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Malaria in Urban vs. Rural Settings

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ABSTRACT

Malaria continues to be a leading cause of morbidity and mortality worldwide, claiming over half a million lives annually, with sub-Saharan Africa accounting for the majority of deaths. Despite substantial global progress, differences in malaria transmission between urban and rural settings persist due to ecological, environmental, socioeconomic, and infrastructural disparities. This review examines how urbanization affects malaria epidemiology, vector habitats, insecticide resistance, healthcare infrastructure, and control strategies. In rural areas, malaria transmission is sustained by abundant natural breeding sites, agricultural practices, and limited healthcare access. Conversely, urban malaria is shaped by artificial breeding habitats such as drains and construction sites, high population density, and urban agriculture, which create localized but persistent transmission. Insecticide resistance particularly to pyrethroids, DDT, and organophosphates poses significant threats to control efforts across both settings, driven by continuous pesticide exposure and urban farming practices. Healthcare infrastructure gaps, including limited access to diagnostics and treatment, further exacerbate the burden in rural areas. Innovative control measures, such as larval management, environmental sanitation, repellent distribution, and integration of novel technologies, are essential to counteract resistance and sustain control gains. Future research should emphasize the spatial heterogeneity of transmission, impacts of climate and land-use change, and urban-rural migration dynamics. Strengthening surveillance systems, tailoring interventions to specific ecological and social contexts, and promoting sustainable, community-led strategies are vital steps toward malaria elimination across Africa.

Keywords: Urban and rural malaria, Vector habitats and resistance, Transmission dynamics, Healthcare infrastructure and Malaria control strategies.

INTRODUCTION

Malaria remains the lifeblood of the tropics, with an incidence still exceeding 200 million and about 400 000 fatalities a year, the vast majority of which occur in Africa [1]. The disease is strictly bound to the environment, i.e., Plasmodium parasites barely survive when the thermic threshold of 16°C is not reached, and the mosquitoes, vectors of the disease, are mostly absent when a place is covered by dry, highaltitude vegetation or sealed with asphalt. The large malaria map of sub-Saharan Africa largely reflects typical rural areas, but important patches of medium to high transmission also appear in urban centres [2]. Malaria topics are traditionally studied separately for urban and rural Africa, and very little is known about the patterns forming in between. Malaria is caused by Plasmodium parasites transmitted by the bite of infectious female Anopheles mosquitoes. It remains a major public health concern worldwide, with an estimated 229 million cases and 409 000 related deaths in 2019, especially among children under five and pregnant women in sub-Saharan Africa [7]. The disease manifests through intermittent episodes of chills, fever, and sweating, leading to anaemia and splenomegaly in some cases [5]. Five species of malaria parasites infect humans, with Plasmodium falciparum causing the most severe cases and deaths [4]. Plasmodium species have a complex life cycle involving development in both the Anopheles mosquito and the human host [1]. Transmission occurs when an infected female mosquito attaches, pierces the skin, and sucks blood. After a developmental phase in the mosquito digestive tract, sporozoites migrate to the salivary glands and are injected into the human host during subsequent bites. Inside the liver, the parasites multiply and invade red blood cells, leading to clinical symptoms [2]. The delay between infection and symptom onset varies from 7 to 30 days. Parasite multiplication, destruction of infected red blood cells, and release of merozoites into the bloodstream cause the characteristic fever cycles of malaria [3].

Overview of Malaria

Malaria is a parasitic protozoan disease caused by Plasmodium species, known for causing febrile illnesses such as P. falciparum and P. vivax[5]. It is transmitted from infected to uninfected individuals through the blood-feeding activity of female Anopheles mosquitoes, with P. falciparum and P. vivax constituting the primary agents of human malaria [1]. The parasite undergoes an obligatory life cycle development in the mosquito before becoming infective [3]. Following transmission by an infected mosquito bite, sporozoites enter the human bloodstream and invade liver cells, culminating in the production of replicative merozoites. Merozoites then infect red blood cells, developing into trophozoite forms that multiply and eventually rupture the cells, releasing additional merozoites. Some merozoites differentiate into sexual stage gametocytes, which establish infection in a mosquito after being ingested during blood feeding [3]. Successful development of gametocytes into sporozoites within the vector is necessary to complete the transmission cycle [2].

