Published in final edited form as:
Am J Trop Med Hyg. 2009 April ; 80(4): 547–554.

Distance Threshold for the Effect of Urban Agriculture on Elevated Self-reported Malaria Prevalence in Accra, Ghana

Justin Stoler*, **John R. Weeks**, **Arthur Getis**, and **Allan G. Hill**
Department of Geography, San Diego State University, San Diego, California

Department of Population and International Health, Harvard School of Public Health, Cambridge, Massachusetts

Abstract

Irrigated urban agriculture (UA), which has helped alleviate poverty and increase food security in rapidly urbanizing sub-Saharan Africa, may inadvertently support malaria vectors. Previous studies have not identified a variable distance effect on malaria prevalence from UA. This study examines the relationships between self-reported malaria information for 3,164 women surveyed in Accra, Ghana, in 2003, and both household characteristics and proximity to sites of UA. Malaria self-reports are associated with age, education, overall health, socioeconomic status, and solid waste disposal method. The odds of self-reported malaria are significantly higher for women living within 1 km of UA compared with all women living near an irrigation source, the association disappearing beyond this critical distance. Malaria prevalence is often elevated in communities within 1 km of UA despite more favorable socio-economic characteristics than communities beyond 1 km. Neighborhoods within 1 km of UA should be reconsidered as a priority for malaria-related care.

INTRODUCTION

Africa's urban population is projected to more than double by 2030,[1] as it struggles through the epidemiologic transition that has accompanied development in the western world; this growth portends potentially severe consequences for urban health in developing nations. With population growth heaviest in cities, there is unrelenting pressure on the health care resources of developing nations. Relative to their rural counterparts, urban residents' close spatial proximity and heightened competition for public resources creates an "urban penalty" that persists until they are protected by an adequate public health infrastructure and availability of effective treatments to suppress disease.[2] In such urban communities, economic development is often hindered by productivity lost to infectious diseases, and the resultant lagging health infrastructure feeds a self-perpetuating cycle of poverty.

Although malaria prevalence remains most intense in rural areas, prevalence is highly variable in urban areas and is driven by many factors including the existence of non-immune populations, irregularity of suitable mosquito breeding habitat, spatial distributions of

---

* Address correspondence to Justin Stoler, Department of Geography, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182. E-mail: E-mail: stoler@rohan.sdsu.edu.
Authors' addresses: Justin Stoler, Department of Geography, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182, Tel: 619−594−5437, Fax: 619−594−4938, E-mail: stoler@rohan.sdsu.edu. John R. Weeks, Department of Geography, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182, Tel: 619−594−8040, Fax: 619−594−4938, E-mail: john.weeks@sdsu.edu. Arthur Getis, Department of Geography, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182, Tel: 619−594−6639, Fax: 619−594−4938, E-mail: arthur.getis@sdsu.edu. Allan G. Hill, Department of Global Health and Population, Harvard School of Public Health, 665 Huntington Avenue, Boston, MA 02115, Tel: 617−432−4075, E-mail: ahill@hsph.harvard.edu.

communities, access to control measures, and climate.[3,4] Several recent studies have highlighted growing urban malaria prevalence though with marked heterogeneity between communities.[4,5] Urban malaria is essentially an unintended consequence of unchecked urbanization, linked to the effects of unplanned land use and the transformed environment.[6,7] Clinical data have suggested an increased risk of malaria caused by proximity to urban agriculture, generally defined as irrigated farmland dedicated to commercial vegetable cultivation.[8,9]

Urban agriculture (UA) irrigation techniques in sub-Saharan Africa have inadvertently created new mosquito breeding grounds,[8] thereby increasing malaria risk in rapidly growing urban centers where anopheline vector densities were lower because of limited availability of suitable breeding sites.[9] Urban agriculture has improved food security, nutrition, and alleviation of poverty, but its impact on the malaria vector has only recently been studied, with no explicit link established between farming practices and malaria prevalence.[10] In Kumasi, Ghana, significantly more self-reported malaria episodes were reported in areas near UA than in areas without UA,[8] and blood microscopy data from children in Accra showed an elevated prevalence of malaria in communities living near UA.[9] A similar pattern was recently observed in Accra from entomologic surveys of the primary vector *Anopheles gambiae* that yielded higher entomologic inoculation rates (EIRs) in communities close to UA.[11] Proximity to UA was also positively associated with malaria infection in Ouagadougou, Burkina Faso, consistent with previously documented clusters of *Anopheles* breeding sites along artificial lakes and canals associated with UA activities.[12] However, proximity to UA was found to be an insignificant predictor of malaria parasitemia in a municipality of Abidjan, Ivory Coast.[13] Although most literature indicates a link between malaria and UA, no previous study of this relationship has included a spatially well-distributed study population sufficient for testing a distance threshold for UA's effect on prevalence. Previous studies have therefore not measured variable distance effects.

The purpose of this study is to quantify the effect of distance from urban agriculture on malaria prevalence after controlling for household predictors and to investigate possible spatial clustering of self-reported malaria rates. Spatial statistical methods were applied to self-report data from the 2003 Women's Health Study of Accra (WHSA) to see if results corroborate the UA relationships previously described in Accra.[9] We conclude by discussing the implications of urban agriculture on malaria prevalence in light of other socioeconomic factors and the potential for defining the epidemiology of urban malaria in Accra and recognizing priority populations for prevention and care.

MATERIALS AND METHODS

Study population

Accra was chosen as representative of growing urban areas in West Africa and for its progress in both health care delivery and its overall epidemiologic transition. Accra remains endemic to malaria given its history of slow transformation from mangrove forest into urban space. The Accra Metropolitan Area, with its southern border on the Gulf of Guinea coast, extends about 11 km north to just past the University of Ghana at Legon, and roughly 20 km east to west. The metropolitan area contains 1.66 million people and 373,540 households, according to the March 2000 Accra census. Local governance of this population rests with the Metropolitan Accra Assembly, and it was deemed advantageous to work with a single administrative body in anticipation of interventions after the study.

Study instrument

The 2003 WHSA is a community-based cross-sectional population study conducted in Accra by the Harvard School of Public Health and associates at the University of Ghana. The WHSA is a comprehensive snapshot of health, disease, and related risk factors among a representative sample of women ≥ 18 years of age in the Accra Metropolitan Area, and designed with the intention of future longitudinal research.

