Review

Does malaria epidemiology project Cameroon as 'Africa in miniature'?

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Cameroon, a west-central African country with a ~20 million population, is commonly regarded as 'Africa in miniature' due to the extensive biological and cultural diversities of whole Africa being present in a single-country setting. This country is inhabited by ancestral human lineages in unique eco-climatic conditions and diverse topography. Over 90% Cameroonians are at risk of malaria infection, and ~41% have at least one episode of malaria each year. Historically, the rate of malaria infection in Cameroon has fluctuated over the years; the number of cases was about 2 million in 2010 and 2011. The Cameroonian malaria control programme faces an uphill task due to high prevalence of multidrug-resistant parasites and insecticide-resistant malaria vectors. Above all, continued human migration from the rural to urban areas as well as population exchange with adjoining countries, high rate of ecological instabilities caused by deforestation, poor housing, lack of proper sanitation and drainage system might have resulted in the recent increase in incidences of malaria and other vector-borne diseases in Cameroon. The available data on eco-environmental variability and intricate malaria epidemiology in Cameroon reflect the situation in the whole of Africa, and warrant the need for in-depth study by using modern surveillance tools for meaningful basic understanding of the malaria triangle (host-parasite-vector-environment).

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1. Eco-biogeography of Cameroon: 'Africa in miniature'

Cameroon, located between latitudes 2°N and 13°N, is located between West and Central Africa and is often described as 'Africa in miniature' because of the diverse natural environment spread across the country in its 10 provinces (Wiysonge *et al*. 2005; Efon *et al*. 2013). Typical African deserts, coasts, mountains, rainforests and savannas are all present in Cameroon, and therefore this country is blessed with the greatest biodiversity in Africa (Ndoye and Kaimowitz 2000). Due to this reason, Cameroon is an ecologically rich country, and in fact can be regrouped into 10 major ecological regions classified into four units: (i) the sudano-sahelian zone, which covers the Mandara mountains, plains of the Far North province (Diamare plains, valley of the Logone-Chari) and Benue valley; (ii) the savanna zone, which encompass Adamaoua highland savanna, Tikar plain, Highland plateaus of the West and Northwest provinces, and lowland savanna of the Centre and East provinces; (iii) the coastal zone and (iv) the tropical forest zone, which include

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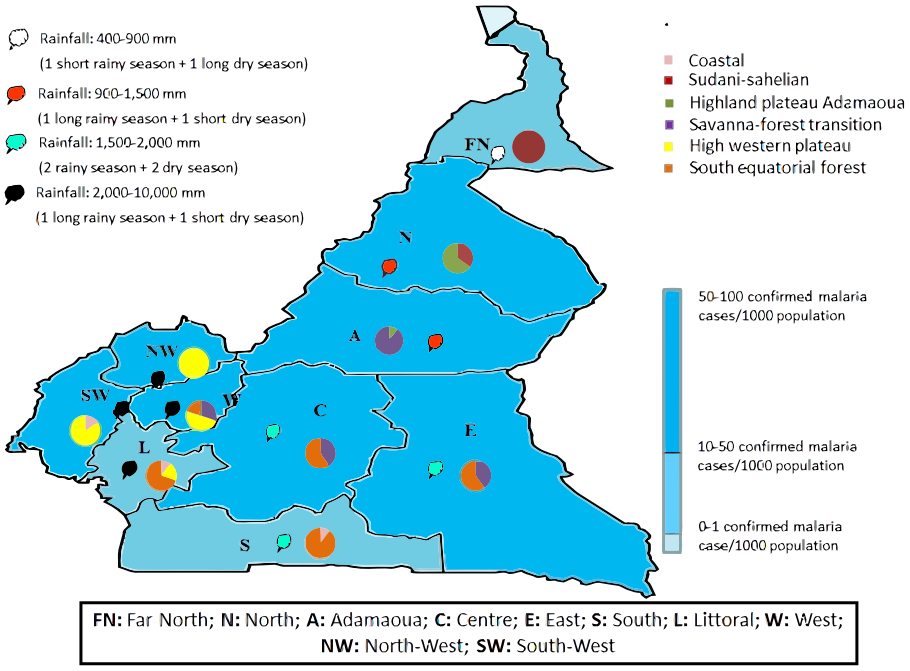

Figure 1. Cameroon eco-climatic facies and malaria epidemiology. **FN:** Far North; **N:** North; **A:** Adamaoua; **C:** centre; **NW:** North-West; **W:** West; **SW:** South-West; **L:** Littoral; **S:** South; **E:** East.

