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Original Contribution

Environmental Management for Malaria Control: Knowledge and Practices in Mvomero, Tanzania

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Abstract: Environmental conditions play an important role in the transmission of malaria; therefore, regulating these conditions can help to reduce disease burden. Environmental management practices for disease control can be implemented at the community level to complement other malaria control methods. This study assesses current knowledge and practices related to mosquito ecology and environmental management for malaria control in a rural, agricultural region of Tanzania. Household surveys were conducted with 408 randomly selected respondents from 10 villages and qualitative data were collected through focus group discussions and in-depth interviews. Results show that respondents are well aware of the links between mosquitoes, the environment, and malaria. Most respondents stated that cleaning the environment around the home, clearing vegetation around the home, or draining stagnant water can reduce mosquito populations, and 63% of respondents reported performing at least one of these techniques to protect themselves from malaria. It is clear that many respondents believe that these environmental management practices are effective malaria control methods, but the actual efficacy of these techniques for controlling populations of vectors or reducing malaria prevalence in the varying ecological habitats in Mvomero is unknown. Further research should be conducted to determine the effects of different environmental management practices on both mosquito populations and malaria transmission in this region, and increased participation in effective techniques should be promoted.

Keywords: malaria, environmental management, Tanzania, community participation

INTRODUCTION

Malaria is the leading cause of death for both adults and children in Tanzania, killing 100,000-125,000 people annually (CDC, 2005). Environmental conditions play an important role in the transmission of malaria, as macroenvironmental factors, such as climatic conditions (temperature and rainfall), microenvironmental factors, such as local topography, and human land use and management greatly influence vector abundance. Environmental management is an underutilized but promising technique for vector control, because it decreases the available breeding habitat for mosquitoes by removing or modifying stagnant

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or slow-moving water sources (Ault, 1994). It is estimated that 42% of the malaria burden in Sub-Saharan Africa could be prevented through environmental management (Pruss-Ustun and Corvalan, 2006).

Environmental management consists of installing and maintaining drains, removing pools of stagnant water, managing vegetation, irrigating intermittently, and altering rivers to create faster flowing water (Keiser et al., 2005). Additional techniques include filling holes and larviciding (Lindsay et al., 2004; Walker 2002; Yohannes et al., 2005).

Multiple studies have shown that the reduction of mosquito-breeding habitat through environmental management has significantly decreased mosquito abundance in surrounding areas (Ault, 1994; Okech et al., 2008; Yasuoka et al., 2006a; Yohannes et al., 2005). Additionally, in Nepal, community-based environmental management consisting of clearing vegetation in ponds, draining and filling areas that collect water, and repairing irrigation canals resulted in a reduction in malaria cases by 35% in the intervention villages in 1983 versus the baseline year (1982) (Ault, 1994). This form of malaria control is relatively inexpensive, simple for local communities to implement and maintain, and not harmful to humans or the local environment (Keiser et al., 2005). Therefore, community-level environmental management, if implemented as part of an integrated vector-management program and paired with control strategies, such as mosquito nets, could prove effective at reducing malaria burden.

Whereas environmental management activities often are performed by a central authority or a set of volunteers/workers (Lindsay et al., 2004; Utzinger et al., 2001; Yohannes et al., 2005), there is increasing emphasis on the need to enlist local communities in ongoing, decentralized malaria control activities. Yet household-level environmental management relies on sufficient community participation to achieve efficacy in reducing mosquito populations. An accurate understanding of mosquito biology and habitat requirements is likely to play a role in one's participation in controlling these habitats to reduce mosquito populations. Studies have illustrated that a lack of understanding of mosquito biology is prevalent in African communities. For example, in a survey of 1,451 households in Kenya, 65% of respondents stated that they did not know what mosquito larvae look like (Opiyo et al., 2007). Educational programs have been used to increase community understanding and participation in malaria control through activities such as identifying breeding habitat, observing larval mosquitoes, and teaching techniques for suppression of mosquito breeding (Mukabana et al., 2006; van den Berg and Knols, 2006; Yasuoka et al., 2006b).