The sampling methodology for the WHSA has been described previously.[14–16] Participants were selected through a two-stage cluster probability sample stratified by socioeconomic status (SES), as determined by the 2000 census. There are 1,731 occupied enumeration areas (EAs) in Accra, each containing an average of 959 people. Two hundred sample EAs were selected (Figure 1) with probability weights proportional to population size, and > 60,000 eligible women resident in these EAs ≥ 18 years of age were listed by name and address. Study women were selected according to the probability of being in 1 of 16 cells formed by the stratification of SES quartile by four age groups, with older women progressively oversampled. Sampling was equally distributed among these 16 cells, yielding 200 women in each and 3,200 in total. A total of 3,183 women completed an initial household survey (HHS), and 1,328 completed a comprehensive medical and laboratory examination (CMLE), although no tests for parasitemia were undertaken.

This study is based on information taken from the HHS. Questions related to malaria were modeled after the SF-36, and self-reports were solicited using a twelve-month window. The WHSA was not originally designed to provide detailed measures of infectious disease burdens, as malaria prevalence was not expected to be significant in Accra. Consequently, potentially confounding information such as travel histories, bed net use, and sleeping quarters were not collected. The publication of Klinkenberg and others[9] noting elevated malaria prevalence among children in UA-proximate communities prompted this research inquiry; self-reported malaria rates from the WHSA were subsequently found during exploratory analysis to be very high.

Data management

All information was stored in a geographic information system, with cases at the household level as well as aggregated by EA. The georeferenced EA map and attribute table for Accra, as well as the map of urban agriculture sites, were produced by the NICHD-funded project on Intra-Urban Health in Accra at San Diego State University (Dr. John Weeks, PI; Dr. Allan Hill, co-PI). The GIS layer of urban agriculture sites in Accra was digitized in ArcGIS 9 from a 2.4-m resolution Quickbird multispectral image of Accra (acquisition date April 12, 2002). Ground verification of urban agriculture training sites was performed in 2004, and sites were cross-checked with recently published maps of UA.[10]

Analysis

Data analysis was initiated on a subset of 3,164 women with valid responses to the malaria questions. Cases were dropped because of missing data during multivariate analysis for a final sample of 2,983. Logistic regression was used to evaluate bivariate relationships between household indicators and malaria self-reports, and a backward elimination method was used to determine a subset of aspatial household control measures before introducing the spatial variable.

Distance to urban agriculture was captured by a series of dummy variables that denoted inclusion or exclusion of a case for a given cumulative distance band from UA. Cumulative distance bands were created in ArcGIS 9 using 100-m buffers around the UA areas; the dummy variables denoted whether a woman lived within the 0- to 100-m band, the 0- to 200-m band,

and so forth. Participant location was estimated by the centroid of the woman's EA, as exact locations were masked for privacy. Distance dummy variables were entered into a multivariate logistic regression model individually to see how the odds of self-reported malaria changed over distance from UA. To distinguish possible effects attributable to UA from those linked to any irrigation source that could harbor mosquito breeding, a spatial control was created by creating similar distance bands around the Odaw River and its tributaries, from which water is often channeled for UA irrigation (see Figure 2 for distance band schematic). The odds ratios (ORs) and confidence intervals (CIs) for self-reported malaria could thereby be compared for the two distributions: distance from UA and distance from the Odaw River system. χ^2 analysis was used to test for household variable differences between women living within and beyond a given distance from UA.

The Getis-Ord G_i* statistic[17] was applied to study spatial clusters of self-reported malaria rates aggregated at the EA scale independently of a presumed source. EAs were again represented geographically by their centroids. To account for differing sample populations in each of the 200 EAs, the empirical Bayes global smoothing method was applied in ArcGIS 9 before performing spatial analysis. The G_i* measure was calculated over multiple distances using the ROOKCASE add-in for Microsoft Excel.[18]

Institutional Review Board approval

This study was approved by the Institution Review Board at San Diego State University, the Human Subjects Committee at Harvard School of Public Health, the Institutional Review Board at Noguchi Memorial Institute for Medical Research, University of Ghana, and data analysis by the Committee on Clinical Investigations at Beth Israel Deaconess Medical Center, Boston, MA.

RESULTS

Household predictors of self-reported malaria

Descriptive information about the study population is shown in Table1, along with simple bivariate relationships between the household measures and self-reported malaria. Slightly more women sampled were from EAs with the lowest SES, whereas piped water access was fairly even (53% piped into the home, 47% not). Most women had access to their own toilet or a public toilet (32.2% and 36.5%, respectively), cooked with charcoal (64.8% versus 27.3% with gas), had access to a contained bathroom for bathing (70.9% versus 24.6% in an open cubicle), and had a refrigerator in the household (64.3%). Solid waste was most commonly disposed of at a public dump (72.7%) or through other informal means such as burning or open dumping (13.8%), rather than through collection service (13.6%), and 88.2% reported informal liquid waste removal (street, gutter, or around the compound), with only 11.8% reporting access to a sewage system; 22.6% reported no formal education, whereas only 7% achieved higher (post-secondary) education. Women were most likely to be ethnically Ga/Adangbe (37.5%), followed by Ewe (12.9%), Fante (11.2%), and Asante (9.7%). Age ranged from 18 to 100 years, with a mean of 38.8 years. When self-reporting overall health, only 12.8% reported excellent health, with most reporting very good (32.7%) or good (34.8%) and 19.7% reporting fair or poor.

Taking each characteristic individually, women who self-reported malaria were generally more likely to be from an EA of lower SES, have poorer toilet access, lack a refrigerator in the household, and give a worse report of overall health. A backward elimination procedure that screened household characteristics with $P < 0.10$ yielded a multivariate model with five characteristics: SES, method of solid waste disposal, education, self-reported overall health, and age (Table 2). Adjusting for other characteristics, women were more likely to self-report malaria if living in an EA of upper middle SES (OR = 1.49, 95% CI = 1.19−1.86, $P < 0.001$), lower middle SES (OR = 1.97, 95% CI = 1.57−2.48, $P < 0.001$), or low SES (OR = 1.42, 95% CI = 1.14−1.77, $P = 0.002$) relative to upper SES. Odds of a malaria self-report were also much higher for women that reported their overall health as very good (OR = 2.14, 95% CI = 1.65 −2.78, $P < 0.001$), good (OR = 3.76, 95% CI = 2.89−4.90, $P < 0.001$), or fair or poor (OR = 6.48, 95% CI = 4.76−8.83, $P < 0.001$) compared with those with excellent overall health, and women were less likely to self-report malaria with every 10 years of age (OR = 0.90, 95% CI = 0.85−0.94, $P < 0.001$). Counter to expectations, women were significantly less likely to self-report malaria if they used a public dump (OR = 0.73, 95% CI = 0.58−0.92, $P = 0.008$) or other informal means of solid waste disposal (OR = 0.61, 95% CI = 0.45−0.81, $P < 0.002$) compared with those with a collection service and were less likely to self-report malaria with just a secondary education (OR = 0.70, 95% CI = 0.50−0.98, $P = 0.045$), middle (OR = 0.72, 95% CI = 0.53−0.98, $P = 0.048$), primary (OR = 0.68, 95% CI = 0.47−0.97, $P = 0.039$), or no education (OR = 0.59, 95% CI = 0.42−0.83, $P = 0.003$) relative to those completing higher education.

