


REVIEW

Open Access



Urban malaria in sub-Saharan Africa: dynamic of the vectorial system and the entomological inoculation rate

P. Doumbe-Belisse^{1,2}, E. Kopya^{1,2}, C. S. Ngadjeu^{1,2}, N. Sonhafouo-Chiana^{1,3}, A. Talipouo^{1,2}, L. Djamouko-Djonkam^{1,4}, H. P. Awono-Ambene¹, C. S. Wondji⁵, F. Njiokou² and C. Antonio-Nkondjio^{1,5*} 

Abstract

Sub-Saharan Africa is registering one of the highest urban population growth across the world. It is estimated that over 75% of the population in this region will be living in urban settings by 2050. However, it is not known how this rapid urbanization will affect vector populations and disease transmission. The present study summarizes findings from studies conducted in urban settings between the 1970s and 2020 to assess the effects of urbanization on the entomological inoculation rate pattern and anopheline species distribution. Different online databases such as PubMed, ResearchGate, Google Scholar, Google were screened. A total of 90 publications were selected out of 1527. Besides, over 200 additional publications were consulted to collate information on anopheline breeding habitats and species distribution in urban settings. The study confirms high malaria transmission in rural compared to urban settings. The study also suggests that there had been an increase in malaria transmission in most cities after 2003, which could also be associated with an increase in sampling, resources and reporting. Species of the *Anopheles gambiae* complex were the predominant vectors in most urban settings. Anopheline larvae were reported to have adapted to different aquatic habitats. The study provides updated information on the distribution of the vector population and the dynamic of malaria transmission in urban settings. The study also highlights the need for implementing integrated control strategies in urban settings.

Keywords: Malaria, Urbanization, Sub-Saharan Africa, *Anopheles*, Entomological inoculation rate, Bionomic

Background

Sub-Saharan Africa still bears the highest burden of malaria morbidity and mortality worldwide despite improvements in the diagnostic of the pathogens and large-scale deployment of vector control measures, such as Long-Lasting Insecticidal Nets (LLINs) and Indoor Residual Spraying (IRS) [1]. In 2019 over 229 million cases and 409,000 deaths were recorded across the world [1]. Although the whole sub-Saharan Africa region is

exposed to malaria transmission risk, high heterogeneity in malaria transmission patterns exists on the continent, particularly between urban and rural settings [2–4]. It is considered that people living in rural settings are more exposed to malaria transmission risk compared to those living in urban settings [3, 5]. Studies conducted so far suggested higher densities and a greater diversity of malaria vector population sizes in rural compared to urban settings [6]. Many factors have been reported to affect malaria transmission intensity in urban settings including pollution, which can affect anopheline larval habitats and reduce their population size as well as impact mosquito life cycles and consequently their vectorial capacity. Urban dwellers may also have greater

*Correspondence: antonio_nk@yahoo.fr

¹ Institut de Recherche de Yaoundé (IRY), Organisation de Coordination Pour la Lutte Contre les Endémies en Afrique Centrale (OCEAC), P.O. Box 288, Yaoundé, Cameroun

Full list of author information is available at the end of the article



© The Author(s) 2021. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

mosquito avoidance behaviour, including the use of repellents, screens on windows, insecticides spray and coils [2, 7–9]. During the last decade, sub-Saharan Africa registered an unprecedented growth of its urban population.

The urban population which was estimated at 491 million in 2015 is projected to grow to nearly 1.5 billion by 2050 [10]. However the rapid unplanned urbanization observed in many sub-Saharan Africa cities characterized by the colonization of lowland areas for house construction, the absence of drainage system for water, the presence of standing water collection everywhere due to the bad state of roads and poor housing are all considered to affect the distribution of vector population and malaria transmission pattern [11]. Now, many cities are reporting increase practice of urban agriculture in both the city centre and periphery; all these activities create favourable breeding habitats for mosquitoes [12–14]. The rapid unplanned urbanization appears as a potential risk factor promoting malaria and arboviral diseases transmission in urban settings [15, 16]. Studies conducted so far suggested higher densities and a greater diversity of malaria vectors in rural compared to urban settings [2, 6, 17]. Besides, it has been reported that the most efficient malaria vectors *Anopheles gambiae sensu lato (s.l.)* namely *Anopheles gambiae*, *Anopheles coluzzii*, *Anopheles arabiensis*, which had a strong preference for unpolluted water [13] now displays a great adaptation pattern to polluted waters in urban cities [18, 19] and breed in different human-made habitats including containers filled with water, swimming pools, tyre tracks, water tanks [20]. Housing construction sites or construction materials were also found to be productive habitats for malaria vectors [21, 22]. The situation of malaria in sub-Saharan African cities is further becoming complex with the recent invasion of the Asian malaria vectors *Anopheles stephensi* [23, 24]. Although the epidemiological consequences of such invasion is still not well understood, it is likely that the addition of new competent vectors in the urban environment may further negatively affect malaria control strategies in urban areas. Considering the potential public health impact that urban malaria could have and potential effects on the economic development of countries, there have been during the last decade a renewed interest with several studies assessing malaria transmission pattern and vector bionomic in urban settings across sub-Saharan Africa [11, 18, 21, 25–29]. However there have been so far not enough studies summarising findings from previous works in order to capture the general trend of malaria transmission, vector distribution and larvae preferred breeding habitats in urban settings. For instance, there have been fewer studies providing an overview of the general distribution pattern of main species in urban settings across Africa. The

present study's objective is to carry out a review of the existing literature on malaria transmission across sub-Saharan Africa in order to provide a better understanding of the evolution of vector populations and malaria transmission pattern.

Methods

Literature search

A search for studies on urban malaria in Africa was conducted to capture the general trend of malaria transmission using the following online databases PubMed, Research Gate, Google scholar and Google. Search terms included a combination of key words such as “EIR Anopheles”, “Urban malaria”, “malaria urban SSA”, “Africa mosquitoes”, “malaria transmission”, “Urbanization”, “cities”, “malaria *P. falciparum*”, “malaria epidemiology”, “urban population”, “malaria prevalence”.

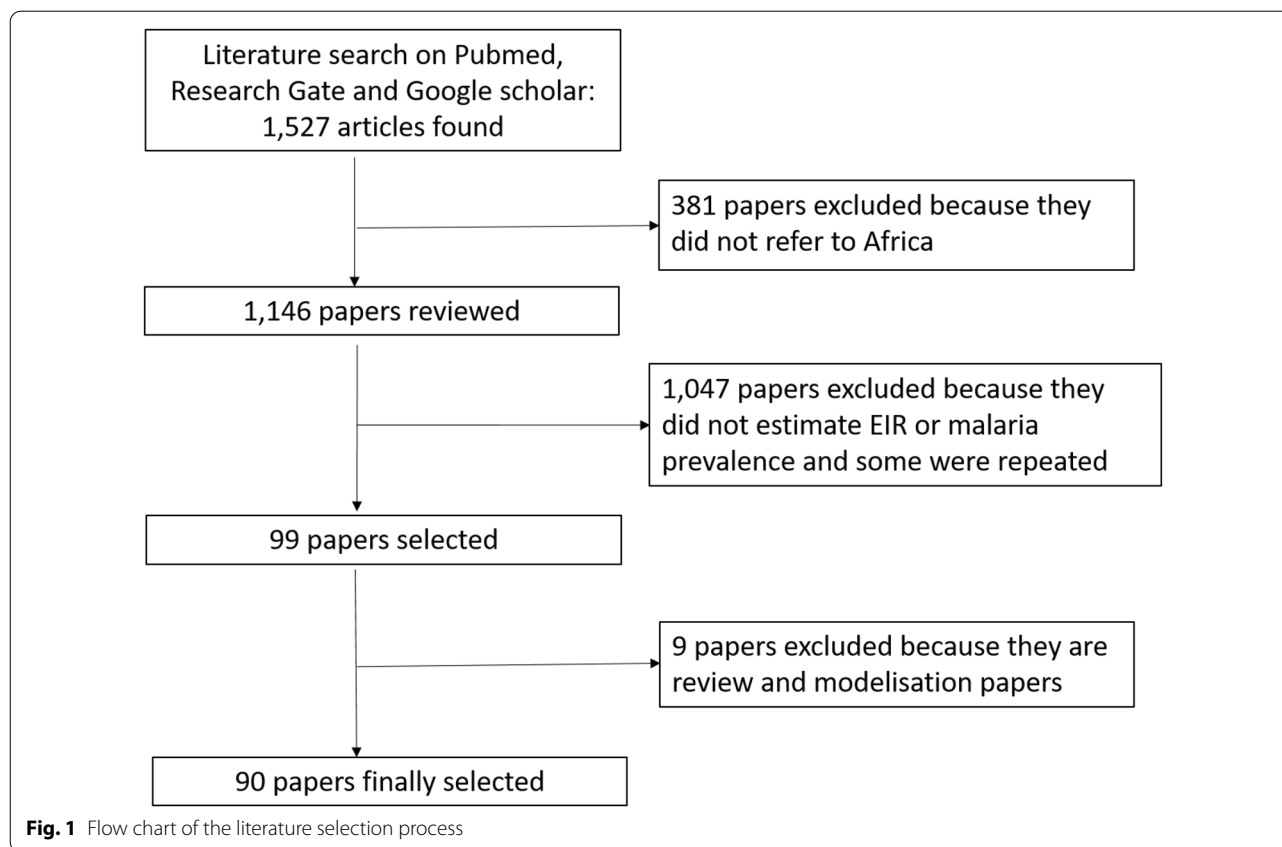
Literature selection process

The selection included papers published between the 1970s to 2020. Initial selection using the above combination of keywords yielded a total of 1527 scientific publications. All studies not conducted in Africa were discarded ($n = 381$). The remaining papers were then selected using the following criteria (i) description of malaria transmission or prevalence in urban and/or rural and/or periurban settings; (ii) studies conducted in sub-Saharan Africa. Papers which did not estimate the EIR or malaria prevalence or appearing several times in the selection were also excluded from the review. After applying this selection criteria, 1047 studies were discarded. Further reading of the abstract and the whole paper permitted to exclude an additional 9 papers leaving 90 for the study (Fig. 1).

Besides, an additional selection was performed to collate information on breeding habitats and anopheline species distribution in urban cities. Over 200 scientific publications were consulted for this purpose. Terms used to guide this search included the name of main cities in West, East and Central Africa followed by a combination of key words such as “malaria Anopheles”; “malaria Anopheles larvae”; “Anopheles urban breeding sites”; “Anopheles aquatic habitats”.

Data analysis

Available information retrieved from each selected publication were registered in a Microsoft Excel spreadsheet for data analysis. This included authors names, the year of publication, country, study site, types of settings, sampling method, study type, malaria transmission indices (entomological inoculation rate (EIR), human biting rate (HBR)), vectors involved in



the transmission, abundance of vectors, study period, malaria prevalence, and parasites (Additional file 1).

EIRs estimates were not always available in selected papers in an adequate format for analysis. The following steps were taken in order to adjust data presentation. (i) When many EIRs were estimated for the same site (EIRs for districts within a city), the average EIR from the area was estimated and used for analysis; (ii) when the EIR value was presented for two different periods in the same site, the highest value was considered; (iii) when indoor and outdoor EIRs were reported, the EIRs were summed to have the total EIR from the area; (iv) when EIRs were presented as daily or monthly or seasonal EIRs, the annual EIR was estimated.

The Spearman correlation coefficient was used to assess the correlation between EIRs and biting rates. The Kruskal–Wallis and Mann–Whitney tests were used to compare EIRs averages between urban, periurban and rural settings. The EIR was also compared between periods before 2003 and after 2003 because after 2003 studies conducted were using more molecular tools for mosquito processing (PCR, ELISA) than before. Analyses were performed using R software version 3.4.0. and GraphPad Prism 7.

Study design

A flowchart representing the study design show data collected in selected papers, indicators assessed and comparisons performed in the review (Fig. 2).

Results

Literature review of EIR estimates in rural, periurban and urban settings

A total of 90 studies conducted in 136 sites in 23 countries were consulted for the present review (Table 1). Data presented derive from studies in 88 rural sites, 18 periurban sites and 31 urban sites.

Dynamic of the EIR between rural, periurban and urban settings

A high heterogeneity in EIR estimates was recorded between urban, periurban and rural settings. The average EIR was 144.05 infective bites per person per year (ib/p/yr) 95% CI [141.9–146.22] in rural area, 45.70 ib/p/yr 95% CI [42.86–48.7] in periurban area and 32.73 ib/p/yr 95% CI [31.13–34.38] in urban sites. A significant difference was recorded when comparing the EIR between rural, periurban and urban areas ($P < 0.05$). When comparing EIR estimates of the urban

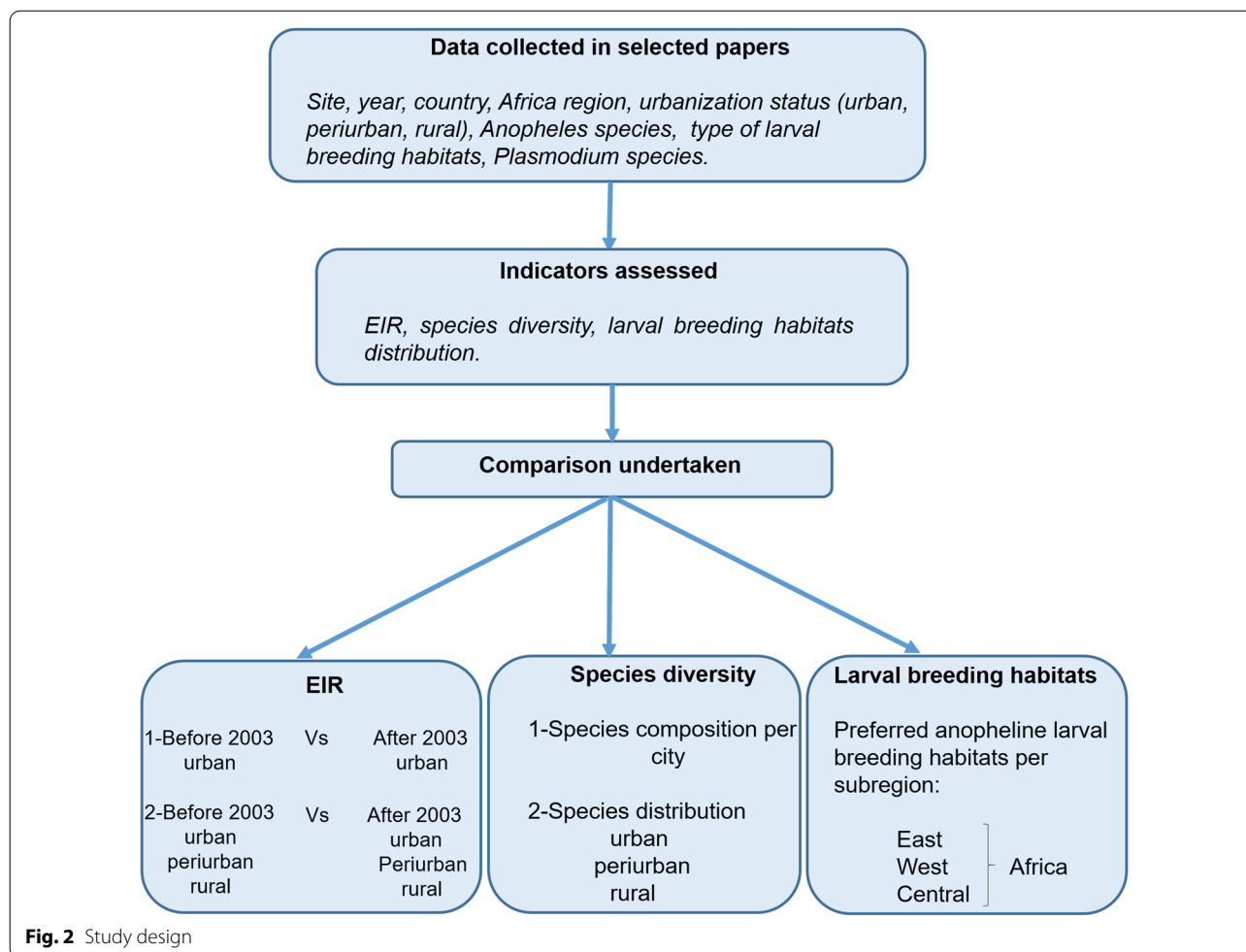


Fig. 2 Study design

centre between the period before 2003 (1977–2003) and the period after 2003 (2004–2020) it appears a significant increase in malaria transmission estimates in urban centres since 2003 ($P=0.0001$), no such increase was recorded for periurban and rural settings (Fig. 3).

