Potential of household environmental resources and practices in eliminating residual malaria transmission: a case study of Tanzania, Burundi, Malawi and Liberia

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Abstract

Background: The increasing protection gaps of insecticide-treated nets and indoor-residual spraying methods against malaria have led to an emergence of residual transmission in sub-Saharan Africa and thus, supplementary strategies to control mosquitoes are urgently required.

Objective: To assess household environmental resources and practices that increase or reduce malaria risk among children under-five years of age in order to identify those aspects that can be adopted to control residual transmission.

Methods: Household environmental resources, practices and malaria test results were extracted from Malaria Indicators Survey datasets for Tanzania, Burundi, Malawi and Liberia with 16,747 children from 11,469 households utilised in the analysis. Logistic regressions were performed to quantify the contribution of each factor to malaria occurrence.

Results: Cattle rearing reduced malaria risk between 26%-49% while rearing goats increased the risk between 26%-32%. All piped-water systems reduced malaria risk between 30%-87% (Tanzania), 48%-95% (Burundi), 67%-77% (Malawi) and 58%-73 (Liberia). Flush toilets reduced malaria risk between 47%-96%. Protected-wells increased malaria risk between 19%-44%. Interestingly, boreholes increased malaria risk between 19%-75%. Charcoal use reduced malaria risk between 11%-49%.

Conclusion: Vector control options for tackling mosquitoes were revealed based on their risk levels. These included cattle rearing, installation of piped-water systems and flush toilets as well as use of smokeless fuels.

Keywords: malaria risk, residual transmission, household environmental resources and practices, insecticide-treated nets, indoor-residual spraying

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Introduction

Malaria is one of the dominant vector-borne diseases threatening humanity in Africa, putting approximately 694 million people at risk[1]. This disease is pronounced in regions where there is little or no interruption in the mosquitoes' life cycle, parasite development cycle[2] and gonotrophic cycle[3], a process of alternating blood feeding and laying of eggs. Recently, a substantial decline in malaria cases has been documented[4,5] especially in Sub-Saharan Africa (SSA) where widespread use of insecticide-treated nets (ITNs) and indoor-residual spraying (IRS) interventions have been promoted[1]. However, this achievement is momentary given the fact that ITNs and IRS methods alone cannot effectively eliminate malaria transmission to zero due to various limitations. Both methods are limited in scope, for example, IRS method only kills or repels mosquitoes which feed and rest indoors, while ITNs prevent night mosquito bites just around the beds[6,7]. Moreover, both methods affect mosquitoes which target human blood sources yet the majority of mosquitoes obtain most of their blood meals from animals[6].

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These limitations provide ample opportunity for outdoor active mosquitoes to multiply while sustaining some level of transmission beyond the reach of insecticide-treated surfaces. Besides, widespread use of ITNs and IRS has led to an apparent shift in mosquito behavioural traits[8] hence presenting a major ecological obstacle. For example both interventions have been observed to stimulate insecticide avoidance and early-exit behaviors among indoor-feeding vectors[6] as well as causing the emergency of insecticide-resistant mosquitoes[9,10]. They have also led to an increase in mosquito populations which feed and rest outdoors as well as those that become active early in the morning or evening when people have no protection[11].

With these behavioural shifts, residual transmission can occur rapidly in communities where large human populations and mosquitoes cohabitate as it has been evidenced in some regions of Uganda, Tanzania and Kenya where ITNs and IRS methods are being implemented[12]. Residual transmission is exacerbated by human movements through exportation and importation of malaria parasites among regions[13]. It is also caused by climate change which enhances mosquito breeding and pathogen development[14,15] and more importantly, the proximity of natural or artificial mosquito breeding sites to human settlements[16].

With the increasing protection gaps of ITNs and IRS methods coupled with a shift in mosquitoes' behaviour traits, achieving malaria elimination will require environmentally based interventions which minimize vector propagation as well as reducing human-vector contact outside human habitations[17]. Nevertheless, despite the fact that household environmental resources and practices such as livestock rearing are crucial in reducing malaria transmission, they have not been sufficiently identified and quantitatively evaluated to justify their contribution[6]. To address this knowledge gap, this study aimed at assessing household environmental resources and practices that influenced malaria risk among children under-five years of age and further identify those resources that can be adopted to control malaria transmission.

