers at different stages of participation. This may, in turn, foster the level of retention in citizen science.

Recommendations for further research

In this thesis, we indicated that the combination of individual and collective factors in malaria control is necessary. Therefore, further studies should explore and specify other factors and to what extent they influence the consistent use of malaria control measures. Other factors to be explored include human activities such as agricultural activities, the influence of mobilization from community health workers or local leaders, and community organization and support. Exploring these factors may contribute to the current theoretical knowledge by either extending the integrated model of determinants of malaria prevention and control behaviour and/or using the model in other behaviour-related research.

In citizen science, provision of feedback is a means of recognition that motivates volunteers to stay engaged in the project. However, it is not clear to what extent different forms of feedback (e.g., SMS, presentations in workshops, flyers), may encourage volunteers and motivate them to share malaria-related information with non-volunteers. Further studies may explore how these different forms of feedback have played a role in retention, and how they can be used in the recruitment of new volunteers. By evaluating these forms of feedback provision, future citizen science projects can select which form to use at a given stage of a citizen science project.

Different motivational factors were explored and it was clear that these motivations vary among different groups (age and gender). These motivations may also affect the impact of citizen science. For example, those who are motivated by learning opportunities may report an increase in knowledge and skills more than others who reported other motivations. In addition, high-quality data may be reported by those who indicated an increase in knowledge and skills. Thus, investigating relationships between motivations and benefits would be of interest to improve both the societal and scientific impacts of citizen science.

Lastly, further studies that involve policy-makers are needed to determine their perceptions and acceptance of the program, and how it can complement the active surveillance of the national malaria control program. This should include the identification of resources (human, financial, and material) required. In turn, such a study can further confirm the scalability of this citizen science program.

Conclusion

This thesis showed that addressing the malaria problem requires an integrated approach that includes both individual and collective factors, and places citizens at the center of every intervention. This implies actively engaging citizens in malaria control interventions. A citizen science program was co-designed with community members and involved both technical and social components. While the technical component (i.e. tools used to collect and report citizen science data) was required to be able to collect data, a social component (i.e. organizational structure: recruitment of volunteers, collection and reporting of citizen science data, and ways of feedback provision) was necessary to agree on when to collect, and how to submit the data. Indeed, a social component was required in the design and maintenance, to generate the full potential of this program. Through involving citizens in the design process, they were able to discuss and decide on the structure to follow while collecting and reporting citizen science data. Furthermore, the social component played a key role in the observed high level of participation and retention by exploring the motivational factors over time and addressing some barriers reported by the volunteers.

The implementation of a citizen science program requires a close follow-up to explore the motivations and barriers to participation. Motivations may differ at each stage of participation, and it is only when volunteers are satisfied and their motivations are fulfilled when a high retention rate can be observed. The program generated societal impacts at both individual and collective levels, and a notable diffusion of the project-related information to non-volunteers was observed. Thus, it contributed to the adoption of malaria control measures. Therefore, to optimize the full potential of a citizen science program, integration of both technical and social components is essential. Finally, I conclude that if set up with close interaction with different stakeholders, citizen science has a potential contribution to malaria control in Rwanda.

Summary

Malaria continues to be a major public health problem around the world, and most prominently on the African continent, with Sub-Saharan Africa carrying the largest burden of malaria. Currently, the World Health Organization calls for malaria control interventions that leave no one behind with the aim to realize a malaria-free world. Consequently, engaging community members in malaria control interventions is crucial for malaria elimination in many countries including Rwanda. However, very little is known about how people can be engaged in malaria control, and how this engagement could, in turn, affect the consistent use of malaria control measures. This thesis used an integrated model of determinants of malaria preventive behaviour with the objective to explore the factors that influence the consistent use of malaria control measures, and investigated how a citizen science program for malaria control could contribute to this use. Specifically, the study designed and implemented a citizen science program and investigated the motivational factors, barriers, and effects of this program on the use of malaria control measures.

A mixed-methods approach was used in four different phases (baseline, design, follow-up, and evaluation) with a citizen science program. This program involved collecting mosquitoes using a handmade trap, reporting mosquito nuisance and confirmed malaria cases using a paper-based form. The first phase involved the development and testing of an integrated model of determinants of malaria preventive behaviour to enhance our understanding of the interrelationships between factors that influence individuals to participate in a citizen science platform and use malaria preventive measures (Chapter 2). In Chapter 3, this integrated model was tested. The objective of Chapter 3 was to assess the relationships between individual perceptions and the intentions to use malaria preventive measures. The study was carried out in the sectors of Ruhuha and Busoro, Rwanda into two phases. Phase one involved a questionnaire survey whereas phase two employed a qualitative approach. The results indicated that the individual perceptions partially explain behavioural intentions to consistently use malaria control measures, and leave room for other factors that play a significant role in the use of malaria preventive and control measures. Other factors include organization that involves careful assessment of the collective management of mosquito breeding sites at the community level. The chapter highlighted three strategies that can be used to promote the consistent use of malaria preventive and control measures, these include

access to LLINs and regular spraying activities, community mobilization, and citizen engagement in malaria control activities.

The second phase elaborated on the co-design process that was employed to engage citizens in malaria control through the citizen science program (Chapter 4). The co-design was conducted through participatory design workshops and involved recruitment of participants in five villages of Ruhuha sector, Rwanda. The results showed that following the involvement of citizens in a co-design process, we arrived at different decisions that we did not always foresee. Community members have their preferences and choices related to the tools to collect citizen science data (mosquito species, mosquito nuisance, and confirmed malaria cases), as well as an organizational structure (for example frequency of reporting, selecting representatives to gather and submit the reports). These choices demonstrate that citizens have context-specific knowledge and skills. Consequently, involving them in the design of a program and considering their preferences facilitated the implementation of the program and retention of volunteers. Finally, a high level of recruitment, participation, and retention showed that a citizen science program is feasible in areas with limited ICT tools.

Volunteers may participate in a citizen science program because of different reasons, and through participation they may encounter different challenges that need to be addressed to retain them. A third phase, therefore, included monitoring of the citizen science program to retain volunteers (Chapter 5). Chapter 5 explored the motivational factors and barriers at different points in the lifetime of a citizen science program on malaria control. A qualitative approach was used and involved 44 interviews of which 30 were volunteers of the citizen science program, and 14 were non-volunteers who attended participatory design workshops used to recruit the volunteers, but decided not to join the program. The findings revealed that there is a change in motivation over time. Desire to learn about and contribute to malaria control motivated people to join the program and start participating. Although these motivations were also present for the subsequent phase of participation, however, other factors including recognition and acknowledgment of volunteers' contributions motivated volunteers to stay involved in the project. Comparing motivational factors among age and gender groups, the results revealed that young volunteers and women were more motivated to join the program because of curiosity and desire to learn new things. However, in general, adult volunteers and men were motivated by contribution to malaria control. This indicates that in a citizen science program, target groups may require different recruitment and retention approaches. Thus, future citizen science projects may consider using different messages at different stages of participation to maximize the recruitment, participation, and retention of volunteers. Barriers encountered include the pressure to report observations (mainly collection of mosquitoes) and low perceived efficacy of the handmade trap. The motivational factors and barriers reported in this study should be considered in citizen science projects to know how to approach community members at what stage of participation in citizen science.

Although the retention of volunteers is important, an assessment should also be conducted to monitor and explore the impact of the program on community members. Phase four assessed the effect of the citizen science program for malaria control (Chapter 6). It involved an evaluation of the benefits of the program to those who are directly involved in the collection and reporting of citizen science data and other community members who are not directly involved. A mixed-method approach was used and included a questionnaire survey, dissemination workshops, and village meetings. The results showed that individual perceptions in general and malaria-related behaviour improved significantly over time (between 2017 and 2019). Comparing the individual perceptions and malaria-related behaviour between volunteers and non-volunteers, a significant difference was observed only for the perceived self-efficacy. However, it was apparent that volunteers interact with others and participate in malaria-related activities more than non-volunteers. Both volunteers and non-volunteers gained knowledge and skills about the use of malaria control measures in general and mosquito species in particular among volunteers. The reported knowledge among non-volunteers shows the diffusion of project-related information. Consequently, this shows that a citizen science program has the potential to not only engage those who are directly involved in the collection and submission of citizen science data but also improves community health by addressing public health problems.

Overall, the results of this thesis clearly showed that the achievement of malaria control needs consideration of both individual and collective factors. To facilitate this, citizens need to be engaged in malaria control interventions. A high participation and retention rate observed throughout the project (one year), clearly demonstrated that the implementation of a citizen

science program in areas with limited technology is feasible. However, the citizens' preferences should be considered during the design process, and their motivations and barriers should be identified and addressed during the program to enhance the retention rate. The benefits of the program are not only limited to those who are directly involved in the program, but there is diffusion of information and benefits of the program to other community members. The citizen science data submitted by the volunteers provide localized information about mosquito density and its relationship with mosquito nuisance. This, in turn, may foster localized and targeted malaria control interventions and this program is likely to improve the consistent use of malaria preventive and control measures. Therefore, I conclude that this citizen science program has a potential contribution to malaria control in Rwanda. Thus, it can complement the existing active surveillance and may be considered by the National Malaria Control Program.

References

Abdullahi, A. A., Zyl-Schalekamp, V. C., & Seneka, A. (2013). Perceived Treat of Malaria and the Use of Insecticide Treated Bed Nets in Nigeria. *African Sociological review, 171*, 25-44.

Aceves-Bueno, E., Adeleye, A. S., Bradley, D., Tyler Brandt, W., Callery, P., Feraud, M., Garner, K.L., Huang, Y., McCullough, I., Pearlman, I., Sutherland, S. A., Wilkinson, W., Yang, Y., Zink, T., Anderson, S. E., & Tague, C. (2015). Citizen Science as an Approach for Overcoming Insufficient Monitoring and Inadequate Stakeholder Buy-in in Adaptive Management: Criteria and Evidence. *Ecosystems, 18*(3), 493-506.

Agudo-Peregrina, Á. F., Hernández-García, Á., & Pascual-Miguel, F. J. (2014). Behavioral intention, use behavior and the acceptance of electronic learning systems: Differences between higher education and lifelong learning. *Computers in Human Behavior, 34*, 301-314.

Ahadzadeh, A. S., Pahlevan Sharif, S., Ong, F. S., & Khong, K. W. (2015). Integrating health belief model and technology acceptance model: an investigation of health-related internet use. *Journal of Medical Internet Resesearch, 17*(2): e45.

Ahmed, S. M., Hossain, M. S., & Kabir, M. (2014). Conventional or interpersonal communication: which works best in disseminating malaria information in an endemic rural Bangladeshi community? *PLoS One, 9*(6): e90711.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*, 179–211.

