INTRODUCTION

Malaria delays the socioeconomic development of affected regions and is a major roadblock on the path toward achieving several of the targets embodied in the Millennium Development Goals, particularly in sub-Saharan Africa. The process of urbanization alters ecologic and sociocultural diversities, and often leads to enhanced spatiotemporal heterogeneities at a small scale. Urban malaria is a common, albeit under-researched topic, and thus needs targeted focus. Important considerations for understanding the epidemiology of urban malaria include the high rate of population growth in urban settings, the lack of acquired immunity among urban inhabitants, the possibility that malaria vectors may adapt to urban ecosystems, and the maintenance of rural lifestyles and livelihoods once populations have migrated to and settled in urban areas. Epidemiology studies on urban malaria in sub-Saharan Africa have focused primarily on large cities; e.g., Brazzaville in Congo, Abidjan in Côte d’Ivoire, and N’Djamena in Chad. To date, only few studies investigated malaria risk factors in small- and medium-sized towns in Africa. Compared with mega-cities, population densities are usually lower, and there are larger open green spaces in smaller towns.

Farming represents an important livelihood strategy for a considerable number of urban dwellers. However, urban farmers are often marginalized and not officially recognized by the national authorities. Urban agriculture has been defined as “the production, processing and distribution of a diversity of foods, including vegetables and animal products in intra-urban or peri-urban areas.” It is important to note that specific types of agricultural land use in urban settings may create suitable mosquito breeding sites and thus increase the risk of malaria, which in turn can affect agricultural land use patterns and household income. For example, in an intensive vegetable farming zone in a small town of central Côte d’Ivoire, malaria accounted for more than half of the work days lost, which significantly reduced yields and revenues.

The objectives of the study presented here were to identify risk factors for malaria among urban farmers and their families in a medium-sized town of Côte d’Ivoire, and to investigate whether the prevalence and intensity of Plasmodium falciparum infections are associated with the distance between specific human-made water bodies and the location of farmers’ houses. This study complements our previous work that focused on agricultural land use and mosquito larval habitats in the same town.

MATERIALS AND METHODS

Study area. Our study was carried out between April 2004 and June 2005 in Man, a district town in western Côte d’Ivoire, which is 630 km northwest of the capital of Abidjan. Entomologic studies in the western forest zone of Côte d’Ivoire identified Anopheles gambiae s.s. and An. funestus as the key malaria vectors (Adja AM and others, unpublished data). In a previous community-based cross-sectional survey in a village 25 km east of Man, the prevalence of P. falciparum was 32.1%. In children < 15 years of age, risk factors for a P. falciparum infection included living in a specific agricultural zone, close proximity to permanent ponds and fish ponds, periodic stays overnight in temporary farm huts, and low socioeconomic status. Our findings indicate that specific crop systems and specific agricultural practices may increase the risk of malaria in urban settings of tropical Africa.
Agricultural zones, farming households, and questionnaire surveys. Seven agricultural zones were identified in April 2004, all characterized by the presence of irrigated crop systems.16 The zones are located within an area of $5 \times 7$ km. Mixed crops are typical for zones 1 and 3, rice is grown in traditional smallholder plots in zones 4 and 6, and a large rice perimeter is found in zones 5 and 7, with traditional smallholder irrigated rice also present in zone 7. Logistic reasons precluded our planned survey in zone 2; thus, no data are presented for this zone.

Farmers were identified during work by our team of five field workers when visiting agricultural zones at different times on six consecutive days. The same method was previously used in a study on health-related issues of urban agriculture in Ouagadougou, Burkina Faso24 (Cissé G, 1997. Impact Sanitaire de l’Utilisation d’Eaux Polluées en Agriculture Urbaine: Cas du Marachiage à Ouagadougou (Burkina Faso)). Lausanne, Switzerland: Ecole Polytechnique Fédérale de Lausanne. Thesis). The two inclusion criteria for a household were (i) farming is the main occupation, and (ii) farming in the actual zone has been conducted for at least one year.

