J. biosoc. Sci. (2005) **37**, 761–771

doi:10.1017/S0021932005007182

SELF-REPORTED MALARIA AND MOSQUITO AVOIDANCE IN RELATION TO HOUSEHOLD RISK FACTORS IN A KENYAN COASTAL CITY

JOSEPH KEATING*, KATE MACINTYRE†, CHARLES M. MBOGO‡, JOHN I. GITHURE§ AND JOHN C. BEIER*

**Department of Epidemiology and Public Health, University of Miami School of Medicine, FL, USA, †Department of International Heath and Development, Tulane University, New Orleans, LA, USA, ‡Centre for Geographic Medicine Research-Coast, Kenya Medical Research Institute (KEMRI), Kilifi, Kenya and §Human Health Division, International Centre of Insect Physiology and Ecology, Nairobi, Kenya*

Summary. A geographically stratified cross-sectional survey was conducted in 2002 to investigate household-level factors associated with use of mosquito control measures and self-reported malaria in Malindi, Kenya. A total of 629 households were surveyed. Logistic regressions were used to analyse the data. Half of all households (51%) reported all occupants using an insecticide-treated bed net and at least one additional mosquito control measure such as insecticides or removal of standing water. Forty-nine per cent reported a history of malaria in the household. Of the thirteen household factors analysed, low (OR=0·23, CI 0·11, 0·48) and medium (OR=0·50, CI 0·29, 0·86) education, mud–wood–coral (OR=0·0·39, CI 0·24, 0·66) and mud block–plaster (OR=0·47, CI 0·25, 0·87) wall types, farming (OR=1·38, CI 1·01, 1·90) and travel to rural areas (OR=0·48, CI 0·26, 0·91) were significantly associated with the use of mosquito control, while controlling for other covariates in the model. History of reported malaria was not associated with the use of mosquito control (OR=1·22, CI 0·79, 1·88). Of the thirteen covariates analysed in the second model, only two household factors were associated with history of malaria: being located in the well-drained stratum (OR=0·49, CI 0·26, 0·96) and being bitten while in the house (OR=1·22, CI 0·19, 0·49). These results suggest that high socioeconomic status is associated with increased household-level mosquito control use, although household-level control may not be enough, as many people are exposed to biting mosquitoes while away from the house and in areas that are more likely to harbour mosquitoes.

Introduction

What people are doing to control or avoid biting mosquitoes at home, including livelihood activities, house construction and design, environmental management, larval control and personal protection, provides powerful baseline information for strengthening existing malaria and mosquito control programmes. Because low socioeconomic status has been associated with high mortality across a range of settings (Rosen, 1979), it is important to understand how socioeconomic factors influence disease, and the extent and type of personal protection practices against disease, in a specific context.

Previous studies have shown relationships between increased malaria and socio-economic factors such as poor house construction (Schofield & White, 1984; Koram *et al*., 1995; Lindsay & Snow, 1988), high human density (Samani *et al*., 1987) and proximity to animal husbandry practices (Subramamian *et al*., 1991); all of which could increase the human–vector contact rate. Other studies have shown that malaria increases as the distance to standing water decreases (Coosemans *et al*., 1984; Lindsay *et al*., 1995; Ghebreyesus *et al*., 1998, 1999, 2000), which also acts to increase human–vector contact. Efforts to control malaria must include a comprehensive assessment of factors that affect the propensity of an area to harbour anopheline mosquitoes, and factors associated with malaria and the use of malaria and mosquito control tools. Such local-level investigations are essential for determining what people are doing in urban areas to affect human susceptibility to malaria disease. Although multiple methods, both modern and traditional, are used to control biting insect populations throughout Africa, the determinants of mosquito control and malaria are largely unknown in the urban context, as few such studies have been conducted (Koram *et al*. 1995; Agyepong & Manderson, 1999).

This paper explores relationships between socioeconomic factors such as land use, house design and materials, education and location, and the use of mosquito control and reported malaria in Malindi, Kenya. It is hypothesized that livelihood activities, access to resources, house design and location, and where people are at peak biting times are important household-level determinants of mosquito control use, as well as general determinants of malaria risk. This paper builds upon studies conducted by Keating and colleagues (2004) and Macintyre and colleagues (2002).

