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Relationship between malaria epidemiology and the human development index in Colombia and Latin America

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SUMMARY

The objective of our study was to establish the relationship between the Human Development Index (HDI), Gini coefficient and Unsatisfied Basic Needs (UBN), with the incidence of malaria in Colombia and five endemic countries of Latin America (Brazil, Venezuela, Ecuador, Mexico and Peru) between 2005 and 2012. Through an ecological study the HDI was obtained from the data base of the United Nations Development Programme; the Gini index and the UBN were obtained from Colombia's National Administrative Department of Statistics, and the malaria incidence from the World Health Organization's programme "Roll Back Malaria" and from the Colombian epidemiological surveillance system. The annual variation of the variables was evaluated, and linear and non-linear regressions (exponentials) were modelled. Upon analysing the data with the regression models, it was noted that countries with higher malaria incidence rates were those with lower values of HDI, the association being significant (r^2=0.4233; p<0.0001). Similarly, it was observed that Colombian departments with higher inequality and poverty rates were those with a higher incidence of malaria (Gini r^2=0.1851; p<0.01; UBN r^2=0.908; p<0.01). An inverse and significant relationship between HDI and malaria morbidity in the countries studied was found, as well as a positive and significant relationship between Gini and UBN with morbidity in these Colombian departments. This information reflects the significant influence of socioeconomic indicators such as HDI, Gini and UBN on the malaria incidence rate.

Keywords: malaria, epidemiology, human development, social indicators, Colombia, Latin America.

INTRODUCTION

Malaria in humans is a systemic parasitic infection caused by five species of *Plasmodium* genus (*P. falciparum, P. vivax, P. malariae, P. ovale* and *P. knowlesii*), which are transmitted to humans mainly through insect vectors, female mosquitoes of *Anopheles* species [1-4]. However, the infection can also be acquired by other ways such as is the case of maternal-fetal transmission, by transfusions, organ transplantation. The human being is the only reservoir of clinical significance for these species, until now. Almost 90% of global cases of malaria are caused by *P. falciparum* and are reported in African territories, where the highest morbidity and mortality rates by this disease occurs. Still a considerable fraction of affected patients develops severe malaria (estimated up to 25% of cases). In Asia, Oceania, Central America and

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South America *P. vivax* prevails (>75% of cases), followed by *P. falciparum*. All of this is influenced by multiples factors, including the access to timely diagnosis and early treatment of the infection, for which mortality rates therefore also tend to be smaller in Central and South America, compared to Africa [1].

Approximately 2.5 billion people (40% of world population), is at risk of acquiring this infection. Vector-borne transmission is affected by the increasing resistance to insecticides by the main species, but also due to climate variability and ecological changes, as well as an increasing travel to endemic areas. During the past decade, between 300 and 500 million new cases and about 3 million deaths were reported annually, with 49% of the world population living in areas where there was active transmission [2]. However, due to extensive control in different areas, decrease has been reached then. In 2016, an estimated 216 million cases occurred worldwide [3]. The incidence rate is estimated to have decreased by 18% globally, from 76 to 63 cases per 1000 population at risk, between 2010 and 2016. In the Americas, 38.4% of the population lives in areas of favorable ecological conditions for malaria transmission. In 2000, of the 1.14 million reported cases, 53.6% occurred in Brazil, followed by 9.45% in Colombia, 8.65% in Ecuador, 6.12% in Peru, 4.68% in Guatemala, 3.08% in Honduras, 2.76% in Venezuela, 2.11% in Guyana, 1.48% in Haiti and, 1.15% in Surinam [4].

According to the World Malaria Report 2013 of the World Health Organization (WHO), Argentina, Belize, Costa Rica, Ecuador, El Salvador, Mexico and Paraguay are currently under pre-elimination phase.

In the case of Mexico, this went from 2,500 cases in 1998 to 833 in 2012. In Ecuador malaria programs managed to reduce from 108,903 cases in 2001 to only 558 in 2012 (>50% in a decade) [5].

Colombia and Peru are on track to achieve a 75% reduction by 2015, being Venezuela the only country that showed an increase in the number of cases between 2000 and 2012 [5, 6].

In Peru, for example, concerning the report done in 2000, it has managed to reduce the incidence rate of malaria by 63%, although the disease remains as problem of public health. Prevalence rates have decreased in the last two decades even though the most resilient and aggressive forms of the disease pose a challenge to retain control over the epidemic [7, 8].