After explaining the purpose of our study and receiving oral consent from the household heads, a list of all household members was established, including their name, age, and sex. We defined a member of a household as a person who lived in the household for at least nine months and who shared meals and income. A total of 131 farming households (with an estimated 1,164 individuals) and 34 control households (with an estimated 272 individuals) were invited to participate in the study. In October 2004, a questionnaire was administered to all household heads to investigate agricultural land use patterns, including crop types, storage and use of water at home and on agricultural plots, livestock ownership, and agricultural activities. In June 2005, heads of households were interviewed on their socioeconomic status, including questions on education attainment, housing characteristics, asset ownership, sanitation facilities, and personal protection against mosquito bites. This was coupled with a cross-sectional malariologic survey as detailed below. Geographic coordinates of each house and the main agricultural plots were collected, using a hand-held global positioning system receiver (Garmin eTrex and 12XL; Garmin International Inc., Olathe, KS).

Field and laboratory investigations. The protocol for our cross-sectional malariologic survey was reviewed and approved by the institutional review boards of the Swiss Tropical Institute (Basel, Switzerland) and the Centre Suisse de Recherches Scientifiques (Abidjan, Côte d’Ivoire), and received ethical clearance from the Ministry of Public Health in Côte d’Ivoire. Convenient meeting places were chosen in the different zones, e.g., community building, empty class room, or yard of a political or religious leader. All members of the selected households were invited to provide a finger prick blood sample.

Thick and thin blood smears were prepared on microscope slides. They were air-dried and transferred to the community health laboratory of Man, where they were stained with Giemsa, following routine procedures. Within four weeks, the slides were read under a light microscope for the presence and density of Plasmodia parasitemia by an experienced laboratory technician, assuming for a standard white blood cell count of 8,000/μL of blood. For quality control purposes, a random sample of 70 (8.7%) of 809 slides was cross-checked by another senior technician. An accuracy rate of 89% was noted, which was considered sufficient to use the data for subsequent analyses.

Individuals who reported malaria symptoms at the time of finger prick blood sampling were diagnosed by an experienced nurse. An antimalarial drug (i.e., amodiaquine) was administered to those with a confirmed diagnosis, according to national guidelines.

Data management and statistical analysis. All data were double-entered and cross-checked, using version 3.1 of EpiData software (EpiData Association, Odense, Denmark). Statistical analyses were carried out with Stata version 9 software (Stata Corporation, College Station, TX) and WinBUGS version 1.4.1 software (Imperial College and Medical Research Council, London, United Kingdom). Maps with the location of the farmers’ houses and agricultural plots were established in ArcMap™ version 9.0 software (Environmental Systems Research Institute, Redlands, CA). Nearest straight-line distances between farmers’ houses and the Kô River and other potential mosquito breeding sites were calculated in ArcMap™ and classified as 0–99 meters, 100–499 meters, and ≥ 500 meters.25

Study participants were grouped into six age classes: < 5, 5–9, 10–14, 15–24, 25–39, and ≥ 40 years.23 Three infection intensity categories for P. falciparum were considered: light infection (1–50), moderate infection (51–500), and heavy infection (> 500) parasites/μL of blood.23

An index of housing characteristics (e.g., type of wall) and assets owned (e.g., bicycle) was used to calculate the household socioeconomic status through principal component analysis. Wealth quintiles were derived from the first principal component (PC).26 The method was adapted to the local context of Man, as described elsewhere.27

Pearsons’ chi-square test and Fisher’s test as appropriate were applied to compare proportions between groups. Risk factors for prevalence and intensity of P. falciparum infection were investigated, using bivariate logistic and negative binomial regression models, respectively. Potential interactions between different variables and age, socioeconomic status and agricultural zone were assessed using the likelihood ratio test. For the variable periodic stay overnight at farming huts, we tested for interactions with all variables.

Explanatory variables significant at a 15% significance level were chosen to enter into Bayesian multiple (logistic and negative binomial) regressions. Between-household variation ($\sigma^2$) was taken into account by introducing in the model household-specific random effects with an exchangeable correlation structure. Similarly, geographic correlation was modeled by location-specific random effects. We assumed that spatial correlation is an exponential function of the distance, i.e., $\sigma^2 \exp(-pd_{kl})$, where $d_{kl}$ is the straight-line distance between households $k$ and $l$, $\sigma^2$ is the geographic variability known as the sill, and $p$ is a smoothing parameter that controls the rate of correlation decay with distance. The range of geographic dependency that is the minimum distance at which spatial correlation between locations is less than 5% was calculated as $3/p$ and expressed in meters.