Distance to urban agriculture

ORs for self-reported malaria were studied for proximity to both UA and the local river system over distance alone and in the multivariate model described above with SES, method of solid waste disposal, education, self-reported overall health, and age. The household predictors did not exhibit any strong confounding of the relationship between distance band and self-reported malaria in either analysis. The distribution of ORs for self-reported malaria by distance, controlling for the five household predictors, are shown in Figure 3. The 95% CIs for the two distributions do not intersect until ~1 km, indicating that the odds of self-reported malaria are significantly higher for women living within 1 km of UA than those living within 1 km of the river system, but not beyond this threshold. The ORs for self-reported malaria ranged from 1.72 (95% CI = 1.42−2.07) to 4.96 (95% CI = 2.85−8.66) within 1 km of UA, and ranged from 0.69 (95% CI = 0.38−1.26) to 1.33 (95% CI = 1.05−1.68) within 1 km of the river system. The curves are smoother at higher distances because of the cumulative nature of the distance measure; the inclusion of additional centroids impacts the OR progressively less in higher cumulative distance bands.

Household differences by UA proximity

Given the significance of 1 km as a threshold for higher likelihood of malaria self-reports, the women living within a 1-km buffer of UA sites were compared with those living beyond this buffer. Table 3 summarizes the household differences between women in these two zones. Women were more likely to be within 1 km of UA if they were upper middle SES (OR = 1.28, 95% CI = 1.01−1.62), relative to upper SES, and were slightly older (OR = 1.05, 95% CI = 1.01−1.10 for every 10 years of age). Households were less likely to be within 1 km if they lacked piped water (OR = 0.78, 95% CI = 0.66−0.92), a refrigerator (OR = 0.81, 95% CI = 0.68−0.97), or a sewage system for liquid waste (OR = 0.66, 95% CI = 0.52−0.84). Households were also less likely to be within 1 km if they used a public dump (OR = 0.61, 95% CI = 0.49 −0.77) or other informal means of solid waste disposal (OR = 0.30, 95% CI = 0.21−0.42) compared with having a waste collection service. Women were less likely to be in the 1-km zone if relying on Kumasi ventilated improved pit (KVIP) access (OR = 0.56, 95% CI = 0.43 −0.74) or a public toilet (OR = 0.74, 95% CI = 0.60−0.91), rather than private toilet access, but were more likely to be near UA if using a bucket or pan (OR = 1.33, 95% CI = 1.01−1.74). Women were less likely to live in the 1-km zone if they only attained a primary education (OR = 0.57, 95% CI = 0.38−0.84) or reported no education (OR = 0.69, 95% CI = 0.49−0.98), relative to those with higher education, or if they self-reported their overall health as very good (OR = 0.44, 95% CI = 0.34−0.58) or good (OR = 0.59, 95% CI = 0.45−0.75), relative to those who reported excellent overall health. Regarding ethnicity, women were more likely living near UA if they were Asante (OR = 1.64, 95% CI = 1.21−2.23), other Akan (OR = 1.90, 95% CI = 1.39−2.60), Ewe (OR = 2.32, 95% CI = 1.79−3.02), Hausa (OR = 2.22, 95% CI = 1.47 −3.35), or other ethnicity (OR = 2.42, 95% CI = 1.84−3.19), relative to Ga.

Cluster analysis for EA rates

Local cluster analysis was performed by applying the Getis-Ord G_i* statistic to the smoothed self-report rates, represented by the geographic centroid of each EA. The G_i* was explored at multiple distances to determine a search distance that maximizes local clustering.[19] The G_i* statistic showed a critical distance of 1,500 m to maximize clustering, and the results are mapped in Figure 4. There are notably more centroids that are members of significant clusters (24 of 200) than would be expected by chance at the 95% level of significance. Clusters of high self-report rates exist within the 1-km buffer of UA, supporting the hypothesis that UA influences self-reported malaria. A second cluster of high rates near the northwestern Accra localities of Abeka, Apenkwa, and Kwashieman suggests other factors that are more salient in these communities. Three clusters of low rates occur outside or on the fringe of the 1-km UA buffer. The clusters of both high and low rates seem spatially distinct, indicative of the high degree of spatial heterogeneity seen in other studies of Accra.[20]

DISCUSSION

This analysis of proximity to UA, controlling for household characteristics, suggests that there is an elevated prevalence of self-reported malaria within 1 km of these sites. A 1-km threshold has previously been noted elsewhere in sub-Saharan Africa as an approximate flight range for female anopheline mosquitoes seeking a blood meal.[21−24] Although household locations were approximated by the centroid of its encompassing EA, the spatial decay of self-report rates beyond 1 km was strong, and the city-wide pattern of elevated self-reports within that range indicates an important health disparity. A recent study showed a similar pattern using entomologic indicators as a proxy for malaria in Accra,[11] consistent with prior epidemiologic findings,[9] but was not designed to test for a distance threshold effect. This study tested self-report rates over multiple distances and explicitly controlled for other major irrigation sources that influence mosquito activity.

The poor and disadvantaged are generally associated with shouldering the most severe burdens of disease and lost productivity[5,25]; however, the women living near UA sites showed many socioeconomic advantages over women throughout the rest of Accra. Households within 1 km of UA were more likely to have piped water, garbage collection, refrigerators, and sewage system access, and the women were generally better educated with better self-reported overall health, although some characteristics were not as easily interpreted (SES, toilet access, ethnicity). However, these counterintuitive differences befit the context of lower-density vegetated areas where neighborhoods are, on average, less likely to be part of an urban slum. It is also likely that the benefits of UA, in terms of improved income and nutrition, play a role in household differences. Given these amenities associated with UA-area households, the data suggest that the effect of higher mosquito densities driven by UA may be strong enough to overcome these socioeconomic advantages and augment the malaria burden. Although the large sample size showed several small effects among women living near UA, a bigger picture looms: should future UA activities expand to areas that border upon poorer neighborhoods, the burden may be that much more severe.

