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Does irrigated urban agriculture influence the transmission of malaria in the city of Kumasi, Ghana?

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Abstract

To verify the possible impact of irrigated urban agriculture on malaria transmission in cities, we studied entomological parameters, self-reported malaria episodes, and household-level data in the city of Kumasi, Ghana. A comparison was made between city locations without irrigated agriculture, city locations with irrigated urban vegetable production, and peri-urban (PU) locations with rain-fed agriculture. In the rainy as well as dry seasons, larvae of *Anopheles* spp. were identified in the irrigation systems of the urban farms. Night catches revealed significantly higher adult anopheline densities in peri-urban and urban agricultural locations compared to non-agricultural urban locations. Polymerase chain reaction (PCR) analysis of *Anopheles gambiae* sensu lato revealed that all specimens processed were *A. gambiae* sensu stricto. The pattern observed in the night catches was consistent with household interviews because significantly more episodes of malaria and subsequent days lost due to illness were reported in peri-urban and urban agricultural locations than in non-agricultural urban locations. In Kumasi, urban agriculture is mainly practised in inland valleys, which might naturally produce more mosquitoes. Therefore more detailed studies, also in other cities with different water sources and irrigation systems, and a better spatial distribution of sites with and without urban agriculture than in Kumasi are needed.
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Keywords: Anopheles; Urban agriculture; Malaria transmission; Economic impact; Irrigation; Ghana

1. Introduction

In Ghana, malaria is the single most important cause of morbidity accounting for about 45% of all out patients' attendance. In 2001, it accounted for 22% of under-5 mortality (MOH, 2001). A review of urban malaria transmission in Africa by Robert et al. (2003) concluded that in general malaria transmission and anopheline density are lower in urban areas than in rural areas. However, there can be large variations in transmission potential in different city areas and the rapid, especially informal, city development will have

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major implications for malaria epidemiology (Warren et al., 1999; Robert et al., 2003). In Africa, the current urban population growth rate of 3.5% is more than thrice the rate of the rural population growth and by 2015 (2030) there will be 25 (41) countries in Sub-Saharan Africa with higher urban than rural populations (UN-Habitat, 2001).The majority of this development is outpacing city infrastructure, such as sanitation, and urban planning. A specific informal sector is urban agriculture, which has been internationally recognised as a means to increase food supply in the growing cities and at the same time contribute to improved nutrition, employment and poverty alleviation (UNDP, 1996). For the city of Kumasi, Ghana, it is estimated that 90% of all lettuce, cabbage and spring onions consumed in Kumasi are produced in the city itself with the rest coming from peri-urban (PU) and rural areas (Cofie et al., 2001). In order to sustain the production of vegetables around the year, these urban farms are irrigated, making use of any water source available. Many urban vegetable farmers occupy lowlands or inland valleys and dig shallow wells or construct conduits to divert water from small streams onto their farms to provide the needed water. These simple irrigation systems, however, could create "rural spots" in the sense of breeding sites for malaria vectors in the city (Birley and Lock, 1999), where malaria prevalence, otherwise, is considered low compared to the surrounding rural areas (Gardiner et al., 1984; Sabatinelli et al., 1986; Trape, 1987). Although several studies mention breeding of anophelines in urban agricultural sites (Vercruysse et al., 1983; Warren et al., 1999; Trape and Zoulani, 1987; El Sayed et al., 2000), we only know about two studies in Sub-Saharan Africa that have investigated the impact of urban agriculture on malaria transmission in cities. Dossou-Yovo et al. (1994, 1998) found high anopheline densities but low sporozoite rates in areas bordering rice cultivation in the city of Bouaké, Ivory Coast, concluding that rice fields did not seem to notably have modified malaria transmission. Robert et al. (1998) conclude from a study on market garden wells in Dakar, Senegal, that although wells serve as breeding grounds for anophelines they might not be the most important, i.e. other sites might be more important in sustaining the mosquito population. The exact role of urban agriculture in malaria transmission remains unclear and will need further investigation. A recent electronic conference on urban agriculture organised by FAO-RUAF[1] highlighted the urgent need of more quantitative data on the malaria risk of urban agriculture (Lock and De Zeeuw, 2001). Therefore a study was launched by the International Water Management Institute (IWMI) and collaborators to investigate the magnitude and impact of irrigated urban agriculture on malaria transmission taking the city of Kumasi, Ghana as example.