Methods

Data sources

Nationally representative population based datasets from the Malaria Indicators Surveys (MIS)[18] conducted in SSA were used. The criteria used to select datasets of countries analysed in this study were: 1) datasets which were publicly available and 2) those containing sufficient information on malaria test results as well as household environmental resources and practices such as, drinking water sources, fecal disposal methods, types of cooking fuel and types of livestock/poultry kept. Datasets of four countries (Burundi, Liberia, Malawi and Tanzania) met these criteria and were used. In these surveys, representative samples were obtained using same probability sampling techniques consisting of a two-stage cluster sampling and probability proportional to estimate cluster size and sampling error. Standardised questionnaires were designed to collect information on the social, economic and environmental aspects of households. Rapid Diagnostic Test (RDT) and the Blood Smear Test (BST) were used to test malaria parasitaemia among children under-five years of age after getting consent from household heads. Further details on data collection exercises can be found on MIS website[18].

Study population, sample size and variable selection

A total of 22,472 households were involved in the MIS for the four countries, but in this study, only 11,469 households with 16,747 malaria-tested children were purposively selected. This was done to minimize the interference of those households without both children and test results in the analysis. In the study, malaria RDT results were used in the analysis. The response variable for each selected country was the malaria RDT results (positive or negative). The explanatory variables were those household environmental resources and practices that potentially influenced the survival, feeding and breeding of mosquitoes. Explanatory variables were categorised (Table 1).

Table 1. Selected explanatory variables that were used for modeling

Explanatory variable	Categories
Drinking-water sources	**Household used/fetched water from**
	1. Piped water in yard/dwelling
	2. Public stand-pipe
	3. Private taps
	4. Borehole
	5. Protected well
	6. Unprotected well
	7. Protected spring
	8. Unprotected spring
	9. River/lake/reservoir/pond/stream
Time required to fetch water	**Intervals of 10 minutes per water source**
Fecal-disposal mechanism	**Household used or had**
	1. No toilet facility/bush/field
	2. Flush toilets
	3. Ventilated improved pitlatrines
	4. Composting toilet
	5. Pitlatrines with slab
	6. Pitlatrines without slab
Livestock/poultry kept	**Household kept**
	1. Cattle
	2. Goats/sheep
	3. Poultry
	4. Pigs
Types of cooking fuel	**Household used**
	1. Firewood
	2. Charcoal

Data analysis

Given the categorical nature of the variables, both univariate and multivariate logistic regression models were developed separately for each country for comparison purposes. The analysis was designed to reveal those explanatory variables that were significant and those that were not, rather than to find the best models for predictive purposes. Each variable was first assessed against the RDT results using univariate logistic analysis and the likelihood ratio test. Variables significant at p-value < 0.05 formed a candidate list for the multivariate logistic regressions. All categorised time intervals for the time required to fetch water were entered into the multivariate model. Variables such as child age, urban residence and use of ITNs were added as covariates in the final model to avoid omitted-variable bias due to confounding. MIS-generated population sample weights were used in all models to obtain representative results with p-value < 0.05 used for all analyses to determine the statistical significance. The analysis was conducted by JMP 10, a product of Statistical Analysis System.

Results

Table 2 shows country-specific logistic regressions of explanatory variables tested against malaria RDT results of children under-five years. The adjusted odd ratios of the time required to fetch water against malaria risk across the four countries were plotted (Figure 1).

Table 2. Household environmental resources and practices associated with malaria risk among children under-five years of age