Methods

Study area

Malindi is located on the coast of Kenya and has an approximate population of 80,000. Its climate is considered tropical with precipitation mainly occurring during April through June and October through December. *Anopheles gambiae* s.s., *An. arabiensis*, *An. merus* and *An. funestus* are the primary vectors of malaria parasites on the coast of Kenya and show highly anthropophillic tendencies (Mbogo *et al*., 1995, 2003). Tourism, fishing, commercial trade and retail, and service professions are the major economic activities. Many residents also engage in small-scale farming for personal consumption and sale. Skilled labour accounts for less than 5% of the total workforce in Malindi (Kenya National Bureau of Statistics, 1999). The informal sector comprises street vendors, sex workers and tour guide services.

Sample frame

A geographically stratified two-stage cluster sample was used to collect cross-sectional household data. A series of 270 m by 270 m grid cells were overlaid on maps to generate the sample frame (Macintyre *et al*., 2002; Keating *et al*., 2003, 2004). Grid cells were characterized as well-drained if functional engineered drainage systems were present or if the area of the grid cell was situated on a slope. Grid cells were classified as poorly drained if no drainage systems were present, or if drainage systems were blocked with debris or vegetation. Drainage, a measure of the propensity of an area to naturally hold water, was used as a stratification criterion to support simultaneous *Anopheles* mosquito habitat studies. Equal allocation (i.e. disproportionate stratification) was used to select 25 grid cells from each stratum ($n=50$). Because household enumeration lists were not available in Malindi, the selected grid cells served as clusters, from which the households were randomly selected (Keating *et al*., 2004).

Household sampling

In the sample size calculation, p was set at 0·50. The alpha level was set at 95% ($\alpha=1{\cdot}96$). The maximum tolerable error was set at 10%. The design effect was equal to 3 (Macintyre *et al*., 2002). The sample size formula was equal to: $n \geq 3(1{\cdot}96)^2(0{\cdot}50)(1-0{\cdot}50)/(0{\cdot}10)^2$, where n was equal to 289 households for each stratum. An additional 10% was added to account for non-response, yielding a target sample size of 318 in each stratum. Equal allocation was used to select households from within the clusters. A random direction method was used to approach approximately thirteen houses from within each selected grid cell. The centre of the cell was located in the field and a random direction was selected for each interviewer. Houses were sampled along the selected axis until the boundary of the grid cell was reached. The process was repeated until thirteen houses had been sampled. All responsive households were taken in grid cells containing fewer than thirteen households. Non-responsive households were re-visited once, and then replaced with the closest house along the same axis.

Households were defined as occupied residential units. Multiple families residing in the same house, as well as family compounds, were considered one ‘household’. The total number of households per selected grid cell was obtained through a count and used in sample weight calculations. Interviews were conducted with any household member (>15 years) willing to participate. A brief explanation of the study was provided and informed consent obtained before each interview. Questions about education, housing materials, water storage practices, rubbish and sewage disposal, land-use, history of malaria treatment, mosquito control practices, travel history and basic demographic information were asked of the respondents. Both Tulane University’s Institutional Review Board and the Kenyan Medical Research Institute’s (KEMRI) National Ethical Review Board approved the study.

Data analysis

The objectives of this paper were to describe the types of mosquito avoidance and control practices used in households, describe the characteristics of the households that report mosquito control, and test whether education, land-use, house design and location, and where individuals are at potential biting times, are associated with either the probability of mosquito control use or the probability of a household reporting a case of treated malaria within the last 6 months.

Independent variables were created based on house descriptions and responses to specific questions during the interview. The education variable was based on the highest level of education attained by the head of household. High education was equal to the completion of a university or college programme. Medium education was equal to upper primary (4–8) or forms 1–4. Low education was considered lower primary (1–3) or no education at all. Land use was equal to residential if the household was located within a totally residential area, commercial if the household was located in a business district, and agricultural if the household was located in an area that had large-scale agricultural activity present. A binary farming variable was created based on whether or not farming or gardening was done within or around the selected household. The house design variable was equal to 1 if the walls were made up of mud or mud–wood–coral combinations, 2 if walls were mud block with plaster, and 3 if walls were made up of cement block. Where people report being bitten most often was equal to 1 if the respondent reported being bitten inside the house more often than outside, and 0 if not. The rural travel variable was equal to 1 if the respondent reported that members of the household travelled to a rural area at least once a month and 0 if travel to rural areas occurred rarely or not at all. The number of people who reportedly slept within the household the preceding night was recorded and analysed as a continuous variable. High access to resources was equal to 1 if the household was owner occupied with electricity, and 0 if not.