In Ecuador, a 99% reduction of the cases was achieved, this result corresponds to immediate actions against the diseases and implementation of surveillance rules prioritized by the Ministry of Public health and the National Service for Control of Arthropod Vector transmitted disease (SNEM). In Brazil, the reduction of cases submitted was 58% and in Mexico 83% [7].

In Colombia, malaria is a disease of high epidemic potential that is endemic in a large part of the national territory, areas located below 1,500 meters above sea level (masl). Nationwide, about 12 million people live in areas at risk for transmission. Although malaria mortality has rapidly decreased, morbidity has done it with less intensity. In 2007, 125,262 cases were reported, while in 2012 were 60,179 cases.

In the country, there is a predominance of *P. vivax*, but the proportion of cases of malaria by *P. falciparum* is considerably important (30%). Thereby, malaria remains as significant endemic infectious disease in the country: an event whose surveillance, prevention and control are of particular interest in public health and is subject to mandatory reporting [5, 8, 9].

Seven of 32 departments of Colombian territory have an Annual Parasite Incidence (API, number of cases of malaria/1,000 inhabitants/year) above the national average of 10.5 cases per 1,000 inhabitants. In 2011, the department with the highest API was Choco (24.09 cases/1,000 inhabitants), followed by Cordoba (6.57 cases/1,000 pop.), Antioquia (4.37 cases/1,000 pop.) and Bolivar (1.01 cases/1,000 pop.). Most of the cases were caused by *P. vivax* (82,856, 70.8%), while *P. falciparum* took second place (32,777, 28.0%) and *P. malariae* in low portion (47, 0.04%). Additionally, 1,428 cases of mixed infection by *P. vivax* and *P. falciparum* (12%) were reported [9].

Among the multiple conditions associated with the incidence of malaria, social factors are recognized increasingly important. Therefore, the use of indicators of social and economic nature can be related to the behavior of the epidemiology of the disease. These social factors can be located on different levels (micro, meso and macrosocials and micro and macroeconomics). Among the macro-indicators of global significance, there is the Human Development Index (HDI). This is a summary measure to evaluate the progress of a country or a region in the long term based on three basic dimensions of human development: a long and healthy life (life expectancy), access to knowledge (education) and a decent standard of living (income) [10]. There are also other important social indicators that might be associated with the epidemiology of malaria, which are Unsatisfied Basic Needs (UBN) and Gini index. According to Economic Commission for Latin America and the Caribbean (ECLAC), the UBN methodology is a tool created with the purpose of measuring and/or characterizing poverty [11]. This indicator can present national characteristics. In the case of Colombia, simple indicators selected for the construction of UBN are: inadequate housing, homes critically overcrowded, homes with inadequate services, high economic dependence homes, and homes with school-age children not attending school. Starting from the calculation of this indicator of percentage of people versus households, over the total population versus total households with at least one UBN [12].

In the case of the methodology of Gini index, also according to ECLAC, this in an indicator for measuring inequality, defined as the ratio of the difference between the line of equidistribution and the values of the Lorenz curve. This indicator takes values between 0 and 1, where 0 indicates that all individuals have the same income and 1 indicates that a single individual has all the income. The closer the indicator is to 1, more inequality exists between the incomes of households in the country or in the corresponding administrative area [13].

Based on the above and considering that there are few prior studies in the literature that relate these socio-economic indicators to malaria, the present study was conducted evaluating the association between the incidence of the disease and social indicators, HDI, Gini index and UBN, of Colombia and other endemic countries of Latin America, as well as at departmental level within Colombian territory.

MATERIALS AND METHODS

An ecological research was conducted, assessing the association between malaria incidence and Human Development Index (HDI) in Colombia and 5 countries of Latin America between 2000 and 2012. Furthermore, the relationship between the incidence of malaria, HDI, UBN and Gini coefficient was assessed in endemic departments of Colombia (a total of 27 of 32).

Latin American countries selected for this study were Brazil, Venezuela, Ecuador, Mexico, Peru, and Colombia, given that these countries have a high incidence of the disease and have been exposed to significant changes in the behaviour of the same for the past 10 years.

Epidemiological data of the disease was obtained from global malaria statistics (World Malaria Data), generated annually by WHO through its "Roll Back Malaria" program (2000-2012). The number of annual cases of malaria by country is reported in this program. Based on the number of cases annual parasite incidence (API), was estimated, it was calculated based on reference population using the data of the United Nations Program for Development (UNDP). Nationwide the epidemiological data were obtained from the National System for Public Health Surveillance (SIVIGILA), the Ministry of Health of Colombia (2008-2011), and incidence rates were estimated by department using population data based on the National Administrative Department of Statistics (*Departamento Administrativo Nacional de Estadisticas,* DANE) (official reference populations by department and years).

