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Point of view

The Driving Forces Model applied to urban malaria control in Colombia

El Modelo de Fuerzas Motrices aplicado al control de la malaria urbana en Colombia

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Abstract

Urban malaria is established as a result of an unplanned urbanization. This occurs mainly in peripheral areas of human settlements. People living in rural areas are pressured by political, economic and social factors that force them to migrate to the cities. These migrants establish themselves in the poorest areas, which lack basic services and sanitation. All of this has negative consequences for the environment, leading to vegetation being modified which creates ideal conditions for malaria to arise.

Understanding malaria is complex because of the multiple variables involved. The inclusion of social determinants of health has been proposed with a view to seeing how these factors influence transmission and then, on the basis of the findings, designing methods to minimize transmission. Under this premise, the Colombian Ministry of Health designed the Ten-Year Public Health Plan 2012-2021 and also proposed the Driving Forces Model within the framework of the Environmental Health Dimension to address the health problems of the populations.

This opinion article takes these two documents as a starting point and discusses how this model can be utilized for malaria control. A literature review is also included in order to address each category of the model.

Resumen

La malaria urbana se establece como consecuencia de una urbanización no planificada. Esto ocurre principalmente en las zonas periféricas de los asentamientos humanos. Las poblaciones rurales se ven presionadas por factores políticos, económicos y sociales que las obligan a migrar hacia las ciudades. Esta migración llega a las zonas mas pobres, con carencia de servicios y saneamiento. Todo esto trae como consecuencia una presión negativa sobre el ambiente, donde se modifica la vegetación y se crean las condiciones para el establecimiento de la malaria.

El entendimiento de la malaria es complejo por las múltiples variables que intervienen. Se ha propuesto la inclusión de los determinantes sociales de la salud, ver como estos influyen en la transmisión y luego diseñar métodos para minimizar la transmisión. Bajo esta premisa el Ministerio de Salud Colombiano diseño el Plan Decenal de Salud Pública 2012 -2021 y propuso ademas el Modelo de Fuerzas Motrices en el marco de la Dimensión de Salud Ambiental para atender los problemas de salud de las poblaciones.

Teniendo en cuenta estos dos documentos que sirven de marco para este articulo de opinión se discute como este modelo puede ser abordado para el control de la malaria. Además se sustenta en una revisión de literatura para abordar cada categoría del modelo.

Key contributions of the study

Model development	There are different theoretical models to describe the prevention and control of malaria. These models allow an understanding of the factors that participate in malarial transmission. They range from models that have, as a fundamental axis, vectors to more integral models (such as the driving force model) that include environmental, social and economic factors. This model establishes a relationship between health, the environment and sustainable development, which includes social determinants of health. The model is based on six hierarchical categories: driving force, pressure, state, exposure, effect and action. In this document, urban malaria will be modelled.
Driving force (human development)	In Colombia, human development has occurred in an unequal manner due to historical, social, economic and political circumstances. This resulted in many groups (such as the Afro-Colombian communities of the Pacific coast or the indigenous peoples of the department of Córdoba) being exposed to diseases such as malaria. Social factors (social determinants) that contribute to the disease load in these communities include disadvantage, with these communities being chaotic and poorly served.
Pressure (deforestation and environmental detriment)	In peripheral areas of human settlements, there is massive deforestation and uncontrolled population growth that causes pressure on ecosystems. This produces a great imbalance and drastic changes in the composition of wild populations, the climate and microclimates. This results in the establishment of malaria outbreaks.
State (environmental modification)	This is a fundamental consequence for the establishment of malaria transmission. This mainly impacts malaria vectors, with adult vectors finding stable sources of blood and also suitable places for their larvae.
Impact (Cases of urban malaria).	Urbanization causes changes that are exploited by vectors, which, in turn, causes deterioration in the health conditions of human populations. There, foci circumscribed mainly to the hatcheries are established.
Responses (Incidence of urban malaria)	The incidence of malaria is mainly concentrated in the foci, where transmission is established and maintained, due to the environmental management on the land and the lack of adequate sanitation.