With a growing focus on community-level environmental management as a component of malaria control, it becomes crucial to determine existing beliefs regarding the link between malaria and the environment, and how these beliefs relate to environmental management practices. The primary objective of this study is to explore community knowledge and practices on environmental management for malaria control. Specifically, our goal is to assess the environmental management practices used by community members and to evaluate the relationships among knowledge, beliefs, and environmental management practices. By providing a picture of the existing knowledge and practices related to environmental management for malaria control in a rural, agricultural region of Tanzania, we hope to identify key challenges and opportunities for improving the effectiveness of environmental management in this region as well as in a larger context.

Methods

Study Area

The study was conducted in Mvomero District, a malaria endemic area located in the Morogoro region of east-central Tanzania. Prevalence of malaria among children younger than aged 5 years in the Morogoro region is 15.7% (Tanzania Commission for AIDS et al., 2008), but parasite rates among residents of seven villages in Mvomero were found to be much higher, averaging 34.5% (Mboera et al., 2007). Higher malaria prevalence was found among residents of villages in Mvomero practicing rice irrigation compared with those from villages practicing sugarcane, maize, and livestock farming (Mboera et al., 2007).

Mountains and highlands are located in the northwest of the District, lowland rainforest in the north and central areas, and drier woodlands in the south. Rainfall is bimodal, with a long wet season from March to May and a short wet season from October to December. Average annual temperatures in Mvomero range from 20 to 30°C (Mlozi et al., 2006). The northern area has a humid to subhumid climate (Lyimo et al., 2004), whereas the southern part of the district is much drier (Karimuribo et al., 2005). The majority of the district's economic activity is derived from agricultural crop production, and the southern region is composed primarily of pastoralist livestock-keeping.

