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Mapping malaria in municipalities of the Coffee Triangle region of Colombia using Geographic Information Systems (GIS)

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Summary Geographical Information Systems (GIS) have been used extensively for the development of epidemiological maps of malaria but not in the Coffee Triangle region of Colombia, endemic for *P. vivax*, *P. falciparum* and *P. malariae*. Surveillance case data (2007—2011) were used to estimate annual incidence rates per *Plasmodium* spp. (cases/100,000 pop) to develop the first malaria maps in the 53 municipalities of this region (departments Caldas, Quindío, Risaralda). The GIS software used was Kosmo Desktop 3.0RC1®. Thirty thematic maps were developed according to the municipalities, years, parasite etiology, and uncomplicated and complicated cases. A total of 6582 cases were reported (6478 uncomplicated and 104 complicated, 77.8% Risaralda), for a cumulated rate of 269.46 cases/100,000 pop. Among

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uncomplicated cases, 5722 corresponded to *P. vivax* (234.25 cases/100,000 pop), 475 to *P. falciparum* (19.45 cases/100,000 pop), 8 to *P. malariae* (0.33 cases/100,000 pop) and 273 mixed (*P. falciparum*/*P. vivax*) (11.18 cases/100,000 pop). The highest rate reported was in the more undeveloped and rural municipality of Risaralda (Pueblo Rico, 57.7 cases/1000 pop, 2009). The burden of disease was concentrated in one department (>75% of the region). The use of GIS-based epidemiological maps helps to guide decision-making for the prevention and control of this public health problem that still represents a significant issue in the region and the country, particularly in children.

Introduction

Malaria still continues to be a significant public health problem in terms of morbidity and mortality, particularly in children in Africa, where more than 90% of global cases occur. However, the burden of malaria is still significant in regions such as Southeast Asia and Latin America, with moderate to low levels of transmission, particularly due to *Plasmodium vivax* [1,2]. Thus, new tools oriented to improve disease control and surveillance, such as epidemiological maps, are still required in countries of such endemic regions of the world.

Historically, one of the first map applications was used in epidemiology in 1832 in the report titled ''Effects of Cholera-Morbus in Paris and Rural Communes of the Seine Department'' (Rapport sur la Marche et les Effets du Choléra-Morbus dans Paris et les Communes Rurales du Departement de la Seine) [3]. In this report, French Geographer Charles Picquet made a map with the 48 districts of the city of Paris, France, using different tones depending on the percentage of cholera deaths per 1000 habitants. Additionally, the father of modern epidemiology, Dr. John Snow, utilized a map of 1854 to spatially identify cases of cholera in London, United Kingdom [3].

Recently, Geographical Information Systems (GIS) have emerged as an innovative and important component and tool in the control of many projects in public health and epidemiology, particularly in infectious diseases, including malaria [4,5]. One of the most useful functions of GIS in epidemiology continues to be its utility in basic mapping and its powerful ability to make geographical analyses. Visual analyses (mapped evidence) strengthen the ability of epidemiologists to make decisions in endemic areas. The wide use of GIS in malaria programs is a promising prospect; however, its implementation has occurred slowly in Latin American countries. In terms of their applicability to the field of tropical medicine, GIS have developed significantly in the last years [6].

The GIS are the organized integration of hardware, software, geographic data, methods and human resources designed to capture, store, standardize, manipulate, analyze and display geographically referenced information to facilitate complex planning and geographical management [4–7]. GIS are tools that allow users to create maps, interactive queries, analyze spatial information, edit data, and present and exchange the results of these operations in scientific studies that aim to show the geographic behavior of a disease or examine health indicators.

Although the use of GIS in malaria has been extensively reported in the rest of the world, this is not the case of Latin America, particularly Colombia and its Coffee Triangle region [8–10]. In this region, Brazil and Colombia are the major sources of malaria cases [2]. Both countries are exerting significant effort to reduce the burden of disease [2], but still require focused efforts in the control of disease, including the wide use of GIS. In the Americas, substantial achievements have been reached toward reduction of this endemic disease, with a 58% decrease in malaria cases (from 1.1 million in 2000 to 469,000 in 2012) [2]. However, this reduction has not been observed in all of the endemic countries. Venezuela, Haiti, and Guyana are clear exceptions to those efforts [2,11,12].