Epidemiology of Malaria

Malaria has a varying distribution worldwide, dependent on the Anopheles mosquito vector population, human population density, and other factors. It is prevalent across most of Central and South America, Asia, and large portions of Africa [3]. Within these broad regions, the seasonal and geographical distribution of malaria corresponds closely to the dynamics of the vector population [6]. The presence of competent Anopheles mosquito vectors capable of transmitting the Plasmodium parasite is the primary cause of malaria incidence, but the population density of the human host and various socioeconomic factors also significantly affect the epidemiology of the disease [7]. The plasticity of the mosquito vector allows it to adapt to a wide range of climatic and ecological conditions, resulting in great variation in its population dynamics both regionally and seasonally. Consequently, annual incidence of the disease varies, reflecting changes in vector abundance and activity [9]. Socioeconomic reasons lead to a division between rural and urban malaria, with each environment possessing distinct hospitable characteristics for the mosquito vectors and unique disease transmission dynamics [16]. Control measures must thus be adjusted for each setting to effectively address the distinct conditions presented in urban and rural areas [2].

Global Statistics

Malaria causes nearly half a million deaths annually worldwide, with the vast majority of cases and deaths occurring in sub-Saharan Africa (SSA). The World Health Organization (WHO) estimated 216 million cases and 445,000 deaths of malaria in 2016 a substantial increase compared with 2015[4]. Malaria remains endemic across most of SSA, and is the leading cause of death in children under five years of age in Malawi [1]. About 17% of the Malawian population currently lives in urban centres, with the annual urban growth rate of 4%. Ongoing rural-to-urban migration coupled with high population growth rates has resulted in rapid urban expansion within much of SSA. Yet despite the degree of urbanization in the region expected to nearly triple by 2050 [4], the urban malaria situation remains poorly defined [5].

Regional Variations

Malaria is a mosquito-borne infectious disease that has been classified as endemic in 91 countries, with approximately 3.2 billion people at risk of infection [4]. According to the World Health Organization (WHO), 213 million cases of malaria were reported globally in 2018, resulting in 405,000 deaths 3. It is the most serious health problem of the tropics and is responsible for enormous mortality, morbidity, social, and economic disruption throughout the region [12]. Most affected are children aged under 5 years, who account for 61% of all malaria deaths worldwide [11].

Vector Dynamics

In malaria-endemic areas, a diversity of Anopheles species participates in transmission, with varying ecological requirements and feeding habits [7]. Most vector species breed in freshwater, either temporary or permanent waterbodies, and are influenced by environmental factors such as temperature, rainfall, water pH, and salinity [6]. The suitability of breeding habitats is a crucial factor limiting Anopheles colony growth and is a key environmental determinant of malaria transmission [6]. In rural Africa, Anopheles gambiae is the most widespread and efficient malaria vector [10]. Its choice of larval habitats is strongly influenced by rainfall and temperature, and it predominantly breeds in temporary, rain-dependent waterbodies, but also occupies semi-permanent sites [5]. Such larval sites are abundant and scattered. Adult An. gambiae females feed nearly exclusively on human blood in villages, exhibiting high anthropophily[15]. However, both the local abundance and survival of adult vectors usually decrease with increasing distance from larval habitats. Contrasting the rural environment, urban areas are characterized by high human densities, substantially altered landscapes, and modified physical and chemical water properties largely dictated by direct human activities [14]. Frequent disturbances prevent microecological stability, and Anopheles colony development is closely constrained by environmental changes [10]. Mosquito breeding habitats typically emerge from human activities and/or are directly linked to man-made sites [11].

Anopheles Mosquito Species

Five genera of mosquitoes are responsible for the transmission of human diseases: Aedes, Culex, Anopheles, Mansonia, and Haemogogus[10]. Of these, Anopheles mosquitoes specifically transmit malaria. Approximately 400 species of Anopheles mosquitoes have been described worldwide, of which about 30–40 species are significant as malaria vectors [10]. These species belong to the A-Neomyzomyia, B-Myzomyia, and C-Myzorhynchus groups.Anopheles mosquito larvae develop in a wide variety of habitats, often determined by the mosquito species. Typical habitats include swamps, marshes, rice fields, and grassy ditches, borrow pits, reed beds, grassy banks of slow-flowing rivers, slow-flowing well-vegetated irrigation drains, shallow wells, partially shaded pools, small shallow pools, and permanent bodies of water such as lakes, reservoirs, ponds, and river backwaters [13].

Breeding Habitats

Anopheles mosquitoes require humidity and warm temperatures for breeding. Naturally, rivers and streams provide these conditions when they become slow-flowing or stagnant, such as existence of pools or wetlands alongside the rivers [7]. These specific breeding sites exist in both urban and rural environments. However, in urban areas, breeding is often associated with domestic water storage containers, construction sites, disused tyres, wells, and drains. Breeding sites within or close to a human settlement (<3 km) can result in persistent malaria transmission [8]. The availability of the various mosquito breeding habitats that exist in rural and urban environments results in marked differences in the epidemiology of malaria [8]. In rural areas, the infection rate shows seasonal variations related to the abundance or otherwise of these sites [1]. In contrast, urban malaria transmission is characterized as being sporadic and focalized, related to the situs of the vector habitats [11].