2. Materials and methods

2.1. Study area

The study was conducted within urban and peri-urban Kumasi, the second largest city in Ghana, located in the rainforest zone of West Africa with a population of 1.2 million inhabitants (Ghana Statistical Service,2002). Kumasi is located between latitude 6°30′ and 7°00′N and longitude l°30′ and 2°00′W. It has a wet semi-equatorial climate with an annual rainfall of around 1400 mm with two distinct rainy seasons. The mean annual temperature is 25.7 °C with a humidity ranging from 53 to 93%. Ten locations were selected in the urban area (Fig. 1), of which five represented urban areas with irrigated agriculture (UA) and the other five urban areas without agriculture (UW). In addition, five locations were selected in the peri-urban area around Kumasi for comparison. The peri-urban area of Kumasi had previously been defined by the Natural Resources Institute, UK, as a radius of 40 km around the city (Adam, 2001). The urban boundary was adapted from the Kumasi Metropolitan Assembly. The selection of sites within the city was constrained by the actual location of open-space urban agricultural sites, which were concentrated in the eastern part of town. For logistical reasons (night catch co-ordination) the peri-urban locations were chosen relatively close to the fringe of the city.

2.1.1. Urban areas without agriculture (UW)

These locations were purely residential settlements with no irrigated open-space vegetable farming. However, there was some backyard cropping of

[1] FAO = Food and Agricultural Organization of the United Nations; RUAF = Resource Center for Urban Agriculture and Forestry.

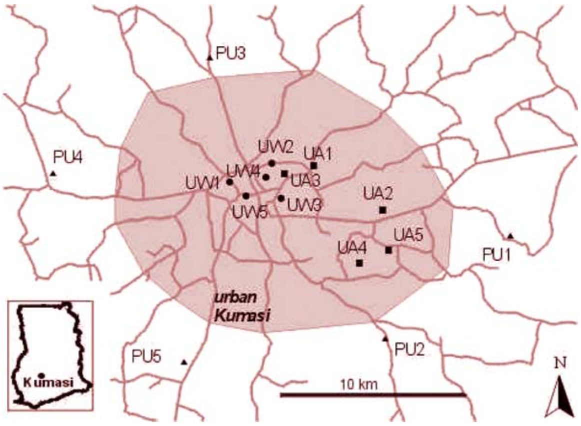

Fig. 1. Map of Kumasi with major roads and urban area as categorised by Adam (2001) indicating the location of the study sites (UW urban without irrigated agriculture; UA: urban with irrigated agriculture; PU: peri-urban).

non-irrigated staple crops such as maize, plantain and cocoyam, which is very common all over Kumasi.

2.1.2. Urban areas with irrigated agriculture (UA)

These were locations within the city, often in lowlands or inland valleys with irrigated vegetable production of, e.g. lettuce, cabbage, spring onions, sweet pepper and carrots. Individual farm sizes were around 0.1–0.2 ha, while the whole area under cultivation ranged between 3 and 20 ha per location. The common irrigation system was informal, often consisting of shallow dugout wells, from which water was fetched with watering cans. In other locations, it consisted of earth conduits from a nearby stream directing water to furrows between raised beds on which vegetables were cultivated. There were between 2 and 36 dugout wells in such locations depending on the area under cultivation.

2.1.3. Peri-urban areas (PU)

These were locations close to Kumasi with urban and rural characteristics representing Kumasi's rural–urban interface (Adam, 2001). Agriculture in these locations was mainly rain-fed with staple crops like maize, cassava and cocoyam.

Our studies were conducted in the dry season (January to March 2002) and in the rainy season (June to September 2002). A pilot sampling over 10 weeks was carried out in the 2001 rainy season (June to October) in the same sampling locations. In the 2002, rainy season only three locations rather than five could be sampled in each area due to logistical limitations. During the sampling periods, daily temperatures ranged from 19.4 to 37.8 °C with an average daily temperature of 28.5 °C in the dry season. In the rainy season, daily temperatures ranged from 19.0 to 35.5 °C with an average daily temperature of 25.8 °C. In the dry season, between January and March 2002, total rainfall was 67.1 mm, while in the rainy season, between June and September 2002, total rainfall was 523.5 mm (data from Meteorological Service Department, Kumasi Airport, unpublished).

2.2. Larval sampling

In each selected location, an inventory was made of anopheline breeding sites by walking through the area. Breeding sites were described according to habitat characteristics, e.g. degree of exposure to sunlight and presence or absence of vegetation in the water. Collection of larvae took place during the same period as night catching of adult mosquitoes (see below) using standard dipping technique after Service (1993). Specimens were brought to the laboratory for subsequent breeding to adult stage for morphological identification using the key of Gillies and De Meillon (1968).

2.3. Adult sampling

Adult mosquitoes were collected using consenting enumerated male students working in pairs and in rotation as human baits. Mosquitoes were caught weekly outdoors during the night at different designated human settlements within each area (UW, UA and PU) from 9:00 p.m. to 5:00 a.m. for 10 weeks. Sampling at the 15 sites was done as follows: at three nights per week mosquitoes were caught simultaneously at five different sites. One person was allowed to catch at a time, and mosquito numbers were recorded on an hourly basis. Monthly man biting rates (MBR) were calculated by multiplying the average number of mosquitoes caught per man night per site by 30 days for a month. Mosquitoes caught were brought to the laboratory for identification and the specimens of *Anopheles* spp. were dissected for their parity. To the parous adults, a standard Vectest malaria panel 'dipstick' assay was applied to determine sporozoite infection rate (Ryan et al., 2001). The entomological inoculation rate (EIR) was calculated by multiplying the sporozoite rate(s) with the man biting rate during the night.