As part of the enhancements to malaria control efforts, the regional information system, together with the Universidad Tecnologica de Pereira (through the Research Group Public Health and Infection) and Health Secretary of Risaralda, are working on the academic analysis of epidemiological information, including malaria. In this setting, this study aims to develop GIS-based epidemiological maps for malaria in the Coffee

Figure 1 The Coffee Triangle region of Colombia and its relative position within the country.

Triangle region of Colombia. This area consists of three departments and 53 municipalities with endemic areas of disease for *P. vivax*, *P. falciparum* and *P. malariae*. The current analyses cover the period from 2007 to 2011.

Until now, this region has not been mapped for malaria or any other infectious diseases, and there are few studies on the epidemiology of infectious diseases in this region [13—15].

Methods

Colombia is a South American country composed of 32 departments (main administrative level) (Fig. 1). These departments are grouped by regions, and one such region located in the Andean area is called the Coffee Triangle (Fig. 1). This is a topographical region including three departments (Caldas, Quindío and Risaralda) with 53 municipalities and a total population of 2,463,507 in the year 2011. Among these municipalities, located in three departments, there is high variation with regard to development and poverty. For reference, in 2011, Bogota, the country's capital city, had an index of unsatisfied basic needs (proportion of homes living with at least one unsatisfied basic need) of 9.2% (optimum value is 0%); however, Risaralda had an index of 17.5%, Caldas 17.8%, and Quindío 17.6%. Among the municipalities, the rural area of Pueblo Rico had an index of 62%. The most urban municipalities in the region are Pereira (Risaralda), Manizales (Caldas), and Armenia (Quindío), the capital cities of the three departments, but in every municipality of the region, the capital is not considered to be a rural town or area; thus, all municipalities are considered to have rural and urban areas.

For this study, the epidemiological data were collected from the surveillance system, obtaining the number of cases for each municipality by year (2007—2011). Data were obtained with agreement from the Ministry of Health through the Protection Information System (SISPRO) through a Client Access server, which allowed us to retrieve cases from the SISPRO server to a local computer. SISPRO surveillance data used for this study were gathered from confirmed cases that have been revised in terms of data quality, initially from data from the National Institute of Health of Colombia and later by SISPRO and its Data Cubes system. Data were processed for this study from 53 primary notification units, one per municipality, later consolidated into 3 secondary notification units at the department level, and finally centralized in Bogotá in the SISPRO system. Currently revised and consolidated data are available for the period from 2007 to 2011. Finally, the quality of malaria surveillance in Colombia has been described elsewhere [11].

Malaria case management in Colombia is focused on early detection, i.e., the diagnosis of malaria cases and the prompt and effective treatment of symptomatic patients. This is based on an extended diagnostic network with >1700 laboratories and 1195 microscopists in the country, including the Coffee Triangle region, where most cases are detected by passive surveillance using thick blood smears (TBS), although there is a growing use of rapid diagnostic tests (RDTs) [11,16].

Using official reference population data (National Administrative Department of Statistics, DANE), 1590 estimates of annual incidence rates for all of the municipalities during the study period were calculated (53 municipalities, for 5 years, for 6 clinical forms and etiological agents) (cases/1000 pop) to develop the first maps of malaria in the Coffee Triangle region of Colombia (departments Caldas, Quindío, Risaralda). Thirty thematic maps were developed according to municipalities, years and parasite etiology (*P. falciparum*, *P. vivax*, *P. malariae*, *P. falciparum*/*P. vivax*), as well uncomplicated and complicated cases.