Evolution of EIR in main sub-Saharan Africa cities

When comparing the EIR estimates in urban centres between 1977 and 2020, it appears that before 2003 there were many cities reporting very low or no transmission of malaria from mosquitoes to man whereas between 2004 and 2020 almost all studies indicated evidence of malaria transmission (Fig. 4). Average EIR values varying annually from 30 to 100 ib/p/yr were recorded in most urban settings (Fig. 4). Extreme values of EIR above 500 ib/p/yr have also been reported in Yaoundé [30] and Bioko [31], but these values were not included in the present analysis. *Plasmodium falciparum* was the main parasite detected in most cases.

Larval sites distribution in urban area

Anopheles larvae were frequently found in man-made water habitats, such as drains, puddles, market gardens, urban agricultural sites, pools drains and tyre tracks. *Anopheles* larvae were also reported in natural breeding sites such as swamps, streams or rivers bed although they are less common and scattered in urban areas. The number of studies highlighting the specific breeding sites of anopheline in urban areas both natural and artificial is presented in Table 2.

Diversity of the Anopheline fauna in urban cities

A total of 12 anopheline species were reported in studies conducted in urban cities. Species of *An. gambiae* complex, including *Anopheles gambiae* sensu stricto (s.s.), *Anopheles coluzzii* and *Anopheles arabiensis* were the most common. Additional species present in urban settings included *Anopheles melas*, *Anopheles funestus* s.s. and *Anopheles stephensi*. Other anopheline species such as *Anopheles coustani*, *Anopheles*

Table 1 EIRs estimates in different studies conducted across sub-Saharan Africa between 1977 and 2020

Authors	Year	Country	Locality	EIR		
				Rural	Periurban	Urban
Abraham et al. [78]	2017	Ethiopia	Sille	63.6		
Akogbeto et al. [79]	2000	Benin	Cotonou	12	47	29
Adja et al. [80]	2011	Côte d'Ivoire	Gbatta, Kpehiri	298.8; 478.8		
Akono et al. [30]	2015	Cameroon	Akonolinga, Yaoundé		813.95	552.61
Akono et al. [81]	2015	Cameroon	Logbessou		47.28	
Antonio-Nkondjio et al. [82]	2002	Cameroon	Simbock	368		
Antonio-Nkondjio et al. [14]	2012	Cameroon	Douala			31
Amawulu et al. [83]	2016	Nigeria	Bayelsa			80.5
Amek et al. [84]	2012	Kenya	Nyanza	25.6		
Amvongo-Adjia et al. [85]	2018	Cameroon	Tiko, Manfe, Santchou			8.4;16.8;26.88
Appawu et al. [86]	2004	Ghana	Kassena Nankana	1218		
Beier et al. [45]	1990	Kenya	Kisian, Saradidi	299; 237		
Bockarie et al. [87]	1994	Sierra Leone	Bo	21–36		
Cano et al. [31]	2004	Equatorial Guinea	Bioko			814.27
Cano et al. [88]	2006	Equatorial Guinea	Yengue	298.8		
Carnevale et al. [89]	1985	Congo	Brazzaville	80–850		
Carnevale et al. [90]	1992	Cameroon	Mbebe	182		
Coene [91]	1993	RD Congo	Kinshasa	455		30
Degefa et al. [92]	2015	Ethiopia	Jimma	0–4781.5		
Diallo et al. [93]	1998	Senegal	Dakar			0
Diallo et al. [94]	2000	Senegal	Dakar			0
Daygena et al. [95]	2017	Ethiopia	Gato	103.2		
Elissa et al. [96]	1999	Gabon	Franceville	365	81	
Epopa et al. [97]	2019	Burkina Faso	Bana, Pala, Souroukoudingan	393.47; 199.65; 151.84		
Getachew et al. [98]	2019	Ethiopia	Ghibe			13.8
Lwetoijera et al. [99]	2014	Tanzania	Kilombero	392.31		
Djamouko-Djonkam et al. [37]	2020	Cameroon	Yaoundé		106.83	9.78
Dossou-yovo et al. [100]	1995	Ivory Coast	Bouake	230		
Dossou-yovo et al. [101]	1994	Ivory Coast	Bouake		126; 88	
Doumbe-Belisse et al. [11]	2018	Cameroon	Yaoundé			0–92
Drakeley et al. [102]	2003	Tanzania	Ifakara		30.7	
Fontenille et al. [103]	1992	Madagascar	St Marie Island	100		
Fontenille et al. [104]	1997	Senegal	Dielmo	159		
Fontenille et al. [105]	1997	Senegal	Ndiop	31		
Fouque et al. [106]	2010	French Guinea	Loca, Twenke	10; 5		
Govoetchan et al. [107]	2014	Benin	Sonsoro, Gansosso	130.75		6.45
Hakizimana et al. [108]	2018	Rwanda	Karambi, Mashasha, Kicukiro	1–329.8		107.5
Himeidan et al. [109]	2011	Sudan	Koka, Um Salala	109.5; 3.65		
Karch et al. [110]	1992	Congo	Kinshasa	620	66	3
Kasasa et al. [111]	2013	Ghana	Navrongo			1.132–157
Kerah-Hinzoumbé [112]	2009	Chad	Goulmoun	311		
Kibret et al. [113]	2014	Ethiopia	Ziway	0.25–27.3		
Klinkenberg et al. [13]	2008	Ghana	Accra			6.6–19.2
Krafsur et al. [114]	1977	Western Ethiopia	Gambela	97		11
Lemasson et al. [115]	1997	Senegal	Barkedji	114		
Lindsay et al. [116]	1990	Gambia	Banjul			1.3
Lochouarn et al. [117]	1993	Burkina Faso	Bobo-Dioulasso			2
Gadiaga et al. [118]	2011	Senegal	Dakar			17.6

Table 1 (continued)

Authors	Year	Country	Locality	EIR		
				Rural	Periurban	Urban
Githeko et al. [119]	1993	Kenya	Ahero	91–416		
Machault et al. [28]	2009	Senegal	Dakar			0–16.8
Mala et al. [120]	2011	Kenya	Kamarimar, Tirion	1.44; 1.61		
Manga et al. [121]	1992	Cameroon	Yaoundé			3; 13
Massebo et al. [122]	2013	Ethiopia	Chano	0–73.2		
Mbogo et al. [123]	2003	Kenya	Malindi	0–120		
Mbogo et al. [124]	1993	Kenya	Kilifi	8		1.5
Mbogo et al. [125]	1995	Kenya	Kilifi	0–59.6		
Mourou et al. [39]	2012	Gabon	Libreville			33.9
Mourou et al. [41]	2010	Gabon	Libreville, Port-Gentil			3.45;66.45
Mutuku et al. [126]	2011	Kenya	Kidomaya, Jego	5.16		
Muturi et al. [127]	2008	Kenya	Kiamachiri, Mbuijeru, Murinduko	4.06; 2.55; 2.50		
Mwangangi et al. [128]	2013	Kenya	Kimudia, Kiwalwa, Mwarusa, Njoro	31.95; 123.92; 59.78; 45.06		
Mwanziva et al. [129]	2011	Tanzania	Gichamedea	0.51		
Ndenga et al. [130]	2006	Kenya	Iguhu, Kombewa, Marani, Mbale	16.6;31.1;0.4;1.1		
Njan Nloga et al. [131]	1993	Cameroon	Ebogo	355		
Okello et al. [132]	2006	Uganda	Jinja, Arua, Apac, Tororo, Mubende, Kyenjojo, Kanungu	397; 1586; 562; 4; 7; 6	6	
Okwa et al. [133]	2009	Nigeria	Bungudu-Gusau, Badagry, Onitsha, Bonny	23.31	74.1;32.1; 34.5	
Olayemi et al. [134]	2011	Nigeria	Ilorin and Minna			0.83
Overgaard et al. [135]	2012	Equatorial Guinea	Bioko			163–840
Owusu-Agyei et al. [136]	2009	Ghana	Kintampo	269		
Richard et al. [137]	1988	Congo	Mayombe		80; 397	
Robert et al. [89]	1985	Burkina Faso	Bobo-Dioulasso	50; 60; 55; 133		
Robert et al. [138]	1986	Burkina Faso	Bobo-Dioulasso		5	0.1;0.5
Robert et al. [139]	1993	Cameroon	Edea			4; 30
Robert et al. [140]	1998	Senegal	Niakhar	9; 12;26		
Rossi et al. [141]	1986	Burkina Faso	Ouagadougou	92; 82; 430	10; 23	7;0;0
Salako et al. [50]	2018	Benin	Alibori, Donga	285.48		49.8
Shiff et al. [142]	1995	Tanzania	Coastal Tanzania	94–703		
Shililu et al. [143]	2003	Eritrea	Anseb, Debub, Gash-Barka, Northern Red Sea	3.45; 15.95; 66.45; 0		
Smith et al. [144]	1993	Tanzania	Kilombero	329		
Tabue et al. [145]	2017	Cameroon	Garoua, mayo Oulo, Pitoa	71.54	33.9	3.45
Tanga et al. [146]	2010	Cameroon	Likoko	460.1		
Tchouassi et al. [147]	2012	Ghana	Kpone-on-sea	62.1		
Tchuinkam et al. [51]	2010	Cameroon	Djuttitsa, Dschang, Santchou	0; 90.5		62.8
Thompson et al. [148]	1997	Mozambique	Maputo		20	0
Trape and Zoulani [149]	1987	Congo	Brazzaville		101	0.3
Trape et al. [150]	1992	Senegal	Pikine, Dakar		0.4	0.01
Vercruyse [151]	1981	Senegal	Pikine, Dakar			43
Vercruyse [152]	1985	Senegal	North Senegal	1; 6.5		
Yadouléton et al. [12]	2010	Benin	Cotonou, Parakou, Porto Novo			102.2; 54.73;83.95
Zogo et al. [153]	2019	Côte d’Ivoire	Korhogo	2.46		

Table 1 (continued)

EIR, infected bites per person per year

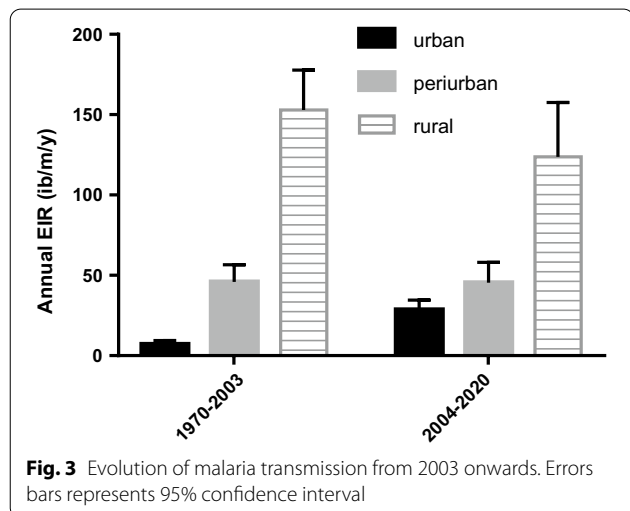


Fig. 3 Evolution of malaria transmission from 2003 onwards. Errors bars represents 95% confidence interval

ziemanni, *Anopheles marshallii*, and *Anopheles rufipes* were reported, but in very low densities (Table 3). Great diversity and higher densities of species in rural areas compared to periurban and urban centres were recorded (Fig. 5). For instance, in the city of Yaoundé, it was common to find fewer than four species at the city centre whereas this number could rise up to ten species in the nearby rural settings.