Urban Malaria

The urban environment consists mainly of built-up landscapes: roads, buildings, sidewalks, and bridges. Services such as sewer and drainage systems, utilities, and public transit often facilitate storm-water drainage and reduce the size of mosquito breeding sites; however, malfunctions in these systems may be sources of standing water, providing potential habitats [5]. Transportation corridors often contribute to flooding during heavy rains and exacerbate the incidence of urban malaria By their very nature, cities usually have denser populations than rural areas [9]. With regard to vector–human contact, increasing population density produces higher human biting rates and disease incidence unless the vector population density decreases proportionately [8]. Urban centres usually also attract a highly migratory population seeking employment, education, and other opportunities. Because people come to the city from surrounding communities as well as more distant places, cities carry increased infection importation potential [7]. Although transmission intensity is lower overall in urban centres than in rural areas, malaria can still exhibit stable transmission patterns [8]. Urban populations do not appear to have the same degree of immunity as their rural counterparts, nor, in many cases, do their working and living conditions put them in regular contact with malaria vectors [9]. The transmission of disease in cities can also vary from year to year as a result of changing environmental conditions or urban development patterns. In addition, low-level transmission in the city, in conjunction with the proximity of the peri-urban and surrounding rural areas where transmission is more intense, can be a significant contributor to the urban disease burden because of the large populations involved[6, 9].

Characteristics of Urban Environments

Although more than three-quarters of sub-Saharan Africans currently live in rural settings, rapid rates of population movement from rural to urban areas are resulting in more frequent introductions of malaria parasites into cities [1]. Urban environments tend to be characterized by irregular or intermittent water supplies, packed housing, open water containers and open/blocked drains, and intermittent garbage collection, all of which can serve as potential sites for vector breeding [4]. Malaria transmission tends to be less intense in urban areas than in surrounding rural settings [3]. Within cities, however, transmission becomes localized and heterogeneous, and may persist where locally elevated vector breeding occurs in association with particular ecological features and environmental management patterns [11].

Transmission Patterns in Cities

Urban environments differ distinctly from rural settings, which impacts malaria epidemiology and control. Urbanization is generally associated with decreased transmission due to higher population density, improved infrastructure, and altered vector ecology [4]. Cities typically exhibit focal transmission, often limited to the urban fringes or areas proximate to suitable breeding sites [5]. Transmission dynamics are influenced by heterogeneous urban structure, land cover, and microclimatic conditions [7]. Urban agriculture may intensify transmission in urban and peri-urban areas. Additionally, the predominant vectors and their relative importance vary according to species-specific capacities to exploit urban habitats [8].

Control Measures in Urban Areas

Malaria control is centered on prevention and treatment. Urban malaria prevention focuses primarily on cutting down mosquito populations [11]. Insecticide-treated nets (ITNs) are widely used in urban areas and have been shown to offer protection against malaria [14]. Indoor residual spraying (IRS), which entails applying long-lasting insecticides to the interiors of all homes at least twice a year, is also highly recommended [2]. Managing aquatic habitats where Anopheles mosquitoes breed such as pools, drains, and ponds through modification or drainage has proven effective. Larvivorous fish contribute to biological control [4]. In malaria risk zones, preventive medications like chemoprophylaxis are advised. In cases of illness, early diagnosis and treatment with antimalarial drugs are critical: uncomplicated malaria is treated with oral medications, while severe cases necessitate parenteral therapy [5]. Insecticide resistance poses a growing challenge for vector control. Continual monitoring is essential to select the most effective insecticides for urban mosquitoes, considering species composition and seasonal and spatial variations [6]. Furthermore, the cost and limited availability of healthcare services in some urban slums can impede the control of infections and outbreaks [13]. Although urban environments have abundant healthcare facilities, their accessibility and affordability vary, especially in impoverished areas [15].