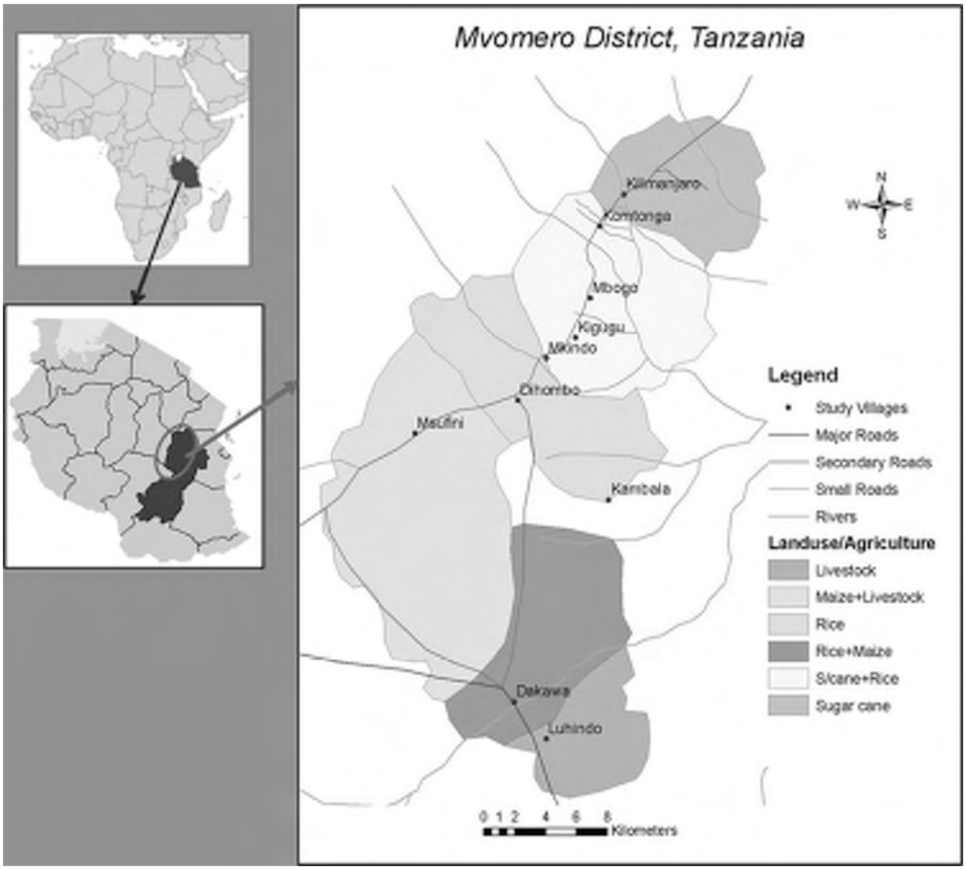

Figure 1. Map of Tanzania showing Morogoro Region and Mvomero District with ten study villages.

Figure 1 shows a geo-referenced map of the main agro-ecological zones in the district. The ten study villages shown in this figure were chosen to represent a range of zones and economic activities.

The primary malaria vectors in Mvomero are *Anopheles gambiae sl* and *A. funestus* (Mboera et al., 2007). *A. gambiae sl* is a species complex, which may be composed of multiple species, including *A. gambiae ss* and *A. arabiensis* (Coluzzi et al., 1979). The particular species composing this complex in Mvomero has not yet been determined. *A. gambiae ss* is a domestic species, breeding in puddles lacking vegetation, hoof prints, rice fields, sunlit pools, and man-made containers. *A. funestus* breeds in large ponds with vegetation, sunlit swamps, rivers, and grassy areas near stream edges. *A. arabiensis* breeds in small, temporary habitats with little or no vegetation as well as in flooded rice fields (Gimning et al., 2009; IAMAT, 2009; Service and Townson, 2002).

Study Design

This cross-sectional study used mixed methods (both quantitative and qualitative). Research activities were performed during June 2007 to describe knowledge and practices related to malaria, mosquito ecology, and environmental management among the study communities. Household data were collected using a survey instrument that was developed based on a previous household survey conducted in the Mvomero District by the National Institute for Medical Research (NIMR) (Mboera et al., 2007), a preliminary visit to the study site by other members of the research team in June 2006, and consultation with agricultural and health experts familiar with the area.

The survey instrument was initially drafted in English and then translated into Kiswahili by Tanzanian collaborators. Five experienced Tanzanian survey enumerators participated in a four-day training session on survey implementation and ethics, and this session also served as a preliminary focus group discussion that helped to refine the translation and wording of the survey. Finally, the survey was field tested via a focus group and formal pretest on June 4, 2007, in Miswe Chini, a rural village in the Kibaha district, approximately 64 km west of Dar es Salaam. Miswe Chini was selected for the pretest because of its similarity to the majority of the study villages in environmental, agricultural, and socioeconomic characteristics.

Data Collection Techniques

A total of 408 household surveys were conducted in the ten study villages in Mvomero District between June 12 and June 29, 2007, with population-weighting used to determine the sample size for each village.[1] Within each village, households were selected for inclusion in the study at random from rosters provided by village leaders. Half of the surveys were conducted with male heads of household and half with female primary caregivers.

Qualitative data collection activities were held in eight of the ten study villages. Four focus group discussions (FGDs) were conducted with village members to discuss the topic matter contained in the surveys in more detail. FGDs were conducted with women in Komtonga and Msufini and with men in Kambala and Mkindo. The length of discussions ranged from two to three hours. One of this study's authors (Shayo) moderated the discussions, which were tape recorded. A research assistant served as a translator for the English-speaking investigators. Each FGD was then transcribed and translated from Kiswahili to English. Additionally, three in-depth interviews (IDIs) were conducted with key informants (village chairmen and community health workers), in Mbogo, Dihombo, and Dakawa. These interviews assessed malaria knowledge, prevention and treatment behaviors; use of and opinions on various antimalarial drugs; priorities of villagers; community programs; and environmental management for malaria control. The interviews were conducted by the investigators with the help of a translator and were transcribed and translated into English.