For this study and the malaria surveillance program in Colombia, a complicated case was defined as any patient with a probable case of malaria complicated by the presence of asexual forms (trophozoites/schizonts) of *P. falciparum* confirmed by parasitological examination and in whom another etiology has been ruled out, or any patient with a confirmed case of malaria with >50,000 parasite asexual forms/μL (hyperparasitemia) and presenting one or more of the following clinical complications: cerebral malaria, renal complications, lung or respiratory distress syndrome, shock, hepatic jaundice, hypoglycemia, hyperemesis, hyperpyrexia, severe anemia and death [11]. Additionally, if the patient presented with complications that corresponded to *P. vivax*, they were also classified as complicated according to the new WHO definitions regarding severe malaria due to *P. vivax* [17]. The rest of the cases with diagnoses of malaria that were not complicated were classified as uncomplicated.

Microsoft Access® was used as the software platform to design the spatial database to import incidence rates by municipalities, years, etiology and clinical forms to the GIS software. The Client GIS open source software used was Kosmo Desktop 3.0 RC1®. To access to geographic data required and share results with institutions, support was provided by the spatial data infrastructure for the Coffee Triangle region by the Regional Information System. The shapefiles of municipalities (.shp) were linked to a data table database through spatial join operations to produce digital maps of the annual parasite index (API) [18].

Results

During the study period, 6582 cases (6478 [98.42%] uncomplicated and 104 [1.58%] complicated) (77.8% from one department, Risaralda) were reported, for a cumulative rate of 269.46 cases/100,000 pop. Among the uncomplicated cases, 5722 (88.33%) corresponded to *P. vivax* (234.25 cases/100,000 pop), 475 (7.33%) to *P. falciparum* (19.45 cases/100,000 pop), 8 (0.12%) to *P. malariae* (0.33 cases/100,000 pop) and 273 (4.21%) mixed (*P. falciparum*/*P. vivax*) (11.18 cases/100,000 pop). The highest rate was reported in the less developed and more rural municipality of one department (Pueblo Rico, Risaralda) with 57.7 cases/1000 pop (717 cases in 2009).

Fig. 2 shows the geographical and temporal variation in uncomplicated malaria incidence rates expressed as the annual parasite index (API) (cases/1000 pop). Between 2007 and 2011, a considerable reduction was seen in the API, with just one municipality remaining in 2011 with more than 5 cases/1000 pop — the town of Pueblo Rico in the department of Risaralda.

Fig. 3 shows the geographical and temporal variation in malaria incidence rates expressed as the annual parasite index (API) (cases/1000 pop) for *P. vivax*, *P. falciparum*, *P. malariae* and mixed infection (*P. falciparum*/*P. vivax*). A significant reduction in *P. vivax* incidence was also seen, with just one municipality with more than 5 cases/1000 pop remaining in 2011 — the town of Pueblo Rico in the department of Risaralda. This was the only municipality with a *P. falciparum* incidence above 0.09 cases/1000 pop (Fig. 3). *P. malariae* remained under 0.09 cases/1000 pop throughout the entire period. Mixed cases only occurred in the Pueblo Rico municipality (Fig. 3).

Discussion

According to the latest World Health Organization (WHO) estimates, 198 million cases of malaria occurred globally in 2013 (uncertainty range 124—283 million) and the disease led to 584,000 deaths (uncertainty range 367,000—755,000) [19]. The burden was heaviest in the WHO African Region, where an estimated 90% of all malaria deaths occur, and in children aged under 5 years, who account for 78% of all deaths. However, in the Americas, although a decrease of 76% was achieved between years 2000 and 2013, over 700,000 cases were reported in this continent during that year [19]. In Colombia, there was a clear trend in reduction from 2007 (125,262 cases) to 2013 (51,722 cases) [2,19]. The most endemic departments in the country are Antioquia, Córdoba, Chocó, Valle, Guaviare, Nariño and Bolivar [11]. The Coffee Triangle (Risaralda,