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Introduction

Malaria has been urbanized in Colombia. In the country, 17 municipalities, distributed mainly in the Pacific Region, were identified as having consistent and persistent cases of urban and peri-urban malaria (1). 10% of municipalities are at high risk of having peri-urban malaria (2). Among these, 23 of them had >100 cases registered in urban areas. The municipalities with the highest cumulative burden of peri-urban malaria cases were Buenaventura (Valle del Cauca), Tumaco (Nariño), El Charco (Nariño) and Quibdó (Chocó) (3). Urban malaria was documented in Tumaco (4), Buenaventura (5), Quibdo (6), Armenia (7), Pereira (8), Guapi (9), Guajira (10). For this reason, it is important to consider a new approach to the prevention and control of malaria in Colombia.

Social determinants of health have an important role to play in the control of malaria. In the 2012-2021 Ten-Year Colombian Public Health Plan, it was established that in order to achieve equity in health, it is necessary to adopt a model including social determinants of health and a differential approach. This document included eight priority dimensions that were identified as fundamental aspects that are necessary to achieve health and well-being in communities; among these dimensions is environmental health (11).

In this context, environmental health was defined as the set of policies that seek to promote quality of life and health and that can help to attain the right to a healthy environment through the fulfilment of four objectives: 1) Promote the health of populations vulnerable to environmental processes . 2) Promote sustainable development with clean production technologies and responsible consumption. 3) Attention to health and environmental needs as a priority; and 4) Improve living conditions through prevention, surveillance and health control (2). This was divided into two components, including public health concerns that are related to environmental conditions, within which malaria should be included.

For the implementation of the Ten-Year Colombian Public Health Plan, the driving force model (DFM) for the environmental health dimension was proposed (12). This model involves five levels of causes/effects: driving force, pressure, state, impact, response and action, with these levels being hierarchical categories (Fig. 1). The first category includes social, economic and demographic structural conditions that affect environmental conditions; the second level includes the expressions that are generated in the first level, which are the economic and social forces that are applied in each territory. The third level is the condition and quality of the environment in terms of natural resources, including the atmosphere, land and water and it is the result of pressure on ecosystems; the fourth level of exposure is all the ways in which environmental risk contact with the human population is established. The fifth is the consequences that are generated from this exposure and, finally, the action is all the possible interventions that can be performed in each of the levels and their interactions (12). The model based on malaria will be developed using these concepts.

The DFM allows a characterization of the health situation according to the structural determinants and the pressures that are exerted on the environments. All this positively or negatively influences health. The possible actions that can be taken to mitigate the problem must be undertaken from the structural point of view' as such this has an important political and social component (11).

This point of view may contribute to decision making in territorial health departments (states) and territorial environmental health councils because this model, and its methodology, allows the identification and characterization of the determining factors – at the structural, intermediate and proximal order - of the problem of urban malaria. In turn, it allows visualization of the complexity of malaria and the components of transmission.

The epidemiological approach to the study of many diseases is complex. Traditionally they are studied independently from the perspective of risk factors, whilst the risks are interdependent, non-linear and adaptive processes that, in turn, interact with each other in the environment (13). To understand malaria, it is necessary to use much more complex models that allow the determination of dynamic and changing interactions between individuals and their environment (14). This approach must be in accordance with the modern public health guidelines, which means that the interactions of the environment with the social and economic aspects of the communities need to be taken into account (15). This is called socio-ecological models applied to health.

The Driving Forces Model

It is essential to integrate all the knowledge about malaria into a model, as this is more in line with the complexity of this disease, in order to design control measures at all levels. The model that can be proposed for malaria control is that of driving forces; this model proposes categories such as driving forces, pressure, state, impact, response and actions. A possible model for urban malaria is represented in Figure 2.

Using these premises, a model for urban malaria will be proposed according to the guidelines of the DFM, supporting this with knowledge generated on urban malaria and the possible methods for its control.