We tested two different multiple regression models for P. falciparum infection prevalence and intensity. Whereas the first model did not take into account the spatial correlation and between-household variation, the second model consid-
erated both geographic correlation and between-household variation. Inference was based on the better fitting model, which was selected using the deviance information criterion (DIC) as a goodness of fit measure. The model with the smallest DIC was considered as the best fitting one. Further details on model specifications and model fit are given in the Appendix.

RESULTS

Profiles of urban farmers in Man. Overall, 672 individuals participated in the cross-sectional studies. Ninety-eight (14.6%) were dropped because they lacked either demographic data or finger prick blood samples (n = 89), or questionnaire data (n = 9). Thus, our final study cohort consisted of 574 individuals from 112 farming households (zone 1 = 63 individuals and 15 households, zone 3 = 75 individuals and 16 households, zone 4 = 57 individuals and 13 households, zone 5 = 128 individuals and 25 households, zone 6 = 168 individuals and 31 households, and zone 7 = 83 individuals and 12 households). There were 247 children less than 15 years of age (43.0%). The mean age of our study cohort was 23.6 years (SD = 18.5 years) and the study population showed a similar age distribution as that of the country. The male-to-female ratio was 1:1.1 with no statistically significant difference between age groups. One-third of the households were inhabited by ≥ 10 people. Most urban farmers were from the region of Man, and one-fourth were immigrants from neighboring countries (i.e., Burkina Faso and Mali). Two-thirds of all household heads were illiterate. One of eight farmers had received agricultural training, mainly in rice cultivation and irrigation techniques, which was provided by the national agricultural research center or extension services. Of all households engaged in agriculture, 82.1% reported farming as their only occupation.

Land property status and livestock. Two-thirds of the farmers cultivated their crops on the current plots for at least five years. Three-fourths of the farmers worked in the zone where they resided. Half of the farmers rented the land and half were owners by purchase or inheritance. We have reported the main crop types in this study area.16 Crop systems were primarily rice- and vegetable-based. In addition, rain-fed food crops, particularly manioc, banana, and maize, were cultivated. Nearly 60% of the households had some livestock (e.g., cattle, fowls, goats, pigs, and sheep). One of eight households maintained fish ponds for aquaculture production.

Socioeconomic status. Wealth quintiles derived from an ensemble of household characteristics and assets owned were calculated. The first PC explained 25.9% of the overall variability. Households in possession of a car had the highest score (1.09), followed by those with a video player (0.96). The lowest scores were attributed to households without electricity (~0.87), and without a radio (~0.49). Although electricity was available in all households belonging to the four wealthiest quintiles, only 53.9% of the poorest households were connected to the power grid. Radio was the most frequently owned electronic equipment (64.3%), followed by television (49.1%), and ventilator (33.1%). Mobile telephones and refrigerators were considerably more common in less poor households, and ownership of a video or a car was restricted to the richest quintile. Bed net ownership increased with socioeconomic status; only 3.9% of the poorest quintile had a bed net, whereas the respective percentage in the richest quintile was 47.6%. More than one-third of the two poorest quintiles lacked any kind of sanitation facility, but almost all of the two richest quintiles had a latrine.

Plasmodium falciparum parasitemia in relation to sociodemographic characteristics. Overall, 184 individuals were infected with P. falciparum, resulting in a prevalence of 32.1% (95% confidence interval [CI] = 28.2–35.9). One person had a mixed infection with P. falciparum and P. malariae. Prevalence and intensity of infection were significantly associated with age ($\chi^2 = 83.5$, degrees of freedom [df] = 5, $P < 0.01$ for prevalence; $\chi^2 = 97.9$, df = 10, $P < 0.01$ for intensity) (Figure 1), but not with sex. In children < 10 years of age, the prevalence of P. falciparum was 51.8%, whereas significantly lower prevalences were observed in older age groups (25.0% and 10.7% in people 15–24 and 25–39 years of age, respectively). Among those people who were infected, 11.4% had a light infection intensity (mean parasitemia = 48.0 parasites/µL of blood), 47.3% had a moderate infection intensity (mean parasitemia = 188.9 parasites/µL of blood), and 41.3% had a heavy infection intensity (mean parasitemia = 1,221.3 parasites/µL of blood). There were 12 individuals (6.5%) with an infection intensity > 5,000 parasites/µL of blood and their mean parasitemia was 13,575.0 parasites/µL of blood (95% CI = 6,966.4–20,173.6 parasites/µL of blood).

