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Risk Factors Associated with Malaria Resurgence in Rosterman Gold Mines and Eluche Sugarcane Growing Regions of Western Kenya Highlands

Kipcho D. Mukabane , Nicholas L.Kitungulu , Philip A. Ogutu · Jackson K. Cheruiyot ,
David H. Mulama & Ayuya Steve.
Biological Sciences Department, Masinde Muliro University of Science and Technology, P.O. Box 190-50100, Kakamega, Kenya

*Corresponding author: kipchomukabane@yahoo.com

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ABSTRACT

Background: Malaria is still a public health concern around the world despite up-scaled prevention methods at both the household and community levels. Environmental modifying activities that aggravate malaria transmission remain focal points in forestalling transmission. This study sought to evaluate the risk factors associated with the resurgence of malaria in Rosterman gold mining and Eluche sugarcane growing villages of Western Kenya highlands despite concerted efforts aimed at its control.

Materials and methods: This was a longitudinal cross-sectional study carried out from November 2018 to October 2019. A pre-tested questionnaire was used to collect data on socio-demographic characteristics and the history of malaria episodes of the participants. Houses were observed for associated risk factors, while the bed nets were physically observed for their status. Anopheline larval habitats were surveyed three consecutive days monthly and their distance from the nearest residence was measured in meters. Data analysis was done using GraphPad Prism statistical software in which descriptive statistics were carried out to determine the relative frequencies of all the surveyed variables. Pearson's Chi-square and Fisher's exact tests were used to determine the association between risk factors and history of malaria episodes.

Results: Of the study population, 54.87% were females, 83.00% had primary or higher education levels, 87.05% were self-employed or employed, and 92.76% were earning less than 50 US dollars monthly. All four socio-demographic factors tested, house structures, the status of the long-lasting insecticidal nets, the distance of the residences from the nearest anopheline larval habitat, and anopheline larval densities were significantly associated with malaria episodes.

Conclusion: The studied factors increased the proportion of people at risk of malaria transmission overriding the impact of the instituted control measures. Thus, could be acting as transmission drivers that have led to the observed upsurge of malaria episodes in the two study sites. This knowledge has the potential to revitalize efforts towards effective malaria control strategies. Further studies should include more parasitological components to provide more evidence and risk maps for future action by the authorities.
Keywords: Risk factors, socio-demographics, bed net status, larval densities, Kenya highlands

Background

Upscaling of malaria control and prevention have had immense results in reducing malaria infection in Sub-Saharan Africa (SSA) (Kamau *et al.*, 2020). These interventions include environmental management, indoor residual spraying (IRS), provision of the long-lasting insecticidal net (LLIN), and case management using artemisinin combination therapy (ACT) (Kapesa *et al.*, 2018). However, despite these efforts, malaria was still a major public health issue in most Sub-Saharan countries.

Sub-Saharan Africa registers 90% of all malaria cases with 92% being fatal (WHO, 2018) mainly in pregnant women and children in which it claims a child under five every 30 minutes (Omukunda *et al*., 2013). In Kenya, one of the 15 high-burden malaria countries, malaria epidemics have been reported in western highlands in recent years (Pascual *et al*., 2006). The last few years have seen malaria bounce back to pre-intervention times (Mukonka *et al*., 2014, Ototo *et al*., 2015). Debate rages on among public health experts about the cause of the observed upsurge of this scourge in these areas. Among the reasons put forth include climate change (Nawa *et al*., 2019), land modifying practices (Paul *et al*., 2018), land cover types (Sewe *et a*l., 2016), the distance of residential houses from the mosquito breeding/resting sites (Kondepati, 2013), house structure (Bashar *et al*., 2012), vector control practices (Aïkpon *et al*., 2020) and socio-economic status of households (Pinchoff *et al*., 2016). A spatial study carried out by Nicholas *et al*., (2021) showed that mosquito breeding habitats due to human activities were abundant and diverse in the Kakamega County, Western Kenya highlands. However, the extent to which all these factors contributed to malaria transmission in artisanal gold mining and sugarcane growing in highlands in Western Kenya had not been documented. Additionally, no data was available to enable a review of the success of the many integrated malaria control strategies put in place. This therefore left a lacuna that needed to be filled. Therefore, this study sought to investigate the risk factors that contributed to the increased malaria cases in gold mining and sugarcane growing regions of Western Kenya highlands. The results from this study would provide information on the factors potentiating the recorded malaria resurgence in the Western Kenya highlands in particular. The findings would further shed light on the level of adoption of the instituted malaria control programs.