Alender, B. (2016). Understanding volunteer motivations to participate in citizen science projects: a deeper look at water quality monitoring. *Journal of Science Communication, 15*, 3.

Allotey, P., Reidpath, D. D., Ghalib, H., Pagnoni, F., & Skelly, W. C. (2008). Efficacious, effective, and embedded interventions: implementation research in infectious disease control. *BMC Public Health, 8*, 343.

Ankomah, A., Adebayo, S. B., Arogundade, E. D., Anyanti, J., Nwokolo, E., Ladipo, O., & Meremikwu, M. M. (2012). Determinants of insecticide-treated net ownership and utilization among pregnant women in Nigeria. *BMC Public Health, 12*, 105.

Aristeidou, M., Scanlon, E., & Sharples, M. (2017). Profiles of engagement in online communities of citizen science participation. *Computers in Human Behavior, 74*, 246-256.

Asiimwe-Kateera, B., Condo, J., Ndagijimana, A., Kumar, S., Mukeshimana, M., Gaju, E., Muhire, A., Muhimpundu, M. A., Kim, M. J., & Kurth, A. (2015). Analysis: Mobile Health Approaches to Non-Communicable Diseases in Rwanda. *Rwanda Journal Series F: Medicine and Health Sciences, 2*(1), 89-92.

Asingizwe, D., Murindahabi, M. M., Koenraadt, C. J. M., Poortvliet, P. M., van Vliet, A. J. H., Ingabire, C. M., Hakizimana, E., Mutesa, L., Takken, W., & Leeuwis, C. (2019). Co-Designing a Citizen Science Program for Malaria Control in Rwanda. *Sustainability, 11*, 24.

Asingizwe, D., Poortvliet, P. M., Koenraadt, C. J. M., van Vliet, A. J. H., Ingabire, C. M., Mutesa, L., & Leeuwis, C. (2019). Role of individual perceptions in the consistent use of malaria preventive measures: mixed methods evidence from rural Rwanda. *Malaria Journal, 18*, 270.

Asingizwe, D., Poortvliet, P. M., Koenraadt, C. J. M., Van Vliet, A. J. H., Murindahabi, M. M., Ingabire, C., Mutesa, L., & Feindt, P. H. (2018). Applying citizen science for malaria prevention in Rwanda: An integrated conceptual framework. *NJAS - Wageningen Journal of Life Sciences, 86-87*, 111-122.

Atieli, H. E., Zhou, G., Afrane, Y., Lee, M. C., Mwanzo, I., Githeko, A. K., & Yan, G. (2011). Insecticide-treated net (ITN) ownership, usage, and malaria transmission in the highlands of western Kenya. *Parasites & Vectors, 4*, 113.

Atkinson, J. A., Bobogare, A., Fitzgerald, L., Boaz, L., Appleyard, B., Toaliu, H., & Vallely, A. (2009). A qualitative study on the acceptability and preference of three types of long-lasting insecticide-treated bed nets in Solomon Islands: implications for malaria elimination. *Malaria Journal, 8*, 119.

Atkinson, J. A., Fitzgerald, L., Toaliu, H., Taleo, G., Tynan, A., Whittaker, M., Riley, I., & Vallely, A. (2010). Community participation for malaria elimination in Tafea Province, Vanuatu: Part I. Maintaining motivation for prevention practices in the context of disappearing disease. *Malaria Journal, 9*, 93.

Babalola, S., Adedokun, S. T., McCartney-Melstad, A., Okoh, M., Asa, S., Tweedie, I., & Tompsett, A. (2018). Factors associated with caregivers' consistency of use of bed nets in Nigeria: a multilevel multinomial analysis of survey data. *Malaria Journal, 17*, 280.

Bamidele, J. O., Ntaji, M. I., Oladele, E. A., & Bamimore, O. K. (2012). Community Participation in Malaria Control in Olorunda Local Government Area, Osun State, Southwestern Nigeria. *African Journal of Infectious Diseases, 6*, 2, 24-28.

Bartumeus, F., Costa, G. B., Eritja, R., Kelly, A. H., Finda, M., Lezaun, J., Okumu, F., Quinlan, M.M., Thizy, D.C., Toé, L.P., & Vaughan, M. (2019). Sustainable innovation in vector control requires strong partnerships with communities. *PLoS Neglected Tropical Diseases, 13*(4): e0007204.

Batson, C. D., Ahmad, N., & Tsang, J. A. (2002). Four motives for community involvement. *Journal of Social Issues, 58*, 3, 429–445.

Baum, F., MacDougall, C., & Smith, D. (2006). Participatory action research. *Journal of epidemiology and community health, 60*(10), 854-857.

Baxter, P., & Jack, S. (2008). Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *The Qualitative Report, 13*(4), 544-559.

Beer, N., Ali, A. S., Eskilsson, H., Jansson, A., Abdul-Kadir, F. M., Rotllant-Estelrich, G., Abass, A.K., Wabwire-Mangen, F., Bjorkman, A., & Kallander, K. (2012). A qualitative study on caretakers' perceived need of bed-nets after reduced malaria transmission in Zanzibar, Tanzania. *BMC Public Health, 12*, 606.

Bennett, A., Smith, S. J., Yambasu, S., Jambai, A., Alemu, W., Kabano, A., & Eisele, T. P. (2012). Household Possession and Use of Insecticide-Treated Mosquito Nets in Sierra Leone 6 Months after a National Mass-Distribution Campaign. *PLoS One, 7*(5): e37927.

Bennett, W. L., & Segerberg, A. (2012). The Logic of Connective Action. *Information, Communication & Society, 15*(5), 739-768.

Berthe, S., Loll, D., Faye, S. L., Wone, I., Koenker, H., Arnold, B., & Weber, R. (2014). "When I sleep under the net, nothing bothers me; I sleep well and I'm happy": Senegal's culture of net use and how inconveniences to net use do not translate to net abandonment. *Malaria Journal, 13*, 357.

Beza, E., Reidsma, P., Poortvliet, P. M., Belay, M. M., Bijen, B. S., & Kooistra, L. (2018). Exploring farmers' intentions to adopt mobile Short Message Service (SMS) for citizen science in agriculture. *Computers and Electronics in Agriculture, 151*, 295-310.

Beza, E., Steinke, J., van Etten, J., Reidsma, P., Fadda, C., Mittra, S., Mathur, P., & Kooistra, L. (2017). What are the prospects for citizen science in agriculture? Evidence from three continents on motivation and mobile telephone use of resource-poor farmers. *PLoS One, 12*(5): e0175700.

Bhatt, S., Weiss, D. J., Cameron, E., Bisanzio, D., Mappin, B., Dalrymple, U., Battle, K. E., Moyes, C. L., Henry, A., Eckhoff, P. A., Wenger, E. A., Briet, O., Penny, M. A., Smith, T. A., Bennett, A., Yukich, J., Eisele, T. P., Griffin, J. T., Fergus, C. A., ... Gething, P. W. (2015). The effect of malaria control on Plasmodium falciparum in Africa between 2000 and 2015. *Nature, 526*(7572), 207-211.

Birhanu, Z., Abebe, L., Sudhakar, M., Dissanayake, G., Yihdego, Y., Alemayehu, G., & Yewhalaw, D. (2015). Access to and use gaps of insecticide-treated nets among communities in Jimma Zone, southwestern Ethiopia: baseline results from malaria education interventions. *BMC Public Health, 15*, 1304.

Bloomfield, G. S., Vedanthan, R., Vasudevan, L., Kithei, A., Were, M., & Velazquez, E. J. (2014). Mobile health for non-communicable diseases in Sub-Saharan Africa: a systematic review of the literature and strategic framework for research. *Globalization and Health, 10*, 49.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., & Wilderman, C. C. (2009). Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. Center for Advancement of Informal Science Education. *CAISE Inquiry Group Report.*

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science, 25*(1), 2-16.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101.

Bremer, S., Haque, M. M., Aziz, S. B., & Kvamme, S. (2019). 'My new routine': Assessing the impact of citizen science on climate adaptation in Bangladesh. *Environmental Science & Policy, 94*, 245-257.

Brouwer, S., & Hessels, L. K. (2019). Increasing research impact with citizen science: The influence of recruitment strategies on sample diversity. *Public Understanding of Science, 28*(5), 606-621.

Bulthuis, S. E., Kok, M. C., Raven, J., & Dieleman, M. A. (2019). Factors influencing the scale-up of public health interventions in low- and middle-income countries: a qualitative systematic literature review. *Health Policy and Planning, 35 (2), 219-234*.

Campbell, J. I., Aturinda, I., Mwesigwa, E., Burns, B., Santorino, D., Haberer, J. E., Bangsberg, D.R., Holden, R.J., Ware, N. C., & Siedner, M. J. (2017). The Technology Acceptance Model for Resource-Limited Settings (TAM-RLS): A Novel Framework for Mobile Health Interventions Targeted to Low-Literacy End-Users in Resource-Limited Settings. *AIDS and Behavior*, 21(11), 3129–3140.

Carballo-Cárdenas, E. C., & Tobi, H. (2016). Citizen science regarding invasive lionfish in Dutch Caribbean MPAs: Drivers and barriers to participation. *Ocean & Coastal Management, 133*, 114-127.

Castro, M. C., Tsuruta, A., Kanamori, S., Kannady, K., & Mkude, S. (2009). Community-based environmental management for malaria control: evidence from a small-scale intervention in Dar es Salaam, Tanzania. *Malaria Journal, 8*, 57.

Chaki, P. P., Dongus, S., Fillinger, U., Kelly, A., & Killeen, G. F. (2011). Community-owned resource persons for malaria vector control: enabling factors and challenges in an operational programme in Dar es Salaam, United Republic of Tanzania. *Human resources for health, 9*, 21-21.

Champion, V. L., & Skinner, C. S. (2008). The Health Belief Model:. In *Health behaviour and health education: Theory, Research and Pracitce* (4th ed., Vol. 4, pp. 45-65).

Church, S. P., Payne, L. B., Peel, S., & Prokopy, L. S. (2019). Beyond water data: benefits to volunteers and to local water from a citizen science program. *Journal of Environmental Planning and Management, 62*(2), 306-326.

Cieslik, K. J., Leeuwis, C., Dewulf, A. R. P. J., Lie, R., Werners, S. E., van Wessel, M., van Wessel, M., Feindt, P., & Struik, P. C. (2018). Addressing socio-ecological development challenges in the digital age: Exploring the potential of Environmental Virtual Observatories for Connective Action (EVOCA). *NJAS - Wageningen Journal of Life Sciences, 86-87*, 2-11.

Clary, E. G., Ridge, R. D., Stukas, A. A., Snyder, M., Copeland, J., Haugen, J., & Miene, P. (1998). Understanding and assessing the motivations of volunteers: A functional approach. *Journal of Personality and Social Psychology, 74*(6), 1516-1530.