Prevalence or intensity of P. falciparum infections were not significantly related to the last reported malaria or fever episode (hot body) when using a recall period of four weeks. Similarly, sleeping under a bed net during the last night or the presence of livestock showed no statistically significant association with the presence or density of P. falciparum. However, infection intensities were significantly related to wealth quintiles ($\chi^2 = 16.2$, df = 8, $P = 0.04$). The highest frequencies of heavy infection intensities were observed in the quintiles ‘very poor’, ‘poor’, and ‘less poor’ (15.8–16.3%), whereas the lowest frequency of heavy infection intensity was observed among the least poor (5.8%).

Malaria in relation to agricultural zones. Figure 2 shows the prevalence and intensity of P. falciparum infection for children less than 15 years of age stratified by agricultural zone. There was a statistically significant difference in the preva-
Results are presented for all age groups and children only (≤ 15 years of age). With regard to children, those living in zones 3, 4, and 5 were at a significantly higher risk of parasitemia when compared with children living in zone 1 (OR = 32.00, 95% Bayesian credible interval [BCI] = 3.97–128.10 for zone 3; OR = 8.77, 95% BCI = 1.04–34.53 for zone 4; and OR = 4.96, 95% BCI = 1.16–14.38 for zone 5). Children residing in zone 7 were 4.3 times less likely to have high levels of parasitemia (P/DR = 0.23, 95% BCI = 0.02–0.95) compared with children living in zone 1. Likewise, children from wealthier households were at lower odds of a *P. falciparum* infection than their poorer counterparts (OR = 0.16, 95% BCI = 0.03–0.46 for children in the poor category).

Another important risk factor for a *P. falciparum* infection was distance to permanent ponds and fish ponds. Children living at least 500 meters from such water bodies were significantly less likely to be infected than those living in close proximity (OR = 0.25, 95% BCI = 0.05–0.72). However, distance did not have any effect on infection intensity among children.

Staying overnight in temporary farm huts was associated with an over 17-fold higher risk of a *P. falciparum* infection when compared with those children from families coming home at night. Malaria infection was not significantly age-related for farming families who periodically stayed overnight in temporary farm huts in contrast to families who stayed home at night.

**Spatial correlation of malaria infection.** The results of the spatial random-effects binomial regression models (Table 3) indicate no significant spatial correlation of a *P. falciparum* infection with distance between the farmers’ houses. The minimum distance at which spatial correlation between farmers’ houses decreased to less than 5% was as low as 3.9 meters for children < 15 years of age. This means that for houses located further from each other than this threshold distance, there is no spatial correlation of infection. In the spatial random-effects models, the between-household variation equals the spatial variation. Given the extremely low threshold of spatial correlation for intensity of *P. falciparum* infection, and the marginal between-household variation, spatial correlation was not significant.

### DISCUSSION

Our results suggest that the risk of *P. falciparum* infection among farmers and their families in a medium-sized town of Côte d’Ivoire is affected by agricultural land use patterns and common agricultural practices. The prevalence of *P. falciparum* among children less than 15 years of age was 51.8%, and the overall prevalence in all age groups was 32.1%. Residence in a specific agricultural zone appeared as a major risk factor for malaria prevalence and intensity among children. We observed significant spatial heterogeneity, with prevalence of infection ranging between 20.5% (traditional smallholder rice plots and large rice perimeter) and 77.8% (mixed crop systems). Recent studies carried out in large towns of...
Kumasi\textsuperscript{26} and Accra\textsuperscript{29} in Ghana reported highest malaria prevalence and frequency of heavy infections in zones of mixed crop systems. Other prominent risk factors for a \textit{P. falciparum} infection in children in the current study included close proximity to permanent ponds and fish ponds, low socioeconomic status, and staying overnight in temporary farm huts. Our study also confirms that \textit{P. falciparum} is the predominant \textit{Plasmodium} species in the western part of Côte d’Ivoire.\textsuperscript{22,23}