2.4. Mosquito identification

The polymerase chain reaction (PCR) technique was used to distinguish between members of the *Anopheles gambiae* complex present in the three study areas. Adult *A. gambiae* from the night catches as well as the larvae from the breeding sites that were raised to adults were processed. DNA was extracted from single mosquito legs after the method described by Collins et al. (1987). Five microlitres of the sample DNA was used as template for PCR amplification of a species-specific rDNA segment. Each PCR was run for 35 cycles following standard conditions after Scott et al. (1993) using an annealing temperature of 55 °C for the oligonucleotide primers. The PCR products were analysed by electrophoresis on a 1.8% agarose gel.

2.5. Household surveys

Household questionnaire surveys were done in the selected 15 locations in both seasons to record household characteristics, malaria episodes, days lost due to malaria, use of preventive measures and behavioural practices such as sitting outside at night. In both seasons, 330 households were surveyed in each of the urban areas (UW and UA) and 340 households in the peri-urban area. The questionnaires were in principle addressed to the mother in the household as she was expected to best know the health history of the household members. In case the mother was not in, the questions were addressed to the father of the household, which happened in a minority of cases. Household members of 18 years and older were asked to recall the number of malaria episodes over the last 3 months and the number of days lost due to illness. For children below 18 years of age, the same data were obtained from the mother. To better asses whether illness episodes reported were really due to malaria, people were asked for the symptoms. Symptoms used to classify episodes as malaria were vomiting, headache, nausea, being hot but cold, shivering and loss of appetite. In addition, it was asked what type of treatment the person had taken to cure the illness. Based on this the interviewer decided if an episode had to be classified as malaria. There were only three interviewers to reduce possible inter-observer bias. A household was defined as the parents and their immediate family, i.e. the woman, her husband and the children under their care. People who were Part of the family but did not sleep in the house were not considered.

2.6. Statistical analysis

Statistical analysis was carried out with SPSS and Statview. ANOVA was used for household data and to test whether differences in mosquito numbers between areas were significant. The Scheffe post hoc test was used to see which groups significantly differed. Data were usually normally distributed, but to obtain homogeneity of variances, mosquito numbers were log transformed where necessary. For the dry season, statistical tests were carried out on the summed value of the 10 weeks of catches, as variances were not homogenous because of many nights during which no mosquitoes were caught. For the rainy seasons statistics were performed on daily numbers as these were normally distributed with homogeneity of variances after log transformation. Mann–Whitney test was used to test for differences between dry and rainy season mosquito numbers. Kruskal–Wallis test was applied to find significant differences in transmission parameters. Results were considered significant at the $P < 0.05$ level unless otherwise stated. Correlation analysis was used to analyse relationships, e.g. between malaria episodes, use of personal protection methods and mosquito densities.

3. Results

3.1. Breeding sites of Anopheles spp.

In the urban areas without agriculture (UW) *Anopheles* spp. larvae were found mostly in temporary pools and puddles created after rains in the unpaved streets and in between houses, exposed directly to the sun and without vegetation. They were thus common in the rainy season and rare in the dry season. In both seasons, clogged drains with domestic wastewater were common breeding sites for *Culex* spp.

In the urban areas with agriculture (UA) *Anopheles* spp. larvae were found in shallow wells that had been dug for irrigation, in ditches of furrow systems, or in human footprints on the irrigated farms. On these farms, 85% of the mosquito larvae found were identified as *Anopheles* spp. and 15% were *Culex* spp. This ratio between the culicine and anopheline larvae was roughly the same in both seasons. In addition, in the housing areas around the farms similar breeding sites were found as in the urban areas without agriculture.

In the peri-urban areas, *Anopheles* spp. breeding sites in the dry season were found at the edges of very slow moving streams, in isolated pools in drying riverbeds and larger abandoned sand mining pits. In the rainy season, additional breeding sites included roadside pools and rainwater collections at building sites. As a result of increased water currents, no larvae were found in the streams in the rainy season.

All anopheline larvae that were found in the investigated sites in the three areas (UW, UA, and PU) were identified as *A. gambiae* sensu lato.