Clary, E. G., Snyder, M., Ridge, R. D., Copeland, J., Stukas, A. A., Haugen, J., & Miene, P. (1998). Understanding and assessing the motivations of volunteers: A functional approach. *Journal of Personality and Social Psychology, 74*(6), 1516-1530.

Cohen, J. M., Smith, D. L., Cotter, C., Ward, A., Yamey, G., Sabot, O. J., & Moonen, B. (2012). Malaria resurgence: a systematic review and assessment of its causes. *Malaria Journal, 11*, 122.

Cohn, J. P. (2008). Citizen Science: Can Volunteers Do Real Research? *BioScience, 58*(3), 192-197.

Cole-Lewis, H., & Kershaw, T. (2010). Text messaging as a tool for behavior change in disease prevention and management. *Epidemiologic Reviews, 32*(1), 56-69.

Coleman, S. J. (1988). Social Capital in the Creation of Human Capital. *American Journal of Sociology, 94*, S95-S120.

Condo, J., Mugeni, C., Naughton, B., Hall, K., Tuazon, M. A., Omwega, A., Nwaigwe, F., Drobac, P., Hyder, Z., Ngabo, F., & Binagwaho, A. (2014). Rwanda's evolving community health worker system: a qualitative assessment of client and provider perspectives. *Human resources for health, 12*, 71.

Conner, M. (2015). Health Behaviors. In *International Encyclopedia of the Social & Behavioral Sciences* (pp. 582-587).

Cox, J., Oh, E. Y., Simmons, B., Graham, G., Greenhill, A., Lintott, C., Masters, K., & Woodcock, J. (2018). Doing Good Online: The Changing Relationships Between Motivations, Activity, and Retention Among Online Volunteers. *Nonprofit and Voluntary Sector Quarterly, 47*(5), 1031-1056.

Crain, R., Cooper, C., & Dickinson, J. L. (2014). Citizen Science: A Tool for Integrating Studies of Human and Natural Systems. *Annual Review of Environment and Resources, 39*, 641-665.

Crall, A., Kosmala, M., Cheng, R., Brier, J., Cavalier, D., Henderson, S., & Richardson, A. D. (2017). Volunteer recruitment and retention in online citizen science projects using marketing strategies: lessons from Season Spotter. *Journal of Science Communication, 16*(01): A01.

Crall, A. W., Jordan, R., Holfelder, K., Newman, G. J., Graham, J., & Waller, D. M. (2013). The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. *Public Understanding of Science 22*(6), 745-764.

Créach, M.-A., Velut, G., de Laval, F., Briolant, S., Aigle, L., Marimoutou, C., Deparis, X., Meynard, J.B., Pradines, B., Simon, Fab., Michel, R., & Mayet, A. (2016). Factors associated with malaria chemoprophylaxis compliance among French service members deployed in Central African Republic. *Malaria Journal, 15*, 174.

Cunha, D. G. F., Marques, J. F., Resende, J. C., Falco, P. B., Souza, C. M., & Loiselle, S. A. (2017). Citizen science participation in research in the environmental sciences: key factors related to projects' success and longevity. *Anais da Academia Brasileira de Ciencias, 89*(3), 2229-2245.

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly. Management Information Systems Research Center, University of Minnesota 13*(3), 319-340.

de Campos, A., Hartley, S., de Koning, C., Lezaun, J., & Velho, L. (2017). Responsible Innovation and political accountability: genetically modified mosquitoes in Brazil. *Journal of Responsible Innovation, 4(1), 5-23.*

de Weger, L. A., Hiemstra, P. S., Op den Buysch, E., & van Vliet, A. J. (2014). Spatiotemporal monitoring of allergic rhinitis symptoms in The Netherlands using citizen science. *Allergy, 69*(8), 1085-1091.

Dem, E. S., Rodríguez-Labajos, B., Wiemers, M., Ott, J., Hirneisen, N., Bustamante, J. V., Bustamante, M., & Settele, J. (2018). Understanding the relationship between volunteers' motivations and learning outcomes of Citizen Science in rice ecosystems in the Northern Philippines. *Paddy and Water Environment, 16*(4), 725-735.

Den Broeder, L., Devilee, J., Van Oers, H., Schuit, A. J., & Wagemakers, A. (2016). Citizen Science for public health. *Health Promotion International*, 33(3), 505-514.

Den Broeder, L., Lemmens, L., Uysal, S., Kauw, K., Weekenborg, J., Schönenberger, M., Klooster-Kwakkelstein, S., Schoenmakers, M., Scharwächter, W., Van de Weerd, A., El Baouchi, S., Schuit, A. J., & Wagemakers, A. (2017). Public Health Citizen Science; Perceived Impacts on Citizen Scientists: A Case Study in a Low-Income Neighbourhood in the Netherlands. *Citizen Science: Theory and Practice, 2*(1), 1-17.

Dessewffy, T., & Nagy, Z. (2016). Born in Facebook: The Refugee Crisis and Grassroots Connective Action in Hungary. *International Journal of Communication, 10*, 2872-2894.

Diiro, G. M., Affognon, H. D., Muriithi, B. W., Wanja, S. K., Mbogo, C., & Mutero, C. (2016). The role of gender on malaria preventive behaviour among rural households in Kenya. *Malaria Journal, 15*, 14.

DiMaggio, P., Hargittai, E., Neuman, W. R., & Robinson, J. P. (2001). Social implications of the internet. *Annual. Review Sociology, 27(27)*, 307–336.

Dlamini, S. V., Liao, C.-W., Dlamini, Z. H., Siphepho, J. S., Cheng, P.-C., Chuang, T.-W., & Fan, C.-K. (2017). Knowledge of human social and behavioral factors essential for the success of community malaria control intervention programs: The case of Lomahasha in Swaziland. *Journal of Microbiology, Immunology and Infection, 50*(2), 245-253.

Domroese, M. C., & Johnson, E. A. (2017). Why watch bees? Motivations of citizen science volunteers in the Great Pollinator Project. *Biological Conservation, 208*, 40-47.

Druschke, C. G., & Seltzer, C. E. (2012). Failures of Engagement: Lessons Learned from a Citizen Science Pilot Study. *Applied Environmental Education & Communication, 11*(3-4), 178-188.

Dunn, C. E., Le Mare, A., & Makungu, C. (2011). Malaria risk behaviours, socio-cultural practices and rural livelihoods in southern Tanzania: implications for bednet usage. *Social Science Medicine, 72*(3), 408-417.

Dye, T. D., Apondi, R., Lugada, E. S., Kahn, J. G., Smith, J., & Othoro, C. (2010). "Before we used to get sick all the time": perceptions of malaria and use of long-lasting insecticide-treated bed nets (LLINs) in a rural Kenyan community. *Malaria Journal, 9*, 345.

Eisele, T. P., Larsen, D., & Steketee, R. W. (2010). Protective efficacy of interventions for preventing malaria mortality in children in Plasmodium falciparum endemic areas. *International Journal of Epidemiology, 39(*1):i88-101.

Elo, S., & Kyngas, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing, 62*(1), 107-115.

Eritja, R., Ruiz-Arrondo, I., Delacour-Estrella, S., Schaffner, F., Alvarez-Chachero, J., Bengoa, M., Puig, M. A., Melero-Alcibar, R., Oltra, A., & Bartumeus, F. (2019). First detection of Aedes japonicus in Spain: an unexpected finding triggered by citizen science. *Parasites & Vectors, 12*(1), 53.

Ernst, K. C., Erly, S., Adusei, C., Bell, M. L., Kessie, D. K., Biritwum-Nyarko, A., & Ehiri, J. (2017). Reported bed net ownership and use in social contacts is associated with uptake of bed nets for malaria prevention in pregnant women in Ghana. *Malaria Journal, 16*, 13.

Ernst, K. C., Erly, S., Adusei, C., Bell, M. L., Kessie, D. K., Biritwum-Nyarko, A., & Ehiri, J. (2017). Reported bed net ownership and use in social contacts is associated with uptake of bed nets for malaria prevention in pregnant women in Ghana. *Malaria Journal, 16*, 13.

Ernst, K. C., Hayden, M. H., Olsen, H., Cavanaugh, J. L., Ruberto, I., Agawo, M., & Munga, S. (2016). Comparing ownership and use of bed nets at two sites with differential malaria transmission in western Kenya. *Malaria Journal, 15*, 217.

Eskenazi, B., Quiros-Alcala, L., Lipsitt, J. M., Wu, L. D., Kruger, P., Ntimbane, T., Nawn, J. B., Bornman, M. S., & Seto, E. (2014). mSpray: a mobile phone technology to improve malaria control efforts and monitor human exposure to malaria control pesticides in Limpopo, South Africa. *Environment International, 68*, 219-226.

Fienieg, B., Nierkens, V., Tonkens, E., Plochg, T., & Stronks, K. (2012). Why play an active role? A qualitative examination of lay citizens' main motives for participation in health promotion. *Health Promotion International, 27*(3), 416-426.

Finkelstien, M. A. (2009). Intrinsic vs. extrinsic motivational orientations and the volunteer process. *Personality and Individual Differences, 46*(5), 653-658.

Fjeldsoe, B. S., Marshall, A. L., & Miller, Y. D. (2009). Behavior change interventions delivered by mobile telephone short-message service. *American Journal of Preventive Medicine, 36*(2), 165-173.

Follett, R., & Strezov, V. (2015). An Analysis of Citizen Science Based Research: Usage and Publication Patterns. *PLoS One, 10*(11): e0143687.

Forrest, J. I., Wiens, M., Kanters, S., Nsanzimana, S., Lester, R. T., & Mills, E. J. (2015). Mobile health applications for HIV prevention and care in Africa. *Cururrent Opinion in HIV and AIDS, 10*(6), 464-471.

Fridlund, B. (1997). The Case Study as a Research Strategy. *Scandinavian Journal of Caring Sciences, 11*, 3-4.

Fritz, S., See, L., Carlson, T., Haklay, M., Oliver, J. L., Fraisl, D., Mondardini, R., Brocklehurst, M., Shanley, L. A., Schade, S., Wehn, U., Abrate, T., Anstee, T., Arnold, S., Billot, M., Campbell, J., Espey, J., M. Gold, M., G. Hager, G., . . . West, S. (2019). Citizen science and the United Nations Sustainable Development Goals. Nature Sustainability, 2(10), 922-930.

Fujiie, M., Hayami, Y., & Kikuchi, M. (2005). The conditions of collective action for local commons management: the case of irrigation in the Philippines. *Agricultural Economics, 33*(2), 179-189.