An important limitation of this study is that instead of our initial plans to carry out two cross-sectional malariologic surveys, one during the dry season and the other during the wet season, we were able to conduct only one survey in the transition period between the dry and the rainy season. The principal reason was the sociopolitical instability in Côte d’Ivoire, which began in September 2002 and was ongoing during our field work.\textsuperscript{30}

In view of large open green areas and the magnitude of subsistence farming, the latter partially explained by the persisting sociopolitical crisis, land use pattern in Man show rural characteristics. In a previous study carried out in the town of Bouaké in central Côte d’Ivoire, malaria transmission was high in irrigated rice paddy zones during the rainy season and showed a positive association with water availability in market gardens and with the rice cropping cycle.\textsuperscript{31} Another investigation on malaria transmission dynamics in irrigated rice and vegetable crop systems in a rural setting of central Côte d’Ivoire showed that the density of the main malaria vector (\textit{An. gambiae}) was higher in rice-based crop systems than in vegetable gardens.\textsuperscript{32}

Our broad classification of crop types into market garden, rain-fed food, rice, and perennial crops was too limited an indicator for identification of high-risk areas for malaria, given the small scale of our study area (i.e., 5 x 7 km). The issues of pattern and scale are partially responsible for this observation.\textsuperscript{33} However, since specific human-made water bodies have been identified as productive \textit{Anopheles} breeding sites and could be linked to typical crop systems (e.g., irrigation wells in market gardens),\textsuperscript{34} we conclude that crop type classifications might be useful for larger study areas, particularly in case data on environmental features and land use are provided by high-resolution satellite imagery. The significant association found between \textit{P. falciparum} infection and the distance to ponds and fish ponds might be explained by this type of water body being relatively large and permanent, thus providing more stable conditions for mosquito breeding than smaller, often temporary water bodies (e.g., agricultural trenches or irrigation wells). Moreover, the latter are often disturbed by human activities. Our findings are in agreement with a recent study in Kampala, Uganda, where living in close proximity to a swamp was a risk factor for malaria incidence.\textsuperscript{25} In another study carried out in Dakar, Senegal, the density of adult \textit{Anopheles} decreased significantly with distance from a swamp.\textsuperscript{34}

Although the number of farmers (n = 15) and children less than 15 years of age (n = 15) who occasionally stayed overnight in temporary farm huts was small, this feature was identified as a risk factor for infection with \textit{P. falciparum}. These temporary farm huts are poorly constructed (wood and thatched roofs), unscreened with open eaves, and usually located at the borders of rice fields, and thus surrounded by potential \textit{Anopheles} breeding sites.\textsuperscript{36} The number of overnight stays in temporary farm huts usually peaks during periods of intensive agricultural labor in the main harvest period at the end of the rainy season. This time of the year coincides with the highest number of potential mosquito breeding sites.

### Table 1

Results of bivariate logistic and binomial regression models, including all ages (n = 574)*

