MALARIA TRANSMISSION IN URBAN SUB-SAHARAN AFRICA

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Abstract. The rapid increase in the world’s urban population has major implications for the epidemiology of malaria. A review of malaria transmission in sub-Saharan African cities shows the strong likelihood of transmission occurring within these sprawling cities, whatever the size or characteristics of their biocologic environment. A meta-analysis of results from studies of malaria transmission in sub-Saharan Africa shows a loose linear negative relationship between mean annual entomologic inoculation rates (EIR) and the level of urbanicity. Few studies have failed to find entomologic evidence of some transmission. Our results show mean annual EIRs of 7.1 in the city centers, 45.8 in periurban areas, and 167.7 in rural areas. The impact of urbanization in reducing transmission is more marked in areas where the mean rainfall is low and seasonal. Considerable variation in the level of transmission exists among cities and within different districts in the same city. This article presents evidence from past literature to build a conceptual framework to begin to explain this heterogeneity. The potential for malaria epidemics owing to decreasing levels of natural immunity may be offset by negative impacts of urbanization on the larval ecology of anopheline mosquitoes. Malaria control in urban environments may be simpler as a result of urbanization; however, much of what we know about malaria transmission in rural environments might not hold in the urban context.

INTRODUCTION

The rapid increase in the world’s urban population has major implications for the transmission and epidemiology of malaria and other vector-borne diseases.1,2 This situation may be particularly true in sub-Saharan Africa (SSA), the most rapidly urbanizing continent,3 with some of the highest rates of Plasmodium falciparum transmission. In SSA, hospitals and clinics regularly report >15% of admissions are due to malaria. Although some cases are referrals from rural areas, malaria transmission in urban and periurban settings is a significant problem.4–6

Despite the severity of the problem, gaps remain concerning urban malaria transmission in SSA. Several explanations exist to account for why urban areas seem to have lower malaria transmission rates compared with rural areas. One explanation is that pollution affects larval habitats, the life cycle of mosquitoes, and vectorial capacity. Other explanations include mosquito avoidance behavior by urban populations, such as screens, doors, insecticides, and bed nets. Higher human population densities may reduce biting rates, owing to the higher ratio of humans to mosquitoes. Few data are available to confirm these theories or to prioritize strategies for malaria control. Many questions remain for public health specialists hoping to regain control over malaria in urban environments.

The objectives of this article are to synthesize existing literature on malaria transmission in urban areas of SSA and to generate a conceptual framework. Following a summary of the main terms, we present a meta-analysis of entomologic inoculation rates (EIR) from urban, periurban, and rural studies. This analysis provides background to a review of the entomologic and social and behavioral literature related to urban malaria. The resulting conceptual framework illustrates factors that may explain the heterogeneity of malaria transmission within and among urban environments in SSA.

BACKGROUND

The study of malaria transmission in urban areas is not new, with significant efforts dating back to the 1930s in East Africa.7–9 More recent measurement of urban transmission began with Krafsur,10 followed in the 1980s by Vercruysse and Jancloes in Pikine,11 Robert et al in Bobo-Dioulasso,12 and Trape et al in Brazzaville.13–15 Despite this history, considerable challenges remain. Measurement of entomologic markers in areas of low transmission is problematic. Human behaviors and socioeconomic variations interact with natural systems in heterogeneous urban populations. As such, applying relevant observational and measurable markers to differentiate levels of urbanicity is arduous at best.

The post–World War II era has been characterized by a rapid increase in the world’s population, especially in tropical areas. In 2000, the population in SSA was estimated to be 784 million; by 2025, this figure is expected to be >1.2 billion.3 Despite intriguing accounts of Africa’s ancient cities, some with 40,000 inhabitants,16–18 the continent’s population remained predominantly rural until recently. In 1900, <10% of Africans lived in an urban area, and by 1950, only 15% lived in an urban area. Today, almost half of the population in SSA lives in urban or periurban areas (45% in 1999), and this proportion is expected to increase dramatically over the next 25 years. Although rapid urban growth is a relatively recent phenomenon in SSA, the cities of approximately 0.5 million population are growing faster than in any other area of the world.19 This is an urbanization rate of 2% for the past 30 years, a doubling of the urban population every 37 years. Pollution, poor housing, lack of sanitation, unprotected water reservoirs, weak services, low productivity, and widespread economic disparity have accompanied this urbanization.19