degraded forest of the Centre and Littoral provinces, and tropical rainforest of the Southwest and East provinces (Molua and Cornelius 2006; figure 1), resulting in heterogeneous environmental conditions (Hervy *et al*. 1998; Awono-Ambene *et al*. 2004). Furthermore, Cameroon also houses the highest volcanic (and active) mountain in West Africa, Mont Cameroon. All these topographic conditions together with two main climate types (tropical and equatorial) in Cameroon are associated with variable average annual rainfall, which decreases steadily from the southern to the northern parts of the country. The tropical and equatorial climate types are further subdivided into four sub-types; (i) the Sahelian climate in the Far North (Maroua) characterized by a long dry season (≥7 months) and a short rainy season with the rainfall average between 400 and 900 mm, (ii) the Sudanese tropical climate in the North (Garoua and Ngaoundere) characterized by a short dry season (3–6 months) and a long rainy season with an average rainfall between 900 and 1500 mm, (iii) the equatorial climate in the southern, central and eastern parts characterized by two dry seasons and two rainy seasons with an abundant rainfall (between 1500 and 2000 mm) and (iv) the Cameroonian equatorial climate in the coast and western highlands with a short dry season and a long rainy season with an abundant rainfall (between 2000 and 10000 mm) (Basco *et al*. 2006). However, as in other countries of the globe, continuous human activities, e.g. changing agricultural practices, deforestation, etc., have also resulted in changing the eco-climatic parameters in Cameroon over the years. This is exemplified by the fact that in recent years, 27.5% of forests have been degraded in Cameroon with a deforestation rate of 0.9% per year, representing the highest in Africa (African Development Fund 2009). These man-made climatic changes have not only impacted the biogeographic situations but have also helped in the transmission of both new and existing infectious diseases (see below).

2. Malaria havoc in Africa with special reference to Cameroon

Almost the whole of Africa is highly endemic to malaria infection, and the sub-Saharan Africa remains the most endemic to malaria with the children below 5 years and pregnant women at the highest risk (WHO 2013). This fact is corroborated by the prevalence of about 80% of 207 million clinical episodes of malaria in 2012 in African regions only with about 90% of 627 thousands malaria deaths reported in the whole world (WHO 2013). Despite of the continuous efforts by various malaria control programmes to trim down the incidence of malaria, a very modest breakthrough has been made so far globally. Thus, malaria remains as one of the principal human infectious diseases in Africa (Frech and Chen 2011). Reflecting the situation of whole of Africa, in Cameroon, malaria is the primary cause of morbidity and mortality and is the major cause of illness and mortality particularly in children under 5 years (WHO 2013), and thus, Cameroon is one of the major contributors to the sub-Saharan African malaria incidences. This is because, out of 46 African regions as categorized by the WHO, Cameroon stands 11th in the list of the most malaria-endemic countries.

Furthermore, among all central African countries recorded by WHO for malaria incidence, Cameroon occupies the 3rd position (WHO 2010, 2012, 2013). Compared to the 1990, when the number of malaria cases was less than 1 million, malaria incidence has drastically increased after 2004 to close to 2 millions in 2009, 2010 and 2011 (figure 2). In fact, malaria is responsible for about 48% of hospital admissions, 30% of morbidity and 67% of childhood mortality per year in Cameroon (WHO 2011; Antonio-Nkondjio *et al*. 2013). Recent records from the Cameroon Ministry of Health have indicated the fact that of the 20 million total populations, over 90% are at risk and about 41% have at least one episode of malaria each year (Antonio-Nkondjio *et al*. 2008; Minsante 2008; Ndo *et al*. 2011). Moreover, severe malaria cases (including cerebral and anemic malaria), which are known to be the two major contributors to overall malaria mortality, are frequent in Cameroon (Forlack *et al*. 2005; Dongho *et al*. 2011). Rapid urbanization in recent years with increased population growth in and around Cameroonian cities, accompanied by poor housing, lack of proper sanitation and drainage facilities, frequently lead to flooding during rainy seasons, therefore increasing the mosquito breeding sites and helping in the spread of several vector-borne diseases that include malaria, dengue or chikungunya (Nimpaye *et al*. 2001; Kamgang *et al*. 2010). Changing man-made eco-climatic conditions (see above) coupled with high diversity in malaria vectors species and insecticides-resistant malaria vectors, complex human histories and evolution and spread of drug-resistant malaria parasites (see below) have put greater challenges on malaria management in Cameroon than before.