<table>
<thead>
<tr>
<th>Distance to potential mosquito breeding sites (m)</th>
<th>No. (%)</th>
<th>Infection prevalence of \textit{P. falciparum}</th>
<th>Infection intensity of \textit{P. falciparum}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OR 95% CI LRT P†</td>
<td>OR 95% CI LRT P†</td>
</tr>
<tr>
<td>Pond and fish pond</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–99</td>
<td>217 (37.8)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>100–499</td>
<td>309 (53.8)</td>
<td>0.80 0.55, 1.16 4.62 0.010</td>
<td>0.36 0.16, 0.82 7.04 0.030</td>
</tr>
<tr>
<td>≥ 500</td>
<td>48 (8.4)</td>
<td>0.47 0.22, 0.99 4.62 0.010</td>
<td>0.28 0.06, 1.19 7.04 0.030</td>
</tr>
<tr>
<td>Rice paddy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–99</td>
<td>281 (48.9)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>100–499</td>
<td>276 (48.1)</td>
<td>1.06 0.74, 1.51 4.27 0.013</td>
<td>1.44 0.66, 3.16 8.32 0.079</td>
</tr>
<tr>
<td>≥ 500</td>
<td>17 (3.0)</td>
<td>0.66 0.21, 2.09 4.27 0.013</td>
<td>1.10 0.11, 11.20 8.32 0.079</td>
</tr>
<tr>
<td>Creek/source</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–99</td>
<td>12 (2.1)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>100–499</td>
<td>159 (27.7)</td>
<td>0.78 0.24, 2.58 2.11 0.348</td>
<td>0.27 0.02, 4.34 3.49 0.175</td>
</tr>
<tr>
<td>≥ 500</td>
<td>403 (70.2)</td>
<td>0.61 0.19, 1.95 2.11 0.348</td>
<td>0.17 0.01, 2.60 3.49 0.175</td>
</tr>
<tr>
<td>Irrigation well</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–99</td>
<td>228 (39.7)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>100–499</td>
<td>333 (58.0)</td>
<td>0.77 0.54, 1.10 4.09 0.014</td>
<td>0.81 0.52, 1.33 8.32 0.079</td>
</tr>
<tr>
<td>≥ 500</td>
<td>13 (2.3)</td>
<td>0.81 0.24, 2.70 4.09 0.014</td>
<td>0.55 0.16, 2.00 4.51 0.105</td>
</tr>
<tr>
<td>Agricultural trench</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–99</td>
<td>139 (24.2)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>100–499</td>
<td>352 (61.3)</td>
<td>0.86 0.57, 1.30 4.09 0.014</td>
<td>0.75 0.48, 1.33 4.51 0.105</td>
</tr>
<tr>
<td>≥ 500</td>
<td>83 (14.5)</td>
<td>0.53 0.28, 0.98 4.09 0.014</td>
<td>0.55 0.16, 2.00 4.51 0.105</td>
</tr>
<tr>
<td>Kô River</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>0–99</td>
<td>53 (9.2)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>100–499</td>
<td>213 (37.1)</td>
<td>0.65 0.35, 1.22 1.74 0.418</td>
<td>0.32 0.08, 1.33 5.03 0.081</td>
</tr>
<tr>
<td>≥ 500</td>
<td>308 (53.7)</td>
<td>0.72 0.40, 1.32 1.74 0.418</td>
<td>0.82 0.21, 3.21 5.03 0.081</td>
</tr>
</tbody>
</table>

* Outcomes were presence and intensity of \textit{P. falciparum} infection. The explanatory variable was distance to potential mosquito breeding sites. OR = crude odds ratio; CI = confidence interval; LRT = likelihood ratio test; PDR = crude \textit{P. falciparum} density ratio.
† Based on LRT.
and an elevated risk of malaria transmission.32 Higher Plasmodia infection rates among adults who sleep in temporary farm huts or forested areas because of agricultural activities have been observed in southwestern Côte d’Ivoire,22 as well as in Thailand,35 Malaysia,36 and Colombia.37 In a recent study, an increased risk of malaria was observed among people who periodically spent time outside Abidjan, and it was speculated that urban dwellers become infected while spending time away from their place of residence.14 These urban-to-rural movements often involve entire families, particularly during harvest and other intensive agricultural work periods. Other reasons include sociocultural obligations (e.g., attending a funeral), or recreational activities (e.g., spending leisure time in the countryside). Consequently, the issue of human mobility with urban-to-rural movement patterns warrants more attention to enhance our understanding of the epidemiology of urban malaria.

Surprisingly, we could not find any significant association between Plasmodium infection and sleeping under an (impregnated) bed net. However, there is evidence from Africa that the use of bed nets reduces the risk of malaria-related morbidity and mortality.38 Despite the lack of a significant association between Plasmodium infection and bed net use in the present study, the higher the socioeconomic status of a farming family, the higher the frequency of bed nets owned. However, ownership does not imply regular use. An enhanced understanding of individual bed net use in the current setting would be useful for adapted community-based prevention approaches. Conversely, our finding of a significant association between socioeconomic status and the risk of Plasmodium infection is in agreement with a previous study carried out in an urban setting of Ghana.39 A low socioeconomic status was associated with low protective housing conditions: i.e., 73.1% of the poorest and 63.2% of the very poor households inhabited houses with wooden walls sealed up with traditional clay.