The binary dependent variables were created based on responses to specific questions during the interview. Household mosquito control activity was equal to 1 if households reported the use of insecticide-treated bed nets (ITNs), and at least one of the following measures: insecticides or sprays, clearing debris from drains and ditches, or removing standing water, and 0 if not. The second dependent variable was equal to 1 if any member of the household had been diagnosed and treated for malaria at a clinic or hospital within the past 6 months, and 0 if not. Malaria cases do not represent slide-confirmed cases; interviewers were trained to ask specific questions about household members regarding history of malaria.

Chi-squared statistics and logistic regression were used to analyse the data. Wald statistics and log-likelihood ratios ($\alpha = 0{\cdot}05$) were used to identify variable significance and model fit. Standardized sampling weights were applied to both regressions. The sampling weights were equal to the inverse of the probability that a household was selected, given that the respective grid cell was also selected. Data management and analysis were done using STATA version 7·2. The *svylogit* option, with the grid cell serving as the primary sampling unit, was used to perform regressions ($n = 629$).

Results

Six hundred and twenty-nine households completed the questionnaire, 355 in the poorly drained stratum and 274 in the well-drained stratum. The number of households sampled per grid cell ranged from one to eighteen, and varied as a

Table 1. Chi-squared results for the proportion of households in each stratum and category of household-level variables ($n=629$)

Variable	Well-drained ($n=274$)	Poorly drained ($n=355$)	p value
Wall type			
Mud–wood–coral	16·3	83·7	
Mud block with plaster	38·5	61·5	
Cement block	58·3	41·7	$p<0{\cdot}001$
Education			
Low	33·3	66·7	
Medium	43·6	58·4	
High	50·5	49·5	$p=0{\cdot}069$
Land use			
Residential	47·1	52·9	
Commercial	73·2	26·8	
Agricultural	0	100	**
Household farming	29·5	70·5	$p<0{\cdot}001$
Usually bitten at home	59·7	40·3	$p=0{\cdot}278$
Travel to rural areas often	40·4	59·6	$p=0{\cdot}262$
Home ownership plus electricity	60·6	39·4	$p<0{\cdot}001$
Mosquito control activity	42·7	57·3	$p=0{\cdot}084$
Reported case of treated malaria	38·4	61·6	$p=0{\cdot}076$

**Insufficient variation in the data; no test statistic calculated.

function of house availability and the willingness of individuals within selected houses to participate. Sixteen households refused to participate in the well-drained stratum, and ten refused in the poorly drained stratum.

Three hundred and twenty-four households (52%) reported all occupants using an ITN year round, and 270 households (43·6%) reported using additional measures such as burning of coils, water source reduction, or insecticides to control or avoid biting insect populations within or around the house. Three hundred and twenty-one households (51%) reported all occupants using an ITN and at least one additional mosquito control measure. Forty-seven per cent of the households sampled had access to electricity, and 52·1% reported house ownership. The proportions of total households occupying the high, medium and low education groups were equal to 11·9%, 70·4% and 17·6%, respectively.

Results from the chi-squared analysis between strata are presented in Table 1. These results suggest that household wall types ($p<0{\cdot}001$), households reporting home ownership plus electricity ($p<0{\cdot}001$) and households engaged in urban agriculture ($p<0{\cdot}001$) variables were significantly different between strata in this analysis. In this survey, the well- and poorly drained strata may be a proxy for the general level of socioeconomic status in the area. For example, the results suggest increased amounts of rural-type activity in the poorly drained areas, as compared with areas classified as well-drained, as evidenced by higher proportions of households reporting farming or

Table 2. Summary regression statistics for logistic model predicting the odds that a household uses multiple mosquito control measures ($n=629$)