Galvin, K. T., Petford, N., Ajose, F., & Davies, D. (2011). An exploratory qualitative study on perceptions about mosquito bed nets in the Niger Delta: what are the barriers to sustained use? *Journal of Multidisciplinary Healthcare, 4*, 73-83.

Garcia-Martí, I., Zurita-Milla, R., Swart, A., van den Wijngaard, K. C., van Vliet, A. J. H., Bennema, S., & Harms, M. (2017). Identifying Environmental and Human Factors Associated With Tick Bites using Volunteered Reports and Frequent Pattern Mining. *Transactions in GIS, 21*(2), 277-299.

Giller, K. E., Leeuwis, C., Andersson, J. A., Andriesse, W., Brouwer, A., Frost, P., Hebinck, P. Heitkönig, I., van Ittersum, M. K., Koning, N., Ruben, R., Slingerland, M., Udo, H., Veldkamp, T., van de Vijver, C., van Wijk, M. T., & Windmeijer, P. (2008). Competing claims on natural resources: what role for science? *Ecology and Society, 13*(2), 34.

Gimnig, J. E., Otieno, P., Were, V., Marwanga, D., Abong'o, D., Wiegand, R., Williamson, J., Wolkon, A., Zhou, Y., Bayoh, M. N., Lobo, N. F., Laserson, K., Kariuki, S., & Hamel, M. J. (2016). The Effect of Indoor Residual Spraying on the Prevalence of Malaria Parasite Infection, Clinical Malaria and Anemia in an Area of Perennial Transmission and Moderate Coverage of Insecticide Treated Nets in Western Kenya. *PLoS One, 11*(1): e0145282.

Gonahasa, S., Maiteki-Sebuguzi, C., Rugnao, S., Dorsey, G., Opigo, J., Yeka, A., Katureebe, A., Kyohere, M., Lynd, A., Hemingway, J., Donnelly, M., Kamya, M. R., & Staedke, S. G. (2018). LLIN Evaluation in Uganda Project (LLINEUP): factors associated with ownership and use of long-lasting insecticidal nets in Uganda: a cross-sectional survey of 48 districts. *Malaria Journal, 17*, 421.

Graves, M. P., Ngondi, M. J., Hwang, J., Getachew, A., Gebre, T., Mosher, W. A., Patterson, E.A., Shargie, B.E., Tadesse, Z., Wolkon, A., Reithinger, R., Emerson, M.P., & Richards Jr, O. F. (2011). Factors associated with mosquito net use by individuals in households owning nets in Ethiopia. *Malaria Journal, 10*, 354.

Gryseels, C., Durnez, L., Gerrets, R., Uk, S., Suon, S., Set, S., Phoeuk, P., Sluydts, V., Heng, S., Sochantha, T., Coosemans, M., & Peeters Grietens, K. (2015). Re-imagining malaria: heterogeneity of human and mosquito behaviour in relation to residual malaria transmission in Cambodia. *Malaria Journal, 14*, 165.

Gryseels, C., Uk, S., Sluydts, V., Durnez, L., Phoeuk, P., Suon, S., Set, S., Heng, S., Siv, S., Gerrets, R., Tho, S., Coosemans, M., & Peeters Grietens, K. (2015). Factors influencing the use of topical repellents: implications for the effectiveness of malaria elimination strategies. *Scientific Reports, 5*, 16847.

Hakizimana, E., Karema, C., Munyakanage, D., Githure, J., Mazarati, J. B., Tongren, J. E., Takken, W., Binagwaho, A., & Koenraadt, C. J. M. (2018). Spatio-temporal distribution of mosquitoes and risk of malaria infection in Rwanda. *Acta Tropica, 182*, 149-157.

Hay, S. I., Rogers, D. J., Randolph, S. E., Stern, D. I., Cox, J., Shanks, G. D., & Snow, R. W. (2002). Hot topic or hot air? Climate change and malaria resurgence in East African highlands. *Trends in parasitology, 18*(12), 530-534.

Haywood, B. K. (2013). A “Sense of Place” in Public Participation in Scientific Research. *Science Education, 98*(1), 64-83.

Haywood, K. B., Parrish, K. J., & Dolliver, J. (2016). Place-based and data-rich citizen science as a precursor for conservation action. *Conservation Biology, 30*(3), 476–486.

Hecker, S., Bonney, R., Haklay, M., Hölker, F., Hofer, H., Goebel, C., Gold, M., Makuch, Z., Ponti, M., Richter, A., Robinson, L., Iglesias, J. R., Owen, R., Peltola, T., Sforzi, A., Shirk, J., Vogel, J., Vohland, K., Witt, T., & Bonn, A. (2018). Innovation in Citizen Science – Perspectives on Science-Policy Advances. *Citizen Science: Theory and Practice, 3*, 1.

Hetzel, M. W., Gideon, G., Lote, N., Makita, L., Siba, P. M., & Mueller, I. (2012). Ownership and usage of mosquito nets after four years of large-scale free distribution in Papua New Guinea. *Malaria Journal, 11*, 192.

Hobbs, J. S., & White, C. L. P. (2012). Motivations and barriers in relation to community participation in biodiversity recording. *Journal for Nature Conservation, 20*, 364-373.

Hollow, B., Roetman, P. E. J., Walter, M., & Daniels, C. B. (2015). Citizen science for policy development: The case of koala management in South Australia. *Environmental Science & Policy, 47*, 126-136.

Honjo, K., & Satake, A. (2014). N-player mosquito net game: individual and social rationality in the misuse of insecticide-treated nets. *Journal of Theoretical Biology, 342*, 39-46.

Hoque, M. R. (2016). An empirical study of mHealth adoption in a developing country: the moderating effect of gender concern. *BMC Medical Informatics Decision Making, 16*, 51.

Houghton, R., Sprinks, J., Wardlaw, J., Bamford, S., & Marsh, S. (2019). A sociotechnical system approach to virtual citizen science: an application of BS ISO 27500:2016. *Journal of Science Communication, 18*, 1.

Hounmanou, Y. M. G., Agonsanou, M. S. S., Dougnon, V., Vodougnon, M. H. B., Achoh, E. M., Mohammed, J., & Karimuribo, E. D. (2016). The Necessity of Mobile Phone Technologies for Public Health Surveillance in Benin. *Advances in Public Health*.

Hsieh, H.-F., & Shannon, S. E. (2005). Three Approaches to Qualitative Content Analysis. *Qualitative Health Research, 15*(9), 1277-1288.

Hung, W. S., Hu, S. C., Hsu, Y. C., Chen, K. L., Chen, K. H., Yu, M. C., & Chen, K. T. (2014). Factors affecting the use of anti-malaria preventive measures among Taiwan immigrants returning to malaria-endemic regions. *Travel Medicine and Infectious Disease, 12*(4), 370-377.

Ingabire, C. M., Alaii, J., Hakizimana, E., Kateera, F., Muhimuzi, D., Nieuwold, I., Bezooijen, K., Rulisa, S., Kaligirwa, N., Muvunyi, C., Koenraadt, C. J., Mutesa, L., Van Vugt, M., & Van Den Borne, B. (2014). Community mobilization for malaria elimination: application of an open space methodology in Ruhuha sector, Rwanda. *Malaria Journal, 13*, 167.

Ingabire, C. M., Hakizimana, E., Kateera, F., Rulisa, A., Van Den Borne, B., Nieuwold, I., Muvunyi, C., Koenraadt, C. J., Van Vugt, M., Mutesa, L., & Alaii, J. (2016). Using an intervention mapping approach for planning, implementing and assessing a community-led project towards malaria elimination in the Eastern Province of Rwanda. *Malaria Journal, 15*, 594.

Ingabire, C. M., Hakizimana, E., Rulisa, A., Kateera, F., Van Den Borne, B., Muvunyi, C. M., Mutesa, L., Van Vugt, M., Koenraadt, J. M. C., Takken, W., & Alaii, J. (2017). Community-based biological control of malaria mosquitoes using Bacillus thuringiensis var. israelensis (Bti) in Rwanda: community awareness, acceptance and participation. *Malaria Journal, 16*, 399.

Ingabire, C. M., Kateera, F., Hakizimana, E., Rulisa, A., Borne, D. V. B., Muvunyi, C., Koenraadt, J. M. C., Mutesa, L., Vugt, V. M. & Alaii, J. (2016). Stakeholder Engagement in Community-based Malaria Studies in a Defined Setting in the Eastern Province, Rwanda. *Mediterranean Journal of Social Sciences, 7*(2), 188-196.

Ingabire, C. M., Rulisa, A., Van Kempen, L., Muvunyi, C., Koenraadt, C. J., Van Vugt, M., & Alaii, J. (2015). Factors impeding the acceptability and use of malaria preventive measures: implications for malaria elimination in eastern Rwanda. *Malaria Journal, 14*, 136.

Iwashita, H., Dida, G., Futami, K., Sonye, G., Kaneko, S., Horio, M., Kawada, H., Maekawa, Y., & Minakawa, N. (2010). Sleeping arrangement and house structure affect bed net use in villages along Lake Victoria. *Malaria Journal, 9*, 176.

Iyer, M., Skelton, J., de Wildt, G., & Meza, G. (2019). A qualitative study on the use of long-lasting insecticidal nets (LLINs) for the prevention of malaria in the Peruvian Amazon. *Malaria Journal, 18*, 301.

Janko, M. M., Irish, S. R., Reich, B. J., Peterson, M., Doctor, S. M., Mwandagalirwa, M. K., Likwela, J. L., Tshefu, A. K., Meshnick, S. R., & Emch, M. E. (2018). The links between agriculture, Anopheles mosquitoes, and malaria risk in children younger than 5 years in the Democratic Republic of the Congo: a population-based, cross-sectional, spatial study. *The Lancet Planetary Health, 2*(2): e74-e82.

Joo, N. S., & Kim, B. T. (2007). Mobile phone short message service messaging for behaviour modification in a community-based weight control programme in Korea. *Journal of Telemedicine and Telecare, 13*(8), 416-420.

Jordan, R., Gray, S., Sorensen, A., Newman, G., Mellor, D., Newman, G., Hmelo-Silver, C., LaDeau, S., Biehler, D., & Crall, A. (2016). Studying citizen science through adaptive management and learning feedbacks as mechanisms for improving conservation. *Conservation Biology, 30*(3), 487-495.

Jordan, R. C., Ballard, H., & Phillips, T. (2012). Key issues and new approaches for evaluating citizen-science learning outcomes. *Frontiers in Ecology and the Environment, 10*(6), 307-309.

Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., & Ehrenfeld, J. G. (2011). Knowledge gain and behavioral change in citizen-science programs. *Conservation Biology, 25*(6), 1148-1154.

Jordan, R. C., Sorensen, A. E., & Ladeau, S. (2017). Citizen Science as a Tool for Mosquito Control. *Journal of the American Mosquito Control Association, 33*(3), 241-245.