Discussion

The present study is an update of previous reviews on urban malaria in sub-Saharan Africa [2–4, 29, 32, 33], it provides new data on malaria transmission pattern and anopheline species distribution. Urbanization is increasingly blamed of influencing the epidemiology and evolution of vector-borne diseases in sub-Saharan Africa. More than half of the world’s population now lives in towns or cities and it is projected that this number could rise to 75% by 2050 [34]. From the review it appears that, the Entomological Inoculation Rate (EIR) is highly heterogeneous in cities across the continent [18, 35, 36]. In many cities centre, malaria transmission is low or absent while others register high EIR estimates [11, 37]. The difference between cities could derive from the scale of urban development, population size and the magnitude of unplanned urbanization. Unplanned urbanization characterized by the colonization of lowland areas for habitat construction, poor drainage system in urban settings, the development of slums and spontaneous habitats and the practice of agriculture in the city centre was reported to deeply influence malaria transmission intensity [15, 38]. Although EIR estimates were always higher in rural and peri-urban settings compared to urban centres [2], it also appeared that, because of increase poverty in urban settings there are an increasing number of people exposed to malaria transmission risk. In the city of Libreville for instance, a high transmission rate was recorded in the city centre characterized by poor

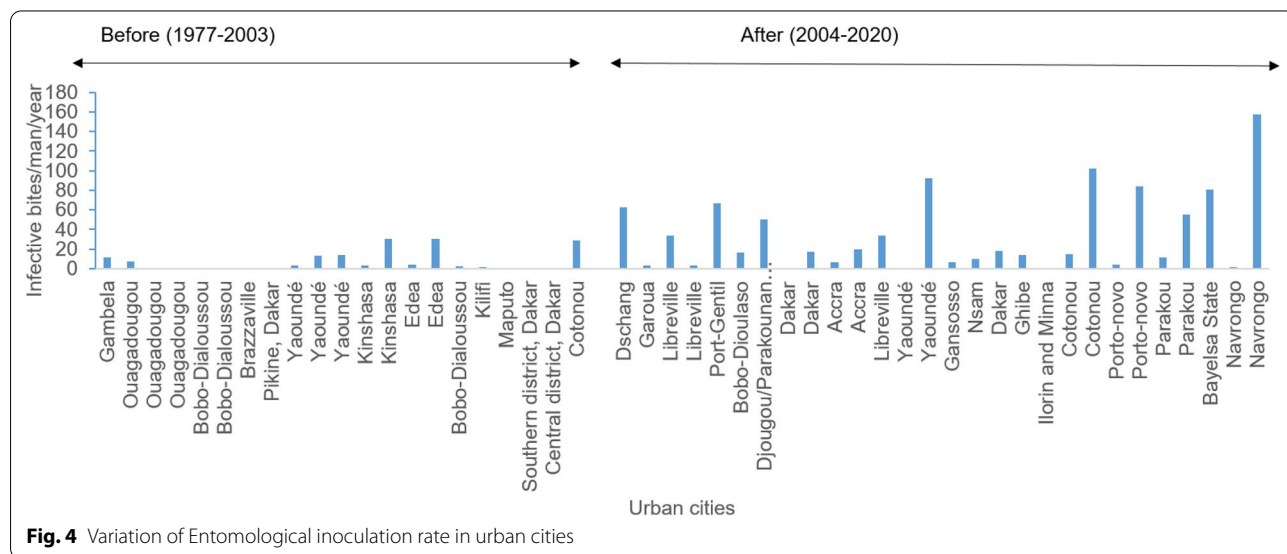


Fig. 4 Variation of Entomological inoculation rate in urban cities

Table 2 Type of breeding habitats found with anopheline larvae in urban settings across sub-Saharan Africa

Type of breeding site	West Africa	References	Central Africa	References	East Africa	References	
Artificial	Urban farms	10	[12, 13, 18, 21, 26, 28, 154–157]		4	[27, 158–160]	
	Tyre tracks	4	[18, 28, 161, 162]	1	[19]	[22, 158, 160, 163–165]	
	Drains/gutter	4	[154, 159, 162, 166]	4	[19, 167–169]	[170, 158, 159, 164, 165]	
	Swimming pool	1	[21]		4	[22, 27, 159, 171]	
	Pools	4	[161, 162, 166, 172]	1	[168]	[160, 164, 165, 173, 174]	
	Polluted water	3	[13, 18, 155]	1	[19]	[175]	
	Pipes	1	[13]		2	[176, 177]	
	Dam	1	[155]	1	[178]		
	Brick holes	1	[155]				
	Domestic containers	2	[162, 166]	2	[19, 168]	3	[163, 165, 179]
	Footsprint			2	[19, 167]	2	[163, 165]
	Ditches/pits	1	[154]	1	[169]	4	[163–165, 174]
	Rice paddies			1	[180]	2	[163, 165]
	Puddles	1	[154]	2	[19, 169]	4	[159, 164, 173]
	Holes					1	[164]
Canoes			2	[168, 169]			
Total	33		18		43		
Natural	Swamps	3	[28, 154, 155]	1	[19]	4	[159, 160, 163, 164]
	Streams/ivers/lagoon	6	[21, 154, 156, 161, 32, 181]	1	[182]	3	[159, 164, 173]
	Ponds	1	[161]	2	[178, 183]	1	[159]
	Well	1	[13]	1	[168]		
	Ground water/springs					2	[27, 158]
	Tree holes			2	[166, 168]	1	[184]
	Clay soil	1	[21]			1	[27]
	Flood plain/ravine	1	[155]			1	[171]
Total	13		7		13		

housing, high population density, low socio-economic level and inadequate management of waste, compared to the periphery where the population had a high socio-economic level and good management infrastructure [39]. In the city of Yaoundé, where slum-like conditions are common across the city, malaria transmission was highly prevalent in both the city centre and the periphery [11]. The close association between malaria and the economic status of the household has been highlighted in different studies across the continent [4]. Additional factors including river overflowing, city landscape and seasonal variations were also found to influence the intensity and pattern of malaria transmission [14, 40]. Important differences were noted when comparing malaria transmission intensity in the city centre before and after 2003. The comparison of the two periods suggested an increase in malaria transmission intensity in urban settings across sub-Saharan Africa after 2003 [11, 13, 31, 39, 41]. Transmission estimates surpassing 50 infected bites/person/year were frequently reported in cities across Africa supporting the existence of high parasite reservoirs in urban settings including migrants coming from highly endemic

rural settings or population moving from urban to rural settings which could be infecting mosquito populations [30, 37]. It is also possible that the introduction of new techniques for the detection of *Plasmodium* infections in mosquitoes, such as ELISA and PCR techniques which were not used before could have increased the EIR estimates [42–44]. These highly sensitive techniques were reported to overestimate the true infection rate after salivary gland dissection by 1.1 to 1.9 folds [45–48]. The use of new molecular techniques or genomic advances could be vital for malaria control and elimination in Africa and there is a need to promote the use of new techniques to improve malaria vector control and surveillance in Africa [49].

The study also indicated high diversity of the vectorial system in different cities [12, 50–53]. Yet members of *An. gambiae* complex were largely predominant in most urban settings [11, 14, 54, 55]. This is in conformity with these species capacities to adapt to anthropogenic and/or environmental changes and to feed exclusively on humans [56]. The preferential breeding habitats of species of the *An. gambiae* complex are temporary water

Table 3 Composition of anopheline species recorded in main cities across Africa

Africa subregion	Country	Cities	Main species (> 90% total)	Others species < 10%	References
Central Africa	Cameroon	Garoua	<i>An. gambiae</i> s.s	<i>An. rufipes</i> / <i>An. pharoensis</i> / <i>An. funestus</i> / <i>An. paludis</i>	[145, 180, 52]
		Yaoundé	<i>An. gambiae</i> s.s./ <i>An. coluzzii</i> / <i>An. funestus</i>	<i>An. nili</i> / <i>An. marshalli</i> / <i>An. ziemanni</i> / <i>An. moucheti</i>	[11, 19, 30, 37, 121, 185, 59, 186]
	Gabon	Douala	<i>An. coluzzi</i>	<i>An. gambiae</i> s.s./ <i>An. ziemanni</i>	[14, 167, 168]
		Libreville	<i>An. gambiae</i> s.s		[39, 41]
		Port-Gentil	<i>An. melas</i> / <i>An. gambiae</i> s.s		[41]
	Equatorial Guinea	Franceville	<i>An. funestus</i> / <i>An. gambiae</i> s.s		[96]
		Bioko	<i>An. funestus</i> / <i>An. gambiae</i> s.s	<i>An. melas</i>	[31, 135, 187–191]
	Tchad	N'Djamena	<i>An. gambiae</i> s.s./ <i>An. arabiensis</i> / <i>An. coluzzii</i>		[192–194]
	Angola	Lobito	<i>An. coluzzii</i> / <i>An. gambiae</i> s.s		[195, 196]
		Luanda	<i>An. gambiae</i> s.s		[197]
	Congo	Brazzaville	<i>An. gambiae</i> s.s	<i>An. moucheti</i>	[149]
	Democratic Republic of Congo	Lodja/Kapolowe	<i>An. gambiae</i> s.s		[198]
		Kinshasa	<i>An. gambiae</i> s.s./ <i>An. funestus</i> / <i>An. paludis</i>	<i>An. moucheti</i> / <i>An. nili</i>	[110, 199–201]
	Central Africa Republic	Kibali	<i>An. gambiae</i> s.s./ <i>An. funestus</i>		[202]
		Bangui	<i>An. coluzzii</i> / <i>An. gambiae</i> s.s./ <i>An. funestus</i> s.s		[203–206]
	Benin	Cotonou	<i>An. gambiae</i> s.l	<i>An. pharoensis</i> / <i>An. ziemanni</i> / <i>An. funestus</i>	[12]
	West Africa	Porto Novo		<i>An. gambiae</i> s.l	<i>An. pharoensis</i> / <i>An. ziemanni</i> / <i>An. funestus</i>
Côte d'ivoire		Yamoussoukro	<i>An. gambiae</i> s.l	<i>An. funestus</i>	[207]
		Abidjan	<i>An. gambiae</i> s.s		[207]
		Bouaké	<i>An. gambiae</i> s.s		[208, 209]
Gambia		Bakau	<i>An. arabiensis</i> / <i>An. coluzzii</i>	<i>An. gambiae</i> s.s./ <i>An. gambiae</i> s.s. and <i>An. coluzzii</i> hybrids	[210]
Senegal		Dakar	<i>An. gambiae</i> s.l./ <i>An. arabiensis</i>	<i>An. pharoensis</i> / <i>An. ziemanni</i> <i>An. melas</i> / <i>An. gambiae</i> s.s	[28, 118, 211]
		Kedougou	<i>An. coustani</i> / <i>An. funestus</i>	<i>An. domicola</i> / <i>An. flavicosta</i> / <i>An. gambiae</i> s.l./ <i>An. hanckockii</i> / <i>An. nili</i> / <i>An. rufipes</i> / <i>An. wellcomei</i>	[212]
Guinea		Conakry	<i>An. coluzzii</i> / <i>An. gambiae</i> s.s		[54, 213, 214]
		Siguiiri	<i>An. gambiae</i> s.s./ <i>An. funestus</i>	<i>An. arabiensis</i>	[215]
Guinea-Bissau		Bissau	<i>An. gambiae</i> s.s./ <i>An. coluzzii</i> / <i>An. arabiensis</i>	<i>An. melas</i> / <i>An. pharoensis</i>	[216–220]
Mauritania		Nouakchott	<i>An. gambiae</i> s.s./ <i>An. arabiensis</i> / <i>An. pharoensis</i>		[221, 222]
Burkina Faso		Bobo-Dioulasso	<i>An. arabiensis</i>	<i>An. coluzzii</i> / <i>An. gambiae</i> s.s	[223, 223–225]
		Ouagadougou	<i>An. gambiae</i> s.l./ <i>An. coluzzii</i> / <i>An. arabiensis</i>		[154, 226, 227]
Cabo-Verde		Praia	<i>An. arabiensis</i>		[228, 229]
Liberia		Montserrado	<i>An. gambiae</i> s.s	<i>An. coluzzii</i>	[230, 231]
		Monrovia	<i>An. gambiae</i> s.s./ <i>An. coluzzii</i>	<i>An. funestus</i>	[232]
Nigeria	Ilorin and Minna	<i>An. gambiae</i> s.l		[134]	
	Lagos	<i>An. gambiae</i> s.s./ <i>An. arabiensis</i>	<i>An. rivulorum</i> / <i>An. funestus</i>	[233–236]	
	Bayelsa	<i>An. gambiae</i> s.s		[83]	
Mali	Bamako	<i>An. coluzzii</i> / <i>An. gambiae</i>	<i>An. arabiensis</i>	[237–239]	
Ghana	Accra	<i>An. gambiae</i> s.s./ <i>An. coluzzii</i>	<i>An. funestus</i> / <i>An. coustani</i>	[13, 170, 240]	
Niger	Niamey	<i>An. gambiae</i> s.s./ <i>An. arabiensis</i>	<i>An. funestus</i> / <i>An. rufipes</i> / <i>An. pharoensis</i> / <i>An. ziemanni</i>	[40]	
	Tessaoua	<i>An. coluzzii</i>		[194]	
Togo	Lomé	<i>An. gambiae</i> s.s./ <i>An. coluzzii</i>		[241]	

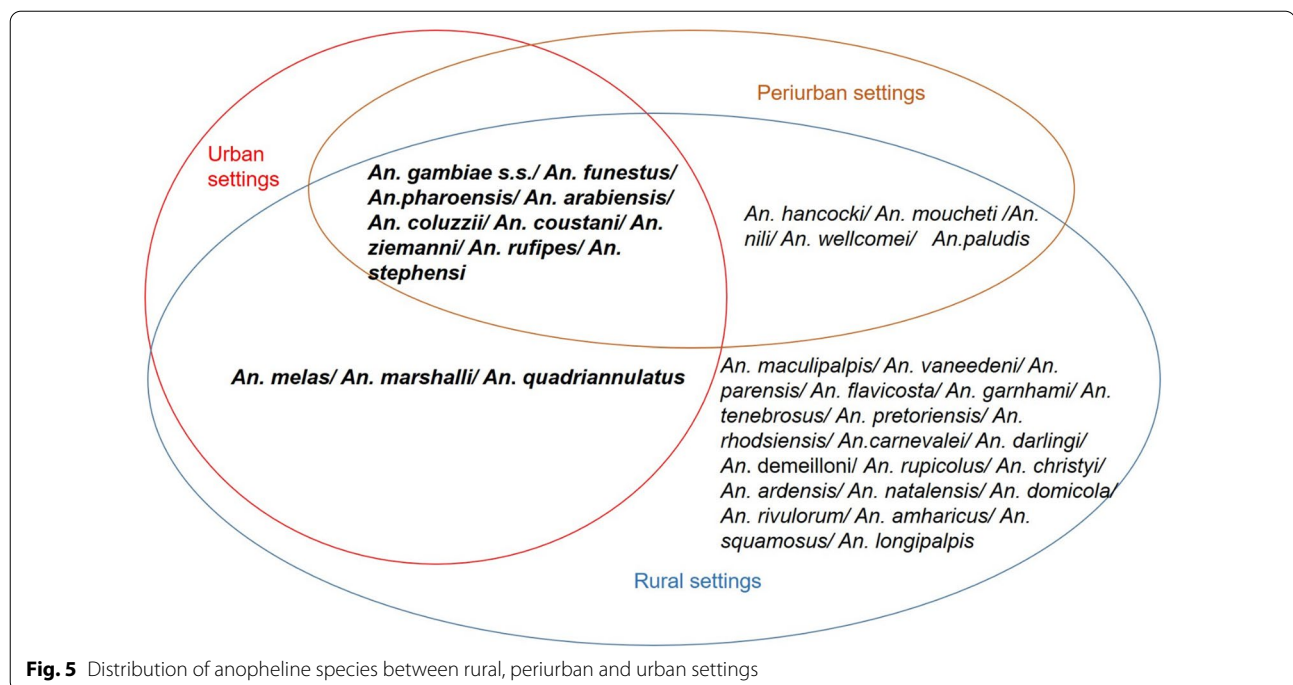
Table 3 (continued)