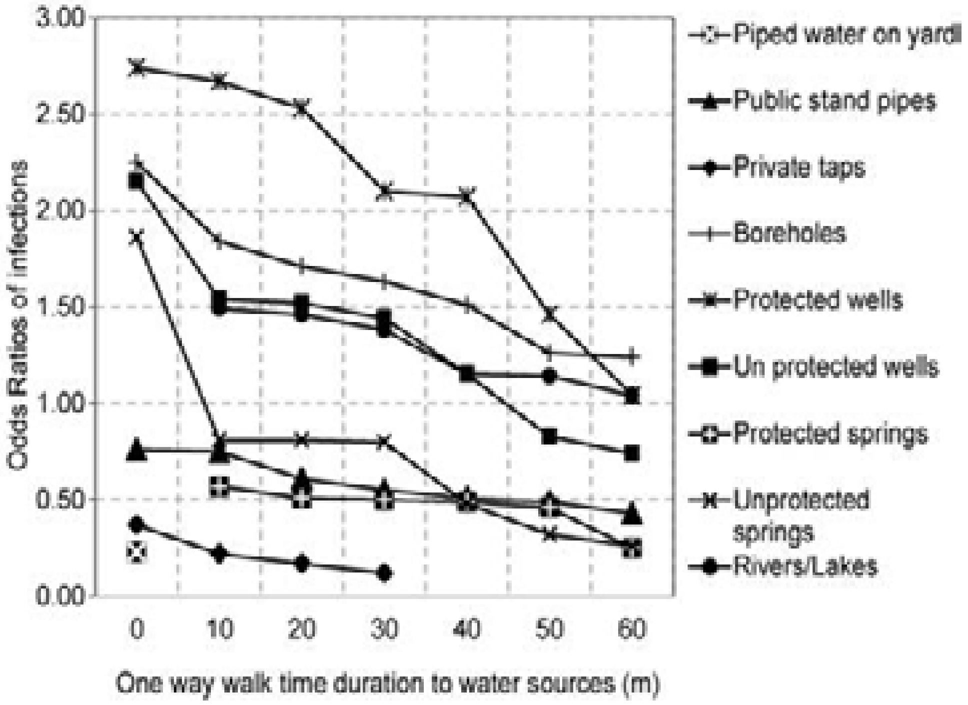
	Tanzania (n=5066, c=7695)				**Burundi (n=2667, c=3750)**			
	Unadjusted		**Adjusted**		**Unadjusted**		**Adjusted**	
Predictors	**OR(95%CI)**	***p*-value**	**AOR(95%CI)**	***p*-value**	**OR(95%CI)**	***p*-value**	**AOR(95%CI)**	***p*-value**
Child's age (Month)	na		1.26(0.94-1.70)	0.128	na		0.79(0.60-1.05)	0.108
Urban residence	0.30(0.21-0.40)	<0.001*	0.94(0.61-1.42)	0.787	0.14(0.08-0.23)	<0.001*	0.26(0.13-0.49)	<0.001*
Child slept in ITN	1.45(1.15-185)	0.001*	1.47(1.16-1.89)	0.001*	0.60(0.54-0.70)	<0.001*	0.65(0.56-0.77)	<0.001*
Livestock types								
Cattle	0.87(0.73-1.03)	0.002*	0.55(0.45-0.67)	<0.001*	0.53(0.41-0.67)	<0.001*	0.51(0.40-0.65)	<0.001*
Goats	1.30(1.11-1.52)	0.001*	1.32(1.09-1.60)	0.005*	1.32(1.14-1.54)	0.000*	1.26(1.07-1.48)	0.006*
Poultry	1.37(1.15-1.63)	<0.001*	1.15(0.95-1.39)	0.155	1.23(1.05-1.43)	0.011*	1.17(0.98-1.38)	0.078
Pigs	0.18(0.09-0.32)	<0.001*	0.18(0.09-0.33)	<0.001*	0.87(0.70-1.07)	0.189	-	
Water sources								
Piped water yard	0.06(0.02-0.16)	<0.001*	0.13(0.03-0.32)	<0.001*	0.01(0.00-0.06)	<0.001*	0.05(0.00-0.58)	0.008*
Public stand-pipes	0.61(0.46-0.80)	0.000*	0.70(0.51-0.95)	0.019*	0.19(1.00-1.42)	0.002*	0.52(1.25-1.84)	<0.001*
Private taps	0.39(0.25-0.57)	<0.001*	0.62(0.39-0.95)	0.029*	0.10(0.02-0.32)	<0.001*	0.23(0.04-0.75)	0.011*
Borehole	1.49(1.16-1.89)	0.002*	1.50(1.10-1.88)	0.008*	5.25(0.06-1.89)	0.560	-	
Protected well	1.18(0.91-1.50)	0.205			1.94(1.38-2.69)	0.000*	2.19(1.53-3.10)	<0.001*
Unprotected wells	1.97(1.66-2.32)	<0.001*	1.56(1.29-1.88)	<0.001*	1.76(1.32-2.34)	0.000*	1.50(0.84-2.57)	0.170
Protected springs	0.69(1.03-2.63)	0.039*	0.78(1.06-2.83)	0.029*	0.79(0.67-0.92)	0.200	-	
Un protected springs	1.93(0.69-1.23)	0.610	-		1.78(0.67-0.91)	0.490	-	
River/lakes	1.93(0.76-1.13)	0.478	-		2.67(2.00-3.55)	<0.001*	2.45(1.81-3.31)	<0.001*
Toilet facilities								
No toilet facility	1.76(1.46-2.10)	<0.001*	1.35(1.11-1.63)	0.003*	3.78(2.60-5.49)	<0.001*	3.57(2.35-5.42)	<0.001*
Flush toilets	0.15(0.07-0.28)	<0.001*	0.40(0.18-0.78)	0.005*	0.03(0.00-0.14)	<0.001*	0.04(0.02-8.01)	0.009*
Ventilated improved pits	0.40(0.15-0.85)	0.148	-		np		-	
Pitlatrines without slab	1.21(1.04-1.42)	0.168	-		1.86(0.71-1.03)	0.105	-	
Pitlatrines with slabs	1.65(0.52-0.81)	<0.001*	1.85(0.67-1.08)	0.190	1.04(0.88-1.24)	0.004*	1.30(1.07-1.58)	0.008*
Cooking fuel								
Charcoal	0.29(0.21-0.39)	<0.001*	0.58(0.38-0.85)	0.005*	0.29(0.19-0.42)	<0.001*	0.79(0.50-1.23)	0.31
Firewood	3.58(2.66-4.94)	<0.001*	1.80(1.23-2.68)	0.002*	3.05(2.19-4.35)	<0.001*	1.44(0.98-2.16)	0.004*