Annual HDI values for each country were obtained from UNPD through its annual worldwide report. The HDI is calculated as the cubic root of the simple product between the life expectancy index (LEI), the education index (EI) and income index (II) [14]:

$$HDI = \sqrt[3]{(LEI \times IE \times II)}$$

To do this, there are the following considerations: LEI is calculated by the following formula: LEI = (LE-minLE)/(maxLE-minLE); to calculate EI the formula used is: IE = IAPE x IAEE/0.951, where IAPE is the index of average years of education, and IAEE is the index of expected years of education; and II is calculated from gross domestic product per capita (GDPpc) using the following formula: II=[ln(GDPpc)- ln(minGDPpc)]/[log(-maxGDPpc) - log(minGDPpc)], where GDPpc is expressed in USD (US dollars) [14]. A value of HDI <0.5 corresponds to a low human develop-

ment, between 0.5 and 0.799 to medium human development and ≥0.8 a high human development [15].
Socioeconomic indicators used for the study at departmental level in Colombia were: UBN (2011) and Gini coefficient (2008-2011), these data were analysed as independent variables to assess their association with incidence rates of the disease [11-13]. Gini coefficient was available for 24 of 27 departments that reported cases during the study period.

Statistical analysis
A Spearman correlation between HDI, UBN, Gini coefficient and malaria incidence was carried out to determine their association and direction. Linear and no linear simple regressions were conducted between socioeconomic variables and morbidity rates. Also, for UBN and Gini (for year 2011), a multivariate linear regression was run with the API as dependent variable. No other possible multivariate analyses were available to perform based on data collected. Statistics analysis were performed using the statistical package Stata IC® v.14 (licensed for Universidad Tecnologica de Pereira) with a confidence level of 95% (significant $p<0.05$).

RESULTS

Malaria and HDI in South American countries
Between 2005 and 2011 the variation in HDI was 0.681 (Colombia, 2005) to 0.773 (Mexico, 2011), while the annual parasite incidence (API) for malaria in all 6 countries included in the study ranged from 0.01 (Mexico, 2011) to 3.26 (Brazil, 2005) cases/1,000 inhabitants.

Table 1 - Annual Parasite Incidence (API) for malaria estimated per the human development index (HDI) range in analyzed countries.

IDH range	*API*	*95%CI*	
	(Cases/1,000 inhabitants)	*IL*	*SL*
0.675-0.699	2.122	1.299	2.944
0.700-0.724	1.414	1.015	1.812
0.725-0.749	1.124	0.795	1.453
0.750-0.774	0.381	0.177	0.939

95%CI=95% confidence interval, IL: inferior limit, SL: superior limit.

Estimating the annual parasite incidence (PAI) for malaria according the HDI it was observed, in general (except for Venezuela) that the highest rates of the disease were in countries with lower ranges of HDI, and countries with the lowest rates had higher ranges of HDI (Table 1). Those