Africa subregion	Country	Cities	Main species (> 90% total)	Others species < 10%	References	
Africa	Ethiopia	Kebri Dehar	<i>An. stephensi</i>		[23, 242]	
		Arjo-Didessa	<i>An. arabiensis</i>	<i>An. amharicus</i> / <i>An. coustani</i> / <i>An. pharoensis</i> / <i>An. squamosus</i> / <i>An. funestus</i>	[159, 243]	
	Djibouti	Djibouti	<i>An. arabiensis</i> / <i>An. stephensi</i>		[244, 245]	
	Sudan	Khartoum	<i>An. arabiensis</i>		[246–250]	
	Tanzania	Dar es Salaam	<i>An. arabiensis</i>	<i>An. funestus</i> / <i>An. gambiae</i> s.s./ <i>An. coustani</i>	[55, 251]	
		Morogoro	<i>An. arabiensis</i>	<i>An. gambiae</i> s.s./ <i>An. coustani</i> / <i>An. quadrianulatus</i>	[162, 252]	
	East Africa	Kenya	Nairobi	<i>An. arabiensis</i> / <i>An. funestus</i>		[253, 254]
			Kisumu	<i>An. funestus</i>	<i>An. rivulorum</i> / <i>An. lesoni</i> , <i>An. parensis</i> / <i>An. longipalpis</i> / <i>An. vaneedeni</i>	[255]
			Kilifi	<i>An. funestus</i>	<i>An. rivulorum</i> / <i>An. lesoni</i> , <i>An. parensis</i> , <i>An. longipalpis</i> / <i>An. vaneedeni</i>	[255, 256]
		Rwanda	Kigali	<i>An. arabiensis</i>	<i>An. funestus</i> / <i>An. ziemanni</i> / <i>An. coustani</i> / <i>An. moucheti</i> / <i>An. gambiae</i> s.s	[108, 257]
Burundi		Karuzi	<i>An. gambiae</i> s.s	<i>An. demeillonii</i> / <i>An. arabiensis</i> / <i>An. funestus</i>	[258]	
Uganda	Tororo	<i>An. arabiensis</i>	<i>An. gambiae</i> s.s	[259]		

collections exposed to sunlight. However, these species were reported to also breed in different types of habitats, including drains, septic tanks, artificial containers, standing water collection full of organic matters in urban settings [2, 15]. Moreover, it appears from the study that species composition could vary significantly between cities [51]. The following observation, highlights the influence of different factors genetic and tolerance level shaping the adaptation capacity of species in different environments [57, 58]. In the city of Yaoundé, the predominance of *An. coluzzii* over *An. gambiae* was attributed to the high tolerance of the species to organic pollutants, such as ammonia [59]. In coastal cities along the Atlantic Ocean, such as Libreville and Malabo, *An. gambiae* was found to be highly predominant whereas it was less abundant in Douala where *An. coluzzii* was the predominant species [60]. Explaining species distribution relying only on species specific data could be more complex as highlighted in a recent meta-analysis [61] and deserve further investigation. Urban agriculture coupled with uncontrolled disposal of containers to collect rainwater is creating an increasing number of favourable aquatic breeding habitats for *Anopheles* in urban cities. It has been reported that some *Anopheles* species are now adapting to this new environment, as described for *An. stephensi*, which breeds in man-made water containers, such as household water storage containers and garden reservoirs [24, 62]. The invasion of Africa by new species,

such as *An. stephensi*, which is now found in many countries across East Africa such as Djibouti, Somalia, Sudan, and Ethiopia, could pose a great challenge for malaria elimination in Africa particularly in urban settings [1, 23, 63–65]. The invasion of Djibouti by *Anopheles stephensi* in 2012 was associated with a 30-fold increase in malaria cases, from 1684 in 2012 to 49,402 in 2019 [1]. *Anopheles stephensi* was also reported to display high resistance to pyrethroids, carbamates and organophosphates [64]. The species bites outdoors and displays a highly opportunistic behaviour feeding on both human and animals, a behaviour which could affect the efficiency of current control measures [64].

Some cities exhibited a high species diversity with three to six species commonly reported whereas low species diversity was recorded in others. This heterogeneity between cities could derive from difference in vegetation, altitude, urbanization level and seasons [66–70]. The presence of forest fringes as observed in the close neighbourhood of some cities [51] could increase the number of potential breeding sites exploited by mosquitoes and explain the diversity. Mosquitoes found in the urban environment are also exposed to a high selection pressure induce by the use of insecticide-treated nets, pollution, deforestation, anthropogenic changes and environmental changes which could reduce the diversity and distribution of species [15]. Indeed high intensity insecticide resistance affecting almost all insecticide families was



reported in *An. gambiae s.l.* populations from most urban settings [12, 19, 71–73]. The rapid expansion of multiresistance pattern was reported to reduce bed nets efficacy in different epidemiological settings [74–76]. In urban settings where vector populations display resistance to insecticide, and outdoor feeding behaviour [11], the addition of targeted interventions such as larval control in hotspot areas could be keys for effective reduction of malaria transmission.

Plasmodium falciparum was the predominant malaria parasites recorded in almost all urban settings. This parasite is also the dominant species in rural settings [77]. Other species commonly found included *Plasmodium malariae* and *Plasmodium ovale* [53]. It is likely that the diversity of *Plasmodium* species in urban settings could be on the rise due to the intensification of travels between different regions of the globe. The exploration of factors favouring mosquito nuisance and malaria transmission in urban settings clearly shows the influence of urban expansion resulting from rapid population growth outpacing infrastructure development and highlight the need for further action by municipalities and public works services in the construction of drains or sewage systems to reduce breeding opportunities for mosquitoes [13].

Conclusion

The current review provides an update of the situation of malaria in urban settings in sub-Saharan Africa during the last decades. Although the risk of malaria transmission remains low in urban compared to rural settings, urban malaria is likely to increase as unplanned urbanization continues. Unplanned urbanization led to a proliferation of suitable breeding habitats for malaria vectors and thus increases the risk of exposition to mosquito bites and malaria transmission. To stop this trend in the disease burden, concerted actions need to be taken quickly at different levels to improve the management of malaria cases and control of vector populations. The development of integrated control approaches could be paramount for the effective control of vector-borne diseases in urban settings.

Abbreviations

EIRs: Entomological Inoculation Rate; PCR: Polymerase Chain Reaction; ELISA: Enzyme-Linked Immunosorbent Assay.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12936-021-03891-z>.

Additional file 1. Database of the entomological inoculation rate estimates reported in the 90 scientific publications selected for the review.

Acknowledgements

Not applicable.

Authors' contributions

Conceived and designed the study: CAN; performed the literature search: PDB, EK; interpreted, analysed data and wrote the paper: CAN, PDB, EK with the contributions of others authors; critically reviewed the manuscript: NCS, SNC, AT, LDD, HPA, CSW, FN. All authors read and approved the final manuscript.

Funding

This work received financial support from Wellcome Trust Senior Fellowship in Public Health and Tropical Medicine (202687/Z/16/Z) to ANC. The funding body did not have any role in the design, collection of data, analysis and interpretation of data and in writing of the manuscript.

Availability of data and materials

Not applicable.

Declarations**Ethics approval and consent to participate**

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

¹Institut de Recherche de Yaoundé (IRY), Organisation de Coordination Pour la Lutte Contre les Endémies en Afrique Centrale (OCEAC), P.O. Box 288, Yaoundé, Cameroun. ²Faculty of Sciences, University of Yaoundé I, P.O. Box 337, Yaoundé, Cameroun. ³Faculty of Health Sciences, University of Buea, Cameroon, P.O. Box 63, Buea, Cameroon. ⁴Faculty of Sciences, University of Dschang Cameroon, P.O. Box 67, Dschang, Cameroon. ⁵Vector Group Liverpool School of Tropical Medicine Pembroke Place, Liverpool L3 5QA, UK.

Received: 28 June 2021 Accepted: 20 August 2021

Published online: 08 September 2021

References

- WHO. World malaria report. Geneva: World Health Organization, 2020. https://cdn.who.int/media/docs/default-source/malaria/world-malaria-reports/9789240015791-eng.pdf?sfvrsn=d7a8ec53_3&download=true
- Robert V, Macintyre K, Keating J, Trape J-F, Duchemin J-B, Warren M, et al. Malaria transmission in urban sub-Saharan Africa. *Am J Trop Med Hyg*. 2003;68:169–76.
- Hay SI, Guerra CA, Tatem AJ, Atkinson PM, Snow RW. Urbanization, malaria transmission and disease burden in Africa. *Nat Rev Microbiol*. 2005;3:81–90.
- Keiser J, Utzinger J, De Castro MC, Smith TA, Tanner M, Singer BH. Urbanization in sub-saharan Africa and implication for malaria control. *Am J Trop Med Hyg*. 2004;71:118–27.
- Mathanga DP, Tembo AK, Mzilahowa T, Bauleni A, Mtimaukenena K, Taylor TE, et al. Patterns and determinants of malaria risk in urban and peri-urban areas of Blantyre. *Malawi Malar J*. 2015;15:590.
- De Castro MC, Yamagata Y, Mtasiwa D, Tanner M, Utzinger J, Keiser J, et al. Integrated urban malaria control: a case study in Dar es Salaam, Tanzania. *Am J Trop Med Hyg*. 2004;71:103–17.
- Wooding M, Naudé Y, Rohwer E, Bouwer M. Controlling mosquitoes with semiochemicals: a review. *Parasit Vectors*. 2020;13:80.
- Norris EJ, Coats JR. Current and future repellent technologies: the potential of spatial repellents and their place in mosquito-borne disease control. *Int J Environ Res Public Health*. 2017;14:124.
- Aguiar RWS, dos Santos SF, da Silva MF, Ascencio SD, de Mendonça LM, Viana KF, et al. Insecticidal and repellent activity of *Siparuna guianensis* Aubl. (Negramina) against *Aedes aegypti* and *Culex quinquefasciatus*. *PLoS ONE*. 2015;10:e0116765.
- Tuholske C, Caylor K, Evans T, Avery R. Variability in urban population distributions across Africa. *Environ Res Lett*. 2019;14:085009.
- Doumbe-Belisse P, Ngadjieu CS, Sonhafouo-Chiana N, Talipouo A, Djamouko-Djonkam L, Kopya E, et al. High malaria transmission sustained by *Anopheles gambiae* s.l. occurring both indoors and outdoors in the city of Yaoundé, Cameroon. *Wellcome Open Res*. 2018;3:164.
- Yadouléon A, N'guessan R, Allagbé H, Asidi A, Boko M, Osse R, et al. The impact of the expansion of urban vegetable farming on malaria transmission in major cities of Benin. *Parasit Vectors*. 2010;3:118.
- Klinkenberg E, McCall P, Wilson MD, Amerasinghe FP, Donnelly MJ. Impact of urban agriculture on malaria vectors in Accra. *Ghana Malar J*. 2008;7:151.
- Antonio-Nkondjio C, Defo-Talom B, Tagne-Fotso R, Tene-Fossog B, Ndo C, Lehman LG, et al. High mosquito burden and malaria transmission in a district of the city of Douala, Cameroon. *BMC Infect Dis*. 2012;12:275.
- De Silva PM, Marshall JM. Factors contributing to urban malaria transmission in sub-Saharan Africa: a systematic review. *J Trop Med*. 2012;2012:819563.
- Ishengoma DS, Francis F, Mmbando BP, Lusingu JPA, Magistrado P, Alifrangis M. Accuracy of malaria rapid diagnostic tests in community studies and their impact on treatment of malaria in an area with declining malaria burden in north-eastern Tanzania. *Malar J*. 2011;10:176.
- Trape J-F, Pison G, Spiegel A, Enel C, Rogier C. Combating malaria in Africa. *Trends Parasitol*. 2002;18:224–30.
- Matthys B, Vounatsou P, Raso G, Tschannen AB, Becket EG, Gosoni L, et al. Urban farming and malaria risk factors in a medium-sized town in Côte d'Ivoire. *Am J Trop Med Hyg*. 2006;75:1223–31.
- Antonio-Nkondjio C, Fossog BT, Ndo C, Djantio BM, Togouet SZ, Awono-Ambene P, et al. *Anopheles gambiae* distribution and insecticide resistance in the cities of Douala and Yaoundé (Cameroon): influence of urban agriculture and pollution. *Malar J*. 2011;10:154.
- Chinery W. Impact of rapid urbanization on mosquitoes and their disease transmission potential in Accra and Tema, Ghana. *Afr J Med Med Sci*. 1995;24:179.
- Matthys B, Koudou B, N'Goran E, Vounatsou P, Gosoni L, Koné M, et al. Spatial dispersion and characterisation of mosquito breeding habitats in urban vegetable-production areas of Abidjan. Côte d'Ivoire *Ann Trop Med Parasit*. 2010;104:649–66.
- Impoinvil DE, Keating J, Mbogo CM, Potts MD, Chowdhury RR, Beier JC. Abundance of immature *Anopheles* and culicines (Diptera: Culicidae) in different water body types in the urban environment of Malindi, Kenya. *J Vector Ecol*. 2008;33:107–16.
- Carter TE, Yared S, Gebresilassie A, Bonnell V, Damodaran L, Lopez K, et al. First detection of *Anopheles stephensi* Liston, 1901 (Diptera: Culicidae) in Ethiopia using molecular and morphological approaches. *Acta Trop*. 2018;188:180–6.
- Takken W, Lindsay S. Increased threat of urban malaria from *Anopheles stephensi* mosquitoes, Africa. *Emerg Infect Dis*. 2019;25:1431–3.
- Antonio-Nkondjio C, Ndo C, Njiokou F, Bigoga JD, Awono-Ambene P, Etang J, et al. Review of malaria situation in Cameroon: technical viewpoint on challenges and prospects for disease elimination. *Parasit Vectors*. 2019;12:501.
- Afrane YA, Klinkenberg E, Drechsel P, Owusu-Daaku K, Garms R, Kruppa T. Does irrigated urban agriculture influence the transmission of malaria in the city of Kumasi, Ghana? *Acta Trop*. 2004;89:125–34.
- Dongus S, Nyika D, Kannady K, Mtasiwa D, Mshinda H, Gosoni L, et al. Urban agriculture and *Anopheles* habitats in Dar es Salaam, Tanzania. *Geospat Health*. 2009;3:189–210.
- Machault V, Gadiaga L, Vignolles C, Jarjaval F, Bouzid S, Sokhna C, et al. Highly focused anopheline breeding sites and malaria transmission in Dakar. *Malar J*. 2009;8:138.
- Massey NC, Garrod G, Wiebe A, Henry AJ, Huang Z, Moyes CL, et al. A global bionomic database for the dominant vectors of human malaria. *Sci Data*. 2016;3:160014.
- Akono PN, Mbida JAM, Tonga C, Belong P, Ngo Hondt OE, Magne GT, et al. Impact of vegetable crop agriculture on anopheline aggressivity and malaria transmission in urban and less urbanized settings of the South region of Cameroon. *Parasit Vectors*. 2015;8:293.