Land use patterns are driven by the socio-economic needs of the study population (Paul *et al*., 2018). Artisanal gold mining and sugarcane farming in the Western Kenya region are perceived as socio-economic drivers that employ people at different levels. However, the association between activities that alter the landscape such as gold mining, to create water-holding pans that act as breeding sites for *Anopheles* needed further study. This is because altering the landscape changes the microclimate for the developmental stages and the adult mosquito (Minakawa *et al*., 2006). The availability of breeding sites increases the population of the vector and, subsequently transmission of malaria (Kondepati, 2013). Studies have suggested entomological variables be included in research involving risk factors associated with malaria transmission (Essendi *et al*., 2019) in different settings in highland areas. Entomological characteristics act as key drivers in the transmission of malaria and hence may override the success of the interventions put in place. Therefore, data on the spatial distribution of malaria risk among populations of high risk amid temporal changes are needed. This will provide more information to the policy framers about the availability of hot spots where interventions need to be channeled more. Studies have shown that unemployed people with little or no education are at a significant risk of catching malaria. It has been reported that as the level of education increased and the income levels increased with formal employment, the risk of contracting malaria inversely reduced(Wanyonyi *et al*., 2018, Protopopoff *et al*., 2009). Higher education, employment, and increased household incomes improved house structures and environmental management. As a result occurrence of malaria within families drastically reduced, (Waiswa *et al*., 2022). The lack of this vital information in artisanal gold mining (AGM) and sugarcane farming regions of Western Kenya highlands is acting as a hindrance to the attainment of the sustainable development goals (SDGs). Kenya being a signatory to international treaties and the African Union (AU) Agenda 2063 envisages that a healthy citizenry is central to achieving socio-economic greatness and equity. The government of Kenya has health as a major plank of its socio-economic agenda (Africa, 2019). Therefore, a need for continuous monitoring of the situation of malaria and other infectious disease, to give evidence-backed information.

House structure characteristics were a major means of removing the risk of malaria among households. Houses that are constructed by many rural communities have a cultural dimension to them. Cultural factors in the house influence the wide adoption of malaria prevention strategies by individual households or the larger community. Human behavior guided the adoption of various malaria prevention practices. Houses with good paintwork/ceiling/more rooms and without cracked openings in walls/roofs/eaves/vents reduced significantly the likelihood of the occupants contracting malaria (Guerra *et al*., 2018, Lwetoijera *et al*., 2013, Liu *et al*., 2014). In village setups, house designs may not be as uniform as in urban estates. This could be a contributory risk factor in the house structure that could be increasing the malaria cases in the larger Kakamega County. Investigation of the risk factors in the structure of the house would provide a clearer picture of the successes of methods of malaria control available.

The bed net is the gold standard malaria prevention method used in large parts of SSA (Lindsay *et al*., 2021). As the net continues to be used, its quality deteriorates and this increases the likelihood of the *Anopheles* gaining access to bite the sleeping occupants. Continued washing diminishes the bed nets' insecticide integrity and consequently puts the users at risk of being bitten by infective mosquitoes (Minta *et al*., 2017). Damaged and regularly washed nets were a feature of low-income earning households who rely on donations by governments and other multi-national agencies. Donations by governments come after a lapse of not less than three years. The long duration between donations of the bed nets means the integrity of the net was lost before subsequent donations (Kawada *et al*., 2014, Mutuku *et al*., 2011). The unavailability of this vital information on the impact of the bed net status on the increase of malaria cases within the larger Kakamega County in Western Kenya highlands inhibits the evaluation of the efficacy of the bed nets as a primary malaria prevention tool.