2.1 *Multiple and insecticide-resistant malaria vectors in Cameroon*

Africa being the major hub of malaria infection in the globe also harbours a large number of (about 20) different species of *Anopheles*, which are vectors for malaria transmission. However, only five species (*Anopheles gambiae, An. arabiensis, An. funestus, An. nili* and *An. moucheti*) are considered as major vectors, as these are responsible for more than 95% of the overall malaria transmission in Africa (Hay *et al*. 2000; Mouchet *et al*. 2004). In Cameroon, out of 48 species of *Anopheles* so far reported (Hervy *et al*. 1998; Ayala *et al*. 2009), at least 14 (*An. gambiae*. s.s., *An. funestus* s.s., *An. moucheti*, *An. arabiensis*, *An. nili*, *An. hancocki*, *An. paludis*, *An. marshalli*, *An. coustani*, *An. wellcomei*, *An. ovengensis*, *An. ziemanni An. pharoensis* and *An. melas)* are known to be capable of transmitting malaria (Fontenille and Simard 2004; PNLP 2007–2010), although three additional species of *Anopheles* as effective malaria vectors (17 species in total) have been suggested (Ayala *et al*. 2009). However, the five major malaria vectors found in Africa are also the most common and efficient ones in Cameroon (Bigoga *et al*. 2012; table 1). Therefore, the distribution of a large number of species of *Anopheles* corresponding to approximately 85% of the total malaria vectors recorded in Africa (17 out of 20 species) itself explains the diversity, complexities and aggressiveness of malaria transmission in Cameroon. The primary cause of abundance of such a large number of *Anopheles* species in Cameroon is often related to variable local environmental factors, such as precipitation and temperature, habitat availability, etc. (Ayala *et al*. 2009; Tanga *et al*. 2010). Furthermore, it is important to note that the most common malaria vector, *An. gambiae sensu stricto* (s.s.), is reported to be resistant to most insecticides across the African continent (Ndjemai *et al*. 2009), possibly due to the presence of knockdown (*kdr*) mutations (Diabate *et al*. 2002; Etang *et al*. 2006). In Cameroon, insecticide-resistance has not only been reported in *An. gambiae*, but also in others species such as *An. arabiensis* (Etang *et al*. 2003). More recent studies have reported a higher prevalence of DDT and Permethrin resistance in Cameroon in recent years in comparison to the past

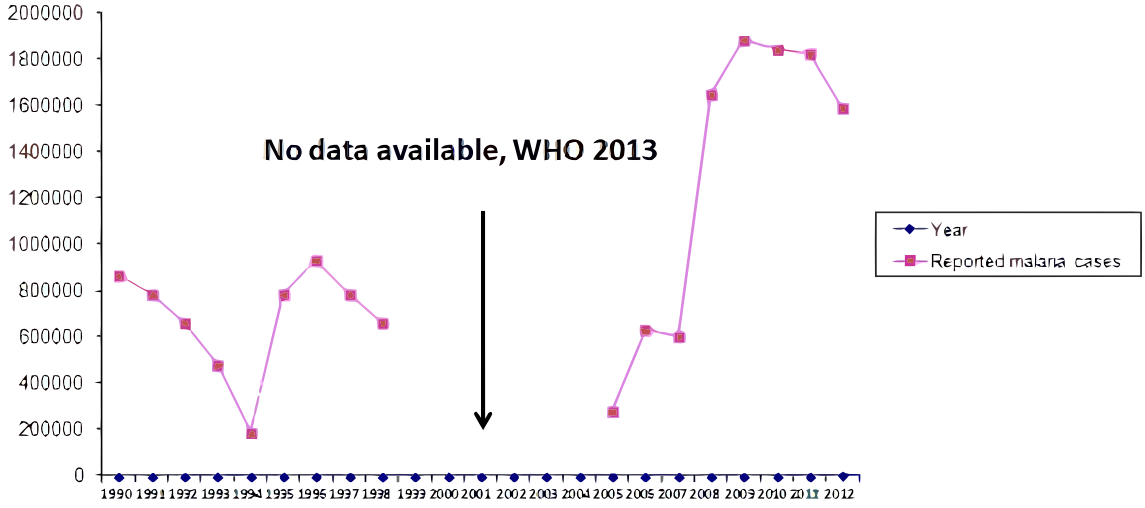

Figure 2. Malaria trend in Cameroon from 1990 to 2012.

Table 1. Distribution of the 5 major malaria vectors in Cameroon

Malaria Vectors	No. of sibling recorded	No. of sibling species in Cameroon	Designation	Ecological distribution
An. gambiae	2	2	M, S	Southern and northern parts
An. funestus	-	-	-	North of Adamaoua
An. Arabiensis	-	-	-	Southern and northern parts
An. Moucheti	-	-	-	Southern part
An. nili	-	-	-	Southern part

-, No sibling recorded, no designation.

M and S: Molecular forms.