31. Cano J, Berzosa P, Roche J, Rubio J, Moyano E, Guerra-Neira A, et al. Malaria vectors in the Bioko Island (Equatorial Guinea): estimation of vector dynamics and transmission intensities. *J Med Entomol*. 2004;41:158–61.
32. Wang S-J, Lengeler C, Smith TA, Vouunatsou P, Akogbeto M, Tanner M. Rapid urban malaria appraisal (RUMA) IV: epidemiology of urban malaria in Cotonou (Benin). *Malar J*. 2006;5:45.
33. Tatem AJ, Guerra CA, Kabaria CW, Noor AM, Hay SI. Human population, urban settlement patterns and their impact on *Plasmodium falciparum* malaria endemicity. *Malar J*. 2008;7:218.
34. UNPD: United Nations Population Division. World Urbanization Prospects; 2014.
35. Bousema T, Drakeley C, Gesase S, Hashim R, Magesa S, Mosha F, et al. Identification of hot spots of malaria transmission for targeted malaria control. *J Inf Dis*. 2010;201:1764–74.
36. Parnell S, Walawege R. Sub-Saharan African urbanisation and global environmental change. *Glob Environ Change*. 2011;21:S12–20.
37. Djamouko-Djonkam L, Nkahe DL, Kopya E, Talipouo A, Ngadjieu CS, Doumbe-Belisse P, et al. Implication of *Anopheles funestus* in malaria transmission in the city of Yaoundé, Cameroon. *Parasite*. 2020;27:10.
38. Kassahun S, Tiwari A. Urban development in Ethiopia: challenges and policy responses. *J Gov Pub Pol*. 2012;7:59–65.
39. Mourou J-R, Coffinet T, Jarjaval F, Cotteaux C, Pradines E, Godefroy L, et al. Malaria transmission in Libreville: results of a one year survey. *Malar J*. 2012;11:40.
40. Labbo R, Fandeur T, Jeanne I, Czeher C, Williams E, Arzika I, et al. Ecology of urban malaria vectors in Niamey, Republic of Niger. *Malar J*. 2016;15:314.
41. Mourou J-R, Coffinet T, Jarjaval F, Pradines B, Amalvict R, Rogier C, et al. Malaria transmission and insecticide resistance of *Anopheles gambiae* in Libreville and Port-Gentil. *Gabon Malar J*. 2010;9:321.
42. Doderer C, Heschung A, Guntz P, Cazenave J-P, Hansmann Y, Senegas A, et al. A new ELISA kit which uses a combination of *Plasmodium falciparum* extract and recombinant *Plasmodium vivax* antigens as an alternative to IFAT for detection of malaria antibodies. *Malar J*. 2007;6:19.
43. Noedi H, Yingyuen K, Laoboonthai A, Fukuda M, Sirichaisinthop J, Miller RS. Sensitivity and specificity of an antigen detection ELISA for malaria diagnosis. *Am J Trop Med Hyg*. 2006;75:1205–8.
44. Bashir IM, Otsyula N, Awinda G, Spring M, Schneider P, Waitumbi JN. Comparison of Pf HRP-2/p LDH ELISA, qPCR and microscopy for the detection of *Plasmodium* events and prediction of sick visits during a malaria vaccine study. *PLoS ONE*. 2013;8:e56828.
45. Beier JC, Perkins PV, Onyango FK, Gargan TP, Oster CN, Whitmire RE, et al. Characterization of malaria transmission by *Anopheles* (Diptera: Culicidae) in western Kenya in preparation for malaria vaccine trials. *J Med Entomol*. 1990;27:570–7.
46. Fontenille D, Meunier J-Y, Nkondjio CA, Tchuinkam T. Use of circumsporozoite protein enzyme-linked immunosorbent assay compared with microscopic examination of salivary glands for calculation of malaria infectivity rates in mosquitoes (Diptera: Culicidae) from Cameroon. *J Med Entomol*. 2001;38:451–4.
47. Adungo N, Mahadevan S, Mulaya N, Situbi A, Githure J. Comparative determination of *Plasmodium falciparum* sporozoite rates in Afro-tropical *Anopheles* from Kenya by dissection and ELISA. *An Trop Med Parasitol*. 1991;85:387–94.
48. Sokhna CS, Diagne N, Lochouarn L, Rogier C, Trape JF, Spiegel A, et al. Comparative evaluation of the plasmodial infection of *Anopheles* using ELISA and dissection. Consequences for the estimation of the transmission of malaria in 1995 in Ndiop, Senegal (in French). *Parasite*. 1998;5:273–9.
49. Choi L, Pryce J, Richardson M, Lutje V, Walshe D, Garner P. Guidelines for malaria vector control. Geneva: World Health Organization; 2019. p. 1–171.
50. Salako AS, Ahogni I, Kpanou C, Sovi A, Azondekon R, Sominahouin AA, et al. Baseline entomologic data on malaria transmission in prelude to an indoor residual spraying intervention in the regions of Alibori and Donga, Northern Benin, West Africa. *Malar J*. 2018;17:392.
51. Tchuinkam T, Simard F, Lélé-Defo E, Téné-Fossog B, Tateng-Ngouateu A, Antonio-Nkondjio C, et al. Bionomics of Anopheline species and malaria transmission dynamics along an altitudinal transect in Western Cameroon. *BMC Infect Dis*. 2010;10:119.
52. Awono-Ambene PH, Etang J, Antonio-Nkondjio C, Ndo C, Eyisap WE, Piameu MC, et al. The bionomics of the malaria vector *Anopheles rufipes* Gough, 1910 and its susceptibility to deltamethrin insecticide in North Cameroon. *Parasit Vectors*. 2018;11:253.
53. Soma DD, Kassié D, Sanou S, Karama FB, Ouari A, Mamai W, et al. Uneven malaria transmission in geographically distinct districts of Bobo-Dioulasso, Burkina Faso. *Parasit Vectors*. 2018;11:296.
54. Kouassi BL, de Souza DK, Goepogui A, Balde SM, Diakité L, Sagnon A, et al. Low prevalence of *Plasmodium* and absence of malaria transmission in Conakry, Guinea: prospects for elimination. *Malar J*. 2016;15:175.
55. Mwakalinga VM, Sartorius BK, Mlacha YP, Msellemu DF, Limwagu AJ, Mageni ZD, et al. Spatially aggregated clusters and scattered smaller loci of elevated malaria vector density and human infection prevalence in urban Dar es Salaam, Tanzania. *Malar J*. 2016;15:135.
56. Oduola AO, Olojede JB, Oyewole IO, Otubanjo OA, Awolola TS. Abundance and diversity of *Anopheles* species (Diptera: Culicidae) associated with malaria transmission in human dwellings in rural and urban communities in Oyo State, Southwestern Nigeria. *Parasitol Res*. 2013;112:3433–9.
57. Kamdem C, Fouet C, Gamez S, White BJ. Pollutants and insecticides drive local adaptation in African malaria mosquitoes. *Mol Biol Evol*. 2017;34:1261–75.
58. Pombi M, Kengne P, Gimonneau G, Tene-Fossog B, Ayala D, Kamdem C, et al. Dissecting functional components of reproductive isolation among closely related sympatric species of the *Anopheles gambiae* complex. *Evol Appl*. 2017;10:1102–20.
59. Tene BF, Poupardin R, Costantini C, Awono-Ambene P, Wondji CS, Ranson H, et al. Resistance to DDT in an urban setting: common mechanisms implicated in both M and S forms of *Anopheles gambiae* in the city of Yaoundé Cameroon. *PLoS ONE*. 2013;8:e61408.
60. Fossog TB, Ayala D, Acevedo P, Kengne P, Mebuy NAI, Makanga B, et al. Habitat segregation and ecological character displacement in cryptic African malaria mosquitoes. *Evol Appl*. 2015;8:326–45.
61. Wiebe A, Longbottom J, Gleave K, Shearer FM, Sinka ME, Massey NC, et al. Geographical distributions of African malaria vector sibling species and evidence for insecticide resistance. *Malar J*. 2017;16:85.
62. Ganguly KS, Modak S, Chattopadhyay AK, Ganguly KS, Mukherjee TK, Dutta A, et al. Forecasting based on a SARIMA model of urban malaria for Kolkata. *Am J Epidemiol Infect Dis*. 2016;4:22–33.
63. Balkew M, Mumba P, Dengela D, Yohannes G, Getachew D, Yared S, et al. Geographical distribution of *Anopheles stephensi* in eastern Ethiopia. *Parasit Vectors*. 2020;13:1–8.
64. Balkew M, Mumba P, Yohannes G, Abiy E, Getachew D, Yared S, et al. An update on the distribution, bionomics, and insecticide susceptibility of *Anopheles stephensi* in Ethiopia, 2018–2020. *Malar J*. 2021;20:35.
65. Sinka M, Pironon S, Massey N, Longbottom J, Hemingway J, Moyes C, et al. A new malaria vector in Africa: predicting the expansion range of *Anopheles stephensi* and identifying the urban populations at risk. *Proc Natl Acad Sci USA*. 2020;117:24900–8.
66. Afrane YA, Zhou G, Lawson BW, Githeko AK, Yan G. Life-table analysis of *Anopheles arabiensis* in western Kenya highlands: effects of land covers on larval and adult survivorship. *Am J Trop Med Hyg*. 2007;77:660–6.
67. Minakawa N, Dida GO, Sonye GO, Futami K, Njenga SM. Malaria vectors in Lake Victoria and adjacent habitats in western Kenya. *PLoS ONE*. 2012;7:e32725.
68. Adamou A, Dao A, Timbine S, Kassogué Y, Diallo M, Traoré SF, et al. The contribution of aestivating mosquitoes to the persistence of *Anopheles gambiae* in the Sahel. *Malar J*. 2011;10:151.
69. Lyons CL, Coetzee M, Chown SL. Stable and fluctuating temperature effects on the development rate and survival of two malaria vectors, *Anopheles arabiensis* and *Anopheles funestus*. *Parasit Vectors*. 2013;6:104.
70. Lee Y, Meneses CR, Fofana A, Lanzaro GC. Desiccation resistance among subpopulations of *Anopheles gambiae* s.s. from Selinkenyi, Mali. *J Med Entomol*. 2009;46:316–20.
71. Antonio-Nkondjio C, Tene Fossog B, Kopya E, Poumachu Y, Menze Djantio B, Ndo C, et al. Rapid evolution of pyrethroid resistance prevalence in *Anopheles gambiae* populations from the cities of Douala and Yaoundé (Cameroon). *Malar J*. 2015;14:155.
72. Ranson H, N'Guessan R, Lines J, Moiroux N, Nkuni Z, Corbel V. Pyrethroid resistance in African anopheline mosquitoes: what are the implications for malaria control? *Trends Parasitol*. 2011;27:91–8.

