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Original article

Mapping the ecoepidemiology of Zika virus infection in urban and rural areas of Pereira, Risaralda, Colombia, 2015–2016: Implications for public health and travel medicine☆

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ABSTRACT

Objective: Geographical information systems (GIS) have been demonstrated earlier to be of great use to inform public health action against vector-borne infectious diseases.
Methods: Using surveillance data on the ongoing ZIKV outbreak from Pereira, Colombia (2015–2016), we estimated incidence rates (cases/100,000 population), and developed maps correlating with the ecoepidemiology of the area.
Results: Up to October 8, 2016, 439 cases of ZIKV were reported in Pereira (93 cases/100,000 pop.), with highest rates in the South-West area. At the corregiments (sub-municipalities) of Pereira, Caimalito presented the highest rate. An urban area, Cuba, has 169 cases/100,000 pop., with a low economical level and the highest Aedic index (9.1%). Entomological indexes were associated with ZIKV incidence at simple and multiple non-linear regressions ($r^2 > 0.25$; $p < 0.05$).
Conclusions: Combining entomological, environmental, human population density, travel patterns and case data of vector-borne infections, such as ZIKV, leads to a valuable tool that can be used to pinpoint hotspots also for infections such as dengue, chikungunya and malaria. Such a tool is key to planning mosquito control and the prevention of mosquito-borne diseases in local populations. Such data also enable microepidemiology and the prediction of risk for travelers who visit specific areas in a destination country.

1. Introduction

Zika virus (ZIKV) has caused epidemics during 2015–2017 in different countries of the Americas, with more than 50 countries/territories affected in this region, from 148 globally affected in any form (including imported cases) [1,2]. After Brazil, probably Colombia is the second most affected country in the region [3–5],

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with over 100,000 cases having been reported from this Northern South American country, reflecting overall incidence rates above 150 cases/100,000 [3]. However, as previously demonstrated; when detailed analyses, at primary, secondary and tertiary territory levels are conducted, incidence rates found tend to be highly variable, and higher [3,6–8].

Early-developed ZIKV epidemiological maps for Colombia using geographical information systems (GIS) at high incidence departments, such as La Guajira [8] and Sucre [7] (Caribbean region), Tolima [6] and Valle del Cauca [3] (Central and Western region), Santander and Norte de Santander (Northeastern area) were published, but these did not include ecoepidemiological analyses that would allow to a better understand the pattern of temporo-spatial distribution of ZIKV infection in these newly-endemic areas. This has been shown to be significant in other vector-borne and arboviral diseases, such as dengue [9–12], where multiple studies have documented the influence of climate variables on its epidemiology, including reports from Colombia [9–12]. Even more, there is a clear need from public health authorities to develop and use GIS-based maps not just for ZIKV, but also for dengue and chikungunya, which are co-circulating in Pereira, in Risaralda, as well Colombia and Latin America at the same time, even co-infecting [1,13,14].

ZIKV and other arboviral diseases could be associated with multiple factors including changes in environmental and social conditions that may influence their epidemiology [15–18]. Up to date, there is a lack of studies assessing eco-epidemiological factors that would be related to ZIKV in Latin America, including Colombia, during ongoing epidemics [19].

Eco-epidemiological information is of utmost importance, which should include the availability of risk maps to address recommendations related to prioritize interventions as well for identification of areas of risk by visitors or people returning from visiting specific places [8,11,20,21]. Linked to educational programs and other interventional measures [10,20–23], eco-epidemiological data should be considered in an integrated and systematic approach for ZIKV and other arboviral diseases control by national and local health authorities, as well at the community level in order to reduce and mitigate the disease impact.

In the current study, we set out to obtain estimates of ZIKV infection incidence rates in the municipality of Pereira, the capital of Risaralda department and the major city of the Coffee-Triangle region of Colombia; which included the development of GIS-based maps for disease, as well as its ecosystems, rainfall, economical classification as well as entomological indicators, among other ecoepidemiological aspects, in 2015–2016.