Ethical approval was granted by the Institutional Review Board of Duke University in Durham, NC, USA, and the National Health Research Ethics Review Subcommittee of the National Institute for Medical Research (NIMR) in Dar es Salaam, Tanzania. Research clearance was granted by the Tanzania Commission for Science and Technology.

Data Analysis

The survey data were coded and entered into machine-readable format by a group of staff members at NIMR, supervised by the Institute's statistician. The data were then analyzed using Stata IC/10.0 for Macintosh. Multivariate analysis using probit regressions was used to determine the correlation between a number of household- and village-level indicators and knowledge of mosquito ecology and its link to malaria. Qualitative data were transcribed and translated to English. The main themes were developed and later data were coded using the NVIVO software and analyzed using matrices.

Results

Study Population

Table 1 summarizes key demographic and socioeconomic characteristics of the 408 survey respondents. As intended, the sample was split nearly evenly between males and females, and the average age of respondents was 42 years. Approximately two-thirds of respondents were Muslims and one-third were Christians. Educational attainment was quite low; 40% of respondents had no education and 53% had only a primary school education. The majority of the sample (83%) engaged in crop farming as their main

Table 1. Demographic and Socioeconomic Characteristics of Respondents (n = 408)

Variable	Number (%)
Age (yr)	
17–29	76 (19)
30–49	207 (51)
50–69	86 (20)
70–95	39 (10)
Gender	
Male	199 (49)
Female	209 (51)
Religion	
Christian	144 (35)
Muslim	264 (65)
Education	
None	160 (40)
Primary school	217 (53)
Secondary school or above	30 (7)
Occupation	
Crop farming	338 (83)
Pastoralist/mixed farming	30 (7)
Business owner/employee	20 (5)
Other	18 (5)
Housing size	
4 or more rooms	76 (19)
2–3 rooms	260 (64)
1 room	68 (17)

[1]The survey instrument is available from the authors upon request.

occupation, 7% were pastoralists or mixed farmers (crops and livestock keeping), and 5% were employed in business activities. People younger than aged 17 years and adult students were not interviewed for the study. Two-thirds of respondents lived in houses consisting of two to three rooms, 19% lived in houses with four or more rooms, and 17% lived in single-room houses.

Community Knowledge on Malaria, Mosquito Ecology, and the Environment

Nearly all respondents (97%) listed mosquitoes as agents for transmitting malaria. In addition to mosquitoes, other common responses included an unclean environment (30%) and dirty water (18%).[2] Eighty-seven percent of respondents believed that greater/heavy rainfall during the wet season increases mosquito populations, leading to more malaria cases during this time. This is supported by a health officer:

> During rainy seasons there [is] stagnated water all over the area, and most of the people have maize farms close to their houses, thus the grasses in the farms contribute to mosquitoes, (IDI, community health worker).

The majority of the respondents (90%) believed that reducing the population of mosquitoes reduces malaria. Environmental cleanliness was a common theme when respondents were asked about methods to reduce mosquito populations (Table 2). Cleaning the environment around one's home (e.g., removing artificial containers and garbage) was the most commonly listed method (50%), followed by using mosquito nets (40%), clearing vegetation around the home (39%), and draining stagnant water (33%). Seventy-three percent of respondents listed at least one of the three environmental management techniques (cleaning, clearing vegetation, and/or draining water) as a method to reduce mosquito populations.

The belief that tall grasses and bushes foster mosquito breeding was pervasive among community members in FGDs as well as among community leaders and health workers in IDIs, because many were confident that cleaning the environment and cutting grasses and bushes around the home could help to reduce mosquito populations. To illustrate this, when asked about ways to reduce mosquito populations, one focus group participant stated,

Table 2. Methods used to Reduce Mosquito Populations in the Community

Response	Number (%)
Clean environment around home	203 (50)
Use bednets	163 (40)
Clear vegetation around home	159 (39)
Drain stagnant water around home	135 (33)
Spray insecticides inside home	126 (31)
Spray insecticides outside of home	120 (29)
Use larvicides	53 (13)
Drain rice fields	10 (2)
I don't know	20 (5)

> Generally it is environmental cleanliness, to destroy all mosquito breeding places like filling with sands all areas with stagnated water, slashing all tall grasses around our houses and so on, (FGD, female community member).