Table 2. Household environmental resources associated with malaria risk among children under-five years of age (*Continued*)

	Malawi (n=1625, c=2115)				**Liberia (n=2111, c=3187)**			
	Unadjusted		**Adjusted**		**Unadjusted**		**Adjusted**	
Predictors	**OR(95%CI)**	***p*-value**	**AOR(95% CI)**	***p*-value**	**OR(95% CI)**	***p*-value**	**AOR(95% CI)**	***p*-value**
Child's age (Month)	na		1.85(1.33-2.56)	0.000*	na		2.10(1.59-2.80)	<0.001*
Urban residence	0.18(0.12-0.25)	<0.001*	0.39(0.25-0.60)	<.0001*	0.36(0.31-0.42)	<0.001*	0.72(0.57-0.92)	0.008*
Child slept in ITN	0.84(0.70-1.00)	0.048*	0.88(0.73-1.07)	0.202	0.93(0.80-1.08)	0.331	0.99(0.85-1.17)	0.945
Livestock types								
Cattle	0.66(0.43-0.98)	0.040*	0.54(0.35-0.83)	0.005*	0.72(0.23-5.05)	0.020*	0.74(0.55-1.00)	0.047*
Goats	1.15(0.94-1.40)	0.170	-		1.17(0.90-1.51)	0.410	-	
Poultry	1.19(1.01-1.41)	0.040*	1.01(0.84-1.21)	0.933	1.25(1.07-1.45)	0.560	-	
Pigs	1.15(0.86-1.53)	0.400	-		1.51(1.03-2.23)	0.360	-	
Water sources								
Piped water yard	0.16(0.09-0.28)	<0.001*	0.23(0.12-0.43)	<.0001*	0.64(0.32-1.20)	0.020*	0.42(0.68-2.88)	0.346
Public stand-pipes	0.27(0.19-0.36)	<0.001*	0.33(0.23-0.47)	<.0001*	0.10(0.05-0.17)	<0.001*	0.27(0.13-0.51)	<0.001*
Borehole	1.31(1.11-1.55)	0.000*	1.75(0.61-0.93)	0.009*	1.70(0.22-1.98)	0.010*	1.19(0.36-3.60)	0.003*
Protectedwell	1.79(0.53-1.16)	0.020*	1.44(0.25-0.78)	0.005*	1.17(1.01-1.37)	0.040*	1.36(1.04-1.78)	0.025*
Unprotected wells	2.41(1.89-3.07)	<0.001*	1.22(0.75-2.00)	0.412	1.73(0.55-0.95)	0.200	-	
Protected springs	0.33(0.02-1.85)	0.220	-		0.10(0.00-2.88)	0.220	-	
Un protected springs	1.64(0.98-2.78)	0.060*	1.90(0.46-1.78)	0.768	1.93(1.27-2.96)	0.000*	1.65(1.01-2.71)	0.047*
River/lakes	1.64(1.07-2.53)	0.240	-		1.79(1.46-2.19)	<0.001*	1.55(1.12-2.16)	0.009*
Toilet facilities								
No toilet facility	2.00(1.59-2.51)	<0.001*	1.66(1.20-2.30)	0.002*	1.62(1.40-1.88)	<0.001*	1.24(0.82-1.28)	0.004
Flush toilets	0.00(0.00-0.14)	0.200	-		0.31(0.24-0.39)	<0.001*	0.53(0.39-0.73)	<0.001
Ventilated improved pits	0.54(0.33-0.85)	0.100	-		0.95(0.66-1.36)	0.780	-	
Pitlatrines without slabs	1.94(0.79-1.13)	0.520						