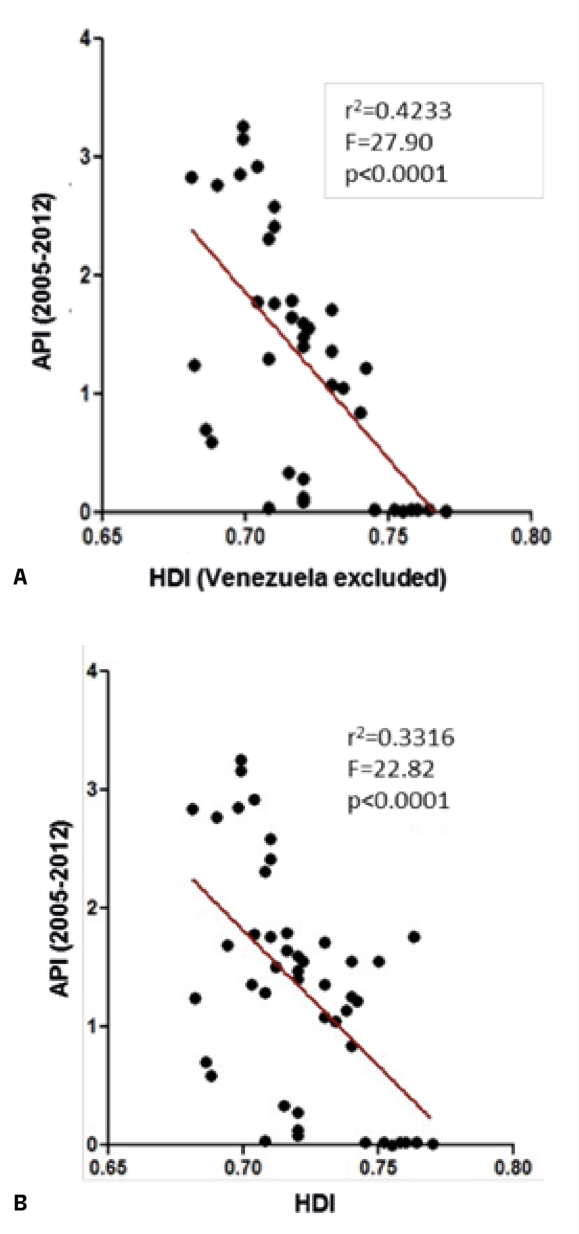

Figure 1 - Linear regression between human development index and annual parasite incidence for malaria in analyzed countries (without and with Venezuela).

countries with an HDI lower than 0.70 have malaria rates above 2 cases/1,000 inhabitants, while the incidence of malaria in countries with HDI higher than 0.70 is below 2 cases/1,000 inhabitants (Table 1).

Spearman's correlation coefficient between HDI and API of malaria was -0.509 (p<0.0001). Whereas in the lineal regression models it was observed that the relationship between the epidemiological and social variable was significant and inverse in all the 6 countries (r^2=0.3316, p<0.0001), however excluding Venezuela greater significance was observed (p<0.0001 r^2=0.4233) (Figure 1).

Analyzing by country, we found that the association was significant and with the same pattern in all years studied (p <0.05). For Peru was found (r^2=0.9422); Brazil (r^2=0.8316); for Ecuador (r^2=0.7289); for Colombia (r^2=0.5611) and Mexico r^2=0.5354.

In the case of Venezuela, the HDI was not significantly associated with the API (r^2=0.0016; p=0.924). In the analysis for the countries studied (Colombia, Ecuador, Peru, Brazil, Mexico, Venezuela) it was found that the decrease in the incidence rates was associated, in most of them (except Venezuela), with increasing values HDI in each country (p<0.05).

Malaria and Gini coefficient in Colombia

Between 2008 and 2011, the variation in the Gini coefficient in the departments of Colombia was 0.45 (Caqueta, 2010) to 0.62 (Choco, 2008) whereas the annual parasite index (API) of malaria in the 24 departments included in the analysis for the Gini coefficient ranged from 0.003 (Cundinamarca, 2008) to 45.28 (Choco, 2010) cases/1,000 inhabitants.

In the estimation of malaria incidence per Gini coefficient it was noted that the highest rates of the disease were the departments with the greatest Gini coefficient ranges, and departments with lower rates had lower values for this (Table 2).

Spearman's correlation coefficient between Gini coefficient and API of malaria was 0.251 (p<0.01) whereas in the exponential regression model it was observed that the relationship between the epidemiological and social variable was significant and direct in all the 24 departments (r^2=0.1851; p=0.0001) (Figure 2). In the individual analysis per year, we found that such association did not show statistical significance.

Table 2 - Annual Parasite Incidence (API) for malaria estimated per the Gini coefficient range in analyzed Colombia departments.

Gini coefficient range	*API*	*95%CI*	
	(cases/1,000 inhabitants)	*IL*	*SL*
<0.4999	0.633	0.209	1.058
0.5000-0.5499	0.704	0.339	1.068
≥0.5500	5.802	1.745	9.895

95%CI=95% confidence interval, IL: inferior limit, SL: superior limit.