(Reimer *et al*. 2008; Nwane *et al*. 2009; Antonio-Nkondjio *et al*. 2011). Surprisingly, *An. gambiae*, known to be highly susceptible to others insecticides (organophosphates and carbamates) in Cameroon has also developed resistance to carbamates (Etang *et al*. 2003; Antonio-Nkondjio *et al*. 2008; Ndjemai *et al*. 2009). Moreover, higher frequencies of the *kdr* mutations have been detected in urban cities (e.g. Douala and Yaounde) than previously reported (Antonio-Nkondjio *et al*. 2011). The probable high rates of migration of mosquito populations (aided either by human migration or by man-made activities) is an eventuality that should not be disregarded as they put additional complexities to movement and successful establishment of favourable alleles causing insecticide resistance in malaria vectors through local adaptation. Whether massive use of insecticides (both spray and by LLINs) have put selection pressure on mosquitoes for evolution of high insecticide-resistant strains in Cameroon is not known, as no such study has ever been conducted to find evolutionary patterns of insecticide-resistant genes. However, it becomes clear that vector control programmes cannot solely rely on the utilization of Insecticides Treated Nets (ITNs).

2.2 *Complexity of malaria infection and drug-resistant Plasmodium falciparum*

Four (*Plasmodium falciparum, P. vivax, P. malariae* and *P. ovale)* of the five species of *Plasmodium* known to infect human are prevalent in Africa as well as in Cameroon (table 2). However, malaria burden due to *P. vivax* (between 1–10%), *P. malariae* (between 2–3%) and *P. ovale* (about 8%) infections are much lesser than *P. falciparum* infection alone (between 80% and 90%) (*http://www.malariasite.com/malaria/MalarialParasite.htm*). Although reports on the existence of a fifth human malaria parasite (*P. knowlesi*) has recently been emerged in Southeast Asia including Andaman Islands of India (Singh *et al*. 2004; Tyagi *et al*. 2013), there is no report yet on its existence in Africa. Historically, Africans are known to be naturally resistant to *P. vivax* malaria infection (the most widespread species in South America and Asia) possibly due to the absence of *Duffy* antigen (Pogo and Chaudhuri 2000; Chittoria *et al*. 2012). However, recent reports from some African countries (e.g. Angola, Equatorial Guinea, Congo, Mauritania, Madagascar, Kenya and Ethiopia) indicate prevalence of *P. vivax* infection in Africans (Ryan *et al*. 2006; Culleton *et al*. 2009; Menard *et al*. 2010; Mendes *et al*. 2011; Wurtz *et al*. 2011; Woldearegai *et al*. 2013). In this concern, initially it was revealed that humans in Cameroon found to be infected with *P. vivax* were in fact of non-African origin (Guerra *et al*. 2010). However, recent studies have demonstrated that native Cameroonians can also be infected with *P. vivax* as in other African countries (Fru-Cho *et al*. 2014; Ngassa and Das 2014). Since the majority of African infected with *P. vivax* have been reported to be *Duffy*-negative, it seems probable that *P. vivax* can infect the *Duffy*-negative Africans by modifying the *Duffy* pathway or this species has

Table 2. Distribution of the principal human malaria parasite species in Cameroon

Ecological facies	*P. falciparum* (%)	*P. malariae* (%)	*P. ovale* (%)
Adamaoua facies	100	0	0
Savannah-forest	93.6–98.7	0–6.4	0–1.3
Transition facies	89.8–100	4.3–8.4	0–1.8
Forest facies	62.0–96.3	0.6–3.0	1.1–35.0
Altitude facies	91.5–96.0	1.7–7.0	0–6.8
Coastal facies	97.7–100	0–0.7	0–2.3

Source: Francis Louis, Armel Reffet, Dominique Louis-Lutinier: Malaria in Cameroon (*http://www.impact-malaria.com*).

found an alternative route to invade human immune system. Furthermore, in Africa, finding of several parasite clones in a single infected individual (multiclonal infections) indicates high rates of genetic recombination in parasites due to cross fertilization (Lekana-Douki *et al*. 2011). Probabilities of many different species of *Anopheles* (see above) biting a single person at a time cannot be entirely ruled out for the occurrence of such multiclonal infections (Read *et al*. 2011). Considering Africa as the homeland to *P. falciparum* (Das *et al*. 2007) and some indirect evidence on the origin of *P. vivax* in Africa (due to fixation of *Duffy*-negative allele in humans as a protective mechanism due to positive natural selection) (Zimmerman *et al*. 1999; Carter and Mendis 2002), mixed parasitic infection and malaria severity can be well justified. A very recent finding on the evidence on the African origin of *P. vivax* (Liu *et al*. 2014) has provided further impetus to understanding malaria epidemiology of Africa in general. Since Cameroon possess all the malaria epidemiological features (multiclonal infections, evidences of *P. vivax* in native Cameroonians, etc.) that are broadly present in other African countries, Cameroon could serve as a model field for understanding malaria epidemiology in African perspectives.