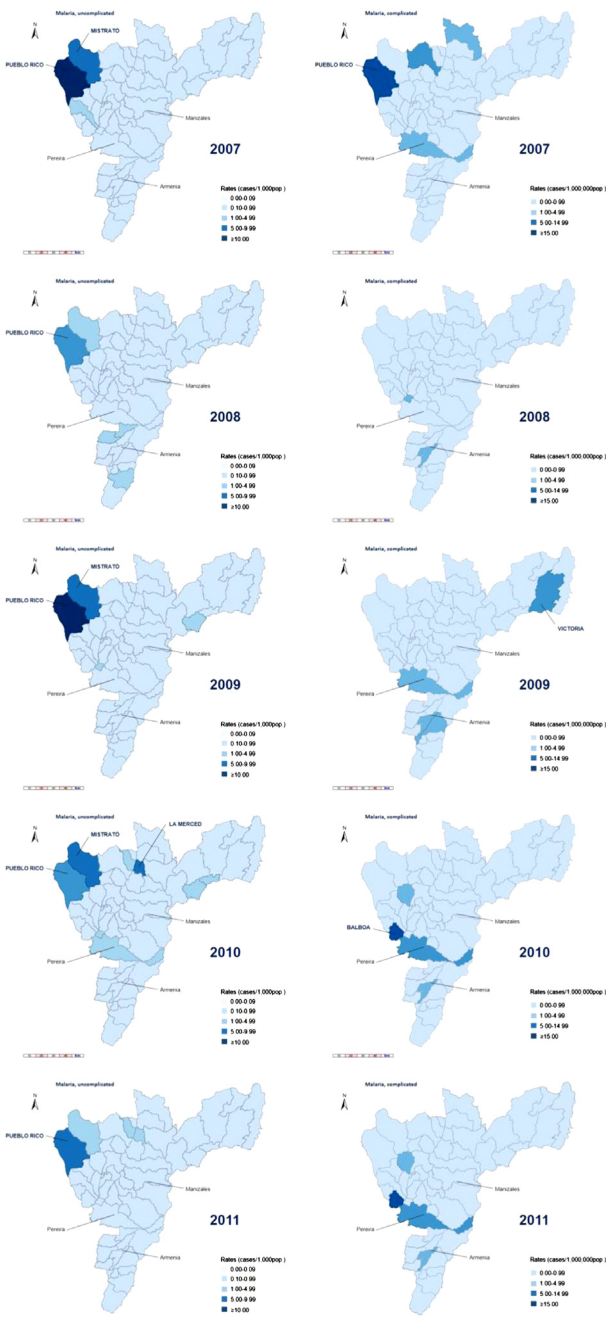

Figure 2 Uncomplicated malaria (left) and complicated malaria (right), API, Coffee Triangle region, Colombia, 2007—2011.

Caldas and Quindío), then, is considered a region of low transmission.

Although there have been significant reductions in malaria incidence in the Americas [12], this tropical disease continues to be a public health threat in many countries and certain areas [20], particularly affecting the most vulnerable populations, in locations where people are living in rural and poverty conditions [21]. This is the case for the endemic zones of Colombia, such as those in the Coffee Triangle region, where the malaria burden is still significant in rural municipalities.

In this setting, basic knowledge on infectious disease epidemiological tools should be highly extended to improve the surveillance and control of this parasitic disease [4]. However, the use of GIS in epidemiology and particularly in malaria epidemiological research is rare in Latin America, especially in Colombia [4,6,7,22]. Thus, the current study offers a clear geographical approach to the distribution of malaria over a region in Western Colombia, including 3 departments and 53 municipalities.

Until now, studies using GIS in malaria in Latin America have been published mostly from Brazil [22—25] and Venezuela [26]. There are few previous reports specifically from Colombia [11,22]. In the case of Brazil, GIS studies in malaria have focused on geographically characterizing the habitat suitability of the vector *Anopheles darling* [25], the patterns of malaria and its determinants in rural settlements [23], as well as the use of GIS analysis and logistic regression as a tool to identify and analyze the relative likelihood and its socio-environmental determinants of malaria rural settlements [24]. In Venezuela, the approach has been to develop GIS based on official cartography with thematic overlays depicting malaria distribution, socio-economic conditions, basic environmental information and specific features associated with the natural wetlands present in one area of malaria transmission [26]. In the case of Colombia, the only specific previous report on a national scale targeted the production of a new high-resolution malaria risk map for Colombia and the surrounding areas of Ecuador, Venezuela, Panama, Brazil, and Peru based on expert opinion guidance and participatory decision-support methods implemented with GIS raster-based software, including data up to 2009 [22].