Variable	Adjusted odds ratio	95% CI	Unadjusted odds ratio	95% CI
Wall type				
Mud–wood–coral	0·394*	(0·236–0·659)	0·357*	(0·210–0·606)
Mud block with plaster	0·466*	(0·250–0·867)	0·417*	(0·176–0·989)
Cement block	1·000	Ref.	1·000	Ref.
Education				
Low	0·234*	(0·114–0·479)	0·190*	(0·078–0·467)
Medium	0·496*	(0·286–0·858)	0·403*	(0·224–0·727)
High	1·000	Ref.	1·000	Ref.
Land use				
Residential	0·739	(0·383–1·428)	1·322	(0·650–2·336)
Commercial	1·539	(0·659–3·598)	2·328	(1·001–5156)
Agricultural	1·000	Ref.	1·000	Ref.
Household farming	1·379	(1·003–1·895)	1·34	(0·843–2·130)
Usually bitten at home	0·806	(0·448–1·448)	0·736	(0·452–1·197)
Travel to rural areas often	0·483*	(0·257–0·909)	0·544*	(0·334–0·887)
Home ownership plus electricity	0·822	(0·347–1·945)	1·692	(0·983–2·192)
Well drained	0·940	(0·527–1·677)	1·299	(0·843–2·000)
Number of people in house**	1·076	(0·987–1·173)	1·042	(0·968–1·123)

*$p<0{\cdot}05$; **continuous variable.

gardening efforts within or around the household, and no households within the well-drained stratum being located in an area classified as agricultural. The well-drained stratum had the highest proportion of households with cement block wall types, education, and home ownership and access to electricity, all indicative of higher socioeconomic status. The poorly drained stratum had the highest number of households reporting that at least one member had been diagnosed and treated for malaria at a hospital or clinic within the previous 6 months.

Results from the first logistic regression indicate that the probability of mosquito control activity being used in a household was a function of education, wall type and rural travel patterns (Table 2). Controlling for other covariates in the model, households having the highest educational attainment were more likely to use mosquito control measures as compared with households reporting medium and low educational attainment. Medium education households were half as likely to use mosquito control (OR=0·506, CI=0·274, 0·933), and low education households were almost 80% less likely to use mosquito control (OR=0·236, CI=0·089, 0·625). Households reporting someone travelled to rural areas at least once a month were half as likely to report use of mosquito control as compared with households that rarely or never travel to rural areas (OR=0·492, CI=0·304, 0·794). Although interesting, it is unclear to what extent this variable is capturing work-related activity associated with lower overall wealth (i.e. rural-type activity), or the perceived lack of need to control mosquito populations in an urban environment. Those who travel regularly, or who are otherwise attached to the rural hinterland, may associate malaria mosquitoes with rural areas only. The existence of wood, mud and coral wall types was also negatively associated with the use of control measures. However, caution should be used when interpreting this result given that it is unclear to what extent household wealth and wall type are confounded. Thus, it is difficult to determine if this variable is reflecting the presence or absence of adult resting places and thus the need to avoid biting insect populations, or simply lower socioeconomic levels for houses with this wall type. Other variables were not significant, and the home ownership plus electricity variable and the drainage variable had signs opposite to what one would expect. That is to say, both have a negative relationship with the probability of the outcome occurring. Although the odds ratios are insignificant, it is unclear to what extent these results are confounded with socioeconomic status and the conspicuous absence of rainfall during this study, which may have resulted in an under-reporting of mosquito control due to reduced numbers of mosquitoes present.

Results from the second logistic regression indicate that the probability of a household reporting a case of treated malaria within the past 6 months was a function of where they report being bitten most often, drainage and rural travel patterns. The unadjusted and adjusted odds ratios are presented in Table 3. Households reporting that biting occurs most often while in the house were less likely to report a case of malaria as compared with households reporting that biting occurs most often while away from the house (OR=0·307, CI=0·173, 0·545). Households occupying the well-drained stratum were also less likely to report a case of malaria as compared with households occupying the poorly drained stratum (OR=0·497, CI=0·294, 0·841). Households reporting frequent travel to rural areas were almost half as likely to report a case of malaria as compared with households reporting infrequent or no travel to rural areas (OR=0·464, CI=0·284, 0·759). As household density goes up, the odds of the outcome occurring also increased, which is what one would expect since increases in the number of people in the household increases the chance of at least one case of malaria being reported.