Another important aspect of our study originates from the use of random-effects models, and household-specific and location-specific random effects multivariate models fitted to our data by using Bayesian statistical specifications. One advantage of Bayesian modeling is that spatial correlation of infection can be incorporated.40 Interestingly, the
prevalence of *P. falciparum* was better explained by non-random effects models, whereas infection intensity data showed better fits by random-effects models. However, when spatial correlation was taken into account, agricultural zone remained the only significant covariate in the model focusing on children only. There is a need to test whether intensity might be a more suitable indicator than prevalence to explain spatial heterogeneity at a small scale, where houses are close to each other and malaria prevalence is moderate to high.

In conclusion, *P. falciparum* infection among families engaged in urban farming of a medium-sized town of Côte d’Ivoire were governed by specific types of agricultural land use, farming practices, close proximity to human-made permanent water bodies, and socioeconomic status. Bayesian statistical approaches at household level can explain spatial heterogeneity at a small scale. Our study is relevant for the ecological understanding at the local level, and might be used to design and implement prevention strategies and vector control programs that are readily adapted to local agro-ecologic settings. Risk factors can be identified successfully at community level because mosquitoes and humans interact at this scale. For medium-sized towns in malaria-endemic settings, we propose in-depth studies combining systematic appraisals of human-made mosquito breeding sites and repeated mosquito collections in selected agricultural zones that would contribute to a better understanding of malaria transmission patterns and dynamics in zones of urban agricultural land use.

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REFERENCES


APPENDIX

Let \( Y_{ijk} \) be the number of \( P. falciparum \) parasites in individual \( k \) within household \( j \) at location \( i \). We assumed that \( Y_{ijk} \) has a negative binomial distribution \( Y_{ijk} \sim Nb(\mu_{ijk}, \ r) \) with mean \( \mu_{ijk} \) and overdispersion parameter \( r \). We modeled the logarithm of the \( \mu_{ijk} \) as an additive function of various determinants of infection intensity, \( X_{ijk} \) (demographic and socioeconomic factors, agricultural zone, and distance to potential mosquito breeding sites), the household \( (u) \) and location-specific random effects \( (\varphi) \), which is \( \log(\mu_{ijk}) = X_{ijk}^T \beta + u_i + \varphi \), where \( \beta \) is the vector of regression coefficients.

For modeling the infection status \( Z_{ijk} \) of individual \( k \) within household \( j \) at location \( i \), we assumed that \( Z_{ijk} \) follows a Bernoulli distribution, \( Z_{ijk} \sim Ber(\pi_{ijk}) \), where \( \pi_{ijk} \) measures the risk of an infection with \( P. falciparum \) for individual \( k \) within household \( j \) at location \( i \). We modeled covariates and random effects on the logit scale, that is \( \logit(\pi_{ijk}) = X_{ijk}^T \beta + u_i + \varphi \).

For the multiple regression models (infection prevalence and intensity), we assumed that \( u_i \sim N(0, \sigma_u^2) \), \( j = 1, \ldots J \) and \( \varphi \sim MVN (0, \Sigma) \) where \( \Sigma_{ij} = \sigma^2 \exp(-d_{ij}/\rho) \) where \( d_{ij} \) is the distance between location \( r \) and \( s \), \( \rho \) is the rate of correlation decay, and \( \sigma_u^2 \) and \( \sigma^2 \) are the between-household and spatial variation, respectively. We adopted the Bayesian approach to inference and choose vague normal prior distributions with large variances (i.e., 10,000) for the regression coefficients and inverse gamma prior distributions for \( \sigma_u^2 \) and \( \sigma^2 \). Markov chain Monte Carlo simulation was used to estimate the model parameters. We run a single chain sampler with a burn-in of 5,000 iterations. Convergence was assessed by inspection of ergodic averages of selected model parameters. The D/C was used to select the models that best fitted the data.