Similar to most urban settlements, African cities are complex, dynamic structures. Western definitions emphasize characteristics that differentiate urban from rural areas, including land use patterns, increased density of households, differences in housing material, economic differentiation in relation to type and abundance of work, access to public transport, access to utility services, and access to social services. In many instances, urban SSA does not fit this conventional definition. Rice fields exist in the heart of Bouaké,20 and market-garden wells are common in Dakar.21 Livestock often are herded through central business districts and are a common
sight in residential, market, and commercial areas. Urban areas can encompass suburban development, affluent neighborhoods, older settlements that have become established shantytowns, business districts, and periurban slum settlements on the outskirts of towns and cities. People who settle in densely populated, undeveloped periurban areas often are met with communities already trying to overcome widespread poverty, pollution, and environmental degradation. These communities often lack the programs, personnel, and resources to combat infectious disease, a situation exacerbated by poverty, low levels of education, deteriorating infrastructure, and continued rural subsistence activity.

It is thought that about 10 anopheline species are responsible for malaria transmission in SSA. By contrast, in the urban context, there are normally 3: Anopheles gambiae, Anopheles arabiensis (both belonging to the An. gambiae complex), and Anopheles funestus. The first 2 species are the most important. An. funestus has not been found in most cities but was found in a district of Franceville, Gabon, and in Maputo, Mozambique.22,23

The value of the EIR lies in the fact that it provides an estimate of the passage of malaria parasites from infective anopheline species to human populations. It is calculated as the product of the human-biting rate (an estimation of the density of mosquitoes per person) and sporozoite index (an estimation of the proportion of vectors with sporozoites in their salivary glands). The EIR is expressed as the number of infective bites per person per year. It ranges from <1 bite per year in low-transmission areas to 2,979 infected bites per person per year in 1 sentinel house.24 Although the EIR is a good indicator of transmission intensity in the context of high mosquito density, logistical problems exist when estimating EIR in areas of low mosquito density.25 The determination of anopheline density at low densities can be difficult, and malaria transmission does occur below the entomologic threshold for detection.

The EIR cannot be considered an exact measure of transmission because not all bites from infected anopheline species succeed in infecting humans. In experiments, Rickman et al,26 using persons without any antimalarial immunity and anopheline species with *P. falciparum* sporozoites in their salivary glands, showed that 1 or 2 infected bites per person infected only 5 of 10 human volunteers. This limiting factor, which is called the infectivity success rate (usually parameter “b” in literature), rarely is taken into account when calculating an EIR from the sporozoite index and human-biting rate. In endemic areas, the infectivity success rate ranges from 5% to 26%, with inverse variations with EIR resulting from higher protective immunity, more multiple infections, and longer episodes with parasitaemia.24,27

**MATERIALS AND METHODS**

The meta-analysis of malaria transmission began with the identification of entomologic studies that focused on malaria transmission in urban SSA and were published before 2001. Studies were evaluated for appropriate entomologic data according to the following inclusion criteria: (1) studies conducted over 12 months; (2) frequency of mosquito sampling, at least monthly throughout the year or during periods of transmission for sites with seasonal patterns of transmission; (3) standard methods, such as human-biting catches, pyrethrum catches, or light traps used for estimating biting rates; (4) dissection or enzyme-linked immunosorbent assay methods used for determining proportion of sporozoite-infected mosquitoes; and (5) studies conducted during periods when no mosquito control operations were in effect. For sites where EIR data were available for >1 year, yearly average figures were used, as provided in the articles. As far as we know, the reference set providing EIRs for urban and periurban sites in SSA is exhaustive and compares closely with another review of EIR in studies across the continent.28 Because it was not feasible to find EIRs from matching rural sites, we selected EIRs from rural sites representative of studies from various parts of SSA, including savannas, rain forests, rice fields, various altitudes, and near large rivers and lagoons.