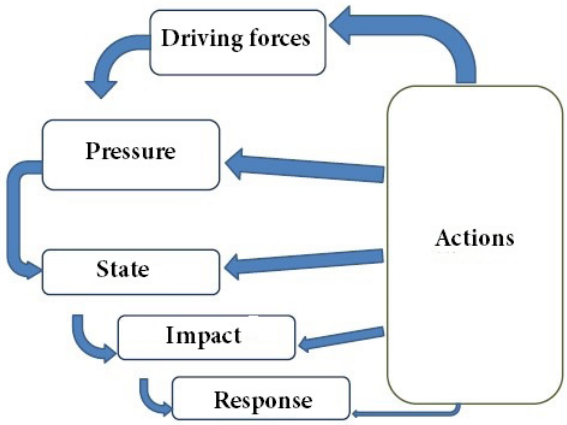

Figure 1. Model of driving forces. Taken from reference 12.

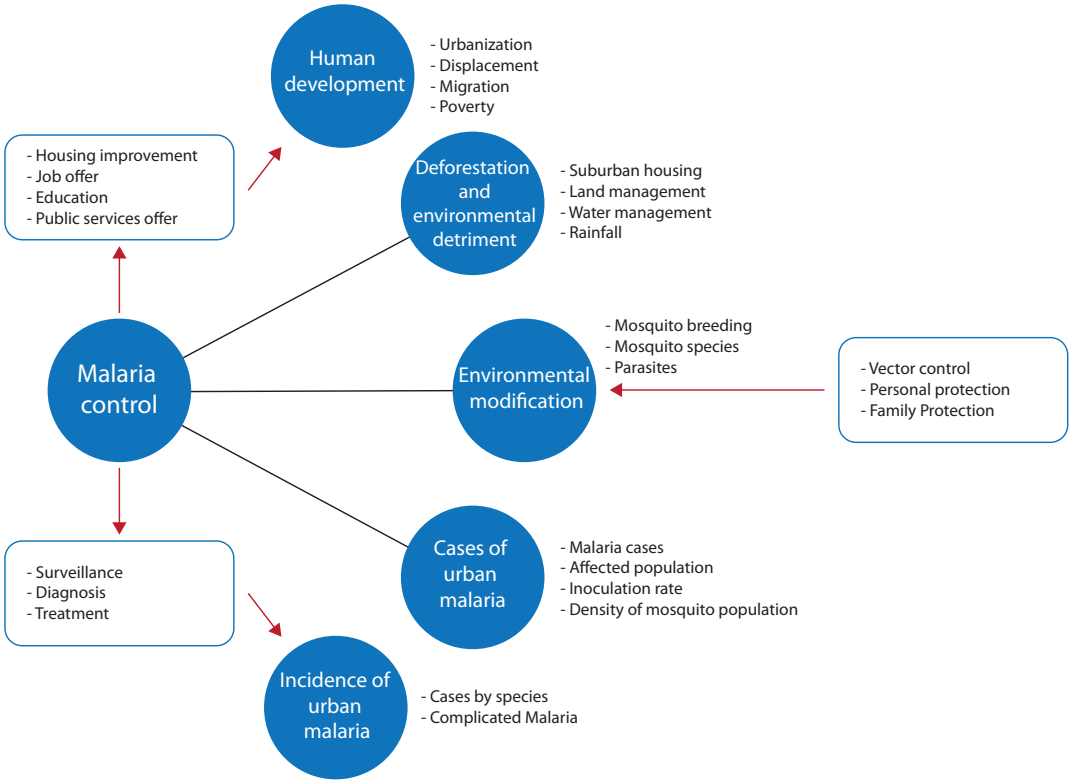

Figure 2. Proposed model of driving forces for Malaria. Small circles represent driving forces **(human development)**, pressures **(deforestation and environmental detriment)**, state **(environmental modification)**, impact **(cases of urban malaria)** and response **(incidence of urban malaria)**. The big circle are the actions complemented in the rectangles.