Whereas knowledge on the link between *adult* mosquitoes, environmental conditions, and malaria was relatively high among respondents, knowledge related specifically to mosquito *larvae* was generally lower. Although 75% of the respondents agreed with the statement that reducing the population of mosquito larvae reduces malaria, 5% said no, and 20% did not know. There also was a wide range of responses when asked about locations where mosquito larvae can be found. Whereas most respondents stated that larvae can be found in stagnant water (65%), nearly 30% stated that they did not know where larvae can be found. In FGDs, beliefs about the habitats in which mosquito larvae live were quite varied, with responses ranging from sources of stagnant water (e.g., ponds and lowland farms) to areas that are ecologically unlikely to support larval *Anopheles* mosquitoes (e.g., bushes, latrine pits, and rubbish pits). One participant said, "*They are found under the bed. You know the larvae like to live in areas where it's cool and quiet*," (FGD, female community member). However, the plenary corrected her by saying that those are not mosquito larvae, rather they are adult mosquitoes.

Environmental Management Practices for Malaria Control

Study participants were asked the question, "What can people do to protect themselves from malaria?" A follow-up

[2] Note that respondents were able to provide more than one answer to a number of the survey questions, so percentages may total greater than 100.

Table 3. Practices used by Respondents to Protect Themselves from Malaria

Response	Number (%)
Use a bednet	356 (87)
Clean residential surroundings	202 (50)
Clear grass/bushes around the home	131 (32)
Drain stagnant water	73 (18)
Spray insecticides inside or outside home	46 (11)
Take anti-malarial drugs intermittently	40 (10)
Use mosquito coils	27 (7)
Burn local herbs/plants	8 (2)

question was asked to determine whether the respondent practiced each method that (s)he mentioned. Table 3 lists the methods used by respondents to prevent malaria.

Mosquito net use was extremely high among respondents, as 87% stated that they used nets for malaria prevention.[3] Other than net use, the next three techniques that were mentioned most frequently by survey respondents were all environmentally related: "cleaning residential surroundings" (50%), "clearing grasses and bushes around the home" (32%), and "draining stagnant water" (18%). Sixty-three percent of respondents stated that they practice at least one of these three environmentally related techniques to protect themselves from malaria. An important issue raised in FGDs and IDIs was the belief that increased community participation is crucial for the success of these environmental management practices. In an interview, a village chairman stated,

> [U]p to this moment few people [drain stagnant water]… hence this cannot help to reduce mosquitoes, thus collaboration is needed…. I suggest that there should be a program emphasizing cleanliness of the environment. [A] few people should attend a seminar concerning environmental sanitation who will later visit house to house to provide education on cleanliness of the environment. I suggest that these people should come from this village.

This statement highlights two important issues: that the village chairman believes a formal educational program on environmental management practices would be highly beneficial and that this program should be implemented by trained community members, not by outside educators.

Factors Associated with Environmental Management Practices

Multivariate analysis was used to determine the correlation between a number of demographic/socioeconomic factors and environmental management practices. Table 4 presents marginal effects calculated from a probit regression testing for these correlations.

The first regression examines whether the respondents indicated that they drain stagnant water to protect themselves from malaria. Education was significantly correlated with this practice. With each increase in educational attainment category (from no education, to primary school education, to secondary or above), the respondent was 9.6% more likely to practice this form of malaria control ($P = 0.004$). Respondents who owned a greater number of durable goods (e.g., radio, television, telephone, motorcycle) also were significantly more likely to perform this practice ($P = 0.042$) and housing size was marginally associated. As the respondent's housing size increased he/she was significantly more likely to drain stagnant water ($P = 0.072$). Gender of the respondent was not significantly associated with performing this malaria control practice.