The EIRs reviewed were assigned a category: central urban, periurban, and rural. Categorical assignment of the respective EIRs was based on the description of the study area in the articles. Assignment in the rural category never posed a problem, whereas differentiating between central and periurban categories posed a challenge. Maps and habitat descriptions were used to differentiate between central urban and periurban when ambiguity was evident. Areas adjoining marshlands, areas adjoining rice fields, market-garden areas, or areas close to a lake were considered periurban; some central quarters of Pikine,11,29 Bouake,20,30 and Ouagadougou31 were classified as periurban. Overall, 39 studies satisfied the inclusion criteria. Because several studies provided estimated EIRs from >1 site, the final data set included 90 values of EIRs distributed across 21 urban centers, 14 periurban sites, and 55 rural sites. In a separate analysis, we categorized study areas according to their ecologic niche with 33 values of EIRs in dry savannas plus Sahel versus 57 values in wet savannas plus forest zones.

**RESULTS**

Table 1 lists the references and the categorization of each result, and Figure 1 illustrates a summary of the EIRs across the 3 different environments. The average level of malaria transmission in urban centers, periurban areas, and rural sites differs tremendously. The arithmetic mean of annual EIRs is 7.1 in the urban centers, 45.8 in periurban areas, and 167.7 in rural areas. These values were significantly different when comparing with Mann-Whitney *U* tests between urban centers and urban peripheries (*P* < 0.001), between urban peripheries and rural areas (*P* = 0.051), between urban centers and rural areas, and between the cities (central urban plus periurban) and rural areas (*P* < 0.001). Malaria transmission is clearly and significantly of a lower magnitude in urban compared with rural environments. Periurban versus rural differences are only marginally significantly different from one another. Ranges of values were large, with minimal values of 0 in urban and periurban areas and maximal values increasing from urban to rural areas.

For most urban areas that have been studied, there is evidence of malaria transmission. Only 5 studies failed to find any entomologic evidence. Of these, 1 was from Maputo,23 2 were from Ouagadougou,31 and 2 were from Dakar.32,33 At these sites, anopheline species had low densities or low infection rates. We did not exclude the possibility, however, of...
local transmission at levels lower than the sensitivity threshold of standard entomologic methods. In Dakar, there is some evidence of local transmission from reports of malaria among permanent residents. The number of infective bites per person has been estimated for the central area as 0.05/year, or 1 infective bite every 20 years.

Variability in EIRs among and within cities is evident (Table 1). Studies in the urban centers of Cotonou, Kinshasa, and Edea report the highest EIRs. The highest EIR reported for any urban area is 30/year; the lowest is 0. The univariate shape of the distribution in central urban areas is skewed toward the lower end, with more than two thirds of the studies reporting EIRs <4/year. The variation across the periurban areas is more diverse, ranging from 0.4/year in Dakar to 126/year in Bouake, Ivory Coast.

Important interquarter or interdistrict variations can be observed. The studies conducted in 3 areas of central Bobo-Dioulasso estimated EIRs at 0.1, 0.5, and 2. In Edea, this figure was 4/year and 30/year across 2 distinct quarters. In 1 quarter in Pikine, large differences were detected for parasitologic incidence in children who lived close to marshland: about 1 infection per year for children residing at a distance of 10 to 160 m and 1 infection every 4 or 5 years for children residing at a distance of 785 to 910 m.

### Table 1

<table>
<thead>
<tr>
<th>Year of publication</th>
<th>Author(s)</th>
<th>Locality, country</th>
<th>Urban center</th>
<th>Urban periphery</th>
<th>Rural</th>
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<td>Robert et al</td>
<td>Bobo-Dioulasso area, Burkina Faso</td>
<td>50; 60; 55; 133</td>
<td>80; 850</td>
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<td>218; 272; 577; 226; 703; 221; 94</td>
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<td>1995</td>
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No. of values 21 14 55

Mean 7.07 45.84 167.74

Median 2.00 36.50 91.00

Sources of data set for the annual entomologic inoculation rates (EIRs) used in the meta-analysis (total references = 39; total values = 90) and assignment in 1 of 3 categories: urban center, urban periphery, and rural area.