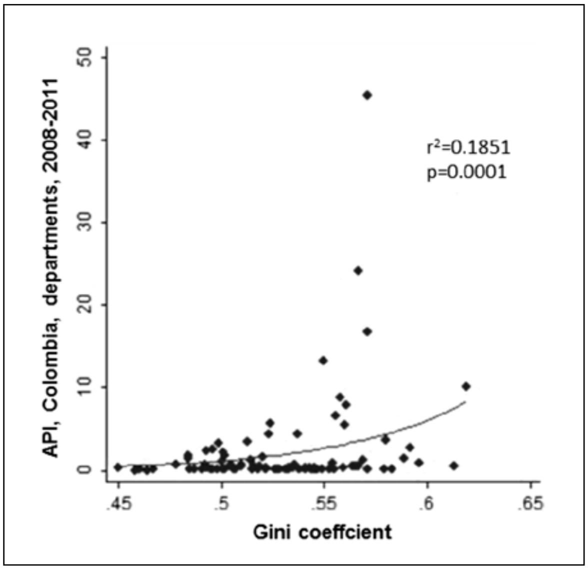

Figure 2 - Exponential regression between Gini coefficient and annual parasite incidence for malaria in analyzed Colombian departments.

Malaria and unsatisfied basic needs (UBN)

In 2011, the variation of unsatisfied basic needs index (UBN) among departments was 9.20% (Bogota D.C) to 79.19% (Choco), while API for the same year across the 27 endemic departments in national territory, included for analysis with UBN of 2011, the variation was 0.015 (Arauca) to 24.09 (Choco) cases/1,000 inhabitants.

In the estimation between API and UBN it is noted that the highest rates of the disease belonged to departments that presented higher UBN, while departments with lower API showed lower UBN (Figure 3).

Pearson´s correlation coefficient between UBN and malaria incidence was 0.577 (p<0.01), whereas in the exponential regression model it was observed that the relationship between the epidemi-

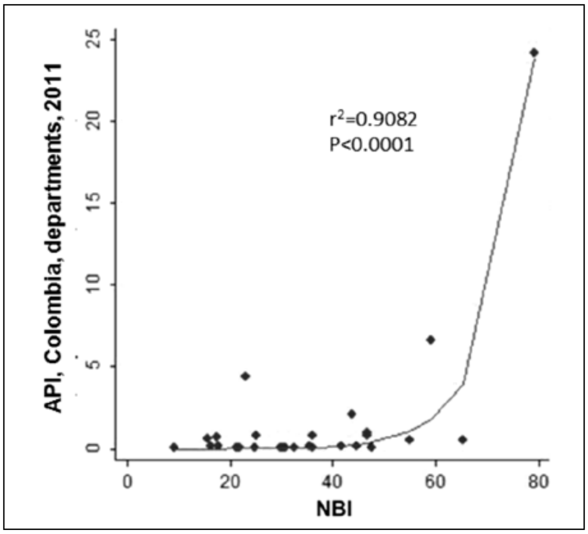

Figure 3 - Exponential regression between UBN index and annual parasite incidence for malaria in analyzed Colombian departments, 2011.

ological and social variable was significant and direct in all the 27 departments (r^2=0.908, p<0.01) (Figure 3).

Multivariate analysis

In a multivariate analysis (linear regression), including UBN (2011) and Gini (2011) as independent socio-economic variables, there was a significant association with the API (r^2=0.3642, p=0.0086). For Gini, its coefficient was 28.36 (95%CI -34.67 to 91.39, p=0.36) whilst for UBN 0.14 (95%CI 0.025 to 0.254, p=0.019).

DISCUSSION

Tropical infections linked to poverty affect several populations worldwide, thereby contributing to perpetuate poverty, among other factors, due to long periods of illness that decrease productivity, generate disabilities and stigma [16]. These diseases pose major obstacles for those countries looking to fight them in order to improve the life quality of its inhabitants. Malaria is an example of a disease whose occurrence indicates great inequalities in social issues, therefore these factors must be recognized with increasing force. Based on this, the use of indicators of social and economic nature can be associated with the behavior of the epidemiology of the disease, as it has been reported in this and other infectious diseases [14, 15].

This entire epidemiological overview has, among other things, a substantial relationship to other significant social issues, including migration of people exposed to infection, which has been investigated not only by tropical medicine, parasitology and public health but also by what is now called travel medicine [7]. Major impacts are evidenced by the lack of preventive educational materials and access to comprehensive health services and medicines. Other social determinants such as unemployment, political instability, low educational level, malnutrition and lack of access to adequate sanitation aggravate the problem [16].

In this study, the association between malaria morbidity and HDI in the years 2005-2011 was significant in 5 of the 6 countries under study, except for Venezuela where no statistical significance was observed between the two variables. In the case of the association between the incidence of malaria and UBN in 27 endemic departments of Colombia, a great statistical significance was presented, which evidenced that the more unsatisfied basic needs a population of a department had, the higher the annual parasite incidence was. Regarding the association held between the epidemiological indicator and Gini coefficient a direct relationship was found, in which it is established that with increasing economic inequality in the population, in 24 of the 27 endemic departments of Colombia, API also increased.