Table 1
Anopheles gambiae densities and malaria transmission parameters in the dry and rainy season in urban areas without agriculture (UW), urban areas with agriculture (UA), and peri-urban areas (PU), in Kumasi, Ghana

Area	Season	*A. gambiae*[a]	MBR[b]	PR[c] (%)	SR[d] (%)	EIR[e]
UW	Dry	6.8 (5.1)a	20a	79a	2.9a	0.6a
	Rainy	32.3 (29.2)I	98i	66i	1.5i	1.5i
UA	Dry	69.8 (57.3)b	210b	87a	2.3a	4.8b
	Rainy	164.3 (98.3)ii	494ii	69i	1.9i	9.4i
PU	Dry	138.2 (92.9)b	415b	89a	2.6a	10.8b
	Rainy	204.3 (118.4)ii	613ii	71i	1.9i	11.6i

Different letters (a and b) in columns indicate significant differences at the $P < 0.05$ level for the dry season. Different numerals (i and ii) in columns indicate significant differences at the $P < 0.05$ level for the rainy season.

[a] Average number of *A. gambiae* caught per area over 10 weeks with standard deviation in parenthesis.

[b] MBR: man biting rate (per month).

[c] PR: parity rate.

[d] SR: sporozoite rate.

[e] EIR: entomological inoculation rate (per month).

3.2. Adult mosquitoes

A. gambiae s.l. adult specimens from night catches ($n = 240$) as well as those reared from larvae were tested with PCR ($n = 240$). The results revealed a PCR product of 390 base pairs indicating that all specimens were *A. gambiae* sensu stricto. This is in line with previous findings from Kumasi (White, 1998).

During the night, catches in 2002 about 17000 mosquitoes were caught of which 2295 (13.5%) were anophelines. As expected, significantly more mosquitoes, anophelines as well as culicines, were caught in the rainy season than in the dry season in all areas ($P < 0.05$) (Fig. 2). Significantly less anophelines were caught in both seasons in UW compared to UA and PU ($P < 0.05$). The same pattern of catches was observed in the 2001 pilot study.

A. gambiae s.s. was present in all areas investigated, while *A. funestus* was rare and largely restricted

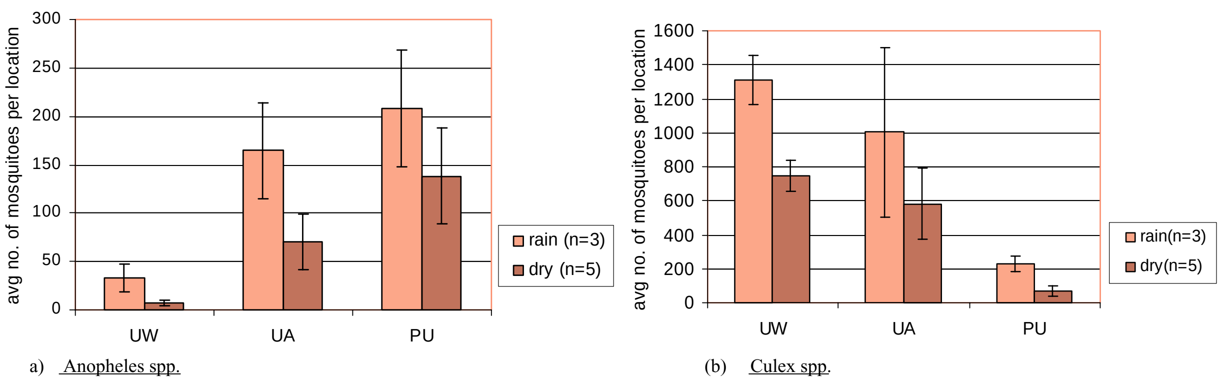

Fig. 2. Average number of mosquitoes caught per area (once a week over 10 weeks) during the dry and rainy season. UW: urban area without agriculture; UA: urban area with agriculture; PU: peri-urban area; bars represent standard deviation.

to PU, where only 37 specimens were caught (3% of the anophelines caught in PU in 2002). The parity rates for *A. gambiae* were significantly higher in the dry season than in the rainy season (77.2 and 68.2%, respectively) but did not differ between areas. The transmission parameters of malaria differed in the three areas investigated (Table 1). The MBR and EIR were significantly higher in both the UA and PU area than in UW ($P < 0.01$ and $P < 0.05$, respectively). Only *A. gambiae* s.s. was found to be infected with sporozoites. In the UW area, only one mosquito of those caught in each season was infected. None of the *A. funestus* caught in the night catches was infective.

In addition to the differences in numbers of mosquitoes between the three types of areas (UA, UW and PU) there was considerable variation within the areas (Table 2). The airport site within the urban agricultural area, for example, showed a low *Anopheles* percentage similar to the UW areas. The malaria case data per site (Table 2) showed less variation and a consistently higher number of episodes reported in UA and PU than in UW (see below).