The heterogeneity of malaria transmission in urban areas results in large differences in malaria prevalence in humans living in different parts of the cities. In Brazzaville, the prevalence among schoolchildren varied from 3% in a central quarter to 81% in peripheral areas, and these differences were
Annual entomologic inoculation rates (EIRs) presented by climatologic areas

<table>
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<th>Annual entomologic inoculation rates (EIRs)</th>
<th>Dry savannas and Sahel</th>
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<td>Mean</td>
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<td>Median</td>
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Four main conclusions are evident from this meta-analysis. First, nearly all studies concluded that anopheline species density and the likelihood of malaria transmission are lower in urban than rural areas. This likelihood of low transmission is stronger in central urban areas compared with periurban areas. Second, although a small difference can be identified between the periurban and rural studies, this is much less dramatic than the comparison between central and rural areas. Third, the variation in the range is much less across the periurban than across the central urban areas. Fourth, the impact of urbanization on transmission is as marked as the mean rainfall is low and seasonal.

There is some evidence that anopheline species may be adapting to urban ecosystems. Chinery42,43 observed some adaptation of *An. gambiae* *s.s.* to urban aquatic habitats, such as water-filled domestic containers and polluted water habitats created as a result of urbanization in Accra, Ghana. In a recently urbanized area of Kenya, Khaemba et al.44 concluded that *An. gambiae* showed a strong preference for man-made, temporary aquatic sites over permanent aquatic habitats in the rainy season, although dams and swamps remained the preferred sites during the dry season.44

Although some adaptation may be occurring, many observers assume that the pollution of aquatic sites most likely has a negative effect on anopheline species density and longevity.45 Robert et al.21 noted that larval populations of *An. arabiensis* in market-garden wells in Dakar are regulated by interacting environmental variables, such as high nitrate concentrations, low pH, murky water, and other factors. Other studies indicated that detergents are important pollutants that may inhibit the development of anopheline larvae.13 Barbazan et al.45 concluded that pollution was a major factor responsible for the scarcity of larval sites in Maroua, a large city in the savanna region of Cameroon.
Another explanation for the low EIRs relates to high human population density, which provides easier access to human blood meals for mosquitoes. This increase in potential hosts is thought to reduce the chance of any single host receiving an infective bite, lowering the overall human-biting rate. Sabatinelli et al found that An. gambiae tend to bite near their breeding places in densely settled environments, however, and that their dispersion is restricted. An alternative hypothesis for low EIR argues that rapid urbanization in periurban areas and increases in population density in and around anopheline aquatic habitats increase the risk of malaria transmission. In other words, a large number of people living in close proximity to mosquito habitat increase blood meals available, which increases the number of mosquitoes an area can support, resulting in a greater number of total infective bites.

Vector biting habits in urban contexts also may help account for some of the measurement challenges. An. gambiae s.s. and An. arabiensis feed on humans inside and outside houses. Preferential biting times may vary across and within small areas. In areas where humans typically stay outside later in the evenings, the protective effect of using bed nets or protection inside their houses is nullified if they are exposed during evening hours outside the home. Given this fact, the low EIRs calculated for urban areas may reflect the fact that finding female mosquitoes that have fed on a human outside as opposed to finding females resting inside houses may reflect challenges to existing entomologic field methods.

Human migration patterns also may explain variation in malaria transmission patterns among and within urban locations. For many urban residents, travel to rural areas on a regular basis is predictable and regular. Depending on immunity, people can be categorized as either active transmitters or passive acquirers. Passive acquirers are exposed to the parasite while traveling to an endemic area, whereas active transmitters harbor the parasite and increase the transmission risk when they travel to an area with an efficient vector. We can predict that when the relatively nonimmune individuals from urban areas travel to rural endemic zones, they may acquire infection and become transmitters when back home. Highland cities may be at risk of becoming malarious through the action of the rural migrants bringing infection with them.