Rural Malaria

Malaria is a mosquito-borne infectious disease caused by protozoan parasites of the genus Plasmodium. It still remains a major public health problem with around 40% of the world's population at risk of acquiring the disease [3]. Plasmodium falciparum is the dangerous form of parasites mostly present in sub-Saharan African region responsible for the maximum number of deaths due to malaria [6]. High ambient temperature, relative humidity and rainfall are the important factors which support the rapid growth and transmission of parasite [8]. Malaria is a leading cause of deaths in children below the age of 5 years in Africa, accounting for approximately 429,000 deaths in 2015. The malaria parasites' life cycle starts when a female Anopheles mosquito carrying the infectious stage of the parasite ("sporozoites") injects these into the human bloodstream [11]. The sporozoites need to reach the liver before they can infect the host. In the hepatocytes, sporozoites multiply and mature, producing thousands of merozoites (Figure 2). Sporogony within the mosquito takes 8 to 35 days, depending on temperature and the Plasmodium species [14]. Parasite development is optimal in Anopheles around 25 °C and does not develop below 16 °C or above 35 °C. Parasite development is faster within an appropriate temperature range, causing a shorter sporogonic cycle[16].

Characteristics of Rural Environments

Rural environments are typically characterized by lower population density and peripheral locations in relation to urban centres [8]. Such environments are often marked by limited or poorly maintained infrastructure [4]. The living spaces of rural communities are frequently situated in close proximity to natural landscapes such as forests, savannahs, swamps, or agricultural areas [7]. Access to healthcare services in these regions is often constrained, and control activities targeting vector-borne diseases like malaria may be minimal or nonexistent. Nonetheless, rural environments tend to offer a more equitable distribution of resources and opportunities than their urban counterparts; while poverty is a concern; its manifestations commonly differ from the severe deprivation experienced in many urban settings [1]. Malaria transmission in rural areas predominantly arises from vector populations inhabiting natural environments [3]. These mosquitoes have greater opportunities to exploit a broad spectrum of accessible water bodies [7]. Although the sheer number of available breeding sites might surpass those in urban zones, the density of vectors per site is generally lower than in cities [5]. Contrary to urban areas, where transmission patterns often exhibit seasonality, rural settings frequently experience perennial malaria transmission, underscoring a fundamental contrast in epidemiological dynamics [8].

Transmission Patterns in Rural Areas

Malaria, an extremely adaptable parasitic disease transmitted by mosquitoes, remains a leading cause of economic loss and trauma throughout the tropics and subtropics [4]. Because the disease is transmitted via contact with infective female mosquitoes of the genus Anopheles, key differences exist between rural and urban settings that have a profound impact on malaria epidemiology [5]. Malaria parasites require a vertebrate and an invertebrate host, with sporozoites being injected into a human host during a blood meal [6]. The life cycle includes an asexual cycle in hepatocytes lasting 6-10 days, trophozoite growth in erythrocytes accompanied by fever and chills, and development of sexual stages taken up by mosquitoes [1]. In rural areas, the environment typically comprises widely dispersed housing with shrubs, forests, or cultivated land surrounding villages. Housing quality is often low with mud walls and thatched roofs [2]. Transmission is both peridomestic and outdoor due to domestic animal presence and farming activities continued after dusk [4]. Plasmodium falciparum often dominates in such stable malaria environments. Control strategies focus on insecticide-treated nets and chemoprophylaxis [3].

Control Measures in Rural Settings

The growth of rural populations has encouraged the continuation of subsistence farming and subsistence fishing, which involve activities such as irrigating, draining, swamp reclamation and fish farming [6]. These practices have increased the abundance of water collections suitable for mosquito breeding [2]. Transmission is also frequently facilitated by travel from high-risk to low-risk areas [5]. A wide range of community-based programmes are normally applied to contain and prevent malaria transmission in rural areas: the use of insecticide treated nets (ITNs); prophylactic chemotherapeutic interventions in infants and children under five; and intermittent preventive treatment in pregnant women [5]. However, the implementation and effectiveness of the control programmes are often hampered by the presence of large tracts of wetlands, poor drainage, limited network of motorable roads, stretched healthcare delivery systems, limited real-time information for decision making, and occasional flooding [7].

Socioeconomic Factors

Malaria risk is generally greater among the poorest because they usually have fewer resources to avoid mosquito bites or to effectively treat malaria [6]. Health outcomes are therefore often related to the average wealth in a geographical setting [7]. Primary control measures typically entail the use of long-lasting insecticide nets (LLINs) and better treatment options [6]. In some countries, urban populations may have better access to malaria treatment. Consequently, malaria burden distribution frequently reflects parasite exposure, and in high-endemicity settings is thus greater in rural than in urban settings [7].