Discussion

This study demonstrates through a cross-sectional survey that few of the human-ecological and socioeconomic variables measured appear to be significantly associated with the use of mosquito control or reported malaria at the household level. As always, caution should be used when generalizing and interpreting these results, as it is unclear to what extent the mechanisms driving the observed relationships are confounded with unmeasured biological factors or human-related factors operating at a scale smaller than what was used in this study. Additionally, measurement error based on non-response or respondent bias may also affect the findings. For example, households located in poorly drained areas were sometimes unwilling to complete the questionnaire without compensation. Conversely, some households in well-drained areas were also unwilling to complete the questionnaire on the grounds that our service, either in terms of mosquito control or in terms of research, was neither needed nor wanted. As well, the fact that the well- and poorly drained strata were

Table 3. Summary regression statistics for logistic model predicting the odds that a household reports at least one case of hospital- or clinic-based treated malaria within the past 6 months ($n=629$)

Variable	Adjusted odds ratio	95% CI	Unadjusted odds ratio	95% CI
Wall type				
Mud–wood–coral	0·582	(0·219–1·546)	0·599	(0·361–0·993)
Mud block with plaster	1·102	(0·732–1·658)	0·988	(0·452–2·159)
Cement block	1·000	Ref.	1·000	Ref.
Education				
Low	0·703	(0·203–2·440)	0·483	(0·201–1·161)
Medium	0·908	(0·502–1·642)	0·745	(0·401–1·386)
High	1·000	Ref.	1·000	Ref.
Land-use				
Residential	0·900	(0·219–3·692)	0·976	(0·531–1·793)
Commercial	1·205	(0·238–6·095)	1·03	(0·464–2·287)
Agricultural	1·000	Ref.	1·000	Ref.
Household farming	1·498	(0·916–2·450)	1·474	(0·924–2·353)
Usually bitten at home	0·305*	(0·190–0·490)	0·317*	(0·181–0·555)
Travel to rural areas often	0·443*	(0·211–0·932)	0·505*	(0·312–0·818)
Home ownership plus electricity	1·204	(0·531–2·732)	1·498	(0·858–2·615)
Well drained	0·495*	(0·256–0·958)	0·674	(0·427–1·064)
Number of people in house**	1·011	(0·936–1·092)	1·015	(0·944–1·092)

*$p<0{\cdot}05$; **continuous variable.

significantly different along some of the key human-ecological variables suggests that the strata may be either measuring two distinct ecosystems as well as measuring relative socioeconomic status and land use of the respective communities.

Three main findings were evident from the respective household-level analyses. First, households with mud, wood, or coral wall types were significantly less likely to use mosquito control activities, after controlling for other covariates in the model. Although this may have some entomological explanation, it seems plausible that this variable was a proxy for wealth. Thus, those who are poor are more likely to have mud, wood or coral walls and less likely to use control measures due to a lack of resources. As well, households reporting the lowest education were less likely to use mosquito control, as compared with the high education households. Previous studies in Malindi concluded that although education was a good predictor of whether a household used mosquito control, no evidence exists to suggest that high education households were necessarily more knowledgeable of malaria parasite transmission dynamics (Macintyre *et al*., 2002). The avoidance of nuisance biting mosquitoes can be incentive enough to control or avoid mosquito populations (Agyepong & Manderson, 1999). In this context, education may also be measuring relative socioeconomic status, as high education individuals generally occupy high paying positions. Travel to rural areas was also significant, although to what extent this variable captured the risk of encountering infectious mosquitoes is unknown. Those who travelled to rural areas at least once a month were less likely to use mosquito control at the urban household as compared with those who rarely or never travelled to rural areas, although those who travel to rural areas may be taking precautions to avoid biting mosquitoes or malaria while travelling. This variable may also be measuring households and families in transition from rural to urban lifestyles. Households in transition may be at greater risk of encountering infectious organisms, as access to urban services and utilities may be lacking, and rural livelihoods are still the main household activities. Communities in transition often maintain rural contacts, thus travel, and the associated expense of maintaining two households, is common.