Like the evolution and spread of insecticide-resistant mosquitoes in Cameroon, malaria parasites in Cameroon have long developed resistance to many antimalarials used in malaria control programmes. The most common cases of resistance are found for the antimalarials chloroquine (CQ) and sulfadoxine-pyrimethamine (SP) and, more recently, artemisinin and its derivatives (Sansonetti *et al*. 1985; Ringwald *et al*. 1996; Basco *et al*. 2002a; Basco *et al*. 2002b; Mbacham *et al*. 2009; Figure 3). Although evidences for *P. falciparum* resistant to Artemisinin-Combined-Therapies (ACTs) has been reported in Southeast Asia (Dondorp *et al*. 2009; Phyo *et al*. 2012), there is no published report yet on any African country including Cameroon. In fact, in Africa, chloroquine resistance (CQR) in malaria parasites was first reported in the eastern part (Kenya) in 1978 (Kihamia and Gill 1982; Trape 2001), followed by a progressive dissemination in the whole of African continent. In Cameroon, CQR was noted for the first time in the south-western region, a hyperendemic area, specifically in Limbe in 1985 (Sansonetti *et al*. 1985), and then it has spread all over the 10 provinces very rapidly (Soula *et al*. 2000; Basco *et al*. 2002a), with occurrence of so-far-unreported haplotypes of the *Plasmodium falciparum* chloroquine resistance transporter

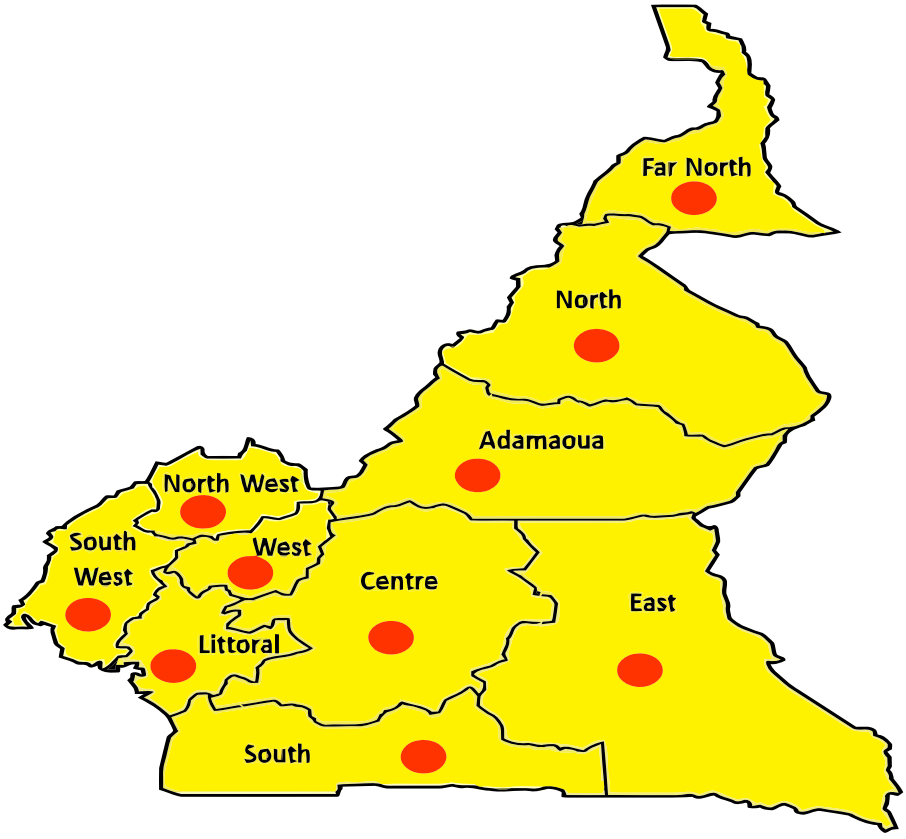

Figure 3. Distribution of chloroquine and sulfadoxine-pyrimethamine resistant *P. falciparum* in Cameroon.