Remote sensing (RS) and GIS have proven to be an innovative and important component in studies of public health and epidemiology and have been used for monitoring, surveillance and spatial modeling of diseases, such as malaria [24,27]. These tools provide examples of how Earth observation satellites can be used in studies of ecology and the prediction of malaria, and have contributed examples for the mapping of malaria vectors using mid-resolution RS-imagery [24,27]. With precise year-to-year malaria epidemiological maps, such as those provided here, focused interventions and planning for integrated vector management and control would be carried out in the important municipalities for better management and control of the disease [28].

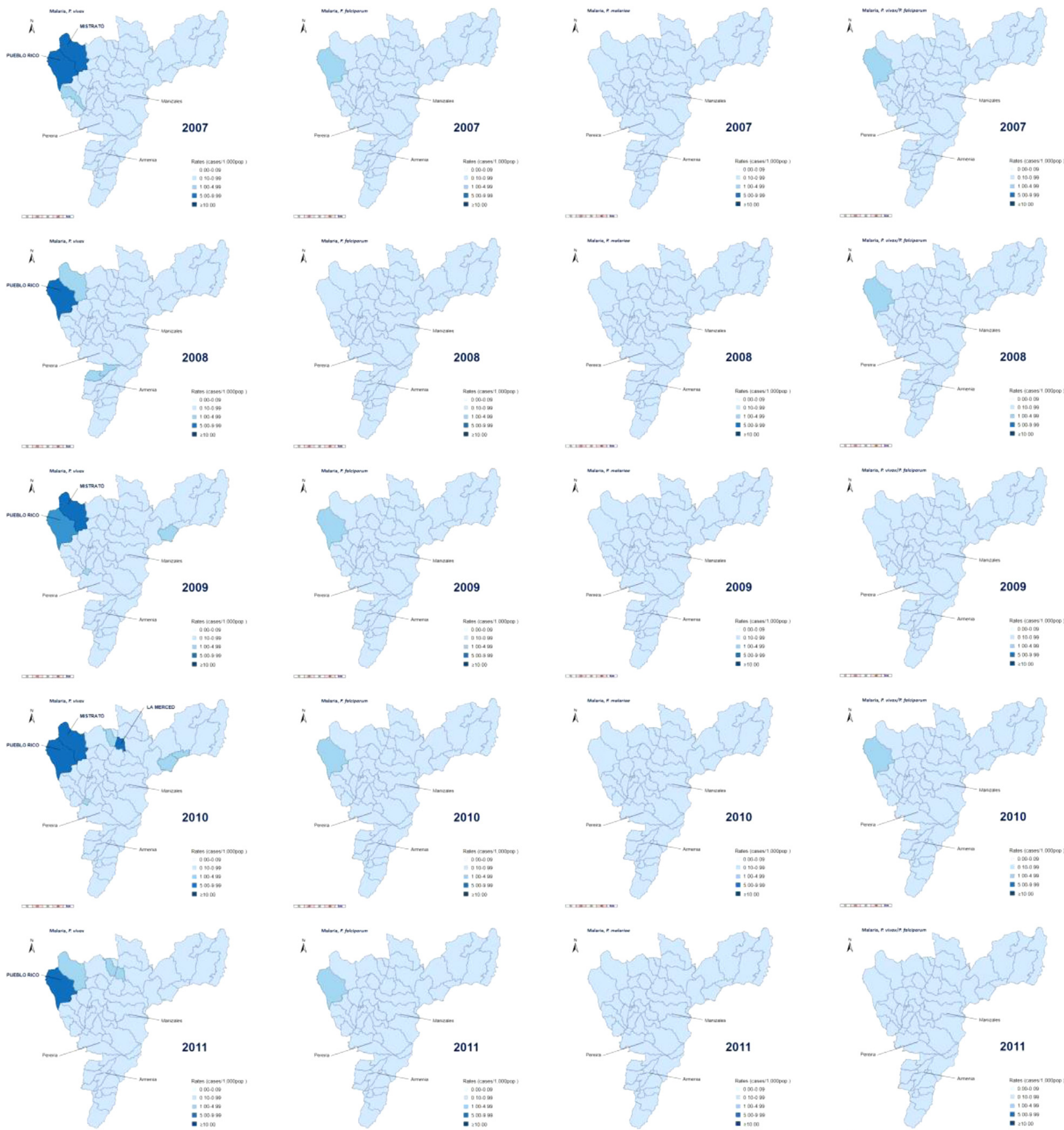

Figure 3 Malaria due to *P. vivax* (left), *P. falciparum* (center left), *P. malariae* (center right) and *P. falciparum*/*P. vivax* (right), API, Coffee Triangle region, Colombia, 2007—2011.

Ideally, all of the health authorities and programs related to malaria control would have and routinely use GIS to support public health surveillance and epidemiological investigations [29]. The development of malaria maps for the Coffee Triangle would be useful for local health authorities as well for physicians assessing imported cases from this region of Colombia when investigating the epidemiological risk according to the geographical destination, which is also part of the post-travel medical consultation [30].

In Colombia, although the National Malaria Control Program has progressed toward a better understanding of malaria epidemiology in endemic areas, GIS-based annual epidemiological maps for malaria in the municipalities of the Coffee Triangle region of Colombia were not developed until recently [11]. This set of 30 malaria maps (according to municipalities, years and parasite etiology, *P. falciparum*, *P. vivax*, *P. malariae*, *P. falciparum*/*P. vivax*, as well as uncomplicated and complicated cases) will be useful immediately for the biomedical and scientific community in the country, as well as for the medical education of regional malaria epidemiology. In addition, this information will be included in the spatial data infrastructure for the Coffee Triangle region supported by the Regional Information System, which would provide maps through standardized web services, such as OGC (Open Geospatial Consortium). The infrastructure is accessible online and makes the access, interchange, visualization, analysis, and monitoring of data possible, facilitating decision making by government institutions.