Municipal initiatives. Heterogeneity in malaria transmission may be explained by minor variations in the quality or type of water and waste management. In many urban contexts, the central business district is the only area with working water and sewage systems. It also may be the most sparsely inhabited area, especially at night during peak biting hours. From these central districts, the urban development is often characterized by growth in approximate concentric circles, with the newest construction in more marginal areas. These marginal areas can include swamplands or steep de-
nuded hillsides. Generally, malaria transmission seems to decline from these peripheral areas toward the center. There are, however, several scenarios that may explain unexpected variations in this general trend. In Niamey, Niger, and Karthoum, Sudan, the city centers are located along rivers, which provides generous larval habitats for anopheline species.

**Individual and household factors.** In general, poorer populations are at greater risk of vector contact and infection, owing to physical proximity to water sources and lowered capacity (lack of education and resources) to use health care services and preventive measures to protect against malaria. Human-vector contact is influenced by housing type (e.g., number of screens, doors), housing and roofing material, and house location (gradient, surrounding drainage, and cleanliness of immediate environment). The use of screens, insecticides, prophylaxis, and bed nets, which is a function of income and education, also can affect the life expectancy of the mosquito, although whether this operates to influence vectorial capacity is unclear. On the one hand, shorter survival times of mosquitoes (reflected by the proportion of mosquitoes that had already laid eggs) were found in cities such as Pikine, Kinshasa, Edea, and Bobo-Dioulasso, in which the parity rate was significantly lower than in the neighboring rural areas. On the other hand, in other cities, including Brazzaville, Franceville, and Yaounde, the parity rate was similar between cities and their neighboring rural areas.

Malaria surveys were conducted during the 1930s in the port cities of Mombassa, Dar es Salaam, and Tanga. The authors of these studies believed that the problem of malaria in urban areas could be solved. The fact that it has not been solved has become a matter of concern. The lower level of transmission, shown through this meta-analysis in urban areas, has important parasitologic, immunologic, clinical, and control implications. With urbanization, cities become populated with individuals who reach adulthood without significant malaria immunity. An increasing proportion of adults have little immunity. Given the rapid urbanization in recent years, such a situation is new for large segments of the population. This transition from a low endemic situation to a potentially epidemic one may be of great public health significance. This situation of islands of low immunity in an ocean of high endemicity is alarming, especially given the fragile eco-
conomic situation. This situation of islands of low immunity in an ocean of high endemicity do not constitute a fragile situation per se and that most cities rarely experience severe, widespread malarial epidemics. This situation is due, for the most part, to the major impact that urbanization (e.g., pollution, human density, increased built environment, protective and treatment measures taken by urban inhabitants) has on the larval ecology of the anopheline mosquitoes. Sudden changes in weather patterns (e.g., El niño) or civil unrest could affect the validity of these respective conclusions.

We propose that the city may be one of the most favorable African environments in which to envisage efficient and efficacious antimalarial activities. Although studies in rural areas report marginally significantly higher EIRs compared with periurban studies, these latter areas are much more densely inhabited. It can be assumed that if vector control can be successful in periurban areas, a greater number of people would be affected. Vector control must take into account variation in transmission patterns at the scale of a district, subdistrict, or quarter. In many urban areas, larval sites are few. They also are easily located and accessible. This fact can constitute a keystone for effective control. The arsenal for the antivectorial includes antilarval insecticide treatments, larvivorous fishes, house spraying, impregnated mosquito nets, and curtains. In some favorable situations, the final goal can be to make cities malaria-free areas. The implementation of a malaria-free area, small in surface area but large with regard to population, would stimulate neighboring areas, local authorities, and eventually funding agencies for their extension.

Many valuable future research areas emerge from this analysis. We need more information not only on the human behavioral determinants, but also on the entomologic characteristics of different districts within cities before we can advise health organizations confidently how best to proceed toward reducing the burden of malaria in urban settings. Vector control seems to be an efficient weapon to reduce transmission with direct consequences in lowering the incidence of malaria cases. This reduction of malaria transmission in the most favorable situations within urban SSA might be efficient enough to create malaria-free areas.