(*pfcrt*) gene that confers high resistance to CQ and amodiaquine (AQ) (Ngassa Mbenda and Das 2014). It is now known from evolutionary genetic studies of the *pfcrt* gene that CQR *P. falciparum* did not originate in Africa but came in mostly from Asia and South America through India (Fidock *et al*. 2000; Awasthi *et al*. 2011, 2012), and a particular *pfcrt*-haplotype (CVIET) is prevalent in almost all of the African countries. In Cameroon, molecular epidemiological studies suggest the association of K76T (lysine amino acid replaced by threonine amino acid at the 76th position) mutation in the *pfcrt* gene with CQR (Basco and Ringwald 1998; Basco *et al*. 2002b; Menard *et al*. 2012). In the face of failure of chloroquine, the Cameroonian Ministry of Public Health had decided to opt for an alternative first-line drug (amodiaquine) with SP as a second-line drug for the treatment of uncomplicated malaria (Basco *et al*. 2002a). Introduced in late 1970s, sulfadoxine-pyrimethamine resistance (SPR) in *P. falciparum* was detected around 1996 in Cameroon. The occurrence of polymorphisms in the *dhfr* (dihydrofolate reductase) gene has been attributed to consumption of sulphadoxine-pyrimethamine as well as some antibiotics containing antifolates (e.g. clotrimazole). The efficiency of monotherapies for the treatment of uncomplicated malaria (chloroquine, mefloquine, etc.) is challenged in Africa due to the ability of the parasite to resist these drugs (Mbacham *et al*. 2009; Menemedengue *et al*. 2011).

2.3 *Complex human histories, migration and host susceptibility*

Several studies on anthropology, archeology, paleontology and molecular genetics have pointed Africa to be the centre of origin of humans (Foley 1998; Raghavan *et al*. 2009). It has been pointed out that human migration in developing countries is generally influenced by urbanization, colonization, trade, agricultural labours and conflicts. All these elements interact with the transmission and epidemiology of some vector-borne diseases (e.g. malaria) (Sutherst 2004). Defined as a social and political disease, malaria transmission and epidemiology can be affected by the migration of human populations as well as the vectors (Garfield 1999). Accordingly, the sub-Saharan Africa is the most rapidly urbanizing continent with the highest rates of *P. falciparum* transmission (Trape *et al*. 1993; Granja *et al*. 1998; United Nations 1999). The flux of Cameroonian populations both within and outside the country is intense, which can be explained by poverty, lack of employment and economic crisis, to name a few (Fleisher 2007). Traditionally, the principal income-generating activities in Cameroon are trade and agriculture. In the migration from Cameroon to Germany, for example, Cameroonian migrants constitute the third largest group after Ghana and Nigeria (Fleisher 2007). Also, Cameroon is one of the African countries having many refugee camps for displaced people coming from Democratic Republic of Congo, Chad, Central African Republic and Sudan, and since 2001, the number of central African refugees inside Cameroon has been increasing (Overview of Displacement in Central African Republic 2011), favouring the movement of parasites among different countries. This also generates chances of evolution of new (virulent and drug-resistant) parasite clones by genetic recombination as well, in association with eco-climatic and environmental factors. These factors both in isolation or in combination possibly have contributed to the spread of drug resistance and increased incidences of malaria morbidity and mortality in Cameroon. This is especially true, as it has been reported in some areas of the country (e.g. Northern Cameroon) that intense population migration was accompanied by an increase in human malaria cases (Antonio-Nkondjio *et al*. 2008). Moreover, it has been shown that international transit of infected people with malaria plays a significant role in the global dispersal of the drug resistance against two most commonly used antimalarial drugs: chloroquine and sulfadoxine-pyrimethamine (Lynch and Roper 2011; Awasthi *et al*. 2012).

Considering malaria is associated with humans since time immemorial, similar to the evolution of resistance in malaria parasites (to antimalarials) and mosquito vectors (to insecticides), humans have also evolved different mechanisms of resistance to malaria parasite infection. In this context, the main scientific evidence comes from the presence of human *Duffy*-negative individuals in Africa, where malaria due to *P. vivax* is very negligible. However, in regions where *P. vivax* malaria is highly endemic, humans are grossly *Duffy*-positive (e.g. India; Chittoria *et al*. 2012). This mechanism is explained by the fact that while the commonly found T nucleotide at the –33rd position of the *Duffy* gene promoter region (Mendis *et al*. 2001) is responsible for the expression of this gene (*Duffy*-positive), the C-mutation at this position dysfunctions the *Duffy* gene (*Duffy*-negative). Because of the C-mutation, the human *Duffy* Antigen Receptor for Chemokines (DARC), which is used by *P. vivax* merozoites to invade the human red blood cells (RBCs) becomes silent, causing blockage of the invasion. However, recent reports have emerged on the capability of *P. vivax* to infect *Duffy*-negative Africans including Cameroonians (Ngassa Mbenda and Das 2014) and on the possible implication of gorillas and chimpanzees in the transmission of *P. vivax* malaria infection in West and Central Africa (Culleton and Ferreira 2012). Cameroon not only belongs to the region where ~95% to 99% of the inhabitants are *Duffy*-negative (Culleton *et al*. 2008), it is also one of the African countries (including those which are borders like Democratic Republic of the Congo, Gabon and Equatorial Guinea) harbouring a great number of gorillas and chimpanzees (Nkemnyi *et al*. 2011; Culleton and Ferreira 2012). This situation points out the fact that the non-human primates might be the reservoir of *P. vivax* malaria (Culleton and Ferreira 2012) and opportunistically infect humans.