Furthermore, based on this GIS approach, other studies linking the impact of ecological and social variables should be conducted in the region, not only describing the epidemiological distribution pattern by year but also assessing the influences of such variables on disease incidence [23—25]. Other demographical variables, such as age and ethnic groups, in countries such as Colombia would also be useful in the geographical assessment of malaria epidemiology.

These studies should be focused particularly in those areas where transmission is still high, such as Pueblo Rico in Risaralda (Fig. 2), where incidence rates are as high as more than 10 cases/1000 pop, including uncomplicated and complicated cases, mainly due to *P. vivax*. The Pueblo Rico index of unsatisfied basic needs (UBN) (proportion of homes living with at least one unsatisfied basic need) was 62% in rural areas for 2011. Its population includes three ethnic groups: mestizo (54%), afro-colombians (14%) and Amerindians (Emberá) (32%), with a high level of illiteracy and people living in rural areas. A similar situation was seen, although to a lesser degree, in Mistrató, which presented a UBN of 55% in rural areas for 2011. Although considerable variations in API between 2007 and 2011 occurred in both municipalities, it should be further studied along with other factors, including the influence of climate change and variability, which has been associated with malaria in other areas of the country [31]. As a consequence, further studies should analyze the potential influences of climate change and variability on malaria epidemiology in the Coffee Triangle region.

In this tropical epidemiological scenario, clinical studies addressing that topic would also be useful, given that few studies in the country have assessed the epidemiology of severe *P. vivax* malaria [11,32], which has been largely documented and reported in other countries of Latin America, such as Venezuela [33—35] and Brazil [36—38], as well in Asia [39—41].

Finally, these preliminary GIS-based epidemiological maps for malaria will also be useful in the future when planning for the development of trials with vaccine candidates, which are also under development today, not only for *P. falciparum* but also *P. vivax* malaria in Latin America and in Colombia [42—44].

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Competing interests

The authors have no conflicts of interest to declare.

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