The need for a wider spatial distribution of sites in assessing the influence of UA was previously noted,[8] and we have enabled that view through examining rates of 200 randomly selected EAs throughout Accra. A pattern emerged where the EAs that were members of clusters of higher rates tended to be nearer to UA, with the converse observed for clusters of low rates. This is consistent with the individual analysis and an underlying spatial process. The members of the high rate significant clusters are spatially grouped both within and outside of the 1-km zone around UA (Figure 4). In one group, 6 of the 12 high rate centers are within this buffer; the very small likelihood of that outcome suggests a strong association of malaria with UA. The cluster centers outside of the 1-km zone indicate that some other factor(s) may be responsible for the elevated malaria rates in the northwest part of Accra. Such heterogeneity has been noted previously. The complexity of Accra is highlighted in a comparison study of malaria and anemia between Accra and Kumasi, which found that malaria prevalence fluctuated wildly within the cities.[26] It has also been reported that, contrary to expectations, water and sanitation quality generally had no effect on health levels in Accra, probably because of the haphazard way that the city's infrastructure had developed in the absence of disciplined urban planning.[20] Given epidemiologic patterns that differ from rural environments, urban malaria control should target specific locations based on known risk factors. This work underscores Accra's spatial complexity and beckons additional research questions regarding the control of urban malaria through neutralizing behaviors at a local level.

This study was limited by several factors, such as the lack of a malaria-specific questionnaire that gauged prevalence of protective behaviors and known risk factors such as travel to rural areas. Use of bed nets, window screens, and access to medication are often associated with socioeconomic characteristics, so it is possible that this bias is minimized by the use of the selected household measures. However, these factors remain critical to any thorough understanding of malaria epidemiology and may confound the relationship observed with proximity to UA. The SES measure itself may have been misleading, given the lack of additional income measures. SES was a quartile measure used for the stratification of EAs and did little to elucidate the variation within Accra's population. Real health differences achieved by higher SES might only be evident in the top 5% or even 1% of the population, but may be lost in quartiles. Spatial error was introduced by locating households in distance bands according to their EA centroids, although it is unlikely that this analysis would be sensitive to households shifting by a band or two. There is potential noise from missed UA sites or naturally occurring mosquito breeding sites that are often small and transient, although this factor is mitigated in an urban environment where much less land cover remains vegetated. Land cover metrics derived from satellite imagery showed low predictive power for malaria prevalence because of the difficulty of differentiating irrigated from non-irrigated vegetation, particularly for transient sites.

The WHSA will be reissued in 2008−2009, and the study hopes to introduce rapid diagnostic tests to directly measure parasite prevalence in young children living in WHSA households, as well as incorporate expanded malaria and income modules to control for additional disease-specific characteristics, finer measures of SES, and seasonality. In this regard, the future work aims to fuse the strategies of both this study and the work of Klinkenberg and others.[9] Neighborhood effects may contribute to the intra-urban variability in malaria seen in Accra, as recently shown in Kenya,[27] and follow-up work will benefit from neighborhood characterization efforts already underway. The authors thereby hope to expand this work and uncover the patterns of urban malaria in Accra that to date have eluded local control efforts.

Malaria is hyperendemic in Ghana; its debilitating symptoms are one of the major causes of poverty and low productivity.[28] It accounts for > 44% of reported outpatient visits, although these cases represent a fraction of actual episodes because most symptomatic infections are treated at home.[3,28] The drain on already-scarce health care services and loss of work productivity are a bane for socioeconomic development. Urban agriculture has shown the ability to alleviate some socioeconomic disparities, but with the unintended consequence of bringing malaria along with it. UA should be not discouraged, but rather used as yet another tool for identifying communities at elevated risk for the disease and promoting preventive measures such as bed nets and medication.

Acknowledgments

The authors acknowledge the generosity of Martin Donnelly and the Vector Group at the Liverpool School of Tropical Medicine in sharing data used in an earlier draft of this paper. The Women's Health Study of Accra was co-directed by Allan G. Hill and Rosemary B. Duda (Beth Israel Deaconess Medical Center) with Ghanaian counterparts, Drs. Rudolph Darko, John K. Anarfi, Richard Adanu, and Richard Biritwum (University of Ghana).

Financial support: This research was supported by Grants R21 HD046612-01 and R01 HD054906-01 from the Ethel Kennedy Shriver National Institute of Child Health and Human Development. The Women's Health Study of Accra was funded by the World Health Organization, the US Agency for International Development, and the Fulbright New Century Scholars Award (AGH).

REFERENCES

1. United Nations. World Urbanization Prospects: The 2007 Revision. United Nations Population Division, Department of Economic and Social Affairs; New York: 2008.
2. Montgomery, MR.; Stren, R.; Cohen, B.; Reed, HE., editors. Cities Transformed: Demographic Change and Its Implications in the Developing World. National Academy Press; Washington, DC: 2003.
3. Breman JG, Alilio MS, Mills A. Conquering the intolerable burden of malaria: what's new, what's needed: a summary. Am J Trop Med Hyg 2004;71(Suppl 2):1–15. [PubMed: 15331814]
4. Robert V, MacIntyre K, Keating J, Trape J, Duchemin J, Warren M, Beier J. Malaria transmission in urban sub-Saharan Africa. Am J Trop Med Hyg 2003;68:169–176. [PubMed: 12641407]
5. Keiser J, Utzinger J, Castro MC, Smith TA, Tanner M, Singer BH. Urbanization in sub-Saharan Africa and implication for malaria control. Am J Trop Med Hyg 2004;71(Suppl 2):118–127. [PubMed: 15331827]
6. Ferreira Gonçalves MJ, Alecrim WD. Non-planned urbanization as a contributing factor for malaria incidence in Manaus-Amazonas, Brazil. Rev Salud Públ 2004;6:156–166.
7. Klinkenberg E, van der Hoek W, Amerasinghe FP. A malaria risk analysis in an irrigated area in Sri Lanka. Acta Trop 2004;89:215–225. [PubMed: 14732243]
8. Afrane YA, Klinkenberg E, Drechsel P, Owusu-Daaku K, Garms R, Kruppa T. Does irrigated urban agriculture influence the transmission of malaria in the city of Kumasi, Ghana? Acta Trop 2004;89:125–134. [PubMed: 14732235]
9. Klinkenberg E, McCall PJ, Hastings LM, Wilson MD, Amerasinghe FP, Donnelly MJ. High malaria prevalence and urban agriculture in Accra, Ghana. Emerg Infect Dis 2005;11:1290–1293. [PubMed: 16102322]
10. Obuobie, E.; Keraita, B.; Danso, G.; Amoah, P.; Cofie, OO.; Raschid-Sally, L.; Drechsel, P. Irrigated Urban Vegetable Production in Ghana: Characteristics, Benefits and Risks. IWMI; Accra, Ghana: 2006.
11. Klinkenberg E, McCall PJ, Wilson MD, Amerasinghe FP, Donnelly MJ. Impact of urban agriculture on malaria vectors in Accra, Ghana. Malar J 2008;7:151. [PubMed: 18680565]
12. Wang S, Lengeler C, Smith TA, Vounatsou P, Diallo DA, Pritroipa X, Convelbo N, Kientga M, Tanner M. Rapid urban malaria appraisal (RUMA) I: epidemiology of urban malaria in Ouagadougou. Malar J 2005;4:43. [PubMed: 16168054]
13. Wang S, Lengeler C, Smith TA, Vounatsou P, Cissé G, Tanner M. Rapid urban malaria appraisal (RUMA) III: epidemiology of urban malaria in the municipality of Yopougon (Abidjan). Malar J 2006;5:28. [PubMed: 16584575]
14. Adanu RMK, Hill AG, Seffah JD, Darko R, Anarfi JK, Duda RB. Secular trends in menarcheal age among Ghanaian women in Accra. J Obstet Gynaecol 2006;26:550–554. [PubMed: 17000505]
15. Hill AG, Darko R, Seffah J, Adanu RMK, Anarfi JK, Duda RB. Health of urban Ghanaian women as identified by the Women's Health Study of Accra. Int J Gynaecol Obstet 2007;99:150–156. [PubMed: 17628563]
16. Duda RB, Kim MP, Darko R, Adanu RMK, Seffah J, Anarfi JK, Hill AG. Results of the Women's Health Study of Accra: assessment of blood pressure in urban women. Int J Cardiol 2007;117:115–122. [PubMed: 16887210]