Second, households reporting that mosquito bites usually occur away from the house were more likely to report a case of malaria than those who report biting usually occurs within the home. This is important from a programme and policy standpoint, as many residents are bitten while away from the house, thus reducing the protective effect of ITN use and environmental management at the household level. This suggests that community- or municipal-level control may also be important for reducing vector populations. The high bed net usage evident in Malindi suggests that residents may already be doing things to control mosquito populations, but this may be a function of social marketing in the recent past and may have little effect on the overall problem of malaria in the community if bites are occurring while away from the household. Less than 15% of those surveyed reported draining standing water or otherwise modifying the environment in ways to decrease mosquito habitat. It may be important to increase awareness with respect to multi-faceted vector control measures that target both larval and adult stage mosquitoes, and promote the use of personal protection measures other than ITNs that also reduce the overall vectorial capacity.

Travel to rural areas was also associated with a decreased risk of malaria in the household. This finding, although opposite to what one would expect in the context of this analysis, may be related to acquired immunity in those who regularly travel to rural areas, where higher rates of malaria transmission intensity may be present (Robert *et al.*, 2003).

In general, the results suggest that few households are doing both adult and larval stage vector control, and that many people may be at risk of malaria, as little immunity is present in urban residents that do not regularly travel to rural areas. As well, people are being exposed to mosquito bites while away from the protective effects of ITNs. It is uncertain to what extent travel to rural areas and being bitten while away from the home are confounded. As well, the extent to which the absence of precipitation, and possibly a perception of low risk, is influencing the outcomes is also unknown. This study suggests that there may be an association between malaria risk and being bitten while away from the home, thus reducing the effect of household-level mosquito control. It is possible that many people are exposed to bites at times when bed nets, coils or insecticides are of little use. Bartenders, security guards and sex-workers all work at times when mosquitoes are most active, which may increase the risk of receiving an infectious bite.

Although communities are rarely uniform in space and character, this study used a 270 m by 270 m grid cell as a sampling unit to capture small-scale heterogeneity in human activity at the household level. The geographic sampling strategy employed, however, was limited in terms of its ability to randomly sample human populations in such a way as to capture heterogeneity in individual behaviour or practices. The size and use of spatial sampling units for the collection of human survey data needs further investigation and development before results of such studies can be generalized to urban areas as a whole. Future research should include a comprehensive assessment of the advantages and disadvantages of spatial sampling of households. Conventional human sampling techniques are based on the size of the population, not the space they occupy. Thus conclusions drawn from the study are representative of the population and may be generalized to other populations with similar characteristics. Because the size of the population in this study was unknown, and time and money were operating constraints, space was used as the sampling unit on which to base the collection of human household data. The sampling was such that these results may not hold true in other urban environments, where individuals are interacting with and modifying the environment in different ways.

In the absence of a vaccine, integrated vector control strategies that combine ITN usage with environmental management and source reduction, may be highly efficacious for reducing mosquito populations and subsequent parasite transmission. Very few residents in Malindi are using environmental management and source reduction for reducing mosquito habitat and many residents are outdoors at times when mosquitoes are biting, which suggests that household-level, as well as community-level mosquito control may be necessary to reduce the burden of malaria disease.

Acknowledgments

National Science Foundation Grant DEB-0083602 and NIH Grant U19 AI45511 supported this research. The authors are grateful for the comments and suggestions of two anonymous reviewers. They are also grateful for the assistance provided by the scientific and technical staff at the Center for Geographic Medicine Research-Coast, KEMRI in Kilifi, Kenya. This paper is published with the permission of the Director of the Kenya Medical Research Institute.

References

Agyepong, L. A. & Manderson, L. (1999) Mosquito avoidance and bed net use in the greater Accra region of Ghana. *Journal of Biosocial Science* **31**, 79–92.

Coosemans, M., Werry, M., Storme, B., Hendrix, L. & Mfisi, B. (1984) Epidemiologie du paludisme dans la plaine de la Rusizi, Burundi. *Annals de la Societe Belge de Medecine Tropicale* **64**, 135–158.

Ghebreyesus, T. A., Haile, M., Getchew, A., Alemayehu, T., Witten, K. H., Medhin, A. *et al.* (1998) Pilot studies on the possible effects on malaria of small-scale irrigation dams in Tigrey region, Ethiopia. *Journal of Public Health Medicine* **20**, 238–240.