The life cycle of a malaria vector involves two critical stages, the aquatic stage, and the infective stage. Female *Anopheles* mosquitoes must oviposit in a suitable water environment and breeding habitats that are heterogeneously dispersed to maintain similarly heterogeneous transmission within the human host population. Further, predictions have shown that when densities of adult mosquitoes peak and the breeding sites are closer to aggregated human settlements, biting rates are often higher (Nixon *et al*., 2014, D. L. Smith *et al*., 2004, Midega *et al*., 2012). In these gold mining regions, malaria transmission mitigation methods might significantly be lacking, more so if the gold mining is illegal or on a small scale (Grillet *et al*., 2021, Sanchez *et al*., 2017). In Rosterman mines and Eluche sugarcane growing regions, modification of the land for socio-economic reasons creates visible larval habitats next to residential houses (Nicholas *et al*., 2021). Studies have shown that when adult mosquitoes emerge, they fly to seek blood meal in the nearest possible residential house. A clear understanding of how the distance of the nearest residential house from the larval breeding sites played in the epidemiology of malaria will provide evidence-based information on the incorporation of appropriate malaria control strategies in addition to larval source management (Munyekenye *et al*., 2005). Additionally, it would point to where the availability of breeding habitats is causing the most malaria episodes to guide the location and nature of the control measures to be instituted.

MATERIALS AND METHODS

Study sites

The study was conducted in two rural villages of Western Kenya highlands. Rosterman mines village 0°28'N and 34°75'E is at a mid-highland altitude of 1450 ± 32 meters above sea level (asl) and is a settlement scheme having been a gold mine. After Rosterman Incorporated vacated in 1952 the locals there still practice small-scale artisanal gold mining. Eluche 0°33'N and 34°48'E at an altitude of 1344 ± 22 metres asl lies in a sugarcane belt of western Kenya. Following the collapse of large-scale sugarcane farming, residents still plant sugarcane on a small-scale basis. Residents of both villages engage in other economic activities such as food crop and livestock farming, small-scale trade, sand/ballast harvesting, and transportation using three-wheelers and motorbikes (locally known as bodaboda). The two sites were purposefully chosen as part of a wider pilot study.

The two villages are each headed by an assistant chief and a community administrator for national and county governments respectively. Both villages have community health volunteers (CHVs) who coordinate and assist in implementing public health issues. Unconfirmed reports indicate that malaria cases fluctuate seasonally and peak during the long rain season (March – June). Rosterman Mines village does not have a public health facility so residents have to seek medical assistance from neighboring villages, while Eluche has a dispensary.

Study design

A descriptive questionnaire adopted from different researchers was modified to suit the study objectives. It was used to survey on socio-demographic factors of the participants and history of malaria episodes. Interviewers with high school grades were used for pretesting and filling the questionnaire under the principal investigators.
A survey of larval aquatic habitats for anophelines was done three consecutive days monthly from November 2018 to October 2019. A 350 ml dipper was used to scoop water on a tray and anopheline larvae were observed, counted, and recorded. The locations of the larval habitats had their latitude, longitude, and elevation recorded using a Trimble GeoExplorer Global Positioning System (GPS) hand-held gadget, and the distance to the nearest residential house was measured up to 100 meters using a tape measure, beyond which the distance was estimated.

Data on house structure, the mosquito net, and malaria episodes were also collected on the same days as the sampling of aquatic habitats for larvae. Data on house characteristics and the status of the mosquito net were collected through direct observation while data on malaria episodes in the household was collected by interviewing the head of the household. The location of the surveyed houses was also taken by a handheld global positioning system device that showed the latitude, longitude, and elevation above sea level.

Data analysis

Statistical analysis was carried out using GraphPad Prism statistical software ver 5.0. Descriptive statistics were used to determine the relative frequencies of all the surveyed variables in which some variables had provisions for multiple responses. Graphs (by MS Excel) and tables were generated to illustrate the differences in the relative frequencies of the study variables. The levels of association among various variables were determined by Pearson's Chi-square test and Fisher's exact test at $p \leq 0.05$, in which appropriate confidence intervals (CI) for odds ratios (OR) were computed.

Informed Consent and Ethical Clearance

The protocols for this research were approved by Masinde Muliro University of Science and Technology Institutional Ethical Review Committee (MMUST-IERC) vide approval number MMUST/IERC/090/19, while the research license was obtained from the National Council for Science, Technology and Innovation (NACOSTI) vide license number: NACOSTI/P/20/3215. National and County administrative authorities permitted the study to proceed. The risks and benefits of participation in the study were explained to the respondents. Participation in the study was voluntary, with no monetary compensation provided to participants for their time. Informed written and verbal consent and assent were provided by heads of the households or the people they nominated for the exercise before the administration of the questionnaire.