The second regression examines whether the respondents indicated that they clean the environment around their homes for malaria control. Gender was correlated with this practice: females are 12.6% more likely than males to perform environmental cleaning to prevent malaria ($P = 0.02$). Education was also positively correlated: with each increase in level of educational attainment the respondent was 9.5% more likely to perform this practice ($P = 0.042$). Additionally, land area was marginally significant: living on a larger plot of land was positively correlated with cleaning the environment for malaria control ($P = 0.053$).

Discussion

The results of the survey indicate that the majority of community members in the study area have a basic understanding of the links between environmental conditions, mosquitoes, and malaria. Knowledge of mosquito ecology appears to influence which environmental management practices people choose to perform. A prevalent

[3] In addition to self-reports, interviewers directly observed nets in 83% of the households. In comparison, household mosquito net ownership for Morogoro Region was determined to be 64.7% in the 2004/2005 Tanzania Demographic and Health Survey.

Table 4. Factors Associated with Environmental Management Practices for Malaria Control: Marginal Effects from Probit Regressions

Household characteristics	Respondent drains stagnant water		Respondent cleans the environment around the home	
	Pseudo R^2 = 0.0697		Pseudo R^2 = 0.0346	
	Coefficient	P value	Coefficient	P value
Age (yr)	0.0009	0.492	−0.0004	0.823
Gender	0.0042	0.916	0.1259	0.02
Education	0.0959	0.004	0.0939	0.042
Religion	0.0378	0.355	−0.0466	0.388
Housing size	0.0601	0.072	−0.0334	0.464
Durables	0.0454	0.042	0.0278	0.381
Land area	−0.0002	0.947	0.0089	0.053
Total livestock	−0.0004	0.572	−0.0013	0.184

belief among respondents is that grass and bushes around the home as well as an unclean environment favor mosquito breeding. Consequently, many households clean around the home (50%) and clear vegetation (32%) in an attempt to prevent malaria. Although the general consensus is that clearing vegetation is of no benefit and might even worsen malaria (Opiyo et al., 2007), evidence exists that clearing may significantly reduce malaria risk in certain environments (Hustache et al., 2007). Both of these practices may limit breeding habitat (e.g., removing artificial containers or large plants that collect water) and may prevent adult mosquitoes from resting outdoors near homes. Therefore, residents who perform these practices may directly observe a decrease in contact with adult mosquitoes, leading them to conclude that the practices are effective in reducing malaria risk.

Another prevalent belief is that the presence of standing water, particularly during the rainy season, influences mosquito populations. Despite this, only 18% of respondents drain stagnant water around their homes. A number of factors may contribute to low levels of participation in draining water, including a lack of knowledge about larval mosquito ecology, the time-consuming nature of draining water, and the fact that decreasing the prevalence of stagnant water near the home does not influence the resting behavior of adult mosquitoes. In addition, although this practice may decrease populations of anopheline mosquitoes, culicine mosquitoes may remain abundant, maintaining high levels of biting and potentially transmitting other diseases. This may lead people to believe that their efforts are not effective in reducing mosquito abundance, which in turn decreases the motivation to continue to drain stagnant water. Furthermore, in lowland villages located close to swamps and flooded rice fields, the majority of mosquito breeding likely occurs in the swamps and flooded fields as opposed to around the homes. In these cases, draining water around the home would have little, if any, effect on mosquito breeding.