73. Ranson H, Lissenden N. Insecticide resistance in African *Anopheles* mosquitoes: a worsening situation that needs urgent action to maintain malaria control. *Trends Parasitol.* 2016;32:187–96.
74. N'guessan R, Boko P, Odjo A, Akogbeto M, Yates A, Rowland M. Chlorfenapyr: a pyrrole insecticide for the control of pyrethroid or DDT resistant *Anopheles gambiae* (Diptera: Culicidae) mosquitoes. *Act Trop.* 2007;102:69–78.
75. Fane M, Cissé O, Traore CSF, Sabatier P. *Anopheles gambiae* resistance to pyrethroid-treated nets in cotton versus rice areas in Mali. *Acta Trop.* 2012;122:1–6.
76. Haji KA, Khatib BO, Smith S, Ali AS, Devine GJ, Coetzee M, et al. Challenges for malaria elimination in Zanzibar: pyrethroid resistance in malaria vectors and poor performance of long-lasting insecticide nets. *Parasit Vectors.* 2013;6:82.
77. Snow RW, Guerra CA, Noor AM, Myint HY, Hay SI. The global distribution of clinical episodes of *Plasmodium falciparum* malaria. *Nature.* 2005;434:214–7.
78. Abraham M, Massebo F, Lindtjörn B. High entomological inoculation rate of malaria vectors in area of high coverage of interventions in southwest Ethiopia: implication for residual malaria transmission. *Parasit Epidemiol Control.* 2017;2:61–9.
79. Le AM. Paludisme côtier lagunaire à Cotonou: données entomologiques. *Sante.* 2000;10:267–75.
80. Adja AM, N'Goran EK, Koudou BG, Dia I, Kengne P, Fontenille D, et al. Contribution of *Anopheles funestus*, *An. gambiae* and *An. nili* (Diptera: Culicidae) to the perennial malaria transmission in the southern and western forest areas of Côte d'Ivoire. *Ann Trop Med Parasit.* 2011;105:13–24.
81. Akono PN, Tonga C, Mbida JM, Hondt ON, Ambene PA, Ndo C, et al. *Anopheles gambiae*, vecteur majeur du paludisme à Logbessou, zone péri-urbaine de Douala (Cameroun). *Bull Soc Pathol Exot.* 2015;108:360–8.
82. Antonio-Nkondjio C, Awono-Ambene P, Toto J-C, Meunier J-Y, Zebaze-Kemleu S, Nyambam R, et al. High malaria transmission intensity in a village close to Yaounde, the capital city of Cameroon. *J Med Entomol.* 2002;39:350–5.
83. Ebenezer A, Noutcha AEM, Okiwelu SN. Relationship of annual entomological inoculation rates to malaria transmission indices, Bayelsa State, Nigeria. *J Vector Borne Dis.* 2016;53:46.
84. Amek N, Bayoh N, Hamel M, Lindblade KA, Gimnig JE, Odhiambo F, et al. Spatial and temporal dynamics of malaria transmission in rural Western Kenya. *Parasit Vectors.* 2012;5:86.
85. Amvongo-Adjia N, Wirsiy EL, Riveron JM, Chounna Ndongmo WP, Enyong PA, Njiokou F, et al. Bionomics and vectorial role of anophelines in wetlands along the volcanic chain of Cameroon. *Parasit Vectors.* 2018;11:471.
86. Appawu M, Owusu-Agyei S, Dadzie S, Asoala V, Anto F, Koram K, et al. Malaria transmission dynamics at a site in northern Ghana proposed for testing malaria vaccines. *Trop Med Int Health.* 2004;9:164–70.
87. Bockarie M, Service M, Barnish G, Maude G, Greenwood B. Malaria in a rural area of Sierra Leone. III. Vector ecology and disease transmission. *Ann Trop Med Parasit.* 1994;88:251–62.
88. Cano J, Descalzo MA, Moreno M, Chen Z, Nzambo S, Bobuakasi L, et al. Spatial variability in the density, distribution and vectorial capacity of anopheline species in a high transmission village (Equatorial Guinea). *Malar J.* 2006;5:21.
89. Robert V, Gazin P, Boudin C, Molez J, Ouedraogo V, Carnevale P. La transmission du paludisme en zone de savane arborée et en zone rizicole des environs de Bobo-Dioulasso (Burkina Faso). *Ann Soc Belg Med Trop.* 1985;65:201–14.
90. Carnevale P, Goff GL, Toto JC, Robert V. *Anopheles nili* as the main vector of human malaria in villages of southern Cameroon. *Med Vet Entomol.* 1992;6:135–8.
91. Coene J. Malaria in urban and rural Kinshasa: the entomological input. *Med Vet Entomol.* 1993;7:127–37.
92. Degefa T, Zeynudin A, Godesso A, Michael YH, Eba K, Zemene E, et al. Malaria incidence and assessment of entomological indices among resettled communities in Ethiopia: a longitudinal study. *Malar J.* 2015;14:24.
93. Diallo S, Konate L, Faye O, Ndir O, Faye M, Gueye A, et al. Malaria in the southern sanitary district of Dakar (Senegal). 2. Entomologic data (in French). *Bull Soc Pathol Exot.* 1998;91:259–63.
94. Diallo S, Konate L, Ndir O, Dieng T, Dieng Y, Bah IB, et al. Le paludisme dans le district sanitaire centre de Dakar (Sénégal). Données entomologiques, parasitologiques et cliniques. *Sante.* 2000;10:221–9.
95. Daygena TY, Massebo F, Lindtjörn B. Variation in species composition and infection rates of *Anopheles* mosquitoes at different altitudinal transects, and the risk of malaria in the highland of Dirashe Woreda, south Ethiopia. *Parasit Vectors.* 2017;10:343.
96. Elissa N, Karch S, Bureau P, Ollomo B, Lawoko M, Yangari P, et al. Malaria transmission in a region of savanna-forest mosaic, Haut-Ogooué, Gabon. *J Am Mosq Control Assoc.* 1999;15:15–23.
97. Epopa PS, Collins CM, North A, Millogo AA, Benedict MQ, Tripet F, et al. Seasonal malaria vector and transmission dynamics in western Burkina Faso. *Malar J.* 2019;18:113.
98. Getachew D, Gebre-Michael T, Balkew M, Tekie H. Species composition, blood meal hosts and *Plasmodium* infection rates of *Anopheles* mosquitoes in Ghibe River Basin, southwestern Ethiopia. *Parasit Vectors.* 2019;12:257.
99. Lwetoijera DW, Harris C, Kiware SS, Dongus S, Devine GJ, McCall PJ, et al. Increasing role of *Anopheles funestus* and *Anopheles arabiensis* in malaria transmission in the Kilombero Valley, Tanzania. *Malar J.* 2014;13:331.
100. Dossou-Yovo J, Doannio J, Riviere F, Chauvancy G. Malaria in Côte d'Ivoire wet savannah region: the entomological input. *Trop Med Parasitol.* 1995;46:263–9.
101. Dossou-Yovo J, Doannio J, Riviere F, Duval J. Rice cultivation and malaria transmission in Bouaké city (Côte d'Ivoire). *Acta Trop.* 1994;57:91–4.
102. Drakeley C, Schellenberg D, Kihonda J, Sousa C, Arez A, Lopes D, et al. An estimation of the entomological inoculation rate for Ifakara: a semi-urban area in a region of intense malaria transmission in Tanzania. *Trop Med Int Health.* 2003;8:767–74.
103. Fontenille D, Lepers JP, Coluzzi M, Campbell GH, Rakotoarivony I, Coulanges P. Malaria transmission and vector biology on Sainte Marie Island, Madagascar. *J Med Entomol.* 1992;29:197–202.
104. Fontenille D, Lochouart L, Diagne N, Sokhna C, Lemasson J-J, Diatta M, et al. High annual and seasonal variations in malaria transmission by anophelines and vector species composition in Dielmo, a holoendemic area in Senegal. *Am J Trop Med Hyg.* 1997;56:247–53.
105. Fontenille D, Lochouart L, Diatta M, Sokhna C, Dia I, Diagne N, et al. Four years' entomological study of the transmission of seasonal malaria in Senegal and the bionomics of *Anopheles gambiae* and *A. arabiensis*. *Trans R Soc Trop Med Hyg.* 1997;91:647–52.
106. Fouque F, Gaborit P, Carinci R, Issaly J, Girod R. Annual variations in the number of malaria cases related to two different patterns of *Anopheles darlingi* transmission potential in the Maroni area of French Guiana. *Malar J.* 2010;9:80.
107. Govoetchan R, Gnanguenon V, Azondékon R, Agossa RF, Sovi A, Oké-Agbo F, et al. Evidence for perennial malaria in rural and urban areas under the Sudanian climate of Kandi, Northeastern Benin. *Parasit Vectors.* 2014;7:79.
108. Hakizimana E, Karema C, Munyakanage D, Githure J, Mazarati JB, Tongren JE, et al. Spatio-temporal distribution of mosquitoes and risk of malaria infection in Rwanda. *Acta Trop.* 2018;182:149–57.
109. Himeidan YE, Elzaki MM, Kweka EJ, Ibrahim M, Elhassan IM. Pattern of malaria transmission along the Rahad River basin, Eastern Sudan. *Parasit Vectors.* 2011;4:109.
110. Karch S, Asidi N, Mnzambi Z, Salaun J. La faune anophélienne et la transmission du paludisme humain à Kinshasa (Zaire). *Commentaire. Bull Soc Pathol Exot.* 1992;85:304–9.
111. Kasasa S, Asoala V, Gosoni L, Anto F, Adjuk M, Tindana C, et al. Spatio-temporal malaria transmission patterns in Navrongo demographic surveillance site, northern Ghana. *Malar J.* 2013;12:63.
112. Kerah-Hinzoombé C, Péka M, Antonio-Nkondjio C, Donan-Gouni I, Awono-Ambene P, Samè-Ekobo A, et al. Malaria vectors and transmission dynamics in Goulmoun, a rural city in south-western Chad. *BMC Infect Dis.* 2009;9:71.

113. Kibret S, Wilson GG, Tekie H, Petros B. Increased malaria transmission around irrigation schemes in Ethiopia and the potential of canal water management for malaria vector control. *Malar J*. 2014;13:360.
114. Krafur E. The bionomics and relative prevalence of *Anopheles* species with respect to the transmission of *Plasmodium* to man in western Ethiopia. *J Med Entomol*. 1977;14:180–94.
115. Lemasson J-J, Fontenille D, Lochouart L, Dia I, Simard F, Ba K, et al. Comparison of behavior and vector efficiency of *Anopheles gambiae* and *An. arabiensis* (Diptera: Culicidae) in Barkedji, a Sahelian area of Senegal. *J Med Entomol*. 1997;34:396–403.
116. Lindsay S, Campbell H, Adiamah J, Greenwood A, Bangali J, Greenwood B. Malaria in a peri-urban area of The Gambia. *Ann Trop Med Parasit*. 1990;84:553–62.
117. Lochouart L, Gazin P. La transmission du paludisme dans la ville de Bobo-Dioulasso (Burkina Fasso). *Ann Soc Belg Med Trop*. 1993;73:287–90.
118. Gadiaga L, Machault V, Pagès F, Gaye A, Jarjaval F, Godefroy L, et al. Conditions of malaria transmission in Dakar from 2007 to 2010. *Malar J*. 2011;10:312.
119. Githeko A, Service M, Mbogo C, Atieli F, Juma F. *Plasmodium falciparum* sporozoite and entomological inoculation rates at the Ahero rice irrigation scheme and the Miwani sugar-belt in western Kenya. *Ann Trop Med Parasit*. 1993;87:379–91.
120. Mala AO, Irungu LW, Shillu JI, Muturi EJ, Mbogo CM, Njagi JK, et al. *Plasmodium falciparum* transmission and aridity: a Kenyan experience from the dry lands of Baringo and its implications for *Anopheles arabiensis* control. *Malar J*. 2011;10:121.
121. Manga L, Robert V, Messi J, Desfontaine M, Carnevale P. Le paludisme urbain à Yaoundé, Cameroun: 1. Etude entomologique dans deux quartiers centraux. *Mem Soc R Belge Entomol*. 1992;35:155–62.
122. Massebo F, Balkew M, Gebre-Michael T, Lindtjorn B. Entomologic inoculation rates of *Anopheles arabiensis* in southwestern Ethiopia. *Am J Trop Med Hyg*. 2013;89:466–73.
123. Mbogo CM, Mwangangi JM, Nzovu J, Gu W, Yan G, Gunter JT, et al. Spatial and temporal heterogeneity of *Anopheles* mosquitoes and *Plasmodium falciparum* transmission along the Kenyan coast. *Am J Trop Med Hyg*. 2003;68:734–42.
124. Mbogo CN, Snow RW, Kabiru EW, Ouma JH, Githure JI, Marsh K, et al. Low-level *Plasmodium falciparum* transmission and the incidence of severe malaria infections on the Kenyan coast. *Am J Trop Med Hyg*. 1993;49:245–53.
125. Mbogo CN, Snow RW, Khamala CP, Kabiru EW, Ouma JH, Githure JI, et al. Relationships between *Plasmodium falciparum* transmission by vector populations and the incidence of severe disease at nine sites on the Kenyan coast. *Am J Trop Med Hyg*. 1995;52:201–6.
126. Mutuku FM, King CH, Mungai P, Mbogo C, Mwangangi J, Muchiri EM, et al. Impact of insecticide-treated bed nets on malaria transmission indices on the south coast of Kenya. *Malar J*. 2011;10:356.
127. Muturi EJ, Muriu S, Shillu J, Mwangangi J, Jacob BG, Mbogo C, et al. Effect of rice cultivation on malaria transmission in Central Kenya. *Am J Trop Med Hyg*. 2008;78:270–5.
128. Mwangangi JM, Muturi EJ, Muriu SM, Nzovu J, Midega JT, Mbogo C. The role of *Anopheles arabiensis* and *Anopheles coustani* in indoor and outdoor malaria transmission in Taveta District, Kenya. *Parasit Vectors*. 2013;6:114.
129. Mwanziva CE, Kitau J, Tungu PK, Mweya CN, Mkali H, Ndege CM, et al. Transmission intensity and malaria vector population structure in Magugu, Babati District in northern Tanzania. *Tanzan J Health Res*. 2011;13:54–61.
130. Ndenga B, Githeko A, Omukunda E, Munyekenye G, Atieli H, Wamai P, et al. Population dynamics of malaria vectors in western Kenya highlands. *J Med Entomol*. 2014;43:200–6.
131. Njan Nloga A, Robert V, Toto J, Carnevale P. *Anopheles moucheti*, vecteur principal du paludisme au sud-Cameroun. *Bull de Liaison et de Documentation OCEAC*. 1993;26:63–7.
132. Okello PE, Van Bortel W, Byaruhanga AM, Correwyn A, Roelants P, Talisuna A, et al. Variation in malaria transmission intensity in seven sites throughout Uganda. *Am J Trop Med Hyg*. 2006;75:219–25.
133. Okwa O, Akinmolayan F, Carter V, Hurd H. Transmission dynamics of malaria in four selected ecological zones of Nigeria in the rainy season. *Ann Afr Med*. 2009;8:1–9.
134. Olayemi I, Ande A, Ayanwale A, Mohammed A, Bello I, Idris B, et al. Seasonal trends in epidemiological and entomological profiles of malaria transmission in North Central Nigeria. *Pak J Biol Sci*. 2011;14:293–9.
135. Overgaard HJ, Reddy VP, Abaga S, Matias A, Reddy MR, Kulkarni V, et al. Malaria transmission after five years of vector control on Bioko Island, Equatorial Guinea. *Parasit Vectors*. 2012;5:253.
136. Owusu-Agyei S, Asante KP, Adjuk M, Adjei G, Awini E, Adams M, et al. Epidemiology of malaria in the forest-savanna transitional zone of Ghana. *Malar J*. 2009;8:220.
137. Richard A, Zoulani A, Lallemand M, Trape J, Carnevale P, Mouchet J. Malaria in the forest region of Mayombe, People's Republic of the Congo. I. Presentation of the region and entomologic data (in French). *Ann Soc Belg Med Trop*. 1988;68:293–303.
138. Robert V, Gazin P, Ouedraogo V, Carnevale P. Le paludisme urbain à Bobo-Dioulasso. 1. Etude entomologique de la transmission. *Cah ORSTOM*. 1986;24:121–8.
139. Robert V, Le Goff G, Toto J, Mulder L, Fondjo E, Manga L, et al. Anthropophilic mosquitoes and malaria transmission at Edea, Cameroon. *Trop Med Parasitol*. 1993;44:14–8.
140. Robert V, Dieng H, Lochouart L, Traore SF, Trape JF, Simondon F, et al. La transmission du paludisme dans la zone de Niakhar, Sénégal. *Trop Med Int Health*. 1998;3:667–77.
141. Rossi P, Belli A, Mancini L, Sabatinelli G. Enquête entomologique longitudinale sur la transmission du paludisme à Ouagadougou (Burkina Faso). *Parasitol*. 1986;28:1–15.
142. Shiff CJ, Minjas J, Hall T, Hunt R, Lyimo S, Davis J. Malaria infection potential of anopheline mosquitoes sampled by light trapping indoors in coastal Tanzanian villages. *Med Vet Entomol*. 1995;9:256–62.
143. Shillu J, Ghebremeskel T, Mengistu S, Fekadu H, Zerom M, Mbogo C, et al. High seasonal variation in entomologic inoculation rates in Eritrea, a semi-arid region of unstable malaria in Africa. *Am J Trop Med Hyg*. 2003;69:607–13.
144. Smith T, Charlwood J, Kihonda J, Mwankusye S, Billingsley P, Meuwissen J, et al. Absence of seasonal variation in malaria parasitaemia in an area of intense seasonal transmission. *Acta Trop*. 1993;54:55–72.
145. Tabue RN, Awono-Ambene P, Etang J, Atangana J, Nkondjio C, Toto JC, et al. Role of *Anopheles* (*Cellia*) *rufipes* (Gough, 1910) and other local anophelines in human malaria transmission in the northern savannah of Cameroon: a cross-sectional survey. *Parasit Vectors*. 2017;10:22.
146. Tanga MC, Ngundu W. Ecological transition from natural forest to tea plantations: effect on the dynamics of malaria vectors in the highlands of Cameroon. *Trans R Soc Trop Med Hyg*. 2010;104:659–68.
147. Tchouassi DP, Quakyi IA, Addison EA, Bosompem KM, Wilson MD, Appawu MA, et al. Characterization of malaria transmission by vector populations for improved interventions during the dry season in the Kpone-on-Sea area of coastal Ghana. *Parasit Vectors*. 2012;5:212.
148. Thompson R, Begtrup K, Cuamba N, Dgedge M, Mendis C, Gamage-Mendis A, et al. The Matola malaria project: a temporal and spatial study of malaria transmission and disease in a suburban area of Maputo, Mozambique. *Am J Trop Med Hyg*. 1997;57:550–9.
149. Trape J-F, Zoulani A. Malaria and urbanization in Central Africa: the example of Brazzaville: part II: results of entomological surveys and epidemiological analysis. *Trans R Soc Trop Med Hyg*. 1987;81:10–8.
150. Trape J-F, Lefebvre-Zante E, Legros F, Ndiaye G, Bouganali H, Druilhe P, et al. Vector density gradients and the epidemiology of urban malaria in Dakar, Senegal. *Am J Trop Med Hyg*. 1992;47:181–9.
151. Verccruysse J, Janclous M. Entomological study on the transmission of human malaria in the urban zone of Pikine, Senegal. *Cah ORSTOM*. 1981;19:165–78.
152. Verccruysse J. Etude entomologique sur la transmission du paludisme humain dans le bassin du fleuve Sénégal (Sénégal). *Ann Soc Belg Med Trop*. 1985;65:171–9.
153. Zogo B, Soma DD, Tchikoi BNC, Somé A, Alou LPA, Koffi AA, et al. *Anopheles* bionomics, insecticide resistance mechanisms, and malaria transmission in the Korhogo area, northern Côte d'Ivoire: a pre-intervention study. *Parasite*. 2019;26:40.
154. Mattah PAD, Futagbi G, Amekudzi LK, Mattah MM, de Souza DK, Kartey-Attipoe WD, et al. Diversity in breeding sites and distribution of *Anopheles* mosquitoes in selected urban areas of southern Ghana. *Parasit Vectors*. 2017;10:25.