Impact of Poverty

The burden of malaria mirrors the overall pattern of burden of poverty, rising to very high levels during the 1990s in economically distressed countries and declining in more stable countries [8] For example, the world's most economic stagnant countries carry more than 25 percent of the world's malaria burden [8]. Malaria disproportionately afflicts the poor, and it restrains economic growth. Poverty serves as both a cause and a consequence of malaria [15]. Although transmission increases during deforestation, agricultural development and development of urban environments, it is the breakdown of public infrastructures that leads to intense transmission of the disease [8]. The presence of slums and the inability to deliver services such as piped water and sewerage, including drainage, electricity and garbage collection, exacerbate the situation. Such conditions increase the vulnerability of the urban poor to malaria and other mosquito transmitted diseases [8]. Differential access to healthcare, the rate of treatment and drug compliance differ substantially between urban poor and urban wealthy and between urban and rural dwellers. These factors determine, in part, the levels of malaria experienced in each area [7].

Access to Healthcare

Physical access to, and financial barriers for, health-care services are important impediments in the search for prompt and effective treatment of malaria, particularly in remote rural areas [8]. As access to curative services improves, the success of initiatives designed to encourage the use of early and appropriate treatments will increase. In general, urban communities have better access to public and private health facilities and a wider range of formal and informal treatment sources than rural communities [9] Malaria and pneumonia are among the main killers of children under five years of age in low-income countries[9]. The World Health Organization recommends the use of community health workers for the management of malaria and pneumonia through community case management. The availability of alternative sources of quality care and medicines in nearby health facilities influences care-seeking patterns, which differ between urban and rural areas [8]. Underlying socioeconomic differences between rural and urban areas further affect behavior towards febrile illnesses [8]. Few studies have evaluated differences in the use of community health workers between urban and rural areas [7]. Assessing who benefits from these programmes and how community health workers are integrated with other healthcare providers is therefore important [7].

Public Health Interventions

In both urban and rural settings, basic preventive measures such as reducing the breeding grounds of malaria vectors, as well as avoiding mosquito bites, must be applied to limit malaria transmission [7]. Malaria control in rural areas includes spraying insecticides, destroying the breeding grounds of the Anopheles mosquitoes, draining stagnant water areas, and avoiding dense vegetation near homes [6]. High population density in urban settings facilitates the spread of malaria, but control is easier because of the nonexistence of malaria vectors in these areas and the availability of medical facilities [3]. In rural areas, these two conditions are reversed, and both contribute to the persistence of the malaria hazard [2]. One of the most important elements of maintaining and controlling the malaria hazard is early diagnosis and treatment [7]. In urban areas, this element is provided by the availability of clinics and hospital services [3]. In rural areas where these services are poorly provided, the malaria hazard remains a constant threat to the health of the people [5]. Several forms of treatment are used during the attack of malaria [3]. The injection of antimalarial drugs by professional health workers remains the best method in both rural and urban areas, as it leads to an immediate accomplishment of complete cure [4]. Because some patients cannot afford to go to the hospital and clinics for treatment, and injections are expensive, oral tablets and malaria herbs are widely used in rural areas for treating malaria [3].

Preventive Measures

Preventive measures form the cornerstone of malaria control in both urban and rural settings [13]. Key strategies include insecticide-treated bed nets (ITNs), indoor residual spraying (IRS), and environmental management techniques that eliminate mosquito breeding sites [7]. Prompt diagnosis and effective antimalarial treatment are essential components of these efforts [10]. Urban areas generally offer better access to effective treatment and experience higher coverage of preventive interventions [11]. Nonetheless, the informal urban settlements where a large proportion of the urban populations reside often lack adequate housing and sufficient access to health services and control measures [1]. In rural settings, the majority of the population still has limited access to health facilities [1]. Socioeconomic status strongly influences the uptake of preventive measures such as IRS and ITNs in both contexts [4].

Treatment Protocols

Current practices for malaria treatment include pursuit of adequate, affordable, and reasonably safe treatment; control of mosquito populations; and avoidance of mosquito bites [8]. Urban malaria prevention and community management of childhood fever in Kampala are discussed separately, and P. falciparum diversity in urban and rural Burkina Faso is examined later. Preventive measures widely used in Kampala include intermittent preventative treatment (IPT) during pregnancy and bed nets [7]. Among a study population, any IPT use was less common than previously reported for urban Ugandan populations, even after the 2002 implementation of the national IPT program[9]. Wealth did not predict prevention measure use during pregnancy; year of pregnancy was the strongest predictor of bed net use, and higher education level predicted IPT use. Prompt treatment of malaria with effective anti-malarials is key for malaria control [10]. Private vendors are an initial source of care for childhood fever, with over half of febrile episodes initially treated with drugs bought at shops or pharmacies. Only 32% of anti-malarial treatments for initial fever management were considered adequate [10]. Although CQ + SP was adopted as the first-line therapy in 2002, it accounted for only 13% of treatments [12]. Chloroquine remained the most commonly used drug, comprising 54% of treatments; combination regimens other than CQ + SP were rarely used. Prompt treatment within 24 hours of fever onset occurred in only 15% of episodes. Caregivers were no more likely to seek prompt treatment outside the formal health sector than at clinics or hospitals. The evidence for the impact of time to treatment within 24 hours on disease outcome is limited [11].