3. Malaria control programme in Cameroon: Progresses and challenges

A highly efficient malaria control programme is in place in Cameroon to not only plan for control but also for actually looking after different strategies of malaria intervention. Based on different strategies undertaken, the control programme can be divided into two distinctive phases, during the fifties, i.e. 1954 to1961, and during the eighties. While the focus of the first phase (during the fifties) was mainly on eliminating malaria vectors by spraying of different insecticides (e.g. DDT and Dieldrin), during the eighties, the focus was shifted more towards treatment of malaria by using new antimalarials in the program (Carnevale and Mouchet 2001). During the fifties, spraying of insecticides in human dwellings was conducted by dividing the country into two distinct zones: the south (with the capital Yaounde as the pilot zone with about 1,50,000 habitants) and the north (centralized with the Maroua city with 2,50,000 habitants). The spraying programme started in 1953 became operational in 1956 and was majorly focused on determining the efficacy of the two insecticides, DDT and dieldrin, by dividing the southern part of Cameroon into two parts, while the western part of the Southern Cameroon was sprayed with DDT, the eastern parts received dieldrin. At the same time the northern Cameroon was mostly sprayed with DDT with malaria chemotherapeutic measures (CQ and SP) (Livadas *et al*. 1958; Carnevale and Mouchet 2001). The forested areas of Cameroon were sprayed with dieldrin until 1960, with an exemption for the capital, Yaounde, which was at that period free of *Anopheles.* Spraying of insecticides (DDT and dieldrin) was successful in most of the southern parts of Cameroon with the plasmodic index dropping below 1% (Carnevale and Mouchet 2001). However, during 1956, emergence and spread of dieldrin-resistant malaria vectors in the southern parts of Cameroon surfaced, forcing the programme to stop usage of dieldrin sprays, and instead DDT was only used (Carnevale and Mouchet 2001). For the northern parts of Cameroon, where chemotherapy was also put together with the spray of DDT and dieldrin, after the report of dieldrin-resistant malaria vectors, dieldrin was also removed from the programme in 1961. However, unlike the southern Cameroon, the plasmodic index did not drop below 30% even with malaria chemotherapeutical measures in place with DDT spray in the programme. The difference in efficacy of malaria control measures between the northern and southern Cameroon has been explained by the differences in several ecological parameters (Mouchet *et al*. 1961; Cavalie and Mouchet 1962; Carnevale and Mouchet 2001). Therefore, it has been realized that like other malaria endemic countries in the globe, in Cameroon, no single or even composite methods of malaria intervention measure could be effective in totally controlling malaria (Carnevale and Mouchet 2001). These observations were intensely discussed during the 22nd World Health Assembly held in Boston, USA, in 1969, and it was decided to focus on malaria treatment by chemotherapy (mainly by chloroquine) more deeply than before (OMS 1969; Carnevale and Mouchet 2001). Unfortunately, resistance to chloroquine by *P. falciparum* surfaced in Africa in 1978 and in Cameroon in 1985, forcing the malaria control programme to revisit the combine usage of vector control measures by insecticide-treated bed nets (ITNs) and chemotherapy (majorly by CQ and SP), as followed by Burkina Faso in 1983 (Kihamia and Gill 1982; Sansonetti *et al*. 1985; Desfontaine *et al*. 1988; Desfontaine 1990). The discovery and successful usage of artemisinin combined therapies (ACTs) in other malaria endemic countries of the globe has attracted the malaria control programme of Cameroon to use ACTs as the first-line antimalarial since 2004, in combination with the long-lasting insecticide treated bed nets (LLINs) (Mbacham *et al*. 2005; Minsante 2008).