Driving forces (human development)

Driving forces are the structural conditions of the communities that allow malaria transmission. In the case of malaria, these could be the social determinants that are immersed in a complex web of ecological, social, economic and cultural interactions. Socio-economic interactions, framed within human social Development, have contributed to the maintenance of transmission.

For many ethnic groups in Colombia, this development meant that they were more exposed to this disease. The communities that were historically displaced to forested areas due to the struggle for territories were socially and economically disadvantaged. This can be observed in the territories along the Colombian Pacific Coast, where indigenous and Afro-Colombian ethnic groups live, or in the department of Córdoba, which is mainly an indigenous area. This is why malaria cases are mainly concentrated in Chocó, Antioquia, Nariño, Amazonas, Valle del Cauca and Córdoba (16). These socio-economic interactions are framed in terms of social determinants. Thus, as Sevilla (17) argued, "…the study of social determinants in health is based on the inequalities between populations that have historically occurred throughout the history of mankind and these studies of the social determinants of health states are finally finalized in studies of the determinants of human inequality". Part of this argument is based on the scarcity of resources for investment in the health sector as they are invested in an unequal and hierarchical manner which results in the origin of inequities between populations. Social determinants cause these inequities (18). It is necessary to clarify that social determinants are a set of social, political, economic, environmental, biological and cultural factors that influence people's health status.

The determining social factors for acquiring malaria are divided into macrosocials determinants (of the place of life) which includes: 1) health conditions, 2) economy, poverty and employment, 3) political situation, 4) urbanization, 5) geography and ecology, 6) transport, and microsocials determinants (of the individual) which includes: 1) race-ethnicity, 2) sex, 3) age, 4) education, 5) social class, 6) job occupation, 7) income, 8) educational level (19). Another proposal utilizing this same approach and circumscribed to a social territory[1] includes three processes. The transmission process which involves all the dynamics, eco-social web and other variables that have to do with the mosquito-host relationship. The contagion process involves all aspects related to the host-parasite relationship and the processes related to health consumption that correspond to the barriers and ease of access to health services (20). On the other hand, in the scientific literature social determinants have been discussed regarding the prevalence of malaria, including a low socio-economic status (21,22), the socioeconomic characteristics of the population, including: education and occupation and geographical characteristics (17), sex (20), Behavior (23), age (24), occupation (25), ethnicity (26). Research based on classical epidemiology, far from the postulates of Latin American social medicine, have supported, with evidence,

1 Understood the social territory as a complex framework of material reality (natural or manufactured) with social dynamics contained inside and outside it, which define the relationships of groups and subjects with the environment (20).

the suggestion that these social determinants are relevant in the presentation of malaria (27).

Malaria has a double role in the model containing social determinants. On the one hand, malaria affects the social and economic development of the regions (28), as it causes poverty and slow economic development in endemic countries (29). In Africa, it has delayed socio-economic development (30) and also the family, and because of this it affects the economy, due to the costs of the disease and also due to reductions in the productivity of people (29).

On the other hand, economic and social development influences the dynamics of the disease (21), with areas with greater Development experiencing a lower the prevalence of malaria. Malaria disproportionately affects the poorest countries and, specifically, the poorest populations in these countries (31); This increases the vulnerability of certain ethnic or community groups to the disease (32,33).

Authors such as Sevilla (17) argue that the ability to differentiate and prioritize the determinants of inequities such as age, sex, ethnicity, education, occupation or geographic location are essential for the design and objectives of health interventions around equity, so a knowledge of the social, economic and cultural determinants is required to implement more appropriate control measures. For example, understanding the sociocultural dimensions of the malaria burden is vital for the development of interventions and for accessing vulnerable groups (34). This allows a certain desired impact of the interventions to be achieved, as was the case in Vietnam, where malaria reduction was achieved due to the synergy between strengthened control programs and strong socio-economic development (35,36). The complexity of the social, economic and cultural factors that influence the dynamics of malaria transmission is also known, so it is necessary to implement these measures according to local conditions and development (21).