Table 2
Percentage *Anopheles* of total mosquitoes caught and malaria episodes reported over the last three months at the 15 study sites

Site	Site code	Anopheles[a] (%)	Malaria episodes[b]
Bantama	UW1	1.3–6.8	0.17/0.43
Krofrom	UW2	0.7–2.7	0.1210.43
Fanti New Town	UW3	0.5–4.0	0.13/0.36
Ashtown	UW4	0–2.5	0.11/0.34
Adum	UW5	1.0–6.5	0.12/0.35
Airport	UA1	0.3–12.4	0.28/0.64
Ayigya	UA2	19.4–52.5	0.62/0.73
Manhyja	UA3	1.8–5.3	0.27/0.52
Gyinyase	UA4	18.8–28.0	0.56/0.74
Ayeduase	UA5	20.8–21.9	0.54/0.71
Domeabra	PU1	48.9–86.4	0.41/0.89
Esereso	PU2	27.1–41.6	0.44/0.93
Afrancho	PU3	20.5–38.8	0.33/0.64
Abuakwa	PU4	23.2–34.4	0.35/0.59
Brofoyedru	PU5	30.8–94.9	0.46/0.96

Site numbers refer to locations in Fig. 1.
[a] Percentage *Anopheles* of total mosquito numbers representing the range from two rainy seasons and one dry season.
[b] Average number of malaria episodes per household member with 3 months recall period as ported in household survey, the two figures represent dry and rainy season, respectively.

3.3. Personal protection

Table 3 shows the protection methods that the interviewed households used against malaria. The use of insecticide sprays and coils was the most common measure in all areas. Bed nets—despite being actively promoted in Ghana—were rarely used except in PU areas where in the rainy season 21% of the households reported their use. Interestingly, more households in both UA and PU seemed to use bednets during the rainy season, while the use of sprays and coils was less in this season. Households in UW areas, had significantly more mosquito-screened windows and doors than households in the other two areas.

Table 3
Use of personal protection methods (%) by households in urban areas without agriculture (UW) urban areas with agriculture (UA), and peri-urban areas (PU) in dry and rainy season in Kumasi, Ghana

			Percentage of households using specified protection method				
Area	Season	Number of households interviewed	Screened windows and doors	Bednets	Sprays and coils	No measures	Other
UW	Dry	330	44a	4a	40a	8a	4a
	Rainy	330	49i	3i	35i	13i	–
UA	Dry	330	12b	6a	62b	16b	4a
	Rainy	330	15ii	13i	55ii	17i	–
PU	Dry	340	15b	7a	55b	18b	5a
	Rainy	340	16ii	21i	44i	19i	–

Different letters (a–c) in columns indicate significant differences at the $P < 0.05$ level for the dry season. Different numerals (i and ii) in columns indicate significant differences at the $P < 0.05$ level for the rainy season.

Table 4
Average number of self-reported malaria episodes per person over a 3 months period in dry and rainy seasons in urban area without agriculture (UW), urban area with agriculture (UA), and peri-urban area (PU) in Kumasi, Ghana

Area	Season	Total no. of people for which data were recorded	Malaria episodes per person over 3 months		
			Children <6 years	Children 6–18 years	Adult
UW	Dry	1422	0.05a	0.10a	0.20a
	Rainy	1847	0.48i	0.32i	0.43i
UA	Dry	1673	0.50b	0.30b	0.35b
	Rainy	2164	0.78ii	0.53ii	0.67ii
PU	Dry	1762	0.45b	0.25b	0.32b
	Rainy	2104	1.10iii	0.52ii	0.46i

Different letters (a–c) in columns indicate significant differences at the $P < 0.05$ level for the dry season. Different numerals (i and ii) in columns indicate significant differences at the $P < 0.05$ level for the rainy season.

3.4. Malaria episodes and days lost due to malaria

Analysis of variance showed that the number of reported malaria episodes and days lost due to illness was significantly higher in UA than UW in both seasons for all age groups (Table 4). The only significant difference between UA and PU was for children under six years of age in the rainy season. Data aggregated by gender did not reveal specific differences. Malaria episodes occurred significantly more often in the rainy than in the dry season. The average number of episodes of malaria was lowest in UW areas in both seasons. Closely related to the frequency of episodes, individuals living in UA areas lost about 0.5 (rainy season) to one (dry season) days more due to malaria than those living in city parts without agriculture during the 3 months recall period (Table 5).

Table 5
Average number of days lost due to malaria over a 3 months period in dry and rainy seasons in urban area without agriculture (UW), urban area with agriculture (UA), and peri-urban area (PU) in Kumasi, Ghana

Area	Season	Average number of days lost per person over 3 months		
		Children <6 years	Children 6–18 years	Adult
UW	Dry	0.3b	0.3b	0.6b
	Rainy	1.0iii	0.7ii	1.2ii
UA	Dry	2.1a	1.3a	l.6a
	Rainy	1.5ii	1.3a	1.7i
PU	Dry	2.0a	1.0a	1.3a
	Rainy	3.1i	1.7i	1.2ii

Different letters (a–c) in columns indicate significant differences at the $P < 0.05$ level for the dry season. Different numerals (i–iii) in columns indicate significant differences ate the $P < 0.05$ level for the rainy season.