RESULTS

Socio-demographic characteristics of the respondents

Fifty-four point eight-seven (54.87%) of the total interviewees were females. Of the study population, 83.00% had attained at least primary school qualification, 87.05% were employed (formal or self-employed), and 92.76% had a monthly average income of 50 US dollars or less as shown in Table 1. When the socio-demographic variables were tested for association with malaria episodes, the result was as in Table 1. All four socio-demographic characteristics studied were significantly associated with the history of malaria episodes in the surveyed households. However, males were more likely to suffer a malaria bout than females (OR = 1.70, p < 0.0001), while people who earned US dollars 50 or less had a higher likelihood to suffer from malaria than earners of more than US dollars 50 (OR = 21.88, p < 0.0001).

Table 1: Association between socio-demographic factors and history of malaria episode (univariate analysis)

Socio-demographic factors	N	%	OR	95% CI
Sex versus malaria episode				
Male	324	45.13	Ref	
Female	394	54.87	1.7010	1.3730 – 2.1080***
Level of education versus malaria episode				
Never been to school	122	17.00	Ref	
Primary or better	596	83.00	0.4234	0.3299 – 0.5434***
Occupation versus malaria episode				
Unemployed	93	12.95	Ref	
Self-employed or employed	625	87.05	0.3078	0.2354 – 0.4024***
Monthly income versus malaria episode				
≤ 50 US dollars	656	92.76	Ref	
> 50 dollars	62	7.24	21.880	16.150 – 29.650***

*** Significant at $p \leq 0.05$

N – Population size, OR – Odds ratio, CI – Confidence interval

Malaria episodes among households in the 12 months

Across the 12 months of the study, on average 37.67% of households reported having had a family member suffering from malaria as shown in Figure 1.

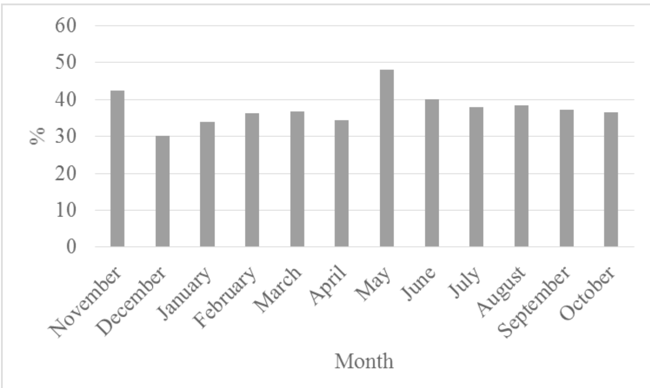

Figure 1: Reported malaria episodes among respondents expressed as a percentage of the total number sampled within the month.

House characteristics

Seventy-eight percent (78.13%) of the houses were old. Mud-walled houses accounted for 92.76% of all the houses with grass thatch at 0.90%. A majority (59.33%) of the houses had eaves and other openings such as cracks. Thirty-seven percent (37.19%) had doors and windows without screens. Eight nine percent (89.55%) had more than one room with 56.41% of them with more than four sleepers at any one given time Table 2. When the house structure characteristics were associated with the risk of malaria transmission, all of them had a significant association as indicated in Table 3. An individual in a grass-thatched house had a greater risk of malaria transmission compared to those in an iron-roofed house (OR = 1.73, $p < 0.0001$). On the other hand, an individual in a single-room house was four times more likely to suffer from malaria than one in a house with more than one room (OR = 4.14, $p < 0.0001$). The number of sleepers was significantly associated with the history of malaria episodes (OR = 0.63, $p < 0.0001$).

Table 2: Distribution of malaria risk factors in house structure

Risk factor	N	%
House		
New	157	21.87
Old	561	78.13
Wall		
Mud	666	92.76
Concrete	52	7.24
Roof		
Grass	5	0.70
Iron sheets	713	99.30
Eaves		
Absent	292	40.67
Present	426	59.33
Doors/windows		
With screen	451	62.81
Without screen	267	37.19
Number of rooms		
1	75	10.45
> 1	643	89.55
Number of sleepers		
≤ 4	313	43.59
> 4	405	56.41

Bed net status

Ninety-two percent of the households had a mosquito bed net. Of these nets, 33.84% had five or more holes and 12.64% were only hanged when it was time for sleep by the owner. The status of the mosquito net was significantly associated with the risk of transmission of malaria.