17. Getis A, Ord JK. The analysis of spatial association by use of distance statistics. Geogr Anal 1992;24:189–206.
18. Sawada M. ROOKCASE EXCEL 97/2000 visual basic (VB) add-in for exploring global and local spatial autocorrelation. Bull Ecol Soc Am 1999;80:231–234.
19. Castro MC, Sawyer DO, Singer BH. Spatial patterns of malaria in the Amazon: implications for surveillance and targeted interventions. Health Place 2007;13:368–380. [PubMed: 16815074]
20. Weeks JR, Hill AG, Getis A, Stow D. Ethnic residential patterns as predictors of intra-urban child mortality inequality in Accra, Ghana. Urban Geogr 2006;27:526–548.
21. Thomson MC, Connor SJ, Quinones ML, Jawara M, Todd J, Greenwood BM. Movement of *Anopheles gambiae* s.l. malaria vectors between villages in The Gambia. Med Vet Entomol 1995;9:413–419. [PubMed: 8541594]
22. Costantini C, Li SG, DellaTorre A, Sagnon N, Coluzzi M, Taylor CE. Density, survival and dispersal of *Anopheles gambiae* complex mosquitoes in a West African Sudan savanna village. Med Vet Entomol 1996;10:203–219. [PubMed: 8887330]
23. Service MW. Mosquito (Diptera: Culicidae) dispersal: the long and short of it. J Med Entomol 1997;34:579–588. [PubMed: 9439109]
24. Diuk-Wasser MA, Toure MB, Dolo G, Bagayoko M, Sogoba N, Sissoko I, Traore SF, Taylor CE. Effect of rice cultivation patterns on malaria vector abundance in rice-growing villages in Mali. Am J Trop Med Hyg 2007;76:869–874. [PubMed: 17488907]
25. Amexo M, Tolhurst R, Barnish G, Bates I. Malaria misdiagnosis: effects on the poor and vulnerable. Lancet 2004;364:1896–1898. [PubMed: 15555670]
26. Klinkenberg E, McCall PJ, Wilson MD, Akoto AO, Amerasinghe FP, Bates I, Verhoeff FH, Barnish G, Donnelly MJ. Urban malaria and anaemia in children: a cross-sectional survey in two cities of Ghana. Trop Med Int Health 2006;11:578–588. [PubMed: 16640609]
27. Siri JG, Lindblade KA, Rosen DH, Onyango B, Vulule J, Slutsker L, Wilson ML. Quantitative urban classification for malaria epidemiology in sub-Saharan Africa. Malar J 2008;7:34. [PubMed: 18298857]
28. World Health Organization. World Malaria Report. WHO; Geneva: 2005. Roll Back Malaria, World Health Organization, UNICEF..

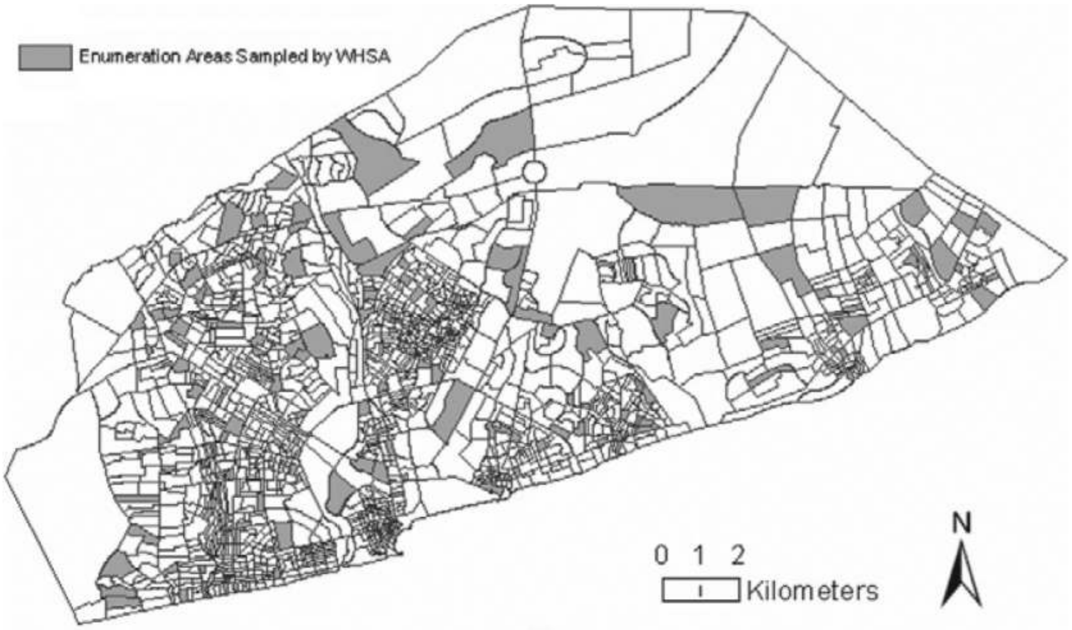

Figure 1.
Map of Accra by enumeration area (EA), highlighting the 200 EAs sampled during the WHSA.