Table 6
Correlation between malaria episodes, Anopheles densities, preventive measure use, and behaviour in Kumasi, Ghana

Malaria episodes reported	Anopheles caught	Chemical sprays/coils	Sitting outside at night time	Bed net use	Use of door/ window screens
Adults	0.415	0.758**	0.406	0.335	0.552*
Children 6–18 years	0.847**	0.644**	0.511	0.295	−0.801**
Children <6 years	0.576*	0.440	0.825**	0.395	−0.605*

* Significant at the $P < 0.05$ level.
** Significant at the $P < 0.01$ level.

To investigate the relationship between malaria episodes, and the use of personal protection methods and mosquito densities per location, correlation analysis was used across all 15 sites (Table 6). The frequency of reported malaria episodes among children between 6 and 18 years was highly correlated with the number of *Anopheles* caught in the same area ($P < 0.01$). This parameter alone explained more then 70% of the variation in malaria episodes reported in this age group ($R^2 = 0.72$). The use of door and window screens were negatively correlated with malaria episodes in all age groups and therefore seemed to be effective measures against malaria. Episodes of adults were significantly related with the use of personal protection and preventive measures. The use of room sprays and mosquito coils was positively correlated with malaria episodes, i.e. households with more frequent malaria episodes also sprayed more. Bed nets were not common in this area and showed no significant relation with the occurrence of malaria. Malaria episodes of smaller children showed a highly significant relation with household members sitting outdoors during the evening ($P < 0.01$).

4. Discussion

The results of this study in Kumasi show that open-space irrigated vegetable fields in cities can provide suitable breeding sites for *A. gambiae*. This is reflected in higher numbers of adult *A. gambiae* in settlements in the vicinity of irrigated urban agricultural sites compared to the control areas without irrigated urban agriculture. Moreover, people living in the vicinity of urban agricultural areas reported more malaria episodes than the control group in the rainy as well as dry seasons. Apparently, the informal irrigation sites of the urban agricultural locations create rural spots within the city of Kumasi in terms of potential *Anopheles* spp. breeding sites. The presence of these sites interrupts the gradual decrease of *Anopheles* occurrence from Kumasi's fringe towards the inner-city area as described by White (1998). This is also shown by the EIR of the urban agricultural sites, which was in between the EIR of the peri-urban sites and urban non-agricultural sites. The values for the EIR found in this study were in the range given for urban areas by Robert et al. (2003).

The increased malaria risk also has economic consequences. Based on a survey among 20 households and key informants from local hospitals (unpublished data) and the report by Asenso-Okyere and Dzator (1997), it was estimated that the cost of treatment for a malaria episode is US$ 2–3. With the reported difference in incidence between the three areas, households in the urban agricultural area would face an additional cost of US$ 12.8–19.2 for malaria treatment per year, depending on whether or not a laboratory test is done. In addition, about 2.5 extra days will be lost per adult and school child in communities with urban agriculture over 1 year (Table 5). With an average estimated household income of US$ 3.0 per working day[2] (that is approximately US$ 1 per adult household member) an employment rate of approximately 82%[3], and about 85% working days in the year (see Maxwell et al., 2000), the working days lost will cost the household about US$ 5.2.

In total, US$ 18–24 (without and with laboratory test) can be attributed to each household over a 12 months period as extra malaria related expenditure in urban communities with irrigated urban agriculture. This represents an average increase of malaria related household expenditures of about 80% to the malaria related costs normally incurred in Kumasi (UW).

In Kumasi, urban agriculture is mainly practised in low-lying areas in the city with easy access to water and it could be that such areas in general produce more mosquitoes. However, irrigated urban agriculture increases the water surface by digging of wells or constructing of conduits where anophelines were found breeding. The importance of these increased water surfaces compared to other (natural) breeding sites needs to be assessed in more detail. A related study on the role of wells in malaria vector production in urban farming in Dakar, Senegal, emphasised that other breeding sites might be more important then these wells as the adult catching pattern did not follow the breeding pattern in the wells (Robert et al., 1998). The significantly higher culicine numbers in the two urban areas, UW and UA (97 and 86%, respectively of total mosquitoes caught) than

[2] 4.5 USD in Accra (Maxwell et al., 2000), a 30% lower value estimated for Kumasi.

[3] Maxwell et al., 2000 (data for Accra).

in the PU area (52% of total mosquitoes caught) in both seasons are likely due to many uncovered and clogged drains in the city of Kumasi, which only breed culicines and no anophelines. However, there are reports that *Anopheles* could be adapting to different breeding conditions. In urban Accra, Ghana, studies by Chinery (1984) suggested adaptation of *A. gambiae* during the process of urbanisation to breeding in domestic water containers and polluted waters. Further studies in larval ecology should address this issue.