Role of Climate Change

Malaria is a disease caused by Plasmodium parasites, with an estimated 290 million infections and 435,000 deaths worldwide in 2017[8]. Climate change is expected to have widespread impacts on malaria transmission and vector habitats, but the consequences differ markedly between locations and delivery scenarios [12]. Even warmer futures will extend the malaria transmission season in some highland and temperate locations, while in others the transmission season will shorten [1]. Adaptation of control programmes to these new environments is therefore crucial.

Effects on Vector Habitats

Malaria kills over half a million people annually, predominantly in sub-Saharan Africa, where a majority resides in rural locations [5]. Anopheles mosquitoes breed and survive in diverse conditions. In rural Africa, larvae favour sunlit tropical and subtropical lowlands [6]. Urbanization drastically alters tropical ecosystems, influencing vector population composition as evidenced by an adapted species collection [7]. Global demands for food and economic development pressure traditional agricultural areas, rendering urban agriculture a critical income source for African urban populations and generating additional larval habitats [4].

Impact on Transmission Dynamics

Both urban and rural settings contribute to substantial malaria transmission, but difficulties in distinguishing the relative contributions of each complicate the assessment of their specific impacts [7]. The effects of land-use change, including the expansion of urban areas and increased urban agriculture, remain poorly understood and partially considered in global assessments [4]. Land-use change introduces complex modifications to mosquito populations, exerting spatially specific impacts; local-scale investigations are required to characterize these effects accurately [5]. The rapid urban transformation of the developing world has profoundly influenced the malaria landscape [8]. Higher population densities and lower mosquito-to-human ratios in urban areas reduce the likelihood of malaria transmission, leading to distinct parasite prevalence. A synthesis of available information on Plasmodium vivax malaria transmission indicates consistently lower transmission within urban areas relative to rural counterparts [5, 4].

Case Studies

Case studies support the contrasting patterns of urban and rural malaria transmission described above. Malaria prevalence often varies between urban and rural sites and within urban centers [3, 6]. Higher prevalence in rural sites suggests that transmission is sustained largely by vectors breeding in natural habitats such as streams, ditches or leafy pools and anopheline densities are higher in rural than urban sites where An. funestus dominates. Further examples illustrate that proximity to open water or malaria clusters is often a predictor of urban malaria risk and spatial and temporal variations in anopheline abundance [9, 8]. However, an urban setting does not invariably result in reduced transmission or lower risk of infection, as moderate to high transmission has been reported from cities such as Blantyre, Dar Es Salaam, Daresalaam, Ouagadougou and Yaoundé. Although An. gambiae s.l./An. funestus densities in urban areas are frequently lower than in nearby rural or peri-urban sites, the efficiency with which these vectors exploit even diminished breeding opportunities, in combination with many people who remain non-immune and therefore highly susceptible to infection, maintains the potential for localized transmission within cities [13, 11].

Urban Case Study

Malaria is a vector-borne infectious disease that predominately affects rural populations but also occurs in an urban context [1]. The relatively few mosquitoes found in urban environments can still sustain malaria transmission, and there is evidence of transmission among urban residents who lack recent travel history to rural areas [15]. The urban landscape alone does not determine transmission dynamics; other factors, including socio-economic status, infrastructure quality, human behavior, and the presence of malaria vectors, contribute to the urban malaria epidemiological profile [13].

Rural Case Study

Rural malaria transmission differs substantially from urban malaria [1]. Most rural African settings are characterized by extensive agriculture and relatively low human population densities [14]. These conditions are typically associated with intense malaria transmission, characterized by high entomological inoculation rates; extensive all-age morbidity and mortality; and often correspondingly low availability of effective case management and control interventions [16]. Thus, rural context can be associated with very high levels of malaria, as is the case at the site in rural Apac District, Uganda. By contrast, most urban settings are densely populated, typically with limited space for agriculture [15]. Under these conditions, malaria transmission tends to be of low intensity, characterized by low entomological inoculation rates; low overall population prevalence and incidence; marked heterogeneity across time and at small spatial scales; and patterns of morbidity and mortality skewed towards children and non-immune migrants [12]. Urban context is therefore typically associated with much lower levels of malaria compared with rural areas, as exemplified by the site in the urban centre of Kampala, Uganda [10].