In the case of urban malaria, some variables that impact malaria could be determined in the driving forces model (Fig. 1). The component of driving forces could be called human development circumscribed to urban growth. As part of this growth, population growth, migration, displacement and poverty are all inter-related. Urbanization is a complex and dynamic process that involves space and time. The growth of settlements is due to the combination of four factors: natural growth, rural to urban migration, mass migration due to extreme events (natural disasters and social problems) and the redefining of administrative boundaries. This results in a high degree of environmental heterogeneity (37).

Human development has impacts mainly in cities. Human development causes great impacts on the uncontrolled growth of cities and, in turn, on the changes in malaria transmission. In peripheral areas of the cities, a complex social, economic and environmental dynamic is established which causes drastic changes to the landscape. The drastic change in the border areas of the cities leads to deterioration in the population's quality of life due to rapid growth without planning.

Urbanization also causes migratory movements between urban and rural areas which allows the importation of parasites (38,39). Population migration patterns explain the variation between and within the urban area, because some urban residents regularly move to high-transmission areas and thus increase the risk of becoming infected. They could also be a source of parasites once they arrive at their residence (40). These movements cause increasing morbidity and mortality from malaria (37,40). A significant relationship between imported and indigenous cases of urban malaria was demonstrated in a city in Madagascar, with characteristics of low transmission, due to the importation of cases (41). This causes the transmission to become focal (42).

How could the problem with malaria generated by human development in cities be mitigated? The discussion generated in this document only covers four components: urbanization, displacement, migration and poverty. The possible solution is improvement to housing and its surroundings, improved public services (water, energy, garbage collection), increasing employment and educational opportunities to the population and improving security conditions in these areas. Based on these solutions, it is determined that mitigation measures do not depend solely on healthcare but do improve the health status of the communities.

Pressure (deforestation and environmental detriment)

This component should include deforestation in peripheral areas of cities and population growth that causes great pressure on natural ecosystems. The most drastic changes in ecosystems occur in areas of rapid urbanization and agricultural development. This produces a great imbalance and changes in the biodiversity of animal and plant populations. The impact on mosquitoes in general is due to the change in diversity and microclimates, for example in houses located in deforested areas, temperatures were found to be between 0.7-1.2° C higher than houses located in areas in forested areas (43).

Ecosystem exploitation impacts malaria. Changes due to deforestation produce changes in the microclimates that affect larvae and adults in different ways (44), so that the environment is listed as one of the main determinants of malaria transmission (45). Rapid deforestation and agricultural practices influence the increase and change in the diversity of mosquitoes and the transmission of malaria (46). Changes in the vegetal composition or the vegetal cover promote the appearance or disappearance of terrestrial or aerial hatcheries of *Anopheles* (47), increasing or diminishing the populations of adult mosquitoes.

Several environmental and demographic factors are combined in cities with malaria (48), with this contributing to malaria transmission. Among the demographic factors, it is speculated that population movements might have a role to play (49). These movements are determined by urbanization, colonization, work in agriculture or mining and social conflicts (26) amongst others. The modification of the environment and its bordering ecosystems are one of the main causes of the increase in malaria in some areas; deforestation and the Implementation of irrigation systems increased cases of malaria, for example (50), as a result of changes in regional agricultural practices. It is documented, for Central

America, that when the cultivation of rice and cotton was changed to that of African palm and banana crops, there were changes in the dynamics of malaria transmission (29).

Human settlements grow physically and cause changes in urban land use with new peri-urban areas being created that extend beyond the boundaries of these villages. The characteristics of the development of the peri-urban area is the modification of the bordering ecosystems, mixing traditional agricultural behaviors and activities that juxtapose with urban land uses and governance conditions. In addition, pressure for land causes drastic physical changes, and land use and urbanization causes cultural and lifestyle changes for the population (51). All this contributes to drastic changes in the environment.