Ghebreyesus, T. A., Haile, M., Witten, K. H., Getchew, A., Yohannes, M., Lindsay, S. W. & Byass, P. (2000) Household risk factors for malaria among children in the Ethiopian highlands. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **94**, 17–21.

Ghebreyesus, T. A., Haile, M., Witten, K. H., Getchew, A., Yohannes, A. M., Yohannes, M. *et al.* (1999) Incidence of malaria among children living near dams in northern Ethiopia: community based incidence survey. *British Medical Journal* **319**, 663–666.

Keating, J., Macintyre, K., Regens, J. L., Swalm, C., Mbogo, C. M., Githeko, A. *et al.* (2003) A geographic sampling strategy for studying relationships between human activity and malaria vectors in urban Africa. *American Journal of Tropical Medicine and Hygiene* **67**, 357–365.

Keating, J., Macintyre, K., Mbogo, C. M., Githure, J. I. & Beier, J. C. (2004) Characterization of potential larval habitats for Anopheles mosquitoes in relation to urban land-use in Malindi, Kenya. *International Journal of Health Geographics.* DOI: 2120296524315870.

Kenya National Bureau of Statistics (1999) *Housing and Population Census*. Nairobi, Kenya.

Koram, K. A., Bennett, S., Adiamah, J. H. & Greenwood, B. M. (1995) Socio-economic risk factors for malaria in a peri-urban area of the Gambia. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **89**, 146–150.

Lindsay, S. W., Armstrong Schellenberg, J. R., Zeiler, H. A., Daly, R. J., Salum, F. M. & Wilkins, H. A. (1995) Exposure of Gambian children to *Anopheles gambiae* malaria vectors in an irrigated rice production area. *Medical and Veterinary Entomology* **9**, 50–58.

Lindsay, S. W. & Snow, R. W. (1988) The trouble with eaves: house entry by vectors of malaria. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **82**, 645–646.

Macintyre, K., Keating, J., Sosler, S., Kibeh, L., Mbogo, C. M., Githeko, A. K. & Beier, J. C. (2002) Examining the determinants of mosquito avoidance practices in cities in Kenya. *Malaria Journal* **1**, 14.

Mbogo, C. M., Mwangangi, J. M., Nzovu, J., Gu, W., Yan, G., Gunter, J. T. *et al.* (2003) Spatial and temporal heterogeneity of *Anopheles* mosquitoes and *Plasmodium falciparum* transmission along the Kenyan coast. *American Journal of Tropical Medicine and Hygiene* **68**, 734–742.

Mbogo, C. M., Snow, R. W., Khamala, C. P., Kabiru, E. W., Ouma, J. H., Githure, J. I. *et al.* (1995) Relationships between of *Plasmodium falciparum* transmission by vector populations and the incidence of severe disease at nine sites on the Kenyan coast. *American Journal of Tropical Medicine and Hygiene* **52**, 201–206.

Robert, V., Macintyre, K., Keating J., McWilson, W., Trappe, J. P., Duchemin, J. B. & Beier, J. C. (2003) Malaria transmission in urban Sub-Saharan Africa. *American Journal of Tropical Medicine and Hygiene* **68**, 169–176.

Rosen, G. (1979) The evolution of social medicine. In Bird, C. E., Conrad, P. & Fremont, A. M. (eds) *Handbook of Medical Sociology.* Prentice-Hall, New Jersey.

Samani, F. Z., Willett, W. C. & Ware, J. H. (1987) Nutritional and socio-demographic risk indicators of malaria in children under five: a cross-sectional study in a Sudanese rural community. *Journal of Tropical Medicine and Hygiene* **90**, 69–78.

Schofield, C. J. & White, G. B. (1984) Engineering against insect-borne diseases in domestic environment: house design and domestic vectors of disease. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **78**, 285–292.

Subramanian, S., Manoharan, A., Sahu, S., Jambulingam, P., Govardhini, P., Mohapatra, S. S. & Das, P. K. (1991) Living conditions and occurrence of malaria in a rural community. *Indian Journal of Malariology* **28**, 29–37.