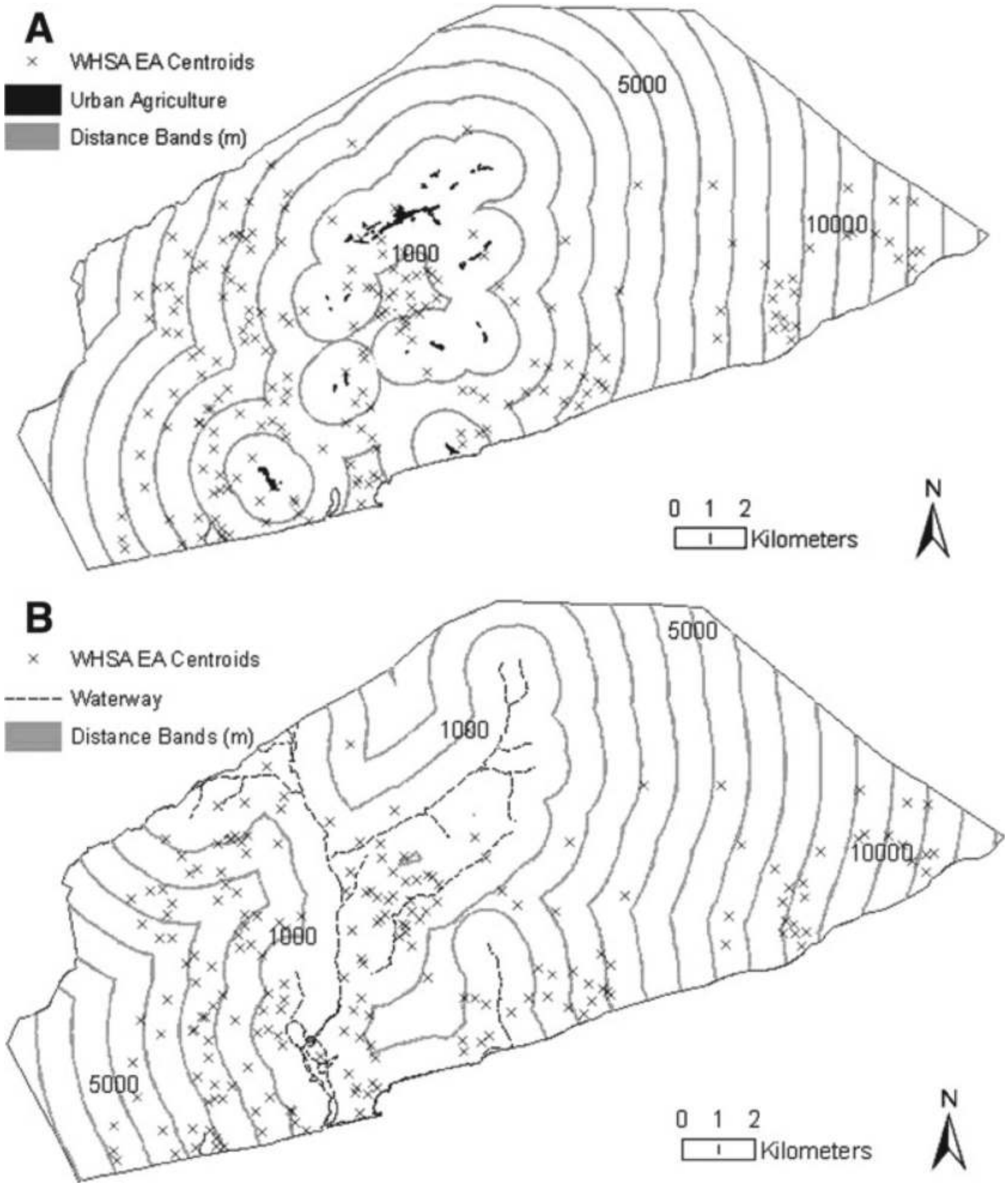

Figure 2.

Distance bands depicted in 1,000-m intervals generated (**A**) from urban agriculture sites and (**B**) from the Odaw River and nearby waterways used to irrigate urban agriculture. Distance effects were analyzed using cumulative 100-m increments.

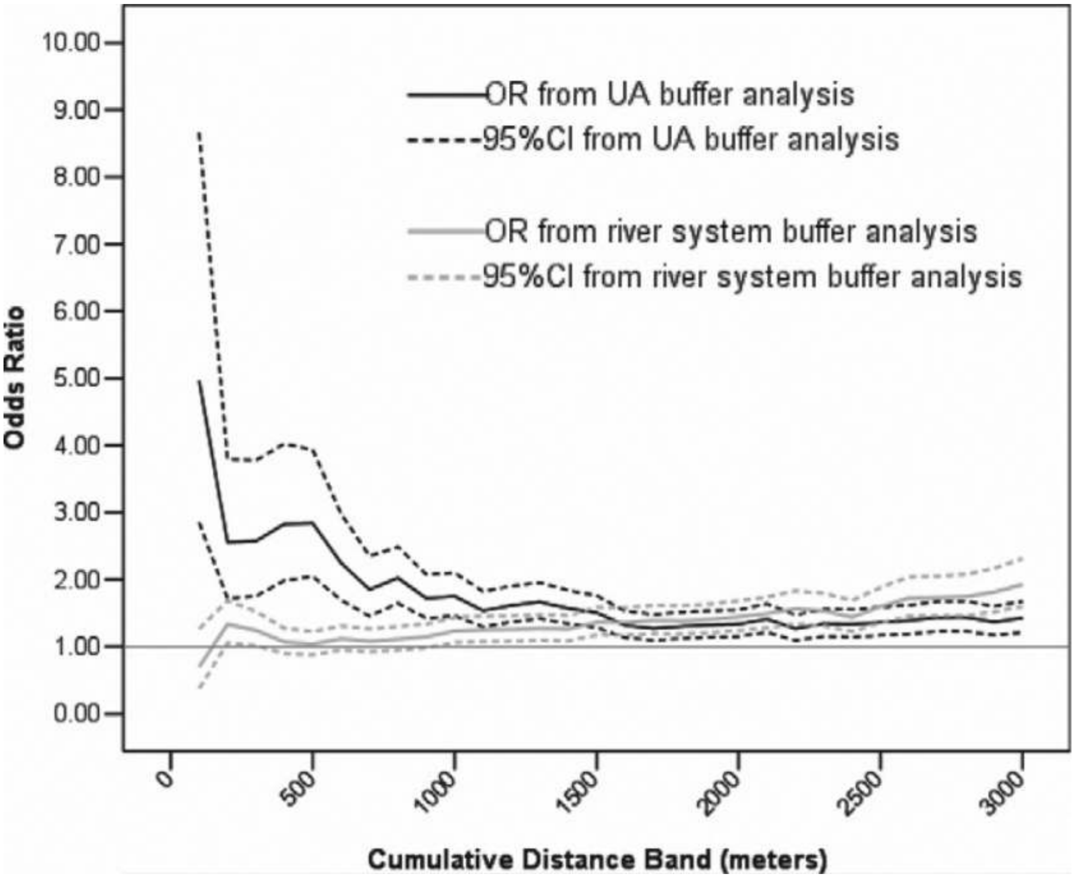

Figure 3.