Kajeechiwa, L., Thwin, M. M., Nosten, S., Tun, S. W., Parker, D., von Seidlein, L., Tangseefa, D., Nosten, F., & Cheah, P. Y. (2017). Community engagement for the rapid elimination of malaria: the case of Kayin State, Myanmar. *Wellcome open research, 2*, 59.

Kampen, H., Medlock, J. M., Vaux, A. G., Koenraadt, C. J., van Vliet, A. J., Bartumeus, F., Oltra, A., Sousa, C. A., Chouin, S., & Werner, D. (2015). Approaches to passive mosquito surveillance in the EU. *Parasites & Vectors, 8*, 9.

Karema, C., Aregawi, W. M., Rukundo, A., Kabayiza, A., Mulindahabi, M., Fall, S. I., Gausi, K., Williams, O. R., Lynch, M., Cibulskis, R., Ngabo, F., Nyemazi, J.P., Ngamije, D., Umulisa, I., Newman, R., & Binagwaho, A. (2012). Trends in malaria cases, hospital admissions and deaths following scale-up of anti-malarial interventions, 2000–2010, Rwanda. *Malaria Journal, 11*, 236.

Kateera, F., Ingabire, C. M., Hakizimana, E., Kalinda, P., Mens, P. F., Grobusch, M. P., Mutesa, L., & van Vugt, M. (2015). Malaria, anaemia and under-nutrition: three frequently co-existing conditions among preschool children in rural Rwanda. *Malaria Journal, 14*, 440.

Kateera, F., Ingabire, C. M., Hakizimana, E., Rulisa, A., Karinda, P., Grobusch, M. P., Mutesa, L., VAN Vugt, M., & Mens, P. F. (2015). Long-lasting insecticidal net source, ownership and use in the context of universal coverage: a household survey in eastern Rwanda. *Malaria Journal, 14*, 390.

Kateera, F., Mens, P. F., Hakizimana, E., Ingabire, C. M., Muragijemariya, L., Karinda, P., Grobusch, M.P., Mutesa, L., & van Vugt, M. (2015). Malaria parasite carriage and risk determinants in a rural population: a malariometric survey in Rwanda. *Malaria Journal, 14*, 16.

Kaufman, M. R., Rweyemamu, D., Koenker, H., & Macha, J. (2012). “My children and I will no longer suffer from malaria”: a qualitative study of the acceptance and rejection of indoor residual spraying to prevent malaria in Tanzania. *Malaria Journal, 11*, 220.

Kim, J., & Park, H.-A. (2012). Development of a Health Information Technology Acceptance Model Using Consumers’ Health Behavior Intention. *J Med Internet Res, 14*(5): e133.

Kiware, S. S., Russell, T. L., Mtema, Z. J., Malishee, A. D., Chaki, P., Lwetoijera, D., Chanda, J., Chinula, D., Majambere, S., Gimnig, J. E., Smith, T. A., & Killeen, G. F. (2016). A generic schema and data collection forms applicable to diverse entomological studies of mosquitoes. *Source code for biology and medicine, 11*, 4-4.

Kleinschmidt, I., Schwabe, C., Shiva, M., Segura, J. L., Sima, V., Mabunda, S. J., & Coleman, M. (2009). Combining indoor residual spraying and insecticide-treated net interventions. *American Journal Tropical Medical Hygiene, 81*(3), 519-524.

Koenker, H., & Kilian, A. (2014). Recalculating the Net Use Gap: A Multi-Country Comparison of ITN Use versus ITN Access. *PLoS One, 9*(5): e97496.

Koenker, M. H., Loll, D., Rweyemamu, D., & Ali, S. A. (2013). A good night's sleep and the habit of net use: perceptions of risk and reasons for bed net use in Bukoba and Zanzibar. *Malaria Journal, 12*, 203.

Kullenberg, C., & Kasperowski, D. (2016). What Is Citizen Science? – A Scientometric Meta-Analysis. *PLoS One, 11*(1): e0147152.

Land-Zandstra, A. M., Devilee, J. L. A., Snik, F., Buurmeijer, F., & van den Broek, J. M. (2016). Citizen science on a smartphone: Participants' motivations and learning. *Public Understanding of Science, 25*(1), 45-60.

Land-Zandstra, A. M., van Beusekom, M. M., Koppeschaar, C. E., & van den Broek, J. M. (2016). Motivation and learning impact of Dutch flu-trackers. *Journal of Science Communication. Special Issue: Citizen Science, Part I, 15*(1): A04.

Lee, J.-W., & Mendlinger, S. (2011). Perceived Self-Efficacy and Its Effect on Online Learning Acceptance and Student Satisfaction. *Journal of Service Science and Management, 4*(3), 243-252.

Lee, T. K., Crowston, K., Harandi, M., Østerlund, C., & Miller, G. (2018). Appealing to different motivations in a message to recruit citizen scientists: results of a field experiment. *Journal of Science Communication, 17*, 01.

Leeuwis, C., Cieslik, K. J., Aarts, M. N. C., Dewulf, A. R. P. J., Ludwig, F., Werners, S. E., & Struik, P. C. (2018). Reflections on the potential of virtual citizen science platforms to address collective action challenges: Lessons and implications for future research. *NJAS - Wageningen Journal of Life Sciences, 86-87*, 146-157.

Lindblade, K. A., Mwandama, D., Mzilahowa, T., Steinhardt, L., Gimnig, J., Shah, M., Bauleni, A., Wong, J., Wiegand, R., Howell, P., Zoya, J., Chiphwanya, J., & Mathanga, D. P. (2015). A cohort study of the effectiveness of insecticide-treated bed nets to prevent malaria in an area of moderate pyrethroid resistance, Malawi. *Malaria Journal, 14*, 31.

Luck, L., Jackson, D., & Usher, K. (2006). Case study: a bridge across the paradigms. *Nursing Inquiry, 13*(2), 103–109.

Macintyre, K., Littrell, M., Keating, J., Hamainza, B., Miller, J., & Eisele, T. P. (2012). Determinants of hanging and use of ITNs in the context of near universal coverage in Zambia. *Health Policy Plan, 27*(4), 316-325.

Mahajan, S., Kumar, P., Pinto, J. A., Riccetti, A., Schaaf, K., Camprodon, G., Smári, V., Passani, A., & Forino, G. (2019). A citizen science approach for enhancing public understanding of air pollution. *Sustainable Cities and Society, 52*, 101800.

Martin, V., Smith, L., Bowling, A., Christidis, L., Lloyd, D., & Pecl, G. (2016). Citizens as Scientists: What Influences Public Contributions to Marine Research? *Science Communication, 38*(4), 495 –522.

Martin, V. Y., Christidis, L., Lloyd, D., & Pecl, G. (2016). Understanding drivers, barriers and information sources for public participation in marine citizen science. , 15. *Journal of Science Communication, 15*, 2.

Martin, V. Y., & Greig, E. I. (2019). Young adults' motivations to feed wild birds and influences on their potential participation in citizen science: An exploratory study. *Biological Conservation, 235*, 295-307.

Meankaew, P., Kaewkungwal, J., Khamsiriwatchara, A., Khunthong, P., Singhasivanon, P., & Satimai, W. (2010). Application of mobile-technology for disease and treatment monitoring of malaria in the "Better Border Healthcare Programme". *Malaria Journal, 9*, 237.

MEASURE Evaluation, MEASURE DHS, President's Malaria Initiative, Roll Back Malaria Partnership, UNICEF, & Organization, W. H. (2013). Household survey indicators for malaria control.

MoH. (2017a). *Revised National Malaria Contingency Plan 2016-2020*.

MOH. (2017b). Rwanda Malaria Indicator Survey Final Report.

MoH, & NISR, (2009). Rwanda Interim Demographic and Health Survey, 2007-2008. *Calverton, Maryland, U.S.A.: MOH, NISR, and ICF Macro*.

Montgomery, C. M., Munguambe, K., & Pool, R. (2010). Group-based citizenship in the acceptance of indoor residual spraying (IRS) for malaria control in Mozambique. *Social Science Medicine, 70*(10), 1648-1655.

Moon, T. D., Hayes, C. B., Blevins, M., Lopez, M. L., Green, A. F., Gonzalez-Calvo, L., Olupona, O., & Ogumaniha, S. Z. C. (2016). Factors associated with the use of mosquito bed nets: results from two cross-sectional household surveys in Zambezia Province, Mozambique. *Malaria Journal, 15*, 196.

Mozumder, P., & Marathe, A. (2007). Role of information and communication networks in malaria survival. *Malaria Journal, 6*, 136.

Msellemu, D., Shemdoe, A., Makungu, C., Mlacha, Y., Kannady, K., Dongus, S., Killeen, G.F., & Dillip, A. (2017). The underlying reasons for very high levels of bed net use, and higher malaria infection prevalence among bed net users than non-users in the Tanzanian city of Dar es Salaam: a qualitative study. *Malaria Journal, 16*, 423.

Mukhopadhyay, D. K., Basu, S. S., Roy, D., Das, N., Akbar, F., & Sarkar, G. N. (2016). Netting the malaria menace: Distribution and utilization of long-lasting insecticidal net in a malaria endemic area in Bankura, West Bengal. *Journal of Vector Borne Diseases, 53*(1), 23-29.

Munguambe, K., Pool, R., Montgomery, C., Bavo, C., Nhacolo, A., Fiosse, L., Sacoor, C., Nhalungo, D., Mabunda, S., Macete, E., & Alonso, P. (2011). What drives community adherence to indoor residual spraying (IRS) against malaria in Manhica district, rural Mozambique: a qualitative study. *Malaria Journal, 10*, 344.

Munro, S., Lewin, S., Swart, T., & Volmink, J. (2007). A review of health behaviour theories: how useful are these for developing interventions to promote long-term medication adherence for TB and HIV/AIDS? *BioMed Central, 7*, 104.

Murhandarwati, E. E. H., Fuad, A., Nugraheni, M. D. F., Sulistyawati, Wijayanti, M. A., Widartono, B. S., & Chuang, T.-W. (2014). Early malaria resurgence in pre-elimination areas in Kokap Subdistrict, Kulon Progo, Indonesia. *Malaria Journal, 13*, 130.

Murindahabi, M. M., Asingizwe, D., Poortvliet, P. M., van Vliet, A. J. H., Hakizimana, E., Mutesa, L., Takken, L., & Koenraadt, C. J. M. (2018). A citizen science approach for malaria mosquito surveillance and control in Rwanda. *NJAS - Wageningen Journal of Life Sciences, 86-87*, 101-110.

Mwenesi, H. A. (2005). Social science research in malaria prevention, management and control in the last two decades: An overview. *Acta Tropica, 95*(3), 292-297.