*indicates statistical significance at *p*-value < 0.05. Dashes indicate that the predictors were excluded from the multivariate regressions. Abbreviation **n** and **c** indicate total number of households and children respectively while **na** stands for not applicable and **np** represents no ventilated improved pits. All *p*-values are within the limits of 95% confidence interval.

Figure 1. Relationship between household proximity to different drinking water sources and malaria risk among children



Discussion

The practice of keeping livestock influenced malaria risk greatly. The adjusted models predicted that malaria risk decreased significantly between 26%-46% among households rearing cattle. There are two possible explanations to this observed protective effect. Cattle generate significant amounts of olfactory cues which attract large numbers of mosquitoes[19,20], and this reduces human exposure to mosquito bites in and around homesteads. Added to this, is a shift in mosquito biting behaviourial traits, that is, from people to cattle which is caused by the continuous use of ITNs and IRS methods[21]. With these scenarios, cattle rearing can benefit malaria control programs in three ways.

First, mosquitoes become frequently attracted to insecticide-treated cattle which reduce their abundance and infection abilities[22]. Second, cattle are not reservoir hosts for malaria parasites, so the transmission cycle is broken when mosquitoes feed on cattle[23].

Third, mosquitoes are part of the broader ecosystem of interactions with other organisms[17] and their behavioral shift to feeding on cattle subject them to predators such as small birds and reptiles. However, integrating malaria control priorities into animal husbandry is paramount since it can ensure that insecticides applied to cattle are those with a purely toxic mode of action without irritant or repellent properties that could chase away mosquitoes[6]. Nevertheless, the models also predicted an increased risk due to goat rearing in Tanzania (32%) and Burundi (26%). Similarly, keeping poultry increased malaria risk between 0.1%-17%, but this increase was not significant.

Drinking water sources were key determinants that influenced malaria risk. The adjusted models indicated that households which used water from piped-water systems (i.e. piped-water on yards, public stand-pipes and private taps) had their malaria risk reduced significantly ranging from 30-87% in Tanzania, 48%-95% in Burundi, 67%-77% in Malawi and 58%-73 in Liberia. There are two explanations for the protective effects of piped-water systems and these can be exploited to reduce residual transmission.

First, piped-water systems are normally located either in or close to households, which reduces the time required to fetch water, thus allowing parents to have ample time to guard their children against mosquito bites. Second, the enclosed nature of piped-water systems significantly reduce the number of mosquito breeding sites[24], thereby prolonging the mosquito gonotrophic cycle as well as interrupting malaria transmission[3]. For households which used water from unprotected wells, malaria risk increased between 22%-56%, though this increase was only significant in Tanzania. This increase is due to the fact that wells serve as meeting places for humans and mosquitoes[24], provide oviposition sites[16] and shorten the gonotrophic cycle[3] especially when located near human habitations. Interestingly, the models predicted that boreholes significantly increased malaria risk between 19%-75%. An explanation to this result is that most boreholes in SSA are normally installed in communities and are usually congested with long queues compared with piped water systems. Thus, when a single borehole with a poorly maintained drainage channel[25] is surrounded by a large number of residents, mosquito biting and parasite transmission among children left at home are inevitable in such communities (Figure 1).