155. Fournet F, Cussac M, Ouari A, Meyer P-E, Toé HK, Gouagna L-C, et al. Diversity in anopheline larval habitats and adult composition during the dry and wet seasons in Ouagadougou (Burkina Faso). *Malar J*. 2010;9:78.
156. Ceesay SJ, Bojang KA, Nwakanma D, Conway DJ, Koita OA, Dombia SO, et al. Sahel, savana, riverine and urban malaria in West Africa: similar control policies with different outcomes. *Acta Trop*. 2012;121:166–74.
157. Machault V, Vignolles C, Pagès F, Gadiaga L, Gaye A, Sokhna C, et al. Spatial heterogeneity and temporal evolution of malaria transmission risk in Dakar, Senegal, according to remotely sensed environmental data. *Malar J*. 2010;9:252.
158. Chaki PP, Govella NJ, Shoo B, Hemed A, Tanner M, Fillinger U, et al. Achieving high coverage of larval-stage mosquito surveillance: challenges for a community-based mosquito control programme in urban Dar es Salaam, Tanzania. *Malar J*. 2009;8:311.
159. Castro MC, Kanamori S, Kannady K, Mkude S, Killeen GF, Fillinger U. The importance of drains for the larval development of lymphatic filariasis and malaria vectors in Dar es Salaam, United Republic of Tanzania. *PLoS Negl Trop Dis*. 2010;4:e693.
160. Hawaria D, Demissew A, Kibret S, Lee M-C, Yewhalaw D, Yan G. Effects of environmental modification on the diversity and positivity of anopheline mosquito aquatic habitats at Arjo-Dedessa irrigation development site, Southwest Ethiopia. *Infect Dis Poverty*. 2020;9:9.
161. Kudom AA. Larval ecology of *Anopheles coluzzii* in Cape Coast, Ghana: water quality, nature of habitat and implication for larval control. *Malar J*. 2015;14:447.
162. Adeleke M, Mafiana C, Idowu A, Adekunle M, Sam-Wabo S. Mosquito larval habitats and public health implications in Abeokuta, Ogun State, Nigeria. *Tanzan J Health Res*. 2008;10:103–7.
163. Mathania MM, Munisi DZ, Silayo RS. Spatial and temporal distribution of *Anopheles* mosquito's larvae and its determinants in two urban sites in Tanzania with different malaria transmission levels. *Parasite Epidemiol Control*. 2020;11:00179.
164. Sattler MA, Mtasiwa D, Kiama M, Premji Z, Tanner M, Killeen GF, et al. Habitat characterization and spatial distribution of *Anopheles* sp. mosquito larvae in Dar es Salaam (Tanzania) during an extended dry period. *Malar J*. 2005;4:4.
165. Imbahale SS, Paajmans KP, Mukabana WR, Van Lammeren R, Githeko AK, Takken W. A longitudinal study on *Anopheles* mosquito larval abundance in distinct geographical and environmental settings in western Kenya. *Malar J*. 2011;10:81.
166. Aigbodion F, Uyi O. Temporal distribution of and habitat diversification by some mosquitoes (Diptera: Culicidae) species in Benin City, Nigeria. *J Entomol*. 2013;10:13–20.
167. Djamouko-Djonkam L, Mounchili-Ndam S, Kala-Chouakeu N, Nana-Ndjangwo SM, Kopya E, Sonhafouo-Chiana N, et al. Spatial distribution of *Anopheles gambiae sensu lato* larvae in the urban environment of Yaoundé, Cameroon. *Infect Dis Poverty*. 2019;8:84.
168. Mbida AM, Etang J, Ntonga PA, Moukoko CE, Awono-Ambene P, Tagne D, et al. Nouvel aperçu sur l'écologie larvaire d'*Anopheles coluzzii* Coetzee et Wilkerson, 2013 dans l'estuaire du Wouri, Littoral-Cameroun. *Bull Soc Pathol Exot*. 2017;110:92–101.
169. Etang J, Mbida Mbida A, Ntonga Akono P, Binyang J, Eboumbou Moukoko CE, Lehman LG, et al. *Anopheles coluzzii* larval habitat and insecticide resistance in the island area of Manoka, Cameroon. *BMC Infect Dis*. 2016;16:217.
170. Keating J, Macintyre K, Mbogo CM, Githure JJ, Beier JC. Characterization of potential larval habitats for *Anopheles* mosquitoes in relation to urban land-use in Malindi, Kenya. *Int J Health Geogr*. 2004;3:9.
171. Peterson I, Borrell LN, El-Sadr W, Teklehaimanot A. A temporal-spatial analysis of malaria transmission in Adama, Ethiopia. *Am J Trop Med Hyg*. 2009;81:944–9.
172. Cisse MB, Keita C, Dicko A, Dengela D, Coleman J, Lucas B, et al. Characterizing the insecticide resistance of *Anopheles gambiae* in Mali. *Malar J*. 2015;14:327.
173. Dida GO, Anyona DN, Abuom PO, Akoko D, Adoka SO, Matano A-S, et al. Spatial distribution and habitat characterization of mosquito species during the dry season along the Mara River and its tributaries, in Kenya and Tanzania. *Infect Dis Poverty*. 2018;7:2.
174. Hamza AM, Rayah EAE. A qualitative evidence of the breeding sites of *Anopheles arabiensis* Patton (Diptera: Culicidae) in and around Kassala town, eastern Sudan. *Int J Insect Sci*. 2016;8:65–70.
175. Mireji PO, Keating J, Hassanali A, Mbogo CM, Nyambaka H, Kahindi S, et al. Heavy metals in mosquito larval habitats in urban Kisumu and Malindi, Kenya, and their impact. *Ecotoxicol Environ Saf*. 2008;70:147–53.
176. Himeidan Y, Rayah EEA. Role of some environmental factors on the breeding activity of *Anopheles arabiensis* in New Halfa town, eastern Sudan. *East Medit Health J*. 2008;14:252–9.
177. Impoinvil DE, Keating J, Chowdhury RR, Duncan R, Cardenas G, Ahmad S, et al. The association between distance to water pipes and water bodies positive for anopheline mosquitoes (Diptera: Culicidae) in the urban community of Malindi, Kenya. *J Vect Ecol*. 2007;32:319–27.
178. Mbakop LR, Awono-Ambene PH, Mandeng SE, Ekoko WE, Fesuh BN, Antonio-Nkondjio C, et al. Malaria transmission around the Memve'ele hydroelectric dam in South Cameroon: a combined retrospective and prospective study, 2000–2016. *Int J Environ Res Public Health*. 2019;16:1618.
179. Keating J, Macintyre K, Mbogo C, Githeko A, Regens JL, Swalm C, et al. A geographic sampling strategy for studying relationships between human activity and malaria vectors in urban Africa. *Am J Trop Med Hyg*. 2003;68:357–65.
180. Ekoko WE, Awono-Ambene P, Bigoga J, Mandeng S, Piameu M, Nvondo N, et al. Patterns of anopheline feeding/resting behaviour and *Plasmodium* infections in North Cameroon, 2011–2014: implications for malaria control. *Parasit Vectors*. 2019;12:297.
181. Akogbeto M, Modiano D, Bosman A. Malaria transmission in the lagoon area of Cotonou, Benin. *Parassitologia*. 1992;34:147–54.
182. Antonio-Nkondjio C, Simard F, Awono-Ambene P, Ngassam P, Toto J-C, Tchuinkam T, et al. Malaria vectors and urbanization in the equatorial forest region of south Cameroon. *Trans R Soc Trop Med Hyg*. 2005;99:347–54.
183. Awolola T, Oduola A, Obansa J, Chukwura N, Yinyimadu J. *Anopheles gambiae* s.s. breeding in polluted water bodies in urban Lagos, southwestern Nigeria. *J Vector Borne Dis*. 2007;44:241–4.
184. Omlin FX, Carlson JC, Ogbunugafor CB, Hassanali A. *Anopheles gambiae* exploits the treehole ecosystem in western Kenya: a new urban malaria risk? *Am J Trop Med Hyg*. 2007;77:264–9.
185. Fondjo E, Robert V, Le Goff G, Toto J, Carnevale P. Le paludisme urbain à Yaoundé (Cameroun). II: étude entomologique dans deux quartiers peu urbanisés. *Bull Soc Path Exot*. 1992;85:57–63.
186. Antonio-Nkondjio C, Simard F, Cohuet A, Fontenille D. Morphological variability in the malaria vector, *Anopheles moucheti*, is not indicative of speciation: evidences from sympatric south Cameroon populations. *Infect Genet Evol*. 2002;2:69–72.
187. Molina R, Benito A, Roche J, Blanca F, Amela C, Sanchez A, et al. Baseline entomological data for a pilot malaria control program in Equatorial Guinea. *J Med Entomol*. 1993;30:622–4.
188. Reddy MR, Overgaard HJ, Abaga S, Reddy VP, Caccone A, Kiszewski AE, et al. Outdoor host seeking behaviour of *Anopheles gambiae* mosquitoes following initiation of malaria vector control on Bioko Island, Equatorial Guinea. *Malar J*. 2011;10:184.
189. Bradley J, Lines J, Fuseini G, Schwabe C, Monti F, Slotman M, et al. Outdoor biting by *Anopheles* mosquitoes on Bioko Island does not currently impact on malaria control. *Malar J*. 2015;14:170.
190. Sharp BL, Ridl FC, Govender D, Kuklinski J, Kleinschmidt I. Malaria vector control by indoor residual insecticide spraying on the tropical island of Bioko, Equatorial Guinea. *Malar J*. 2007;6:52.
191. Fuseini G, Nguema RN, Phiri WP, Donfact OT, Cortes C, Von Fricken ME, et al. Increased biting rate of insecticide-resistant culex mosquitoes and community adherence to IRS for malaria control in urban Malabo, Bioko Island, Equatorial Guinea. *J Med Entomol*. 2019;56:1071–7.
192. Kodindo ID, Kana-Mbang A, Moundai T, Fadel AN, Yangalbé-Kalnoné E, Oumar AM, et al. Susceptibility of *Anopheles gambiae* s.l. and *Culex quinquefasciatus* to diverse insecticides in the city of N'Djamena. *Med Sante Trop*. 2018;28:154–7.
193. Witzig C, Parry M, Morgan J, Irving H, Steven A, Cuamba N, et al. Genetic mapping identifies a major locus spanning P450 clusters associated with pyrethroid resistance in *kdr*-free *Anopheles arabiensis* from Chad. *J Hered*. 2013;110:389–97.