Ng'ang'a, P. N., Jayasinghe, G., Kimani, V., Shililu, J., Kabutha, C., Kabuage, L., Githure, J., & Mutero, C. (2009). Bed net use and associated factors in a rice farming community in Central Kenya. *Malaria Journal, 8*, 64.

Ngabo, F., Nguimfack, J., Nwaigwe, F., Mugeni, C., Muhoza, D., Wilson, R. D., Kalach, J., Gakuba, R., Karema, C., & Binagwaho, A. (2012). Designing and Implementing an Innovative SMS-based alert system (RapidSMS-MCH) to monitor pregnancy and reduce maternal and child deaths in Rwanda. *Pan African Medical Journal, 13*, 31.

NISR. (2017). *The Fifth Integrated Household Living Conditions Survey EICV5*, Kigali, Rwanda.

Nov, O., Arazy, O., & Anderson, D. (2011). *Dusting for science: motivation and participation of digital citizen science volunteers.* Paper presented at the iConference

Nov, O., Arazy, O., & Anderson, D. (2014). Scientists@Home: What Drives the Quantity and Quality of Online Citizen Science Participation? *PLoS One, 9* (4): e90375.

Ntuku, H. M., Ruckstuhl, L., Julo-Réminiac, J.-E., Umesumbu, S. E., Bokota, A., Tshefu, A. K., & Lengeler, C. (2017). Long-lasting insecticidal net (LLIN) ownership, use and cost of implementation after a mass distribution campaign in Kasaï Occidental Province, Democratic Republic of Congo. *Malaria Journal, 16*, 22.

Obala, A. A., Mangeni, J. N., Platt, A., Aswa, D., Abel, L., Namae, J., & Prudhomme O'Meara, W. (2015). What Is Threatening the Effectiveness of Insecticide-Treated Bednets? A Case-Control Study of Environmental, Behavioral, and Physical Factors Associated with Prevention Failure. *PLoS One, 10*(7): e0132778.

Obermayer, J. L., Riley, W. T., Asif, O., & Jean-Mary, J. (2004). College Smoking Cessation using cell phone text messaging. *Journal of American College Health, 53*(2), 71-78.

Okumu, O. F., Mbeyela, E., Lingamba, G., Moore, J., Ntamatungiro, J. A., Kavishe, R. D., Kenward, G.M., Turner, E., Lorenz, M. L., & Moore, J. S. (2013). Comparative field evaluation of combinations of long-lasting insecticide treated nets and indoor residual spraying, relative to either method alone, for malaria prevention in an area where the main vector is Anopheles arabiensis. *Parasites & Vectors, 6*, 46.

Oladepo, O., Tona, G. O., Oshiname, F. O., & Titiloye, M. A. (2010). Malaria knowledge and agricultural practices that promote mosquito breeding in two rural farming communities in Oyo State, Nigeria. *Malaria Journal, 9*, 91.

Oliver, P., & Marwell, G. (1985). A Theory of the Critical Mass. I. Interdependence, Group Heterogeneity, and the Production of Collective Action. *American Journal of Sociology, 91*(3), 522-556.

Olsen, S., Smith, S., Oei, T., & Douglas, J. (2008). Health belief model predicts adherence to CPAP before experience with CPAP. *European Respiratory Journal 32*(3), 710-717.

Olson, M. (1971). The Logic of Collective Action: Public Goods and the Theory of Groups. In *Book review* (pp. 107-114).

Oria, P. A., Hiscox, A., Alaii, J., Ayugi, M., Mukabana, W. R., Takken, W., & Leeuwis, C. (2014). Tracking the mutual shaping of the technical and social dimensions of solar-powered mosquito trapping systems (SMoTS) for malaria control on Rusinga Island, western Kenya. *Parasites & Vectors, 7*, 523.

Overdevest, C., Orr, C. H., & Stepenuck, K. (2004). Volunteer Stream Monitoring and Local Participation in Natural Resource Issues. *Human Ecology Review, 11*(2), 177-185.

Palmer, J. R. B., Oltra, A., Collantes, F., Delgado, J. A., Lucientes, J., Delacour, S., Bengoa, M., Eritja, R., & Bartumeus, F. (2017). Citizen science provides a reliable and scalable tool to track disease-carrying mosquitoes. *Nature Communication, 8*, 916.

Panter-Brick, C., Clarke, S. E., Lomas, H., Pinder, M., & Lindsay, S. W. (2006). Culturally compelling strategies for behaviour change: a social ecology model and case study in malaria prevention. *Social Science Medicine, 62*(11), 2810-2825.

Panzano, P. C., & Roth, D. (2006). The Decision to adopt evidence-based and other innovative mental health practices: Risky business? *Psychiatric Services, 57*(8), 1153.

Peachey, J. W., Lyras, A., Cohen, C., Bruening, J. E., & Cunningham, G. B. (2014). Exploring the motives and retention factors of sport-for-development volunteers. *Nonprofit and Voluntary Sector: Quarterly, 43*(6), 1052–1069.

Pluess, B., Tanser, F. C., Lengeler, C., & Sharp, B. L. (2010). Indoor residual spraying for preventing malaria. *Cochrane Database Syst Rev*(4), CD006657.

Pocock, M. J. O., Roy, H. E., August, T., Kuria, A., Barasa, F., Bett, J., Githiru, M., Kairo, J., Kimani, J., Kinuthia, W., Kissui, B., Madindou, I., Mbogo, K., Mirembe, J., Mugo, P., Muniale, F. M., Njoroge, P., Njuguna, Ed. G., Olendo, M. I., ... McKenzie, A. (2018). Developing the global potential of citizen science: Assessing opportunities that benefit people, society and the environment in East Africa. *Journal of Applied Ecology, 56*(2), 274-281.

Pocock, M. J. O., Tweddle, J. C., Savage, J., Robinson, L. D., & Roy, H. E. (2017). The diversity and evolution of ecological and environmental citizen science. *PLoS One, 12*(4): e0172579.

President's Malaria Initiative. (2015). *Rwanda Malaria Operational Plan FY 2015*

President’s Malaria Initiative. (2016). *Rwanda Malaria Operational Plan FY 2016*

President’s Malaria Initiative. (2017). *Rwanda Malaria Operational Plan FY 2017*

President's Malaria Initiative. (2018). *Rwanda Malaria Operational Plan FY 2018*

President's Maliaria Initiative. (2019). *Rwanda Malaria Operational Plan FY 2019*

Pulford, J., Hetzel, W. M., Bryant, M., Siba, M. P., & Mueller, I. (2011). Reported reasons for not using a mosquito net when one is available: a review of the published literature. *Malaria Journal, 10*, 83.

Putnam, R. D. (1995). Tuning In, Tuning Out: The Strange Disappearance of Social Capital in America *Polical Sciences and Politics, 28*(4), 664-683.

Quinlivan, L., Chapman, D. V., & Sullivan, T. (2020). Validating citizen science monitoring of ambient water quality for the United Nations sustainable development goals. *Science of The Total Environment, 699*, 134255.

Raddick, M. J., Bracey, G., Gay, P. L., Lintott, C. J., Murray, P., Schawinski, K., Szalay, A.S., & Vandenberg, J. (2010). Galaxy Zoo: Exploring the Motivations of Citizen Science Volunteers. *Astronomy Education Review, 9*,1.

Raddick, M. J., Bracey, G., Gay, P. L., Lintott, C. J., Murray, P., Schawinski, K., Szalay, A.S., & Vandenberg, J. (2013). Galaxy Zoo: Motivations of citizen scientists. *ArXiv E-Prints*.

Rambonnet, L., Vink, S. C., Land-Zandstra, A. M., & Bosker, T. (2019). Making citizen science count: Best practices and challenges of citizen science projects on plastics in aquatic environments. *Marine Pollution Bulletin, 145*, 271-277.

Ramos-Pinto, P. (2006). Social Capital as a Capacity for Collective Action. *Assessing Social Capital: Concept, Policy, Practice*.

RDHS. (2015). *Rwanda Demographic and Health Survey 2014-2015*.

Rickard, G. D., Dudovitz, N. R., Wong, D. M., Jen, C. H., Osborn, D. R., Fernandez, E. H., & Donkor, I. C. (2011). Closing the gap between insecticide treated net ownership and use for the prevention of malaria. *Progress in Community Health Partnerships, 5*(2), 123-131.

Ricotta, E. E., Boulay, M., Ainslie, R., Babalola, S., Fotheringham, M., Koenker, H., & Lynch, M. (2015). The use of mediation analysis to assess the effects of a behaviour change communication strategy on bed net ideation and household universal coverage in Tanzania. *Malaria Journal, 14*, 15.

Rittel, W. J. H., & Webber, M. M. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences, 4*(2), 155-169.

Roetman, P., Tindle, H., & Litchfield, C. (2018). Management of Pet Cats: The Impact of the Cat Tracker Citizen Science Project in South Australia. *Animals, 8*, 190.

Rogers, M. E. (1983). Diffusion of innovations (3 ed.). New York: Collier Macmillan Canada, Inc.

Rose, J., & Fogarty, G. (2006). Determinants of perceived usefulness and perceived ease of use in the technology acceptance model: senior consumers' adoption of self-service banking technologies. *Academy of World Business, Marketing & Management Development 2*(10), 122-129.

Rotman, D., Hammock, J., Preece, J., Hansen, D., Boston, C., Bowser, A., & He, Y. (2014). Motivations Affecting Initial and Long-Term Participation in Citizen Science Projects in Three Countries. *Paper presented at the In iConference.*

Rotman, D., Hammock, J., Preece, J. J., Boston, C. L., Hansen, D. L., Bowser, A., & He, Y. (2014). Does motivation in citizen science change with time and culture? 229-232.

Rotman, D., Preece, J., Hammock, J., Procita, K., Hansen, D., Parr, C., Jacobs, D. (2012). Dynamic Changes in Motivation in Collaborative Citizen-Science Projects. Paper presented at the *Proceedings of the ACM conference on Computer Supported Cooperative Work Seattle, WA*.

Russell, C. L., Sallau, A., Emukah, E., Graves, P. M., Noland, G. S., Ngondi, J. M., Ozaki, M., Nwankwo, L., Miri, E., McFarland, D. A., Richards, F. O., & Patterson, A. E. (2015). Determinants of Bed Net Use in Southeast Nigeria following Mass Distribution of LLINs: Implications for Social Behavior Change Interventions. *PLoS One, 10*(10): e0139447.