Household proximity to water sources had significant influence on malaria risk (Figure 1). Households with piped-water systems on their premises had a low malaria risk and this continued to reduce gradually as walk-time duration to fetch water increased. This reduction is attributed to a fact that piped-water systems discourage oviposition[24] and thus makes it difficult for mosquitoes to complete their gonotrophic cycles. Households which had boreholes, unprotected springs, protected and unprotected wells on their premises had a high malaria risk and as time to obtain water from these water sources increased, the risk kept on reducing gradually. A possible explanation to this result is that open water sources in household premises created potential breading sites that shortened the gonotrophic cycles while increasing transmission. As fetching water time increased, malaria risk reduced due to prolonged gonotrophic cycles attributed to limited long-range flight abilities of mosquitoes[3]. However, although distant water sources reduced malaria risk, this observation should not jeopardize efforts geared to improve water access near households, because reducing the time to fetch water has been observed to improve child health[26]. Thus, improving drainage channels, reducing unnecessary open water surfaces and implementing larvicidal treatments is crucial in reducing malaria risk of these water sources[27].

Regarding household sanitation, malaria risk varied greatly with different types of human fecal disposal methods. The adjusted models indicated that households with flush toilets had their malaria risk reduced between 47%-96%. Households which did not have any form of toilet facility were at a high risk ranging from 24%-66%. This increase was not surprising because mosquitoes have overtime started changing their breeding preference to contaminated surroundings[16]. Interestingly, households which used pitl atrines with slabs had their malaria risk increased between 10%-85%. An explanation to this finding is that when water is used for anal cleansing, it creates breeding sites inside the pit latrines[16]. Additionally, poorly maintained pit latrines can become ideal places for mosquito breeding when floods occur during the rainy season. In such situation, mosquitoes can only be suppressed when expanded polystyrene beads are used[27].

Household domestic fuel had some influence on malaria risk. The models estimated that the use of firewood for cooking greatly increased the risk between 22%-75%. The reasons for this increase are varied. First, smoke from domestic fuel increases the frequency with which ITNs are washed, thus reducing their effectiveness in repelling or killing mosquitoes[28]. Moreover, women and children gather much of the firewood in SSA countries which exposes them to frequent mosquito bites in the forests[8]. Additionally,the shift in mosquito behaviour from indoor late-night biting to outdoor early-evening biting[11] coincides well with major outdoor cooking activities in most homesteads of SSA countries. Charcoal use lowered malaria risk between 11%-49% with significance of this reduction presented in Tanzania. Although charcoal use may have this protective effect, it is one of the fundamental drivers of deforestation in SSA, thus, its use in malaria control programs is not advisable in both short and long run. Alternatively, promotion of other renewable indoor cooking fuels such as gas, solar and electricity can be paramount in reducing outdoor evening mosquito bites which normally occur during meal preparations. Besides, some plant leaves have been proved to be able to function as mosquito repellent protecting individuals from host-seeking mosquitoes according to a valuable review from Maia and Moore[29]. Therefore, policies to effectively manage forest resources in malaria control should be comprehensively considered in future prevention programs.

Conclusion

In order to sustain and consolidate the recent gains achieved by ITNs and IRS towards malaria reduction in SSA, significant investment is required to promote supplementary environmentally- based vector control strategies that can divert mosquitoes from humans, suppress vector propagation and parasite development. This study provided useful insights of vector control options for tackling mosquitoes that persist and mediate residual transmission. These include cattle rearing, use of flush toilets as well as installation of piped-water systems mainly piped-water on yards, public standpipes and private taps. Additionally, the use of indoor smokeless fuels like gas, electricity, and solar energy can reduce exposure to outdoor mosquito bites. We believe that these vector control options can be used to increase the efficacy of ITNs and IRS interventions and produce synergistic effects in reducing malaria risk among children and other vulnerable people.

Competing interests

The authors declare that they have no competing interests.

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