The household surveys showed that in the urban agricultural areas every second household is using mosquito sprays or coils while in other urban areas window and door screens are significantly more often used than in urban agricultural or peri-urban areas. The reasons behind this difference could be socio-economic. The positive correlation between the use of chemical sprays/coils and malaria episodes could point to the fact that people who are at risk use the spray and coils to protect themselves from mosquito bites. The use of mosquito coils, repellents and aerosols insecticides lowers the risk of developing severe malaria (Snow et al., 1998). Therefore further investigations are useful to study the efficacy of different methods to prevent malaria infection and severe disease.

In Kumasi, a considerable variation in transmission parameters was observed between locations of the same type. The Airport location (UA, see Fig. 1), for example, showed several UW characteristics (Table 2) as the water source is a polluted stream, which is likely to favour culicine breeding rather than anopheline breeding. Other UA sites were located more towards the city boundary and therefore the role of the distance to the city centre should be included in future studies. For this study the selection of sites was limited by the location of existing UA sites. Future studies should therefore preferably be done in cities with a better spatial distribution of study sites. We also suggest that future studies should include epidemiological surveys to verify if the reported increased risk is also reflected in higher parasite prevalence and density in populations in UA areas. With a recall period of 3 months self-reported malaria episodes are not very reliable. However, we are confident that the data reported reflect the variation between the different areas as we have no indication that this systematic error could vary between the different areas due to for example educational differences.

Based on this study, IWMI and collaborators are planning an extension of the investigations to other cities where different water sources (e.g. wastewater) and irrigation practices can be less or more suitable for *Anopheles*. It is suggested, that the studies should be carried out throughout a full year instead of limiting it to rainy and dry seasons to take into account the transitional periods.

The increased malaria risk in urban agricultural areas would have to be weighed against the benefits that inner-city vegetable production brings to the households and the local economy. The way forward in such a scenario might be to advocate adjustments in irrigation practices in combination with increased protection from mosquito bites for the population affected rather than discouraging the setting up of irrigated urban farms. In fact, Ijumba and Lindsay (2001) reported an inverse link between irrigation development and malaria prevalence as the agricultural development would lead to increased income allowing farmers to construct better houses and use bed nets and medication. In urban areas, this issue might be different as people in the communities around urban agricultural sites are in general not the farmers but normal city dwellers. As breeding grounds in urban areas are often more focal, environmental management might be a good option for control, as also suggested by Robert et al. (2003) for the urban environment, in general.

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References

Adam, M.G., 2001. Definition and boundaries of the peri-urban interface—patterns in the patchwork. In: Drechsel, P., Kunze, D. (Eds.), Waste Composting for Urban and Peri-urban Agriculture—Closing the Rural–Urban Nutrient Cycle in Sub-Saharan Africa. IWMI/FAO/CABI, Wallingford, pp. 193–208.

Asenso-Okyere, W.K., Dzator, J.A., 1997. Household cost of seeking malaria care. A retrospective study of two districts in Ghana. Soc. Sci. Med. 5, 659–667.

Birley, M., Lock, K., 1999. The Health Impacts of Peri-urban Natural Resource Development, Health Hazard Classification. Cromwell Press, pp. 23–26.

Chinery, W.A., 1984. Effects of ecological changes on the malaria vectors *Anopheles funestus* and the *Anopheles gambiae* complex of mosquitoes in Accra, Ghana. J. Trop. Med. Hyg. 87, 75–81.

Cofie, O.O., Drechsel, P., Amoah, P., Danso, G., Gyiele, L., 2001. Improving rural–urban nutrient flows through urban and pen-urban agriculture. In: Rural–Urban Encounters: Managing the Environment of the Peri-urban Interface. DPU international Conference Paper, London, November 2001 [Abstract under http://www.ucl.ac.uk/dpu/pui/pui-abst.htm].

Collins, F.H., Mendez, M.A., Rasmussen, M.O., Mehaffey, P.C., Besansky, N.J., Finnerty, V., 1987. A ribosomal RNA gene probe differentiates member species of the *Anopheles gambiae* complex. Am. J. Trop. Med. Hyg. 37, 37–41.

Dossou-Yovo, J., Doannio, J., Riviere, F., Duval, J., 1994. Rice cultivation and malaria transmission in Bouake city (Cote d'Ivoire). Acta Trop. 57, 91–94.

Dossou-Yovo, J., Doannio, J.M., Diarrassouba, S., Chauvancy, G., 1998. Impact d'aménagements de rizières sur la transmission du paludisme dans la ville de Bouaké, Côte d'Ivoire. Bull. Soc. Pathol. Exot. 91, 327–333.