Distance of residential house from the nearest anopheline larval habitat

The distance of residential houses from anopheline larval habitats had a median distance of 251 ± 50 m. Thirty-seven percent (37.88%) of the houses were less than 100 m from the nearest anopheline-positive larval habitats. The distance of the residential house from the nearest larval habitat was significantly associated with the risk of transmission of malaria.

Table 3: Association between risk factors in house structure and malaria episodes (univariate analysis)

Risk factor	Odds ratio (OR)	95% CI
House versus malaria episode	1.7280	1.3640 – 2.1870***
Wall versus malaria episode	0.0378	0.0273 – 0.0521***
Roof versus malaria episode	68.94	28.210 – 168.50***
Eaves versus malaria episode	0.7053	0.5685 – 0.8752***
Screen versus malaria episode	0.2862	0.2303 – 0.3560***
Number of rooms versus malaria episode	4.1450	3.1150 – 5.5150***
Number of sleepers versus malaria episode	0.6256	0.5047 – 0.7755***
Holes in bed net versus malaria episode	0.3254	0.2598 – 0.4077***
Distance from larval habitat versus malaria episode	0.1177	0.1170 – 0.1864***

*** Significant at $p \leq 0.05$

Anopheline larval densities

During the survey period, all the sampled habitats had mosquito larvae except for a few containers in people's compounds. Of the sampled developmental stages, anophelines accounted for 8.33%. The density of the anophelines sampled is shown in Figure 2. There was a significant association between anopheline larval densities and malaria episodes among the respondents ($\chi^2 = 268.7$, df 11, 95% CI, $p < 0.0001$).

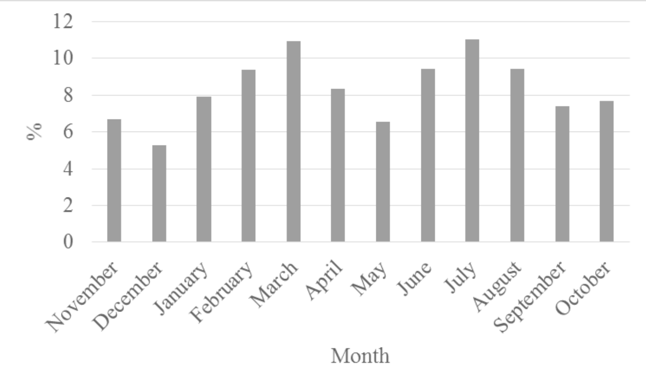

Figure 2: Monthly anopheline larval density expressed as a percentage of the total larvae sampled.

DISCUSSION

This study has shown that the epidemiology of malaria is influenced by socio-demographic characteristics, house design, bed net status, the distance of the residential houses from anopheline aquatic habitats, and anopheline larval densities. These factors could be contributing to the observed resurgence of the malaria disease in the highlands of Western Kenya. Malaria transmission dynamics have been shown to vary significantly between regions, villages, or households (Pinchoff *et al.*, 2016), and socio-demographic characteristics of households have a significant association with the risk of its transmission, as was also shown in Zambia (Nawa *et al.*, 2019) in which changes in demographics increased the risk of malaria transmission by contributing to weakness in program interventions such as the use of LLINs in rural settings. This study in the two sites in Western Kenya highlands has reported that males were more likely to suffer from malaria than their female counterparts. A study in Burkina Faso attributed this to the nature of males' work which keeps them outdoors more than females (Guglielmo *et al.*, 2021), and people aged over 21 years and males were more likely to be bitten by mosquitoes. A study in Tanzania showed that an educated population with knowledge of malaria transmission mechanics helped in reducing malaria incidences (Paul *et al.*, 2018), and in Kenya, house structure has been associated with incidences of clinical malaria (Essendi *et al.*, 2019). However, a study in India showed that there was no significant association between socio-demographics with malaria prevalence (Thomas *et al.*, 2018). It is considered by many kinds of research that impoverished families are poor consumers of services aimed at improving their health status (Ricci, 2012). Therefore, households should partner with authorities to improve their economic situation and hence consumption of malaria control services.