Distribution of odds ratios for self-reported malaria by cumulative distance band from UA sites (exposure of interest) and from river system used to irrigate UA (spatial control).

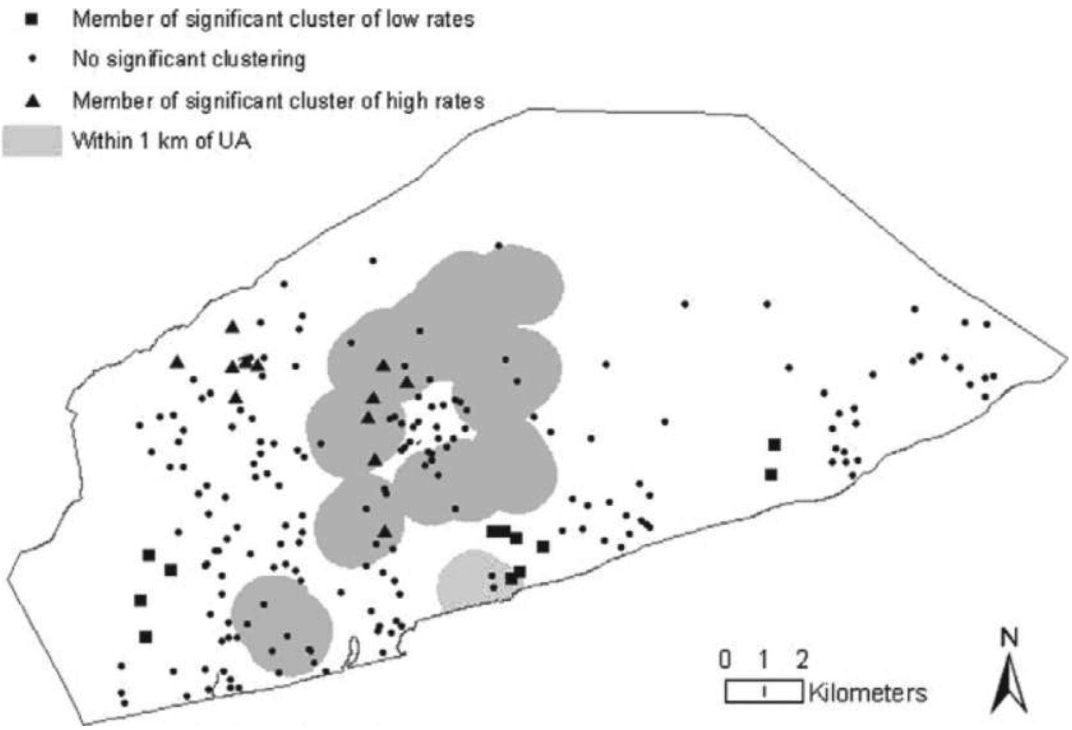

Figure 4.
Clusters of high and low self-reported malaria rates by EA observed using the Getis-Ord G_i* statistic.

Table 1

Descriptive frequencies of select household characteristics from the Women's Health Study of Accra and bivariate associations between each indicator and self-reported malaria in logistic regression

Characteristic	Women	Percent	P^*	OR	95% CI
Socioeconomic status ($N = 3{,}160$)			< 0.001		
Upper quartile	712	22.5		1.00[†]	
Upper middle quartile	740	23.4		1.35	1.10−1.66
Lower middle quartile	740	23.4		1.84	1.49−2.27
Lowest quartile	968	30.6		1.30	1.07−1.57
Source of drinking water ($N = 3{,}159$)			0.678		
Piped water in the home	1,673	53.0		1.00	
No piped water in the home	1,486	47.0		0.97	0.84−1.12
Type of toilet access ($N = 3{,}063$)			0.027		
Water closet (WC)	985	32.2		1.00	
Pit latrine	103	3.4		1.18	0.79−1.77
KVIP	528	17.2		1.17	0.95−1.45
Bucket or pan	330	10.8		1.40	1.09−1.80
Public toilet	1,117	36.5		1.28	1.08−1.52
Type of cooking fuel ($N = 3{,}162$)			0.099		
Gas	862	27.3		1.00	
Charcoal	2,050	64.8		1.12	0.96−1.31
Other	250	7.9		0.87	0.66−1.16
Type of bathing facility ($N = 3{,}160$)			0.101		
Bathroom	2,240	70.9		1.00	
Open cubicle	777	24.6		0.84	0.71−0.99
Other	143	4.5		1.02	0.72−1.45
Method of solid waste disposal ($N = 3{,}160$)			0.065		
Collection service	429	13.6		1.00	
Public dump	2,296	72.7		0.74	0.56−0.96
Other informal (burning, open dumping, etc.)	435	13.8		0.90	0.74−1.11
Method of liquid waste disposal ($N = 3{,}155$)			0.157		
Sewage system	372	11.8		1.00	
Other informal (street, gutter, compound, etc.)	2,783	88.2		1.17	0.94−1.45

Characteristic	Women	Percent	P^*	OR	95% CI
Refrigerator ownership (N = 3,156)			0.010		
Refrigerator owned within household	2,029	64.3		1.00	
Refrigerator not owned within household	1127	35.7		1.21	1.05–1.40
Education (N = 3,140)			0.343		
Higher	220	7.0		1.00	
Secondary/SSS	505	16.1		0.76	0.55–1.05
Middle/JSS	1,324	42.2		0.90	0.68–1.20
Primary	380	12.1		0.92	0.66–1.28
None	711	22.6		0.82	0.61–1.11
Ethnicity (N = 3,136)			0.206		
Ga/Adangbe	1,175	37.5		1.00	
Asante	303	9.7		1.25	0.97–1.62
Akwapim	178	5.7		0.90	0.66–1.24
Fante	351	11.2		0.82	0.64–1.04
Other Akan	261	8.3		1.01	0.77–1.32
Ewe	405	12.9		1.03	0.82–1.29
Hausa	125	4.0		0.79	0.55–1.14
Other	338	10.8		0.94	0.74–1.20
Overall health (N = 3,164)			< 0.001		
Excellent	404	12.8		1.00	
Very good	1,035	32.7		1.93	1.51–2.47
Good	1,101	34.8		3.10	2.43–3.96
Fair or Poor	624	19.7		4.59	3.50–6.01
Age (10 years) (N = 3,164)	Mean 38.8	SE 0.32	0.863	1.00	0.97–1.04

[*] P values from χ^2 test of differences between malaria self-report cases and non-cases across each characteristic.

