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Entomological assessment of the potential for malaria transmission in Kibera slum of Nairobi, Kenya

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Abstract

Background & objectives: Malaria in urban and highland areas is emerging as a significant public health threat in Kenya which has seen a dramatic increase in malaria transmission in low risk highland areas. The objectives of the study were to find and incriminate potential vectors of malaria in Kibera, Nairobi.

Methods: One hundred and twenty houses within Lindi area of the southern central section of Kibera slum in Nairobi were chosen randomly and global positioning system (GPS) mapped. Day resting indoor mosquitoes were collected from January 2001 to December 2003. Larvae were collected between 2002 and 2004 and reared in the insectary to adults.

Results: A total of 176,993 mosquitoes were collected. Out of this, 176,910 were *Culex fatigans* and 83 were *Anopheles gambiae* s.l. Mosquito population peaked during the long rains in April to May and the short rains in November and December. Blood meal analysis of *An. gambiae* s.l. female mosquitoes revealed 0.97 human blood index. No mosquito was found positive for *Plasmodium falciparum* sporozoites. *Anopheles gambiae* s.l. mosquitoes were found breeding in polluted water and 95% of the larvae were identified as *An. arabiensis*.

Interpretation & conclusion: Anopheles gambiae s.l., malaria vector is present in Nairobi and it breeds in polluted water. *Anopheles arabiensis* is predominantly preferring humans as blood meal source, thus, showing ecological flexibility within the species.

Key words *Anopheles arabiensis* – *Anopheles gambiae* – Kenya – malaria transmission – urban area

Introduction

Every year, an estimated 300–500 million new infections and 1–3 million deaths result from malaria worldwide[1]. Malaria alone kills more than a million people each year in the African continent[2]. East African highlands had infrequent epidemic malaria between the 1920s and 1950s but a series of malaria epidemics had occurred since 1960s[3]. In western highlands of Kenya, malaria has returned after an absence of over 30 yr[4]. In these regions, there has been a dramatic increase in the numbers of all admissions (6.5 to 32.5%), case fatality (1.3 to 6%) and patients originating from low risk highland areas (34 to 39%)[5]. Malaria in the highlands is emerging as one of the most serious problems of the country and malaria ranks among the major causes of morbidity and mortality in the country[6].

Important mosquito vectors of malaria in the country are *Anopheles gambiae* s.s. Giles, *An. arabiensis* Patton and *An. funestus* Giles[7](Diptera: Culicidae).

Anopheles gambiae is usually the predominant species in saturated environments, but *An. arabiensis* is more common in arid areas[8]. Distribution of *An. funestus,* however, is strongly affected by the availability of permanent waters[9].

Nairobi is an East African city of approximately three million people (Central Bureau of Statistics, Population projections by Province). It is located in south-central Kenya on the eastern edge of the Rift Valley at an altitude of over 1624 m (5328 ft). It has been considered a "malaria-free" city in the past because of two factors: (i) it is an urban area where breeding habitats are normally not conducive for *Anopheles* spp, and (ii) the environment at high altitudes is generally not favourable for malaria transmission because mosquito development is slower and the maturation of malaria sporozoites in the mosquito takes longer time[10]. Longer mosquito development time decreases the likelihood of an individual reaching blood meal seeking stage. Additionally, slower sporozoite development means that fewer vectors will survive long enough after ingestion of gametocytes to become infective. The temperature threshold below which *Plasmodium falciparum* sporogony fails to occur has been estimated to fall between 16 and 19°C[11].

Local landuse and other anthropogenic factors can increase the availability of suitable breeding sites for specific vectors. Rapidly increasing population in Kenya has led to the explosive growth of urban centres, including Nairobi. As people move to cities, they tend to settle in fringe areas. They cultivate and conduct other activities that lead to the establishment of new breeding places. Reports of malaria at local hospitals are on the rise and this could be due to improved transportation and increased population movement. The combination of a larger reservoir population and vector breeding sites leads to potential for increased transmission or transmission where there was once no malaria. Some of the people moving to Nairobi come from areas of intense malaria transmission while others have probably rarely been exposed to the disease. The presence of the vector and the parasite in combination with a large immunologically naive population and potential source of introduced gametocytes creates a situation where transmission could become established. In recent years researchers and health care workers in sub-Saharan Africa have begun to recognize the importance of malaria in urban environment.