Challenges in Malaria Control

Insecticide resistance constitutes a principal threat to the effectiveness of the front-line class of insecticides targeting malaria vectors [15]. Because of continued reliance on pyrethroids for control, resistance at various levels has been detected across the African continent and a much broader investigation documenting resistance across a wide range of insecticides and African settings is upon completion [16]. Other important limiting factors for insecticide-based interventions are related to access and uptake, indicated by the high levels of malaria in some African settings with good coverage of insecticide-based protection [16]. The physical durability and effective lifetime of insecticidal material such as bed nets or indoor residual spraying formulations also constrain the overall impact of these approaches [12]

Resistance to Insecticides

Insecticide resistance poses significant challenges to malaria control in both urban and rural settings [11]. High levels of resistance to pyrethroids and DDT have been reported, with the frequency of the kdr 1014F mutation often exceeding 80% in urban environments [14]. Such resistance patterns constrain the effectiveness of interventions based on insecticide-treated nets and indoor spraying [15]. Among urban populations of Anopheles arabiensis, the kdr 1014S mutation commonly occurs at frequencies above 40%, surpassing the values observed in nearby rural areas [11]. While the 1014S allele is detected at low frequencies in several African countries, including Burkina Faso and Ghana, its occurrence remains limited within the An. arabiensis species complex [13].

Quantitative assays suggest that 1014S confers a greater degree of resistance to DDT compared to the 1014F variant, although the latter imparts stronger protection against pyrethroids [9]. Certain urban farming practices also accelerate insecticide selection pressures, thereby increasing resistance frequencies among the principal urban malaria vectors [13].

Healthcare Infrastructure

Malaria interventions are vulnerable to insecticide resistance [5]. Pyrethroids provide the only option for treating net surfaces [2]. Resistance to pyrethroids is widespread and increasing in intensity, while organophosphate resistance is now emerging in Africa. DDT resistance remains common in many vectors but is decreasing in some areas, and dichlorodiphenyltrichloroethane (organophosphate) resistance remains patchy, although the latter presents a complicated picture [5]. Highly resistant populations of Anopheles funestus have recently been identified in southern Malawi, where organochlorines have never been used [1]. Resistance to carbamates is associated with reduced IRS capacity in West Africa [7]. Manufacture and distribution of IRS products based on micro-encapsulation of pirimiphos-methyl have improved the persistence of organophosphate-based insecticides, potentially decreasing the risk of resistance development [7]. Malaria surveillance and alert strategies urgently need to be strengthened in response to these evolving challenges [6]. The World Health Organization (WHO) estimates that only 34% of rural and 38% of urban health facilities in sub-Saharan Africa can provide malaria diagnosis, while 40% (rural) and 38% (urban) are unable to administer artemisinin-based combination therapies (ACTs)[6]. Infrastructure challenges extend to diagnostics and water and sanitation services [7]. For example, 64% of rural health facilities lack lighting, and 38% lack basic water services, compared to 11% and 13% of urban sites, respectively [6]. Laboratory-based diagnoses for malaria are available in 30% of rural and 34% of urban health facilities; rapid diagnostic tests (RDTs) are offered in 29% of rural and 38% of urban facilities. Access to formal health facilities is commonly associated with improved health status and is linked to a decreased risk of severe malaria [12].

Future Directions

Although malaria incidence has been on the decline for decades, recent reports indicate resurgence in the numbers of infection and death, particularly in low-income regions such as sub-Saharan Africa [2]. To curb this rising trend, novel interventions and strategies are needed to halt the spread of the disease while existing public health strategies are maintained [1]. One future option is to introduce the use of repellents in public spaces and provide national governments with information regarding the effectiveness of these products [2, 5]. This informs policymakers about improved protection methods, especially when other measures cannot be fully implemented or when large gatherings occur, such as at political rallies and markets [16]. Heterogenous uptake of repellents can generate protection among users and non-users alike, as high use allows for the diversion of mosquitoes away from those who do not 10. Repellents remain relatively unexplored as tools to control malaria but could be crucial in overcoming challenges for existing interventions [8]. In 2018, about 74% of deaths related to this parasitic disease were recorded in five sub-Saharan countries: Nigeria, the Democratic Republic of Congo, the United Republic of Tanzania, Mozambique, and Niger [11]. Due to its rising health burden, effective control measures must be developed as soon as possible to prevent further exacerbation and the hard work of previous decades being in vain. The current resurgence has primarily occurred in rural areas, but those living in cities remain at risk while the disease is actively managed [13]. Therefore, enhanced, continued progress and greater action in both rural and urban regions must go hand in hand to significantly lessen the burden of the disease and help progress towards complete eradication [14].