[†] Referent category.

Table 2

Stepwise logistic regression model of associations between household indicators and self-reported malaria (N = 2,983) using backward elimination and removal criteria of $P > 0.10$

Characteristic	β	SE	OR	95% CI	P
Socioeconomic status					< 0.001*
Upper quartile			1.00†		
Upper middle quartile	0.397	0.114	1.49	1.19−1.86	< 0.001
Lower middle quartile	0.679	0.118	1.97	1.57−2.48	< 0.001
Lowest quartile	0.348	0.112	1.42	1.14−1.77	0.002
Method of solid waste disposal					0.003*
Collection service			1.00		
Public dump	−0.311	0.118	0.73	0.58−0.92	0.008
Other informal (burning, open dumping, etc.)	−0.503	0.152	0.61	0.45−0.81	< 0.001
Education					0.046*
Higher			1.00		
Secondary/SSS	−0.357	0.173	0.70	0.50−0.98	0.045
Middle/JSS	−0.328	0.158	0.72	0.53−0.98	0.048
Primary	−0.392	0.186	0.68	0.47−0.97	0.039
None	−0.533	0.176	0.59	0.42−0.83	0.003
Overall health					< 0.001*
Excellent			1.00		
Very good	0.761	0.133	2.14	1.65−2.78	< 0.001
Good	1.325	0.135	3.76	2.89−4.90	< 0.001
Fair or Poor	1.869	0.158	6.48	4.76−8.83	< 0.001
Age (10 years)	−0.011	0.003	0.90	0.85−0.94	< 0.001*

[*] P values from Type III analysis of overall effects.

[†] Referent category.

Table 3

Descriptive frequencies of select household indicators stratified by location (within or beyond 1 km of UA) and bivariate associations with odds ratios for being within the 1-km zone

	Within 1 km		Beyond 1 km				
Characteristic	***N***	**Percent**	***N***	**Percent**	P^*	**OR**	**95% CI**
Socioeconomic status ($N = 3{,}160$)					< 0.001		
Upper quartile	156	21.8	556	22.7		$1.00^{\dagger}$	
Upper middle quartile	195	27.3	545	22.3		1.28	1.01–1.62
Lower middle quartile	185	25.9	555	22.7		1.19	0.93–1.52
Lowest quartile	179	25.0	789	32.3		0.81	0.64–1.03
Source of drinking water ($N = 3{,}159$)					0.003		
Piped water in the home	413	57.8	1260	51.5		1.00	
No piped water in the home	301	42.2	1185	48.5		0.78	0.66–0.92
Type of toilet access ($N = 3{,}063$)					< 0.001		
Water closet (WC)	256	36.7	729	30.8		1.00	
Pit latrine	20	2.9	83	3.5		0.69	0.41–1.14
KVIP	87	12.5	441	18.7		0.56	0.43–0.74
Bucket or pan	105	15.0	225	9.5		1.33	1.01–1.74
Public toilet	230	33.0	887	37.5		0.74	0.60–0.91
Type of cooking fuel ($N = 3{,}162$)					0.922		
Gas	194	27.2	668	27.3		1.00	
Charcoal	461	64.6	1589	64.9		1.00	0.83–1.21
Other	59	8.3	191	7.8		1.06	0.76–1.48
Type of bathing facility ($N = 3{,}160$)					< 0.001		
Bathroom	519	72.7	1721	70.4		1.00	
Open cubicle	191	26.8	586	24.0		1.08	0.89–1.31
Other	4	0.6	139	5.7		0.09	0.04–0.26
Method of solid waste disposal ($N = 3{,}160$)					< 0.001		
Collection service	139	19.5	290	11.9		1.00	
Public dump	521	73.0	1775	72.6		0.61	0.49–0.77
Other informal (burning, open dumping, etc.)	54	7.6	381	15.6		0.30	0.21–0.42
Method of liquid waste disposal ($N = 3{,}155$)					< 0.001		

	Within 1 km		Beyond 1 km				
Characteristic	*N*	Percent	*N*	Percent	P^*	OR	95% CI
Sewage system	110	15.4	262	10.7		1.00	
Other informal (street, gutter, compound, etc.)	603	84.6	2180	89.3		0.66	0.52–0.84
Refrigerator ownership (*N* = 3,156)					0.021		
Refrigerator owned within household	485	67.9	1544	63.2		1.00	
Refrigerator not owned within household	229	32.1	898	36.8		0.81	0.68–0.97
Education (*N* = 3,140)					0.042		
Higher	62	8.7	158	6.5		1.00	
Secondary/SSS	112	15.8	393	16.2		0.73	0.51–1.04
Middle/JSS	315	44.4	1009	41.5		0.80	0.58–1.10
Primary	69	9.7	311	12.8		0.57	0.38–0.84
None	152	21.4	559	23.0		0.69	0.49–0.98
Ethnicity (*N* = 3,136)					< 0.001		
Ga/Adangbe	193	27.4	982	40.4		1.00	
Asante	74	10.5	229	9.4		1.64	1.21–2.23
Akwapim	39	5.5	139	5.7		1.43	0.97–2.10
Fante	53	7.5	298	12.3		0.91	0.65–1.26
Other Akan	71	10.1	190	7.8		1.90	1.39–2.60
Ewe	127	18.0	278	11.4		2.32	1.79–3.02
Hausa	38	5.4	87	3.6		2.22	1.47–3.35
Other	109	15.5	229	9.4		2.42	1.84–3.19
Overall health (*N* = 3,164)					< 0.001		
Excellent	129	18.0	275	11.2		1.00	
Very good	178	24.9	857	35.0		0.44	0.34–0.58
Good	237	33.2	864	35.3		0.59	0.45–0.75
Fair or Poor	171	23.9	453	18.5		0.81	0.61–1.05
Age (10 years) (*N* = 3,164)	715	mean 40.1 SE 0.67	2442	mean 38.5 SE 0.36	0.031	1.05	1.01–1.10

---

[*] *P* values from χ^2 test of differences between cases within and beyond 1 km from UA across each characteristic.

[†] Referent category.