A clinical study carried out in 1999 reported that some children who tested positive for malaria parasites did not have recent travel history out of Nairobi[12]. Some of these children lived in Kibera, an estate with approximately 25% of Nairobi's population. Entomological data in the area are scanty, yet with the increasing urbanization in many parts of Africa, there are justified concerns that the vectors will introduce (or re-introduce) malaria into urban areas[13].

The objectives of this study were to identify and incriminate malaria vectors in the Kibera estate of Nairobi, Kenya.

Material & Methods

Study area: Lindi, one of the nine villages of Kibera estate was chosen for the study based on earlier clinical surveillance data[12]. Kibera, roughly 2 km^2, is an administrative division of Nairobi City to the south-west and the largest slum in Africa with a population of about one million people and estimated population density of 2000 people/ha (Amnesty International Video—The Women of Kibera). A railway line separates the two malaria endemic areas, Mombasa and Kisumu. There are no tarmac roads but a lot of foot paths. There are private health clinics and medical laboratories run by private practitioners and non-governmental organizations. The population is generally poor comprising of many ethnic groups but predominantly Luhya, Luo, Kamba and original dwellers from Sudan, the Nubi. Majority of the houses are made of mud/wooden walls and tin roofs with open eaves. The floors are either cemented or not. A few stone buildings are present. There are both natural and man-made mosquito breeding sites. Natural ones include springs and streams whereas man-made ones are leaking water pipes, shallow drains, garden pools, culverts and the Nairobi Dam. Springs, streams and the dam are permanent while temporary sites are mainly animal footprints. Sanitation is poor. The main pollutants are human and animal faecal waste, water from domestic use and industrial waste. These pollutants flow into nearby water collection drains and depressions. The area gently slopes towards Kibera's only stream which drains into a dam south of the city centre on the edge of the study area. Crops such as sugarcane, banana, maize and vegetables are grown in small gardens around the houses mainly close to the river. Domestic animals include cattle, pigs, goats, sheep, chicken, cats, dogs, rabbits, turkeys and geese.

Adult mosquito collection and microscopic identification: Between 2001 and 2003, ten collectors carried out visual surveillance for indoor day resting mosquitoes. They visited 100–120 mapped houses five times per week from which they captured mosquitoes using mouth and backpack aspirators. Two people collected mosquitoes per house for a period of 15 min. Household mosquito containers were labeled according to collection area, house number and date, and then transported to the laboratory. The mosquitoes were microscopically identified to species using an identification manual[14]. Female *Anopheles* mosquitoes were assigned sample numbers and their physiologic status indicated and then stored at –70°C for further processing.

Larval surveys: Larval habitats were identified, mapped and characterized depending on permanence and habitat type. Main habitat types were grouped as follows; cattle hoof /human foot prints, large open marsh, open well with vegetation, spring/broken water pipes, seepage-fed pools, canals/ditches with stagnant water, stream/dam margins and water standing in open fields. Larval survey was done from May 2002 to April 2004 using WHO standard dippers and transfer pipettes from large and small habitats respectively. Ten dips per habitat were made and all the anopheline larvae brought back to the laboratory. Collected larvae were reared in the insectary to adults for morphological identification and subsequent polymerase chain reaction (PCR) for identification of *An. gambiae* complex members. Briefly, larvae were fed on TetraMin® baby Food (fish powder) on shallow plastic trays (35 x 25 x 5 cm) with water that was changed daily. Larvae (100–150) were transferred to fresh water trays using transfer pipettes and fed again on larval food until they pupated. Pupae (100–150) were picked using pipettes into water in small containers within mosquito cages provided with 10% sugar solution on cotton wool. Pupae emerged into adults in 2–3 days within the cages.

PCR and ELISA tests: Genomic DNA was extracted from wings and legs of *An. gambiae* s.l. samples using alcohol precipitation method[15]. Species identification for these samples was then determined using PCR[16]. Presence/absence of sporozoites in vectors was determined by circumsporozoite enzyme-linked immunosorbent assay (CS-ELISA) on homogenates of heads and thoraces of female *An. gambiae* mosquitoes[17]. Abdomens of the blood-fed females were ground and analyzed for blood meal sources against human, bovine, chicken, sheep, goat and dog sera using blood meal ELISA method[18].

Results

A total of 176,993 adult mosquitoes were collected from houses and *Culex fatigans* where in overwhelming majority. Eighty-three mosquitoes were microscopically identified as *An. gambiae* s.l. while the rest were *Cx. fatigans* (Table 1). PCR analysis of *An. gambiae* s.l. samples revealed that 81 (97.6%) of them were *An. arabiensis* and 2 (2.4%) of *An. gambiae* s.s. *Anopheles gambiae* s.l. showed seasonal distribution with population showing peaks after the rainy season in 2001 and 2003. Mean minimum monthly temperature ranged from 11.9–14.3°C whereas the maximum ranged from 22.3–28.7°C. The monthly distribution of *An. gambiae* s.l. with weather data of Kibera (Kenya Meteorological Department) are shown in Fig. 1.