The rapid urbanization alters the dynamics of malaria transmission, with significant effects on the disease. Urbanization causes profound demographic, ecological and socioeconomic changes characterized by unplanned growth which causes a high degree of temporal and spatial heterogeneity (37,40).

In developing countries this urbanization is characterized by being unplanned, with poor sanitation and drainage constructions (26). In addition to this, low socioeconomic status, urban agricultural practices and poor monitoring of land use contribute to increased transmission of malaria (52), because these factors allow the increase of breeding sites in the urban fringes and increased vector-human contact because vectors adapt to urban ecosystems (53). In urban areas, blood sources are stable and abundant, but the dispersion of vectors is low and malaria transmission is associated with the proximity of breeding sites (54,55). The risk of malaria in these areas is very heterogeneous in the area of influence, so it can vary between neighbourhoods (56.57), as established in Ghana (58).

Possible mitigations for the problems that deforestation brings include the intervention of suburban housing, improving the management of land and water and planning the mitigation of risk due to environmental conditions. None of these interventions are part of any activities carried out in the area of health.

State (environmental modification)

Environmental modification could be the main component for malaria transmission. Environmental factors mainly affect vectors. Some species of mosquitoes have the ability to adapt to new environments and this is clearly seen in urban environments. Taking advantage of natural or artificial water reservoirs, populations are established and transmission becomes focal. The hypothesis is that mosquito populations tend to bite close to breeding sites and their dispersal is restricted (59), with the risk of becoming infected increasing in the human population that is closest to these sites (40). Together, hatcheries, stable blood supply and parasites result in an increase in infective bites (60).

Another component of an environmental health model applied to malaria is the environment. Rainfall (61), temperature (62), climate change (63) and environment (64) are risk factors that modify transmission. In most cases, environmental conditions allow the proliferation of mosquitoes and thus the transmission of malaria. All these factors primarily impact the vector: ecosystems impact the distribution and abundance of vectors; while the rainfall and temperature affects their abundance (65). Climate changes in general impact the life cycle of Plasmodium (66), mainly temperature.

The increase in temperature impacts the net reproductive rate and the intrinsic growth rate in adult mosquitoes (44), with deforestation causing an increase in vector capacity (63). Deforestation increases the water temperature of mosquito farms. This shortens the development time of the larvae and, at the same time, allows the establishment of more hatcheries (47,64). At the same time, this shortens the development of the parasite inside the mosquito. All this contributes to the change in the dynamics of malaria transmission.

The problem generated here is the presence of mosquito breeding sites and the presence of parasites which is exclusive to the health area with vector control, personal and family protection with mechanical methods and barriers. Usually vector control is performed using insecticides and the use of mosquito with thresholds needing to be met given the environmental Behavior of mosquitoes and humans. New control methods must therefore be implemented. For parasites, it has been shown that there are asymptomatic people within the community that allow continuity of transmission, so it is recommended that these people be detected so that they are treated promptly.

Impact (cases of urban malaria)

Urbanization modifies the climate and ecosystems (50). It causes changes in temperature and precipitation (67). Urban development patterns determine how natural habitats fragment, affecting local biodiversity, allowing or restricting the development of certain wildlife species. This increases the deterioration of the population's health conditions, including the transmission of wild zoonoses (68). In the case of malaria, the greatest impact is observed mainly at the limits of the cities. These have been called the peri-urban area, to differentiate it from the city, as these areas have their own social, cultural, economic and landscape conditions. The heterogeneity and the modification of the climate and the ecosystems in the new urbanized areas do not precisely delineate the urban from the rural, so it is difficult to establish borders between these two areas. There is no consensus regarding the impact of urbanization on the dynamics of malaria transmission. Some authors found that urbanization causes a decrease in malaria transmission (59). It is predicted that by 2030, 53.5% of malaria reduction in Africa will be due to demographic changes (69) with this encouraging greater development, such as infrastructure improvement, housing quality, health coverage and site reduction of mosquito breeding. In Tanzania, malaria transmission in the urban area is low compared to rural areas (40,70), whilst in peri-urban areas, this can be high or low (71). This can be associated with the ability of vectors to colonize these areas (53) and the entomological rate of inoculation (number of infective bites per person/year) which is lower in urban area, followed by peri-urban areas and very high in rural areas (40.72). It was determined that in the urban area, the availability of Anopheles breeding sites was low due

to contamination of the wells or their eradication due to urban planning (71).