The observed malaria episodes during the one-year study period were a clear indicator that malaria was still a public health issue in these villages. Malaria incidences and prevalence around the world are a major challenge in public health. House structure characteristics play a role in thwarting transmission by limiting the ability of the vector to get into the house to bite the occupants. Better housing significantly reduced malaria prevalence in the studied households (Thomas *et al.*, 2018), and residing in well-constructed houses reduced mosquito numbers within the houses (Liu *et al.*, 2014). Haphazardly constructed residential houses are associated with malaria transmission (Ng'ang'a *et al.*, 2019), and houses with eaves and without screens sustained transmission of malaria. This current study has shown that the number of rooms in a house and the number of sleepers in that same house had a key role in malaria cases reported. The number of rooms and number of occupants or family size has been shown elsewhere to be associated significantly with increased malaria incidences (Ayele *et al.*, 2012). The presence of the net alone was meant to reduce the number of mosquito vectors in the house (Lwetoijera *et al.*, 2013) thus reducing the risk of the occupants being bitten by the vector. The LLINs were to break human-vector interaction during sleeping completely. However, a finding of this study in Rosterman mines and Eluche showed that the status of the LLINs significantly contributed to sickness due to malaria. The holes in the bed net provide points of entry for the vector to bite those sleeping under the net. A study in Zimbabwe supported the finding that the status of the net significantly contributed to malaria transmission (Kanyangarara *et al.*, 2018), particularly if the net was old, dirty, or needed re-treatment. The information obtained from this study adds to the existing need for proper house design and further knowledge on the involvement of members of a household in mitigating malaria infections through having a quality bed net.

The survey of aquatic habitats for the developmental stages of the vector showed that the vector stages were available all year round. Economic activities of the study sites involving artisanal mining, sugarcane farming, and sand/ballast harvesting may be potential drivers of the prevalence of the anopheline larvae. Therefore, larval source management (LSM) should come in to help forestalling the availability of the vector. This was supported by a study in Tanzania (Lowassa *et al.*, 2012) in which larval control was observed to reduce vector population. Another study suggested that proper environmental management by households and communities collectively reduced the mosquito burden (Alam *et al.*, 2018) in which removal of natural and human-made habitats reduced vector abundance. The distance of residential houses from larval habitats played a major role in enabling the mosquito vector to access the houses and thus sustain transmission. However, a study in India found that proximity to a larval habitat was not a guarantee that the household would have malaria bouts more often than those far away from such habitats (Thomas *et al.*, 2018). The knowledge of larval habitat availability is a requisite for the success of LSM (Thomas *et al.*, 2016) regardless of the distance from the nearest house. As people carry on with their economic activities, they should be made aware of the risks they are exposing themselves or their households to.

Limitations of the study

The study participants included household heads only and perhaps could have had an impact on the outcomes obtained which might not be representative. The study could have considered including other segments of the population such as professionals in public health.

Conclusion and recommendation

The study findings underpin the role of socio-demographic factors, house structure, availability of mosquito breeding sites and their distance from the residential houses, and the status of the LLINs in the transmission of malaria in rural areas in the highlands of Western Kenya. This study adds to the pool of information available by affirming that the studied factors may be drivers of the observed malaria resurgence in these areas. Therefore, this knowledge has the potential to revitalize efforts towards effective malaria control strategies amid socioeconomic gaps. Further research has to be done in different settings with more entomological and parasitological components to avail more evidence and provide risk maps for future action by the authorities.

Availability of data and supplemental material

Data and supplemental material are available from the corresponding author on request.

Competing interests

The authors declare that they do not have any competing interests.

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Author contributions

KDM conceptualized the study as partial fulfillment of the requirements of the award of Ph.D., data collection, curation, manuscript writing, NLK, PAO, JKC, and DHM assisted in refining the concept, methodology, and supervising the fieldwork, KDM and SA were the field guides, and KDM carried out data management, analysis, and interpretation, and all authors assisted in editing the article and gave authority for it to be sent for consideration for publication.

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Author information

KDM is a Ph.D. in Medical Parasitology student, NLK is a senior technologist, NST and SA are MSC students, PAO, JKC, and DHM are senior lecturers at MMUST. All authors belong to the Department of Biological Sciences, Masinde Muliro University of Science and Technology (MMUST), Kenya.

Declaration of Competing Interests

The authors wish to confirm that there are no known conflicts of interest associated with this manuscript and that there has been no financial support for this work that could have influenced its outcome.

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