Of the 80/83 adult *An. gambiae* s.l. females collected during the three year collection period, 16% were

Table 1. Number of adult mosquitoes collected from Kibera during 2001–03

Year	Mosquito species		
	An. gambiae s.l.	*Cx. fatigans*	Total
2001	38	60,085	60,123
2002	11	65,290	65,301
2003	34	51,535	51,569
Total	83	176,910	176,993

gravid, 19% unfed and 65% fed. Blood meal analysis by ELISA on blood-fed female mosquitoes showed that 3% fed on sheep blood, 6% on both dog and human blood and 91% on human blood alone, hence, a human blood index of 0.97. When tested by circumsporozoite ELISA, none of the 80 *An. gambiae* s.l. females was found infected with *P. falciparum.*

Distribution of *Anopheles* larvae collected from various habitats and reared in the insectary are shown in Table 2. *Anopheles gambiae* s.l.*, An. funestus, An. costani*, and other species constituted 35, 1, 47 and 17%, respectively. Other *Anopheles* mosquito species included, *An. christya* (Theobald)*, An. garnhami* (Edwards)*, An. maculipalpis* (Giles)*, An. pharoensis*

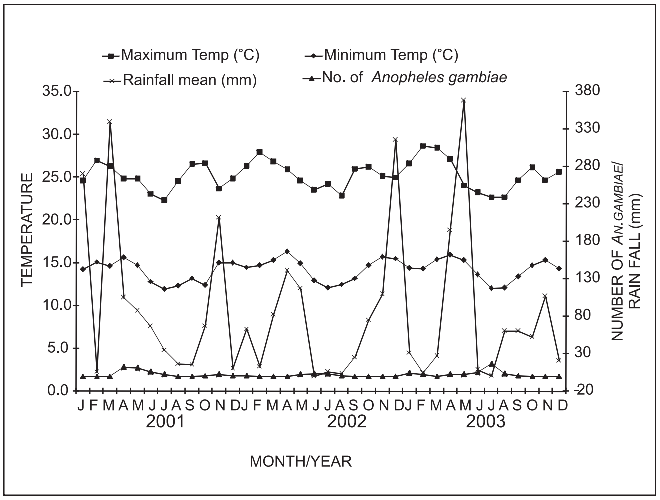

Fig. 1: Seasonal distribution of *An. gambiae* s.l. with temperature and rainfall data in Kibera for the period 2001–03 (Weather data from Wilson Airport, Kenya Meteorological Department)

Table 2. Distribution of *Anopheles* spp in various habitats for the period 2003–04 in Kibera slum

Nature of habitat	*Anopheles* species			
	An. gambiae	*An. funestus*	*An. costani*	Others
Cattle hoof/ Human foot prints	42	0	5	8
Large open marsh	80	4	103	48
Open well	12	1	26	9
Spring/Seepage-fed pool	18	1	36	13
Canal/Ditch with stagnant water	42	3	128	17
Standing water in open field	69	1	61	32
Stream/ Dam margin	3	0	2	0
Total	266	10	361	127

(Theobald), *An. pretoriensis* (Theobald) and *An. rufipes* (Gough). Ninety-five percent of *An. gambiae* s.l. were identified as *An. arabiensis*.

Of the known malaria vector species in Kenya, all *An. funestus* larvae were collected in semi-permanent habitats. These habitats haboured 98% of *An. gambiae* s.l. Permanent and transient habitats had 1% each of *An. gambiae* s.l.

Discussion

Nairobi presents a unique scenario in malaria transmission studies because of its high altitude that qualifies it as a highland area and it being an urban area has been regarded malaria-free since World War II. Many studies of urban malaria have not been conducted in areas generally regarded as highlands. However, malaria in both highlands and urban areas presents important aspects of malaria epidemiology in Kenya.