Table 3. Comparative assessment of different eco-environmental and malaria epidemiological parameters between Cameroon and whole of Africa

Eco-environmental and Epidemiological Factors	Africa	Cameroon
Biodiversity: major climates and vegetation	Desert, coast, mountains, rainforests and savannas	Desert, coast, mountains, rainforests and savannas
Malaria vectors	20 different species	17 different species (~85%)
Major malaria vectors	5 (*Anopheles gambiae, Anopheles arabiensis, Anopheles funestus, Anopheles nili* and *Anopheles moucheti*)	5 (*Anopheles gambiae, Anopheles arabiensis, Anopheles funestus, Anopheles nili* and *Anopheles moucheti*)
Malaria vectors which developed resistance to insecticides	*An. gambiae*; *An. Arabiensis*; *An. funestus*	*An. gambiae*; *An. Arabiensis* (~67%)
Prevalent malaria parasites	*P. falciparum*, *P. vivax P. malariae* and *P. ovale*	*P. falciparum*, *P. malariae*, *P. ovale* and *P. vivax*
Environmental factors influencing malaria epidemiology	Urbanization, deforestation, human migration	Urbanization, deforestation, human migration
Main antimalarial drugs resistance reported	Chloroquine, Sulfadoxine-Pyremethamine,	Chloroquine, Sulfadoxine-Pyremethamine,

It is widely known that the awareness and attitudes of the community in face of malaria are very important aspects for better design and monitoring control strategies. In fact, to curb the burden of malaria across Cameroon, the government has taken additional initiatives since 2003, which include the free distribution of ITNs to pregnant women and children under 5 years, and subsidizing of the cost of ACTs for its use as first-line treatment for uncomplicated malaria cases (Minsante 2008). Furthermore, different training programmes in the community of local health assistants have enabled management of uncomplicated malaria cases and provided adequate advices to families (Minsante 2008). In addition, frequently practiced mass promotion campaigns and advertising through audiovisual networks and newspapers are regular practices in Cameroon (Etang *et al*. 2007). Recent surveys on the awareness, attitudes and home management of malaria cases in two cities, namely Douala and Yaounde, have shown that most Cameroonians have knowledge on malaria transmission and its prevention measures (Ndo *et al*. 2011). Due to this awareness programme, sensitizing mass population and increase of the ownership to ITNs in Cameroon have possibly resulted (Ndo *et al*. 2011). However, this is not enough; there is still need for regular educational campaigns to increase bed net use and to promote environmental sanitation measures in communities. This is because, despite such awareness programmes for malaria prevention, usage of bed nets is still low, possibly due to social, ethnicity, level of education, financial problems, etc., similar to many others African countries (Eisele *et al*. 2009; Atieli *et al*. 2011; Ndo *et al*. 2011). The control measures often are jeopardized by several other factors as well, namely, evolution and spread of insecticide-resistant malaria vectors and drugs-resistant malaria parasites. With conducive environment for high survivability of mosquitoes distributed in Cameroon (as evidenced by large number of *Anopheles* species; see above) and probable exchanges of parasite populations through high incidences of human migration, the malaria control programme in Cameroon faces an uphill task. Practice of self-medication in high numbers (more than 60%) (Ongolo-Zogo and Bonomo 2010) has further complicated the malaria control measure in Cameroon.

4. Conclusion and future prospects

Unquestionably, malaria situations in Cameroon, as in most of African countries, seem to be grim. While Cameroon offers excellent opportunities for malaria infection due to favourable eco-climatic situations for vectors and malaria susceptible humans, additional factors, like presence of insecticide-resistant vectors and drug-resistant parasites, pose further hindrances in malaria control programmes. Despite these obstacles, the malaria control programme in Cameroon has been taking necessary steps to minimize, if not to completely eradicate, malaria in the country. The malaria control programme should ensure strict antimalarial usage following WHO guidelines with less over-the-counter sales of antimalarials and educating the mass (through information-education-communication methods), to follow usage of insecticide-treated bed nets and minimize the vector breeding sites in and around their dwelling places. It is also important to conduct regular surveillance for drug and insecticide resistance and change the drug policies in the country as frequently as possible. Mandatory screening practices for malaria infections in immigrants to Cameroon would also prohibit inflow of different parasite strains (drug-resistant, virulent) to the country. Whatever the cases may be, Cameroon, with the presence of all the above factors favouring malaria and intricate malaria epidemiology, perfectly represents the whole of Africa (table 3). Termed as 'Africa in miniature' for presenting the most eco-climatic and biological diversities among other African countries (Wiysonge *et al*. 2005; Efon *et al*. 2013), for malaria too, Cameroon can serve as a model place for further in-depth research using modern biological tools (e.g. bioinformatics, genomics and next-generation sequencing) for meaningful basic understanding of the malaria triangle (host-parasite-vector-environment). Such basic understanding would provide the necessary platform to devise new control measures in Africa in general and in Cameroon in particular.

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