Innovative Control Strategies

The increasing spread of pyrethroid resistance among African malaria vectors represents a critical threat for the continued effectiveness of insecticide-treated nets (ITNs) and indoor residual spraying [14]. Studies in Dar es Salaam, Tanzania, indicate that malaria control in Africa is most tractable in urban settlements, yet most research has focused on rural settings [13]. Elimination of malaria transmission from urban areas may require larval control strategies that complement adult mosquito control using ITNs or houses, particularly where vectors feed outdoors [16].

Research Priorities

Studies on malaria and urbanization have highlighted important research priorities [7]. Extracting information from the diverse body of literature is challenging because transmission varies widely from area to area and across time [10]. A literature review to aggregate recent evidence from sites across sub-Saharan Africa of zones where malaria risk is associated with rapid urban growth helps in identifying important priorities for future research and interventions [2]. In the few cities with reliable surveillance data, reported malaria cases in urban districts tend to increase sharply in years following rural-to-urban migration of malaria-infected populations [3]. Do more symptomatic malaria infections occur in urban than in rural areas because of lower immunity, or is the apparent prevalence of clinical cases higher in urban areas due to better clinical access? Counter to intuition, parasite genotype diversity and density are higher for symptomatic cases in urban than in rural areas, although asymptomatic parasitemia (a probable marker of immunity) is higher in rural zones, perhaps due to higher parasite exposure; these findings help to show how urban-rural differences in malaria burdens may reflect both exposure and immunity, and how more parasites are associated with symptoms [15]. Are city-wide burdens higher or lower than rural ones? Demographically weighted evidence from across sub-Saharan Africa suggests a clear negative, rather than a positive, relationship between settlement size and malaria prevalence, and transmission measured from vector entomological data [13]. If the evidence from sub-Saharan Africa regarding urban impacts on malaria transmission holds, this means that the burden of infection experienced by urban residents may also be lower and that other factors probably explain the higher numbers of clinical cases that urban clinics tend to report after rural inward migration [14]. Very few studies have systematically examined spatial variation in malaria prevalence within cities, due, in part, to the difficulty of conducting large-scale community surveys [14]. However, spatial meteorological models of climate, radiation and vegetation are able to describe environmental conditions favouring vector survival in and around urban areas. Urban climate, air quality and especially land cover significantly modify space use, survival, development and abundance of vectors. Even if parasite diversity is more intense in urban than in rural areas, environmental conditions inside cities are adverse to vector development and thus to malaria transmission [15]. The future of sub-Saharan Africa, its health and adaptation to rapid urban growth, is impossible to predict [13]. Inter-disciplinary and innovative research in quickly growing settlements based on an improved architecture of malaria empirical data gathering and a renewal of urban malaria modelling should improve the ability to raise relevant urban issues on the national and international malaria agendas [16].

CONCLUSION

Malaria remains an enduring challenge in sub-Saharan Africa, with distinct epidemiological patterns across urban and rural landscapes. Rural areas experience higher transmission intensity due to extensive agriculture, natural breeding habitats, and limited healthcare infrastructure. In contrast, urban malaria, though less intense, persists through artificial breeding sites, poor sanitation, and urban agricultural practices that sustain mosquito populations. The interplay of socioeconomic disparities, land-use changes, and population mobility shapes malaria dynamics across both settings. Insecticide resistance presents one of the most formidable barriers to malaria control, undermining the efficacy of insecticide-treated nets and indoor residual spraying. The emergence of kdr gene mutations in Anopheles species, coupled with increased pesticide use in urban agriculture, exacerbates this threat. Moreover, gaps in healthcare infrastructure especially in rural areas limit timely diagnosis, effective treatment, and sustained disease surveillance. To address these challenges, malaria control strategies must be context-specific and sustainable. In rural regions, priorities should include enhancing access to healthcare, strengthening community health systems, and promoting integrated vector management. In urban areas, environmental control measures, improved sanitation, and targeted larval habitat elimination should complement existing interventions. The development and widespread use of repellents in public spaces, along with the exploration of next-generation insecticides, could significantly enhance protection. Future directions require a multidisciplinary approach that integrates public health, urban planning, climate science, and community engagement. Research should focus on understanding urban-rural transmission interactions, resistance mechanisms, and the long-term impacts of rapid urbanization on malaria epidemiology. Ultimately, achieving malaria elimination will depend on the sustained political will, adequate funding, innovation in control tools, and equitable access to healthcare across all populations. By strengthening surveillance, investing in local research, and fostering cross-sector collaboration, sub-Saharan Africa can make decisive progress toward eradicating malaria and improving population health outcomes.

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