Ryan, S. F., Adamson, N. L., Aktipis, A., Andersen, L. K., Austin, R., Barnes, L., Beasley, M. R., Bedell, K. D., Briggs, S., Chapman, B., Cooper, C. B., Corn, J. O., Creamer, N. G., Delborne, J. A., Domenico, P., Driscoll, E., Goodwin, J., Hjarding, A., Hulbert, J. M., . . . Dunn, R. R. (2018). The role of citizen science in addressing grand challenges in food and agriculture research. *Proceedings Biology Sciences, 285*, 1891.

Sahan, K., Pell, C., Smithuis, F., Phyo, A. K., Maung, S. M., Indrasuta, C., Dondorp, A. M., White, N. J.,Day, N. P. J., von Seidlein, L., & Cheah, P. Y. (2017). Community engagement and the social context of targeted malaria treatment: a qualitative study in Kayin (Karen) State, Myanmar. *Malaria Journal, 16*, 75.

Samadoulougou, S., Pearcy, M., Yé, Y., & Kirakoya-Samadoulougou, F. (2017). Progress in coverage of bed net ownership and use in Burkina Faso 2003–2014: evidence from population-based surveys. *Malaria Jorunal, 16*, 302.

Sanoff, H. (2007). Special issue on participatory design. *Design Studies, 28*(3), 213-215.

Setbon, M., & Raude, J. (2009). Population response to the risk of vector-borne diseases: lessons learned from socio-behavioural research during large-scale outbreaks. *Emergency Health Threats Journal, 2*, e6.

Sherrard-Smith, E., Skarp, J. E., Beale, A. D., Fornadel, C., Norris, L. C., Moore, S. J., Mihreteab, S., Charlwood, J. D., Bhatt, S., Winskill, P., Griffin, J. T., & Churcher, T. S. (2019). Mosquito feeding behavior and how it influences residual malaria transmission across Africa. *Proceedings of National Academy of Sciences U S A, 116*(30), 15086-15095.

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B. V., Krasny, M. E., & Bonney, R. (2012). Public Participation in Scientific Research: a Framework for Deliberate Design. *Ecology and Society, 17*, 2.

Skelton, C. J., Cook, A. S., West, P., Spencer, R.-J., & Old, J. M. (2019). Building an army of wombat warriors: developing and sustaining a citizen science project. *Australian Mammalogy, 41*, 2.

Smallegange, R. C., Schmied, W. H., van Roey, K. J., Verhulst, N. O., Spitzen, J., Mukabana, W. R., & Takken, W. (2010). Sugar-fermenting yeast as an organic source of carbon dioxide to attract the malaria mosquito Anopheles gambiae. *Malaria Journal, 9*, 292.

Steinhardt, L. C., Yeka, A., Nasr, S., Wiegand, R. E., Rubahika, D., Sserwanga, A., Wanzira, H., Lavoy, G., Kamya, M., Dorsey, G., & Filler, S. (2013). The Effect of Indoor Residual Spraying on Malaria and Anemia in a High-Transmission Area of Northern Uganda. *American Journal of Tropical Medicine and Hygiene, 88*(5), 855-861.

Stevens, M., Vitos, M., Altenbuchner, J., Conquest, G., Lewis, J., & Haklay, M. (2014). Taking Participatory Citizen Science to Extremes. *IEEE Pervasive Computing – Special Issue on Pervasive Analytics and Citizen Science*, 20-29

Strachan, C. E., Nuwa, A., Muhangi, D., Okui, A. P., Helinski, M. E., & Tibenderana, J. K. (2016). What drives the consistent use of long-lasting insecticidal nets over time? A multi-method qualitative study in mid-western Uganda. *Malaria Journal, 15*, 44.

Stuckey, H. L. (2013). Three types of interviews: Qualitative research methods in social health. *Journal of Social Health and Diabetes, 1*,2

Sullivan, B. L., Wood, C. L., Iliff, M. J., Bonney, R. E., Fink, D., & Kelling, S. (2009). eBird: A citizen-based bird observation network in the biological sciences. *Biological Conservation, 142*(10), 2282-2292.

Teo, T. (2010). Examining the influence of subjective norm and facilitating conditions on the intention to use technology among pre-service teachers: a structural equation modeling of an extended technology acceptance model. *Asia Pacific Education Review, 11*(2), 253-262.

Theobald, E. J., Ettinger, A. K., Burgess, H. K., DeBey, L. B., Schmidt, N. R., Froehlich, H. E., . . . Parrish, J. K. (2015). Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. *Biological Conservation, 181*, 236-244.

Tinati, R., Luczak-Roesch, M., Simperl, E., & Hall, W. (2017). An investigation of player motivations in Eyewire, a gamified citizen science project. *Computers in Human Behavior, 73*, 527-540.

Tobin-West, C. I., & Asuquo, E. O. (2013). Utilization of Intermittent Preventive Treatment of Malaria by Pregnant Women in Rivers State, Nigeria. *International Journal of Preventive Medicine, 4*(1), 63-71.

Toé, L. P., Skovmand, O., Dabiré, K. R., Diabaté, A., Diallo, Y., Guiguemdé, T. R., Doannio, J. M. C., Akogbeto, M., Baldet, T., & Gruénais, M.-E. (2009). Decreased motivation in the use of insecticide-treated nets in a malaria endemic area in Burkina Faso. *Malaria Journal, 8*, 175.

Tong, A., Sainsbury, P., & Craig, J. (2007). Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *International Journal for Quality in Health Care, 19*(6), 349–357

Tong, M. X., Hansen, A., Hanson-Easey, S., Cameron, S., Xiang, J., Liu, Q., Liu, X., Sun, Y., Weinstein, P., Han, G-S., Williams, C., & Bi, P. (2017). Perceptions of malaria control and prevention in an era of climate change: a cross-sectional survey among CDC staff in China. *Malaria Journal, 16*, 136.

Toomey, H. A., & Domroese, C. M. (2013). Can citizen science lead to positive conservation attitudes and behaviors? *Human Ecology Review, 20*, 50-62

Turrini, T., Dörler, D., Richter, A., Heigl, F., & Bonn, A. (2018). The threefold potential of environmental citizen science - Generating knowledge, creating learning opportunities and enabling civic participation. *Biological Conservation, 225*, 176-186.

Van Brussel, S., & Huyse, H. (2019). Citizen science on speed? Realising the triple objective of scientific rigour, policy influence and deep citizen engagement in a large-scale citizen science project on ambient air quality in Antwerp. *Journal of Environmental Planning and Management, 62*(3), 534-551.

van der Wal, R., Sharma, N., Mellish, C., Robinson, A., & Siddharthan, A. (2016). The role of automated feedback in training and retaining biological recorders for citizen science. *Conservation Biology, 30*(3), 550-561.

van Woezik, A. F., Braakman-Jansen, L. M., Kulyk, O., Siemons, L., & van Gemert-Pijnen, J. E. (2016). Tackling wicked problems in infection prevention and control: a guideline for co-creation with stakeholders. *Antimicrobial Resistnce & Infection Control, 5*, 20.

Venkatesh, V., & Bala, H. (2008). Technology Acceptance Model 3 and a Research Agenda on Interventions. *Decision Sciences, 39*(2), 273-315.

Venkatesh, V., & Davis, F. D. (2000). A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Management Science, 46*(2), 186-204.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User Acceptance of Information Technology: Toward a Unified View. *Management Information Systems Quarterly, 27*(3), 425-478.

Vogels, C. B., van de Peppel, L. J., van Vliet, A. J., Westenberg, M., Ibanez-Justicia, A., Stroo, A., Buijs, J.A., Visser, T.M., & Koenraadt, C. J. (2015). Winter Activity and Aboveground Hybridization Between the Two Biotypes of the West Nile Virus Vector Culex pipiens. *Vector Borne Zoonotic Diseases, 15*(10), 619-626.

Wadunde, I., Mpimbaza, A., Musoke, D., Ssempebwa, J. C., Ediau, M., Tuhebwe, D., Aduke, Y., & Wanyenze, R. K. (2018). Factors associated with willingness to take up indoor residual spraying to prevent malaria in Tororo district, Uganda: a cross-sectional study. *Malaria Journal, 17*, 5.

Walther, D., & Kampen, H. (2017). The Citizen Science Project 'Mueckenatlas' Helps Monitor the Distribution and Spread of Invasive Mosquito Species in Germany. *Journal of medical entomology, 54*(6), 1790-1794.

Wang, Y.-S., Lin, H.-H., & Luarn, P. (2006). Predicting consumer intention to use mobile service. *Information Systems Journal, 16*(2), 157-179.

Wangdi, K., Furuya-Kanamori, L., Clark, J., Barendregt, J. J., Gatton, M. L., Banwell, C., Kelly, G.C., Doi, S.A.R., & Clements, A. C. A. (2018). Comparative effectiveness of malaria prevention measures: a systematic review and network meta-analysis. *Parasites & Vectors, 11*, 210.

Watanabe, N., Kaneko, A., Yamar, S., Leodoro, H., Taleo, G., Tanihata, T., Lum, J.K., & Larson, P. S. (2014). Determinants of the use of insecticide-treated bed nets on islands of pre- and post-malaria elimination: an application of the health belief model in Vanuatu. *Malaria Journal, 13*, 441.

Watanabe, N., Kaneko, A., Yamar, S., Taleo, G., Tanihata, T., Lum, J. K., Larson, P.S., & Shearer, N. B. (2015). A prescription for sustaining community engagement in malaria elimination on Aneityum Island, Vanuatu: an application of Health Empowerment Theory. *Malaria Journal, 14*, 291.

Wehn, U., & Almomani, A. (2019). Incentives and barriers for participation in community-based environmental monitoring and information systems: A critical analysis and integration of the literature. *Environmental Science & Policy, 101,* 341-357.

Weidman, J., Dickerson, D. E., & Koebel, C. T. (2015). Prevention through Design Adoption Readiness Model (PtD ARM): An integrated conceptual model. *Work, 52*, 865–876.

West, S., & Pateman, R. (2016). Recruiting and Retaining Participants in Citizen Science: What Can Be Learned from the Volunteering Literature? *Citizen Science: Theory and Practice, 1*, 2.

WHO. (2016). World malaria report. Geneva, Switzerland: World Health Organization

WHO. (2017a). Global vector control response 2017–2030

WHO. (2017b). World malaria report. Geneva, Switzerland: World Health Organization

WHO. (2018). World Malaria Report. Geneva, Switzerland: World Health Organization

WHO. (2019). World malaria report. Geneva, Switzerland: World Health Organization

WHO/EXPANDNET. (2009). *Practical Guidance for Scaling Up Health Service Innovations.* Geneva, Switzerland: World Health Organization

WHO/EXPANDNET. (2011). *Beginning with the End in Mind: Planning Pilot Projects and Other Programmatic Research for Successful Scaling Up*. Retrieved from Geneva, Switzerland: World Health Organization

Widmar, M., Nagel, C. J., Ho, D. Y., Benziger, P. W., & Hennig, N. (2009). Determining and addressing obstacles to the effective use of long-lasting insecticide-impregnated nets in rural Tanzania. *Malaria Journal, 8*, 315.