El Sayed, B.B., Arnot, D.E., Mukhtar, M.M., Baraka, O.Z., Dafalla, A.A., Elnaiem, D.E.A., Nugud, A.H.D., 2000. A study of the urban malaria transmission problem in Khartoum. Acta Trop. 75, 163–171.

Gardiner, C., Biggar, R.J., Collins, W.E., Nkrumah, F.K., 1984. Malaria in urban and rural areas of southern Ghana: a survey of parasiteamia, antibodies, and antimalarial practices. Bull. WHO 62, 607–613.

Ghana Statistical Service, 2002. 2000 Population and housing census. Special Report on 20 Largest Localities. Ghana Statistical Service, March 2002.

Gillies, M.T., De Meillon, B., 1968. The Anophelinae of Africa South of the Sahara. No. 54. Publication of the South African Institute of Medical Research.

Ijumba, J.N., Lindsay, S.W., 2001. Impact of irrigation on malaria in Africa: paddies paradox. Med. Vet. Entomol. 15, 1–11.

Lock, K., De Zeeuw, H., 2001. Mitigating the health risks associated with urban and periurban agriculture. Results of the E-conference "Urban and Periurban Agriculture on the Policy Agenda". Urban Agric. Mag. 1, 6–8.

Maxwell, D., Levin, C., Armar-Klemesu, M., Ruel, M., Morris, S., Ahiadeke, C., 2000. Urban livelihoods and food and nutrition security in Greater Accra. IFPRI Research Report, vol. 112, 72 pp.

MOH, 2001. Health Management Information Bulletin. Ministry of Health, Accra, pp. 1–3.

Robert, V., Awono-Ambene, H.P., Thioulouse, J., 1998. Ecology of larval mosquitoes with special reference to *Anopheles arabiensis* (Diptera: Culicidac) in market-garden wells in urban Dakar, Senegal. J. Med. Entomol. 35, 948–955.

Robert, V., MacIntyre, K., Keating, J., Trape, J.F., Duchemin, J.B., McWarren, W., Beier, J., 2003. Malaria transmission in urban sub-Saharan Africa. Am. J. Trop. Med. Hyg. 68, 169–176.

Ryan, J.R., Dave, K., Emmerich, E., Gareja, L., Coleman, R.E., Sattabongkot, J., Dunton, R.F., Chan, A.S.T., Wirtz, R.A., 2001. Dipsticks for rapid detection of *Plasmodium* in vectoring Anopheles mosquitoes. Med. Vet. Entomol. 15, 225–230.

Sabatinelli, G., Bosman, A., Lamizana, L., Rossi, P., 1986. Prévalence du paludisme a Ouagadougou et dans le milieu rural limitrophe en période de transmission maximale. Parassitologia 28, 17–31.

Scott, J.A., Brogden, W.G., Collins, F.H., 1993. Identification of single specimens of the *Anopheles gambiae* complex by the polymerase chain reaction. Am. J. Trop. Med. Hyg. 49, 520–529.

Service, M.W., 1993. Sampling the adult resting population. Mosquito Ecology. Field Sampling Methods. Chapman and Hall, UK, pp. 210–290 (Chapter 3).

Snow, R.W., Peshu, N., Forster, D., Bomu, G., Mitsanze, E., Ngumbao, E., Chisengwa, R., Schellenberg, J.R., Hayes, R.J., Newbold, C.I., Marsh, K., 1998. Environmental and entomological risk factors for the development of clinical malaria among children on the Kenyan coast. Trans. R. Soc. Trop. Med. Hyg. 92, 381–385.

Trape, J.Y., 1987. Malaria and urbanization in Central Africa: the example of Brazzaville. Part IV. Parasitological and serological surveys in urban and surrounding rural areas. Trans. R. Soc. Trop. Med. Hyg. 81 (S2), 26–33.

Trape, J.F., Zoulani, A., 1987. Malaria and urbanization in Central Africa: the example of Brazzaville, part III: Relationships between urbanization and the intensity of malaria transmission. Trans. R. Soc. Trop. Med. Hyg. 81 (S2), 19–25.

UNDP, 1996. Urban agriculture. Food, jobs and sustainable cities. United Nations Development Programme, Publications Series for Habitat II, vol. 1. UNDP, New York.

UN-Habitat, 2001. Cities in a globalizing world. Global Report on Human Settlements 2001. UNCHS, Earthscan Publications, London.

Vercruysse, J., Jancloes, M., Van de Velden, L., 1983. Epidemiology of seasonal falciparum malaria in an urban area of Senegal. Bull. WHO 61, 821–831.

Warren, McW., Billig, P., Bendahmane, D., Wijeyaratne, P., 1999. Malaria in urban and peri-urban areas in Sub-Saharan Africa. EHP Activity Report no.71.

White, C.J., 1998. Mosquito population densities and natural resource production in Kumasi. M.Sc. Thesis. The Liverpool School of Tropical Medicine, Liverpool, pp. 1–29.