Among the analyzed countries (Colombia, Mexico, Ecuador, Peru and Brazil), it was observed that as the human development index increased there was a decrease in API. This was often associated to the efforts and plans implemented by the Ministries of Health of each government, especially in the context of fulfilling the Millennium Development Goals (6th goal) [17]. Nevertheless, in the case of Venezuela, despite showing an "apparent" increase in the HDI, a decreased in API was not observed. On the contrary, it reached levels not seen since before the 1970s, and the trend in the last 15 years is continuing its considerable increase [6, 18]. In this case, these results may be related to the fact that Venezuela is a country where the last two governments have declined significantly its investment in prevention and mitigation of malaria, whereby the disease has virtually no control and gradually increases, with over 300,000 cases in 2017 [5]. In addition, HDI values belonging to this country may not necessarily reflect the economic reality, which would help to explain the reason of the inconsistency of the results compared to other countries [6]. Also it is noticeable that the HDI can have large variations within the country in different territories [18-20].

Regarding the results on the association between UBN and API at the departments in Colombia, it can be said that it is a reflection that poverty is closely related to the incidence of tropical and parasitic infectious diseases such as malaria, since the department of Choco, which has the highest rate of UBN nationwide, shows in turn the largest API; it can be deduced that the conditions in which the population lives in this department are conducive to the transmission of the parasite. Furthermore, in departments such as Chocó, a considerable proportion of the population lives in rural areas with high presence of *Anopheles* species capable of transmitting malaria.

By contrast, Bogota (the capital of Colombia) has the lowest UBN of the departments, which is reflected in a low API (0.03, 2011); because of unfavorable climatic and ecological conditions for the proliferation of the vector (is 2650 masl) as well as social and sanitary conditions that allow greater access to basic services and health care, all this combined with lower poverty rates, thus having only imported cases and sporadic cases in indigenous people through different forms of transmission to the vector (*e.g.*, transfusions and pregnancy) [21, 22].

When analyzing the Gini coefficient in the departments of the country by the period 2008-2011, it was also found that Chocó has the highest value (0.62), reflecting the existing unequal distribution of resources, and mainly the low investment made in health and control of endemic diseases. Although the economy of Choco has improved steadily, this growth has not been enough to close the gap in terms of poverty, basic health, education and nutrition, making this department the most vulnerable and endemic to malaria in Colombia [19].

Although the employed approach would be considered over-simplistic, it has not specifically explored in Colombia and scarcely in Latin America. Certainly, other variables (altitude, climatic suitability to the vector, malaria control intervention over time, population movements, among others) should be included in further detailed studies in order to be able to develop models with multi-variate analysis. The dynamic decreasing situation of malaria epidemiology in most countries require more accurate data and statistic approaches to account for individual countries' trend when assessing the relationship between malaria indicators and socio-economic indicators. Unfortunately, such socio-economic indicators are not widely available and are not yet enough uniform across countries in Latin America.

Currently, the Ministry of Health in Colombia has developed and begun to implement the Ten-Year Public Health Plan (*Plan Decenal de Salud Pública*, PDSP, 2012-2021), which is based on the conceptual framework of social determinants of health [23]. The PDSP include the dimension of healthy life and communicable diseases, in which one of its main components is "endemic and epidemic diseases". This component objective is "To contribute to reducing the burden of Vector Borne Diseases, including malaria", where it aims by 2021 to gradually reduce malaria mortality by 80% in all territories (compared to 2012) [20].

That is why it is important to consider the social vulnerability that may have certain departments in malaria endemic countries, and promote not only health interventions but also social ones, which ultimately lead to improved living and health conditions, in the specific context of achieving malaria elimination and eventual eradication [21].

In conclusion, social conditions significantly influence malaria, still a persistent tropical parasitic vector-borne disease, with multiple implications in terms of the considerations for its epidemiology, education, prevention and control in areas where still malaria needs to be focused in terms of intense and final interventions to reduce its impact and achieve in the future its elimination [3-6, 14]. Then, more research is needed to get closer to those goals [3].

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Conflict of interest

This study was previously presented in part at the 17th Pan-American Congress of Infectious Diseases, Quito, Ecuador, May 15-19, 2015, Selected for Oral Session Presentation (ITV-5).

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