Wiggins, A. (2013). *Free As In Puppies: Compensating for ICT Constraints in Citizen Science.* Paper presented at the CSCW '13: Proceedings of the conference on Computer supported cooperative work, San Antonio, TX, USA.

Wisdom, J. P., Chor, K. H., Hoagwood, K. E., & Horwitz, S. M. (2014). Innovation adoption: a review of theories and constructs. *Administration and Policy in Mental Health, 41*(4), 480-502.

Witte, K. (1992). Putting the fear back into fear appeals: the Extended Parallel Process Model. *Communication Monographs, 59*, 329-349

Worthington, J. P., Silvertown, J., Cook, L., Cameron, R., Dodd, M., Greenwood, R. M., McConway, K., & Skelton, P. (2012). Evolution MegaLab: a case study in citizen science methods. *Methods in Ecology and Evolution, 3*(2), 303-309.

Wotodjo, A. N., Richard, V., Boyer, S., Doucoure, S., Diagne, N., Touré-Baldé, A., Tall, A., Faye, N., Gaudart, J., Trape, J-F., & Sokhna, C. (2015). The implication of long-lasting insecticide-treated net use in the resurgence of malaria morbidity in a Senegal malaria endemic village in 2010–2011. *Parasites & Vectors, 8*(267).

Wu, T.-P., Tian, J.-H., Xue, R.-D., Fang, Y.-L., & Zheng, A.-H. (2016). Mosquito (Diptera: Culicidae) Habitat Surveillance by Android Mobile Devices in Guangzhou, China. *Insects, 7*(4), 79.

Wu, W.-N., & Tsai, C.-C. (2017). What Motivates Citizens to Volunteer in Schools? Determinants in the Local Context. *Education and Urban Society, 50*(9), 769-792.

Yamey, G. (2012). What are the barriers to scaling up health interventions in low and middle income countries? A qualitative study of academic leaders in implementation science. *Globalization and Health, 8*(11).

Yasuoka, J., Jimba, M., & Levins, R. (2014). Application of loop analysis for evaluation of malaria control interventions. *Malaria Journal, 13*(140).

Yin, R. K. (1992). The Case Study Method as a Tool for Doing Evaluation. *Current Sociology, 40*(1), 121-137.

Yin, R. K. (1999). Enhancing the Quality of Case Studies in Health Services Research. *HSR: Health Services Research, 34*(5), 1209-1224.

Zhang, X., Han, X., Dang, Y., Meng, F., Guo, X., & Lin, J. (2016). User acceptance of mobile health services from users' perspectives: The role of self-efficacy and response-efficacy in technology acceptance. *Informatics for Health and Social Care, 42*(2), 194-206.

Zhou, G., Afrane, Y. A., Vardo-Zalik, A. M., Atieli, H., Zhong, D., Wamae, P., Himeidan, Y.E., Minakawa, N., Githeko, A.K., & Yan, G. (2011). Changing patterns of malaria epidemiology between 2002 and 2010 in Western Kenya: the fall and rise of malaria. *PLoS One, 6*(5): e20318.

Zurovac, D., Talisuna, A. O., & Snow, R. W. (2012). Mobile Phone Text Messaging: Tool for Malaria Control in Africa. *PLOS Medicine, 9*(2): e1001176.

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About the author

Domina Asingizwe was born on the 1st of January, 1986 in Gasabo, Rwanda. In 2011, she completed her Bachelor of Science in Physiotherapy at Kigali Health Institute, now College of Medicine and Health Sciences, University of Rwanda. After graduating, she continued to work at the same institution as a research assistant. In 2013, she started her masters of Public Health – Epidemiology at Mount Kenya University. For her MSc research, she worked on community practices towards malaria elimination. She completed her MSc studies in 2014 and she got promoted to Assistant Researcher at the same institution, where she is still working. In January 2016, she was admitted as a PhD student in the School of Social Science of Wageningen University under a scholarship from Interdisciplinary Research and Education Fund (INREF), Wageningen University & research. Her PhD focused on exploring factors that influence the consistent use of malaria control measures and how a citizen science program may contribute to this use. This was done through designing and implementing a citizen science program for malaria control in order to understand the motivational factors and barriers to participate, as well as the effects of this program on the use of malaria control measures. She is currently holding a lecturer position at the College of Medicine and Health sciences, University of Rwanda.

List of publications

Peer-reviewed journal publications

1. Ngabonzima, A., Asingizwe, D., & Kouveliotis, K. (2020). Influence of nurse and midwife managerial leadership styles on job satisfaction, intention to stay, and services provision in selected hospitals of Rwanda. *BMC Nursing*, 19, 35.
2. Asingizwe, D., Murindahabi, M. M., Koenraadt, C. J. M., Poortvliet, P. M., van Vliet, A. J. H., Ingabire, C. M., Hakizimana, E., Mutesa, L., Takken, W., & Leeuwis, C. (2019). Co-designing a citizen science program for malaria control in Rwanda. *Sustainability,* 11, 7012. (Chapter 4 in this thesis).
3. Asingizwe, D., Poortvliet, P. M., Koenraadt, C. J. M., van Vliet, A. J. H., Ingabire, C. M., Mutesa, L., & Leeuwis, C. (2019). Role of individual perceptions in the consistent use of malaria preventive measures: mixed methods evidence from rural Rwanda. *Malaria journal*, 18, 270. (Chapter 3 in this thesis)
4. Urimubenshi, G., Dahir, A. J., Niyotwiringiye, S., Furaha, D., & Asingizwe, D. (2019). Exploring the Perception of the Educational Environment among Health Sciences Students at The University of Rwanda: A Mixed Methods Study. *Education in Medicine Journal*, 11(1), 21–30.
5. Asingizwe, D., Poortvliet, P. M., Koenraadt, C. J. M., Van Vliet, A. J. H., Murindahabi, M. M., Ingabire, C. M., Mutesa, L., & Feindt, P. H. (2018). Applying citizen science for malaria prevention in Rwanda: An integrated conceptual framework. *NJAS - Wageningen Journal of Life Sciences*, 86-87, 111-122. (Chapter 2 in this thesis).
6. Murindahabi, M. M., Asingizwe, D., Poortvliet P. M., van Vliet, A. J. H., Hakizimana, E., Mutesa, L., Takken, W., & Koenraadt, C. J. M. (2018). A citizen science approach for malaria mosquito surveillance and control in Rwanda. *NJAS - Wageningen Journal of Life Sciences,* 86-87, 101-110.
7. Ewing, H., Pyburn, R., Asingizwe, D., Asiimwe-Kateera, B., Njunwa, K., & Kim, M. J. (2017). Facilitating Health Professional Scholarship Through A Workshop Series At The University Of Rwanda. *Rwanda Medical Journal,* 74 (2), 12-16.
8. Mukeshimana, M., & Asingizwe, D. (2016). Nurse-Doctor Relationship in Rwanda: A Questionnaire Survey. *IOSR Journal of Nursing and Health Science (IOSR-JNHS),* 5 (4), 68-74.
9. Habimana, A., Harerimana, A., Asingizwe, D., Nyandwi, T., & Njunwa, K. J. (2016). Community Health Workers' knowledge, attitudes and practices about malaria prevention in Gicumbi District, Rwanda. *Rwanda Journal Series F: Medicine and Health Sciences,* 3 (1), 27-35 .
10. Asingizwe, D., Rulisa S., Asiimwe-Kateera, B., & Kim, M. J. (2015). Malaria elimination practices in rural community residents in Rwanda: A cross sectional study. *Rwanda Journal Series F: Medicine and Health Sciences*, 2(1), 53-58.

11. Mukeshimana, M., Hakizimana, G., Mwali, C., Umuhoza, C., Uwambajimana, J., & Asingizwe, D. (2015). The knowledge and practice of self-care management among patients attending a diabetes clinic in Kigali, Rwanda. *Rwanda Journal Series F: Medicine and Health Sciences,* 2(1), 24-30.
12. Bushaija, E., Sunday, F. X., Asingizwe, D., Olayo, R., & Abong'o, B. (2013). Factors that hinder parents from communicating of sexual matters with adolescents in Rwanda. *Rwanda journal of health sciences*, 2, 2.

Publication Accepted

1. Asingizwe D., Poortvliet P.M., Koenraadt C.J.M., van Vliet A.J.H., Ingabire C.M., Mutesa L., & Leeuwis C. Why (not) participate in citizen science? Motivational factors and barriers to participate in a citizen science program for malaria control in Rwanda. Accepted for publication in PLOS ONE (Chapter 5 in this thesis).
2. Asingizwe D., Poortvliet P.M., Koenraadt C.J.M., van Vliet A.J.H., Ingabire C.M., Mutesa L., & Leeuwis C. What benefits do community members get from citizen science? Evidence from a Rwandan citizen science program on malaria control. Accepted for publication in Malaria Journal (Chapter 6 in this thesis).

Conference

Citizen Science Approach as a way to improve Malaria Risk Perception, Society for Risk Analysis, Cape Town, South Africa, 2019.

Domina Asingizwe
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
EVOCA courses	WASS	2016	6
Change, inter-human processes and communication CPT-32806	WUR	2016	6
Introduction to Interpretive Research Design	WASS	2016	3
Statistics for the Life Sciences	WIAS	2016	2
Companion modelling	PE&RC	2016	1.5
Extreme citizen science	EVOCA Project	2016	1.3
B) General research related competences			
PhD research proposal writing	WUR	2016	6
WASS Introduction course	WASS	2016	1
Qualitative data analysis with Atlas. ti a hands on practical	WASS	2016	1
Information literacy including endnote introduction	WUR Library	2016	0.4
Research methodology: from topic to proposal	WASS	2016	4
Reviewing a scientific paper	WGS	2018	0.1
Critical thinking and argumentation	WGS		0.3
NVIVO based Qualitative Data Coding and Management Training for Social Scientist	WASS	2019	1
Four EVOCA workshops	EVOCA Project	2016-2019	4
C) Career related competences/personal development			
'Perceived threat, efficacy, and use of malaria preventive measures in Rwanda'	WASS PhD Day	2018	1
'Citizen Science Approach as a way to improve Malaria Risk Perception'	Fifth World Congress on Society for Risk Analysis, Cape Town, South Africa	2019	1
Communication with the Media and the General Public	WGS	2019	1
Efficient Writing Strategies	WGS	2018	1.3
Scientific Integrity	WGS	2019	0.6
Providing Evidence for Policy Making	WTMC	2020	1
Total			**43.5**

*One credit according to ECTS is on average equivalent to 28 hours of study load

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