Only 83 *An. gambiae* s.l. mosquitoes were collected in a three year period as opposed to 176,910 *Cx.*

fatigans. Urban environments, especially where population density is high under poor sanitary conditions are considered less conducive for *Anopheles* breeding because of the presence of pollutants in the available breeding habitats. This could have contributed to low numbers of *An. gambiae* mosquitoes captured in houses. Although not reported in Nairobi, recent work in other parts of Africa has shown that *An. gambiae* larvae can develop in polluted temporary pools in peri-urban areas[19,20]. In the current study, *An. gambiae* larvae were collected mainly in temporary habitats containing pollutants such as detergents, human and animal faecal waste and an assortment of domestic debris. Semi-permanent habitats become important breeding areas for the malaria vectors during and immediately after the rainy season. Availability of *An. gambiae* larvae in more permanent breeding areas such as edges of the stream or dam in Kibera reveals the likelihood of per animal breeding of malaria vectors.

Anopheles gambiae and *An. costani* were predominant species of *Anopheles* larvae collected. *Anopheles gambiae* larvae numbers did not, however, reflect the adult collections because larvae abundance is not a good predictor of adult mosquito densities in households. Other *Anopheles* larvae, including *An. funestus* collected in Kibera were not represented in the adult collections. This could be an indication that *An. gambiae* has adapted to tolerating pollutants in breeding environments better than other *Anopheles* species. A few 'suitable' *Anopheles* breeding sites in the study which included water collections from broken underground water pipes and water standing in open fields were observed to contain *An. gambiae* larvae. *Anopheles gambiae* larvae were also collected in polluted environments such as stream/dam margins and canal/ditch with stagnant water indicating adaptability to these habitats. Adaptation to habitats other than putative ones has also been observed in Kisumu City where flamboyant trees showed repeated presence of *An. gambiae* s.s. in tree holes with water[21]. Open fields mainly towards the stream are used for growing crops. This practice has been observed to be malaria risk factor in Dar-es-Salaam where areas used for farming in backyard gardens had the proportion of habitats containing *Anopheles* larvae 1.7 times higher in agricultural areas compared to other areas[22]. The role of such typical breeding sites in urban malaria transmission ecology requires further investigation.

In western Kenya, *An. gambiae* s.s. is the primary indoor resting malaria vector[23] whereas *An. arabiensis* frequently feeds on cattle[24]. Cattles were present in the study area though scarce. Blood meal analysis on blood-fed female mosquitoes showed that *An. arabiensis* were predominantly biting humans, demonstrating ecological flexibility within the species.

Parasitological data for the period coinciding with that of mosquito sampling from African Medical Research Foundation health clinic in Lindi revealed malaria positive cases without travel histories to endemic areas. Despite the clinical evidence that suggests transmission occurs in the city, none of the *Anopheles* samples tested positive for *P. falciparum* infection. High human population density, such as in Kibera, is postulated to provide additional blood meal opportunities as well as additional habitats in the form of artificial water storage containers, debris or man-made depressions that retain water. In the presence of *Anopheles* mosquitoes, high human population density may act to reduce the overall chance of receiving an infectious bite as an increase in the number of potential hosts may result in fewer overall bites per person[25]. The number of potential vectors collected was low. However, malaria transmission can occur below the detectable entomologic threshold. For example, five of 39 studies in urban areas failed to find entomological evidence of malaria transmission because of low vector densities[26].

Though the study failed to incriminate the potential malaria vector, it achieved important objectives in identifying malaria vectors and their breeding sites in the study area. There exists possibility of local transmission in the study area because of favourable temperatures (>17°C) during the study. At these temperatures, malaria parasite development and transmission could be possible[11]. Furthermore, the vector population dynamics showed response to precipitation meaning higher levels of local transmission could occur after rainy season.

A rise in population of urban dwellers is expected to increase in Kibera where there is an ever increasing number of people some of whom frequently travel to indigenous malaria endemic rural areas. The shift is likely to have profound epidemiological and public health impacts[27] especially in the light of significant risk of malaria infection to more vulnerable individuals.

People can protect themselves from malaria infection through the use of a number of interventions. Bed nets have shown to be effective in reducing the risk of malaria contraction[28]. Many Kibera residents are poor and therefore may have high chances of vector contact and parasite infection because of limited access to these preventive measures against malaria. Another remedy could be long-awaited slum upgrading which would rid the area of malaria vectors breeding sites. The programme is however hampered by lack of resources and logistical problems. Therefore, due to the large population at potential risk of malaria infection, we recommend large-scale study in Kibera and other slum estates of Nairobi to better understand the epidemiology of malaria in this highland urban environment.

In conclusion, malaria vectors known to bite bovines elsewhere in Kenya are breeding in the polluted water in Nairobi and are predominantly biting man, indicating ecological flexibility within the species.

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