A significant issue to consider is the complex relationship between agriculture, mosquito populations, and malaria. Studies have found that increased populations of mosquitoes in irrigated agricultural communities do not always correlate with a greater prevalence of malaria in areas of stable transmission—called the "Paddies Paradox" (Ijumba and Lindsay, 2001; Ijumba et al., 2002). Ijumba and colleagues proposed a number of potential reasons for this phenomenon, including the displacement of the highly anthropophilic vector *A. funestus* with the less anthropophilic *A. arabiensis*, and the increased wealth generated in irrigation communities, which leads to greater usage of bednets and antimalarial treatments. Thus, the relationship between mosquito populations and malaria transmission is not necessarily direct, and the belief of 90% of respondents that reducing mosquito populations reduces malaria may not be entirely correct in some of the study villages. Whereas environmental-management techniques may be effective in reducing mosquito populations in certain agro-ecological zones, reducing exposure to mosquitoes through improved housing conditions and greater bednet usage is a more crucial control technique in areas where the majority of mosquito breeding occurs in large bodies of water (e.g., irrigated rice fields and swamps).

Another important finding is that certain household characteristics were associated with environmental management practices. Although gender was not a determinant for draining stagnant water, women are significantly more likely to report that they clean around their homes for malaria prevention than men. Educational attainment was significantly positively correlated with both draining stagnant water and cleaning the environment and socioeconomic factors (ownership of durable goods and land area, respectively) were associated with each practice. This indicates that people of higher socioeconomic status tend to perform environmental management techniques around their homes more frequently. This is important to note, considering that poorer people may have a higher exposure to malaria by living in houses that offer less protection from mosquitoes (e.g., no screens on the windows and fewer bednets). Thus, it may be beneficial to target programs toward those of lower socioeconomic status.

Although increasing knowledge of mosquito ecology is likely to have a positive effect on participation in environmental management, there are a number of inherent barriers that could limit high levels of community participation. These barriers include not wanting to drain useful water sources (Mutuku et al., 2006), not perceiving immediate benefits from environmental management (Lindsay et al., 2004), and lack of time and economic incentives. Ng'ang'a and colleagues (2008) found that 77% of respondents stated that lack of time was the primary reason for not draining stagnant water; 67% provided the same primary reason for not clearing vegetation along canals. Additionally, issues surrounding collective action are important to consider. If only a small percentage of community members engage in environmental management activities, it is unlikely that significant reductions in mosquito populations will occur.

This discussion highlights the fact that knowledge alone may not be a strong enough motivating force to encourage people to undertake the time-consuming practice of draining stagnant water or engaging in other environmental management techniques. Consequently, it is important to note that education is merely one component of a successful community-based environmental management program. Such a program must understand time and resource constraints along with other drivers of household behaviors. Incorporating incentives, whether economic or social, and/or mandates for participation will likely increase the effectiveness of environmental management schemes.

Additionally, the complex relationship between malaria transmission and environmental conditions emphasizes the need for further research to determine the efficacy of environmental management techniques in the different agro-ecological zones. The efficacy of different techniques should be evaluated both in relation to a reduction in anopheline mosquito populations and malaria transmission. In areas where household-level environmental management has substantial effects on reducing transmission, programs should be developed to encourage greater participation among community members. In contrast, in areas where environmental management has little effect on transmission, malaria control should focus more on preventing contact with mosquitoes through the use of bednets and improved housing conditions.

Conclusions

Starting from the belief that community-level environmental management is a promising component of an integrated vector management program, our study sheds light on current knowledge and practices among residents in one part of east-central Tanzania. Most respondents understand that there is a link between environmental conditions and malaria, and the majority engages in environmental management practices for malaria control. Yet, with limited time and resources to devote toward malaria control, it is crucial that environmental management efforts are focused on techniques that actually lead to reductions in anopheline mosquitoes in a given area. Additionally, it is important to identify areas in which environmental management will not be an effective malaria control technique and to focus control resources elsewhere for those communities.

The creation of an educational program on environmental management for malaria control, paired with incentives or regulations, could lead to significant increases in community participation in effective techniques. The program should concentrate on teaching participants about mosquito ecology, clarifying which environmental management techniques effectively lower *Anopheles* spp. mosquito abundance versus those that are ineffective, and stressing the importance of community participation and cooperation in the success of this form of malaria control. With greater knowledge and participation, environmental management could result in lasting, sustainable reductions in malaria burden for many communities in Tanzania and other malaria-endemic areas.

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