Urban malarial outbreaks are limited to mosquito breeding sites and these outbreaks tend to be more numerous in areas of low socioeconomic status (73). They are regularly found in areas where urban agriculture is practiced (74). There is a relationship between vegetation and malaria, with research in Vietnam showing that plant cover and poverty influence the increase in the number of malaria cases (60). On the other hand, deforestation contributes to the breeding sites of certain species of mosquitoes as occurs along the Colombian Pacific coast (75). This results in a decrease of species with respect to the rural area (56) and, in turn, the population density of the vectors and the probability of infecting are much lower in the urban area than in the rural area (40). These hatcheries can also be found in other areas of the urban area (e.g., river banks) where the centre of the urban area is established and it is there where there is a greater risk of becoming infected (76).

In summary, malaria transmission is influenced by multiple variables which all have complex interactions. There are human activities that cause a negative or positive pressure on transmission, causing positive or negative changes in the ecosystems that allow transmission; climate also contributes to this transmission dynamic. This is how urban malaria varies according to local conditions such as geographical location (altitude, proximity to the sea or rivers or geographical accidents), climate, land uses, human movement patterns, local vectors, vector breeding sites and local malaria interventions (73). The relationships between malaria and human development are complex and bi-directional.

This component is the compound effect of the other components, where malaria cases are detected. In this case, rapid diagnosis should be continued without any barriers such as those given by the IPS and the national diagnostic system. On the one hand, the collection of the moderating fee prevents equitable access to the service by people with a contributory regime, since the national counterpart has no cost and is free. This increases the demand for the service in the public counterpart.

Response (incidence of urban malaria)

Urbanization, mainly on the periphery of human settlements, contributes to the transmission of malaria. As in cities in Africa, where it was determined that there are sites where the entomological rate of inoculation is above 80 infective bites/person/year (76). There are other settlements where there is no transmission in the peri-urban areas because the sub-human living conditions are found around the urban area and the peri-urban area is inhabited by people with better living conditions (77). This suggests that the dynamics of urban malaria transmission cannot be generalized, due to the high heterogeneity caused by both environmental conditions and demographic conditions that contribute to differences between cities (37). What is clear is that if the spatial and temporal patterns of urban malaria are known, an integrated program of more appropriate control could be implemented (37).

It has been found in both Quibdó and Buenaventura (Colombia) that the transmission of malaria could be concentrated in peri-urban areas characterized by unplanned urbanization, poor housing infrastructure, lack of adequate sanitation, poor drainage of surface waters, lack of public services, low socioeconomic status and areas rich in water and vegetation (6). The characteristics of these areas could allow the urbanization of malaria which would have serious effects on the increase in malaria cases, changing the frequency and mode of transmission with serious implications in the control which, by extension, would increase the population at risk.

To mitigate the incidence of malaria, surveillance systems, diagnosis and treatments should be improved. In the surveillance system, the SIVIGILA file needs to be accurately maintained and updated, with the place of residence and the probable site of infection needing to be duly filled out. Most of the time, however, they are not filled out, leaving the question as to whether it is a case of urban malaria or a malaria that has been imported from the rural area.

Conclusion

The proposed driving force model included in the 2012-2021 Ten-Year Public Health Plan could be implemented, meaning that the factors responsible for malaria transmission would have to be determined. This would also allow a clear visualize of which components maintain this transmission, who are the political and social actors who need to be involved and which sectors need to take actions to mitigate the problems that malaria causes.

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