194. Ibrahim SS, Fadel AN, Tchouakui M, Terence E, Wondji MJ, Tchoupo M, et al. High insecticide resistance in the major malaria vector *Anopheles coluzzii* in Chad Republic. *Infect Dis Pov*. 2019;8:100.
195. Toto J, Besnard P, Le Mire J, Almeida D, Dos Santos M, Fortes F, et al. [Preliminary evaluation of the insecticide susceptibility in *Anopheles gambiae* and *Culex quinquefasciatus* from Lobito (Angola), using WHO standard assay](in French). *Bull Soc Path Exot*. 2011;104:307–12.
196. Carnevale P, Toto JC, Besnard P, Santos MAD, Fortes F, Allan R, et al. Spatio-temporal variations of *Anopheles coluzzii* and *An. gambiae* and their *Plasmodium* infectivity rates in Lobito, Angola. *J Vector Ecol*. 2015;40:172–9.
197. Calzetta M, Santolamazza F, Carrara GC, Cani PJ, Fortes F, Di Deco MA, et al. Distribution and chromosomal characterization of the *Anopheles gambiae* complex in Angola. *Am J Trop Med Hyg*. 2008;78:169–75.
198. Matubi EM, Bukaka E, Luemba TB, Situakibanza H, Sangaré I, Mesia G, et al. Determination of biological and entomological parameters of *Anopheles gambiae s.l.* in malaria transmission in Bandundu city, Democratic Republic of Congo. *Pan Afr Med J*. 2015;22:108.
199. Watsenga F, Agossa F, Manzambi EZ, Illombe G, Mapangulu T, Muyembe T, et al. Intensity of pyrethroid resistance in *Anopheles gambiae* before and after a mass distribution of insecticide-treated nets in Kinshasa and in 11 provinces of the Democratic Republic of Congo. *Malar J*. 2020;19:169.
200. Riveron JM, Watsenga F, Irving H, Irish SR, Wondji CS. High *Plasmodium* infection rate and reduced bed net efficacy in multiple insecticide-resistant malaria vectors in Kinshasa, Democratic Republic of Congo. *J Infect Dis*. 2018;217:320–8.
201. Karch S, Mouchet J. [*Anopheles paludis*: important vector of malaria in Zaïre](in French). *Bull Soc Path Exot*. 1992;85:388–9.
202. Nardini L, Hunt RH, Dahan-Moss YL, Christie N, Christian RN, Coetzee M, et al. Malaria vectors in the Democratic Republic of the Congo: the mechanisms that confer insecticide resistance in *Anopheles gambiae* and *Anopheles funestus*. *Malar J*. 2017;16:448.
203. Kamgang B, Tchappa W, Ngoagouni C, Sangbakembi-Ngounou C, Wondji M, Riveron JM, et al. Exploring insecticide resistance mechanisms in three major malaria vectors from Bangui in Central African Republic. *Pathog Glob Health*. 2018;112:349–59.
204. Sangba MLO, Sidick A, Govoetchan R, Dide-Agossou C, Ossè RA, Akogbeto M, et al. Evidence of multiple insecticide resistance mechanisms in *Anopheles gambiae* populations in Bangui, Central African Republic. *Parasit Vectors*. 2017;10:23.
205. Sangba MLO, Deketramete T, Wango SP, Kazanji M, Akogbeto M, Ndiath MO. Insecticide resistance status of the *Anopheles funestus* population in Central African Republic: a challenge in the war. *Parasit Vectors*. 2016;9:230.
206. Ndiath MO, Eiglmeier K, Sangba MLO, Holm I, Kazanji M, Vernick KD. Composition and genetics of malaria vector populations in the Central African Republic. *Malar J*. 2016;15:387.
207. Assouho KF, Adja AM, Guindo-Coulibaly N, Tia E, Kouadio AM, Zoh DD, et al. Vectorial transmission of malaria in major districts of Côte d'Ivoire. *J Med Entomol*. 2020;57:908–14.
208. Zoh DD, Alou LPA, Toure M, Pennetier C, Camara S, Traore DF, et al. The current insecticide resistance status of *Anopheles gambiae* (sl) (Culicidae) in rural and urban areas of Bouaké, Côte d'Ivoire. *Parasit Vectors*. 2018;11:118.
209. Traoré DF, Sagna AB, Adja AM, Zoh DD, Adou KA, Lingué KN, et al. Exploring the heterogeneity of human exposure to malaria vectors in an urban setting, Bouaké, Côte d'Ivoire, using an immuno-epidemiological biomarker. *Malar J*. 2019;18:68.
210. Opondo KO, Jawara M, Cham S, Jatta E, Jarju L, Camara M, et al. Status of insecticide resistance in *Anopheles gambiae* (s.l.) of The Gambia. *Parasit Vectors*. 2019;12:287.
211. Pagès F, Texier G, Pradines B, Gadiaga L, Machault V, Jarjaval F, et al. Malaria transmission in Dakar: a two-year survey. *Malar J*. 2008;7:178.
212. Diallo D, Diagne CT, Buenemann M, Ba Y, Dia I, Faye O, et al. Biodiversity pattern of mosquitoes in Southeastern Senegal, epidemiological implication in arbovirus and malaria transmission. *J Med Entomol*. 2019;56:453–63.
213. Coulibaly B, Kone R, Barry MS, Emerson B, Coulibaly MB, Niare O, Beavogui AH, et al. Malaria vector populations across ecological zones in Guinea Conakry and Mali, West Africa. *Malar J*. 2016;15:191.
214. Keita K, Camara D, Barry Y, Osse R, Wang L, Sylla M, et al. Species identification and resistance status of *Anopheles gambiae s.l.* (Diptera: Culicidae) mosquitoes in Guinea. *J Med Entomol*. 2017;54:677–81.
215. Vezenegho S, Brooke B, Hunt R, Coetzee M, Koekemoer L. Malaria vector composition and insecticide susceptibility status in Guinea Conakry. *West Africa Med Vet Entomol*. 2009;23:326–34.
216. Fonseca L, Deco MD, Carrara G, Dabo I, Rosario VD, Petrarca V. *Anopheles gambiae* complex (Diptera: Culicidae) near Bissau City, Guinea Bissau, West Africa. *J Med Entomol*. 1996;33:939–45.
217. Dabire K, Diabaté A, Agostinho F, Alves F, Manga L, Faye O, et al. Distribution of the members of *Anopheles gambiae* and pyrethroid knock-down resistance gene (*kdr*) in Guinea-Bissau, West Africa. *Bull Soc Path Exot*. 2008;101:119–23.
218. Gordicho V, Vicente JL, Sousa CA, Caputo B, Pombi M, Dinis J, et al. First report of an exophilic *Anopheles arabiensis* population in Bissau City, Guinea-Bissau: recent introduction or sampling bias? *Malar J*. 2014;13:423.
219. Sanford MR, Cornel AJ, Nieman CC, Dinis J, Marsden CD, Weakley AM, et al. *Plasmodium falciparum* infection rates for some *Anopheles* spp. from Guinea-Bissau, West Africa. *F1000Res*. 2014;3:243.
220. Silva R, Mavridis K, Vontas J, Rodrigues A, Osório H. Monitoring and molecular profiling of contemporary insecticide resistance status of malaria vectors in Guinea-Bissau. *Acta Trop*. 2020;206:105440.
221. Ouldabdallahi Moukah M, Ba O, Ba H, Ould Khairy ML, Faye O, Bogreau H, et al. Malaria in three epidemiological strata in Mauritania. *Malar J*. 2016;15:204.
222. Lemine MMA, Ould Lemrabort MA, Niang EHA, Basco LK, Bogreau H, Faye O, et al. Pyrethroid resistance in the major malaria vector *Anopheles arabiensis* in Nouakchott, Mauritania. *Parasit Vectors*. 2018;11:344.
223. Diabate A, Baldet T, Chandre F, Akogbeto M, Guiguemde TR, Darriet F, et al. The role of agricultural use of insecticides in resistance to pyrethroids in *Anopheles gambiae s.l.* in Burkina Faso. *Am J Trop Med Hyg*. 2002;67:617–22.
224. Dabiré RK, Namountougou M, Sawadogo SP, Yaro LB, Toé HK, Ouari A, et al. Population dynamics of *Anopheles gambiae s.l.* in Bobo-Dioulasso city: bionomics, infection rate and susceptibility to insecticides. *Parasit Vectors*. 2012;5:127.
225. Jones CM, Toé HK, Sanou A, Namountougou M, Hughes A, Diabaté A, et al. Additional selection for insecticide resistance in urban malaria vectors: DDT resistance in *Anopheles arabiensis* from Bobo-Dioulasso, Burkina Faso. *PLoS ONE*. 2012;7:e45995.
226. Namountougou M, Soma DD, Kientega M, Balboné M, Kaboré DPA, Drabo SF, et al. Insecticide resistance mechanisms in *Anopheles gambiae* complex populations from Burkina Faso, West Africa. *Acta Trop*. 2019;197:105054.
227. Sabatinelli G, Rossi P, Belli A. Dispersion of *Anopheles gambiae s.l.* in an urban zone of Ouagadougou (Burkina Faso). *Parassitologia*. 1986;28:33–9.
228. Pires S, Alves J, Dia I, Gómez LF. Susceptibility of mosquito vectors of the city of Praia, Cabo Verde, to Temephos and *Bacillus thuringiensis* var *israelensis*. *PLoS ONE*. 2020;15:e0234242.
229. Da Cruz DL, Paiva MHS, Guedes DRD, Alves J, Gómez LF, Ayres CFJ. Detection of alleles associated with resistance to chemical insecticide in the malaria vector *Anopheles arabiensis* in Santiago, Cabo Verde. *Malar J*. 2019;18:120.
230. Fahmy N, Villinski J, Bolay F, Stoops C, Tageldin R, Fakoli L, et al. The seasonality and ecology of the *Anopheles gambiae* complex (Diptera: Culicidae) in Liberia using molecular identification. *J Med Entomol*. 2015;52:475–82.
231. Obenauer P, Abdel-Dayem M, Stoops C, Villinski J, Tageldin R, Fahmy N, et al. Field responses of *Anopheles gambiae* complex (Diptera: Culicidae) in Liberia using yeast-generated carbon dioxide and synthetic lure-baited light traps. *J Med Entomol*. 2013;50:863–70.
232. De Souza DK, Koudou BG, Bolay FK, Boakye DA, Bockarie MJ. Filling the gap 115 years after Ronald Ross: the distribution of the *Anopheles coluzzii* and *Anopheles gambiae s.s.* from Freetown and Monrovia, West Africa. *PLoS ONE*. 2013;8:64939.
233. Oyewole I, Awolola T. Impact of urbanisation on bionomics and distribution of malaria vectors in Lagos, southwestern Nigeria. *J Vector Borne Dis*. 2006;43:173–8.

234. Oduola AO, Idowu ET, Oyebola MK, Adeogun AO, Olojede JB, Otubanjo OA, et al. Evidence of carbamate resistance in urban populations of *Anopheles gambiae* s.s. mosquitoes resistant to DDT and deltamethrin insecticides in Lagos, South-Western Nigeria. *Parasit Vectors*. 2012;5:116.
235. Awolola TS, Adeogun A, Olakiigbe AK, Oyeniyi T, Olukosi YA, Okoh H, et al. Pyrethroids resistance intensity and resistance mechanisms in *Anopheles gambiae* from malaria vector surveillance sites in Nigeria. *PLoS ONE*. 2018;13:e0205230.
236. Fagbohun IK, Oyeniyi TA, Idowu TE, Otubanjo OA, Awolola ST. Cytochrome P450 mono-oxygenase and resistance phenotype in DDT and deltamethrin-resistant *Anopheles gambiae* (Diptera: Culicidae) and *Culex quinquefasciatus* in Kosofe, Lagos, Nigeria. *J Med Entomol*. 2019;56:817–21.
237. Klinkenberg E, Takken W, Huijbers F, Toure Y. The phenology of malaria mosquitoes in irrigated rice fields in Mali. *Acta Trop*. 2003;85:71–82.
238. Sogoba N, Vounatsou P, Bagayoko M, Doumbia S, Dolo G, Gosoni L, et al. The spatial distribution of *Anopheles gambiae* sensu stricto and *An. arabiensis* (Diptera: Culicidae) in Mali. *Geospat Health*. 2007;1:213–22.
239. Tandina F, Doumbo O, Yaro AS, Traoré SF, Parola P, Robert V. Mosquitoes (Diptera: Culicidae) and mosquito-borne diseases in Mali, West Africa. *Parasit Vectors*. 2018;11:467.
240. Pwalia R, Joannides J, Iddrisu A, Addae C, Acquah-Baidoo D, Obuobi D, et al. High insecticide resistance intensity of *Anopheles gambiae* (s.l.) and low efficacy of pyrethroid LLINs in Accra, Ghana. *Parasit Vectors*. 2019;12:299.
241. Ahadjji-Dabla KM, Amoudji AD, Nyamador SW, Apétogbo GY, Chabi J, Glitho IA, et al. High levels of knockdown resistance in *Anopheles coluzzii* and *Anopheles gambiae* (Diptera: Culicidae), major malaria vectors in Togo, West Africa: a 2011 monitoring report. *J Med Entomol*. 2019;56:1159–64.
242. Yared S, Gebressielasie A, Damodaran L, Bonnell V, Lopez K, Janies D, et al. Insecticide resistance in *Anopheles stephensi* in Somali Region, eastern Ethiopia. *Malar J*. 2020;19:180.
243. Demissew A, Hawaria D, Kibret S, Anmut A, Tsegaye A, Lee M-C, et al. Impact of sugarcane irrigation on malaria vector *Anopheles* mosquito fauna, abundance and seasonality in Arjo-Didessa, Ethiopia. *Malar J*. 2020;19:344.
244. Seyfarth M, Khaireh BA, Abdi AA, Bouh SM, Faulde MK. Five years following first detection of *Anopheles stephensi* (Diptera: Culicidae) in Djibouti, Horn of Africa: populations established—malaria emerging. *Parasitol Res*. 2019;118:725–32.
245. Faulde MK, Rueda LM, Khaireh BA. First record of the Asian malaria vector *Anopheles stephensi* and its possible role in the resurgence of malaria in Djibouti, Horn of Africa. *Acta Trop*. 2014;139:39–43.
246. Seidahmed O, Abdelmajed M, Mustafa M, Mnzava A. Insecticide susceptibility status of the malaria vector *Anopheles arabiensis* in Khartoum city, Sudan: differences between urban and periurban areas. *East Mediterr Health J*. 2012;18:769–76.
247. Abuelmaali SA, Elaagib AH, Basheer MA, Frah EA, Ahmed FT, Elhaj HF, et al. Impacts of agricultural practices on insecticide resistance in the malaria vector *Anopheles arabiensis* in Khartoum State, Sudan. *PLoS ONE*. 2013;8:e80549.
248. El Sayed BB, Arnot DE, Mukhtar MM, Baraka OZ, Dafalla AA, Elnaiem DEA, et al. A study of the urban malaria transmission problem in Khartoum. *Acta Trop*. 2000;75:163–71.
249. Ismail BA, Kafy HT, Sulieman JE, Subramaniam K, Thomas B, Mnzava A, et al. Temporal and spatial trends in insecticide resistance in *Anopheles arabiensis* in Sudan: outcomes from an evaluation of implications of insecticide resistance for malaria vector control. *Parasit Vectors*. 2018;11:122.
250. Ageep TB, Cox J, Moawia MH, Knols BG, Benedict MQ, Malcolm CA, et al. Spatial and temporal distribution of the malaria mosquito *Anopheles arabiensis* in northern Sudan: influence of environmental factors and implications for vector control. *Malar J*. 2009;8:123.
251. Mlacha YP, Chaki PP, Muhili A, Massue DJ, Tanner M, Majumbar S, et al. Reduced human-biting preferences of the African malaria vectors *Anopheles arabiensis* and *Anopheles gambiae* in an urban context: controlled, competitive host-preference experiments in Tanzania. *Malar J*. 2020;19:418.
252. Mathania MM, Kimera SI, Silayo RS. Knowledge and awareness of malaria and mosquito biting behaviour in selected sites within Morogoro and Dodoma regions Tanzania. *Malar J*. 2016;15:287.
253. Ogola EO, Odero JO, Mwangangi JM, Masiga DK, Tchouassi DP. Population genetics of *Anopheles funestus*, the African malaria vector, Kenya. *Parasit Vectors*. 2019;12:15.
254. Braginets OP, Minakawa N, Mbogo CM, Yan G. Population genetic structure of the African malaria mosquito *Anopheles funestus* in Kenya. *Am J Trop Med Hyg*. 2003;69:303–8.
255. Ogola EO, Fillingier U, Ondiba IM, Villinger J, Masiga DK, Torto B, et al. Insights into malaria transmission among *Anopheles funestus* mosquitoes, Kenya. *Parasit Vectors*. 2018;11:577.
256. Okara RM, Sinka ME, Minakawa N, Mbogo CM, Hay SI, Snow RW. Distribution of the main malaria vectors in Kenya. *Malar J*. 2010;9:69.
257. Hakizimana E, Karema C, Munyakanage D, Iranzi G, Githure J, Tongren JE, et al. Susceptibility of *Anopheles gambiae* to insecticides used for malaria vector control in Rwanda. *Malar J*. 2016;15:582.
258. Protopopoff N, Van Bortel W, Marcotty T, Van Herp M, Maes P, Baza D, et al. Spatial targeted vector control in the highlands of Burundi and its impact on malaria transmission. *Malar J*. 2007;6:158.
259. Musiime AK, Smith DL, Kilama M, Rek J, Arinaitwe E, Nankabirwa JI, et al. Impact of vector control interventions on malaria transmission intensity, outdoor vector biting rates and *Anopheles* mosquito species composition in Tororo, Uganda. *Malar J*. 2019;18:445.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more biomedcentral.com/submissions