2. Methods

Scientific publications using GIS for development of epidemiological maps in ZIKV in Latin America are still lacking [6–8,20,24]. Pereira is the major city of the Coffee-Triangle region, which includes three departments (first administrative territory level) and 53 municipalities (second administrative territory level). This is the capital of Risaralda (957,250 habitants in 2016), a department surrounded by six other western departments (Antioquia, Caldas, Tolima, Quindio, Valle del Cauca and Choco) [10,25]. Pereira is constituted by two major areas, urban and rural; the first consisting of 20 communities (the city) and the second by 12 corregiments (sub-municipalities) (both, tertiary administrative territory level) (Fig. 1). There is a total population of 472,023 habitants in 2016, per the national statistics department (www.dane.gov.co). The communities of Rio Otun, Centro, San Joaquin, Del Café, Boston, El Oso, Consota and Cuba, are the most populated areas of the municipality, making up for 51% of its population (Fig. 2).

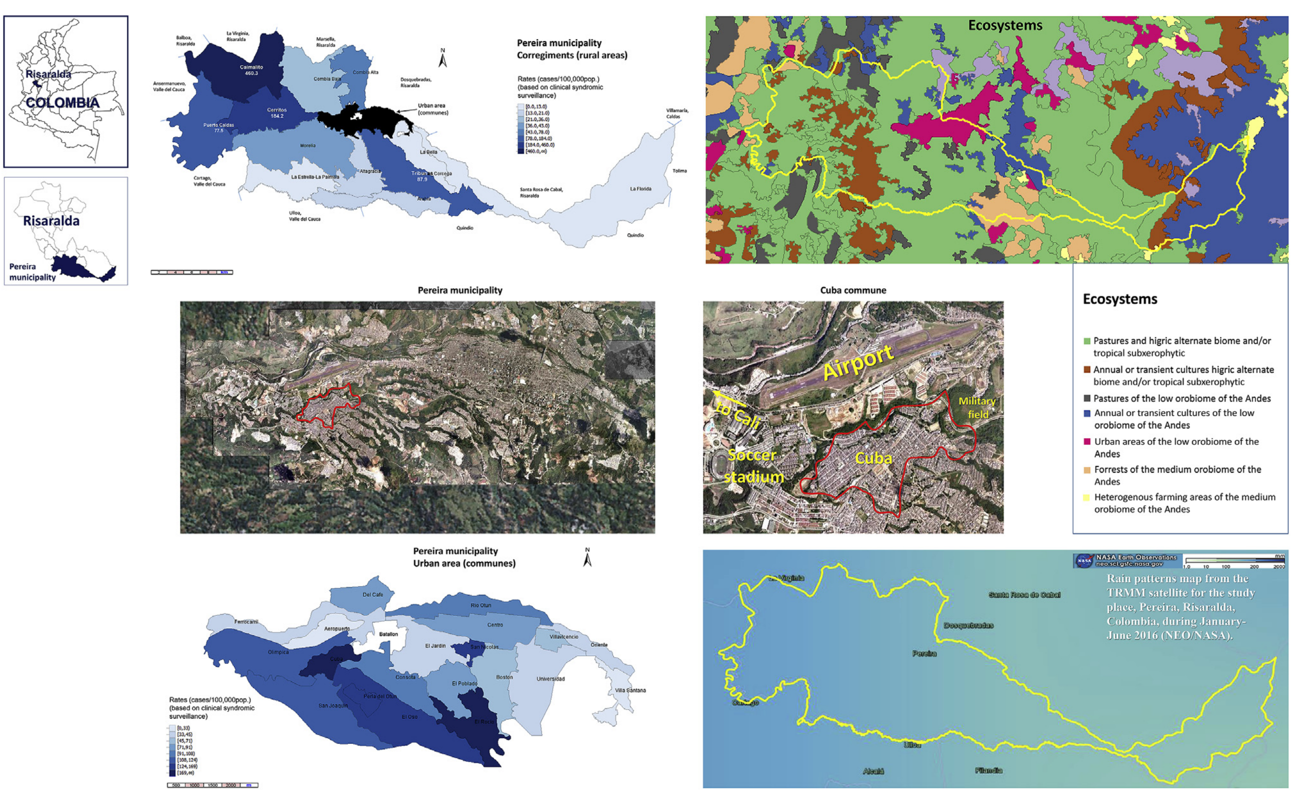

Fig. 1. Geographic distribution of ZIKV incidence rates (cases/100,000pop) in Pereira municipality, Risaralda department, Colombia, 2015–2016. Ecosystems and rainfall patterns for the municipality are shown. Cuba community within the municipality is shown from an aerial photography. (*Up to epidemiological week 40th, October 8, 2016).

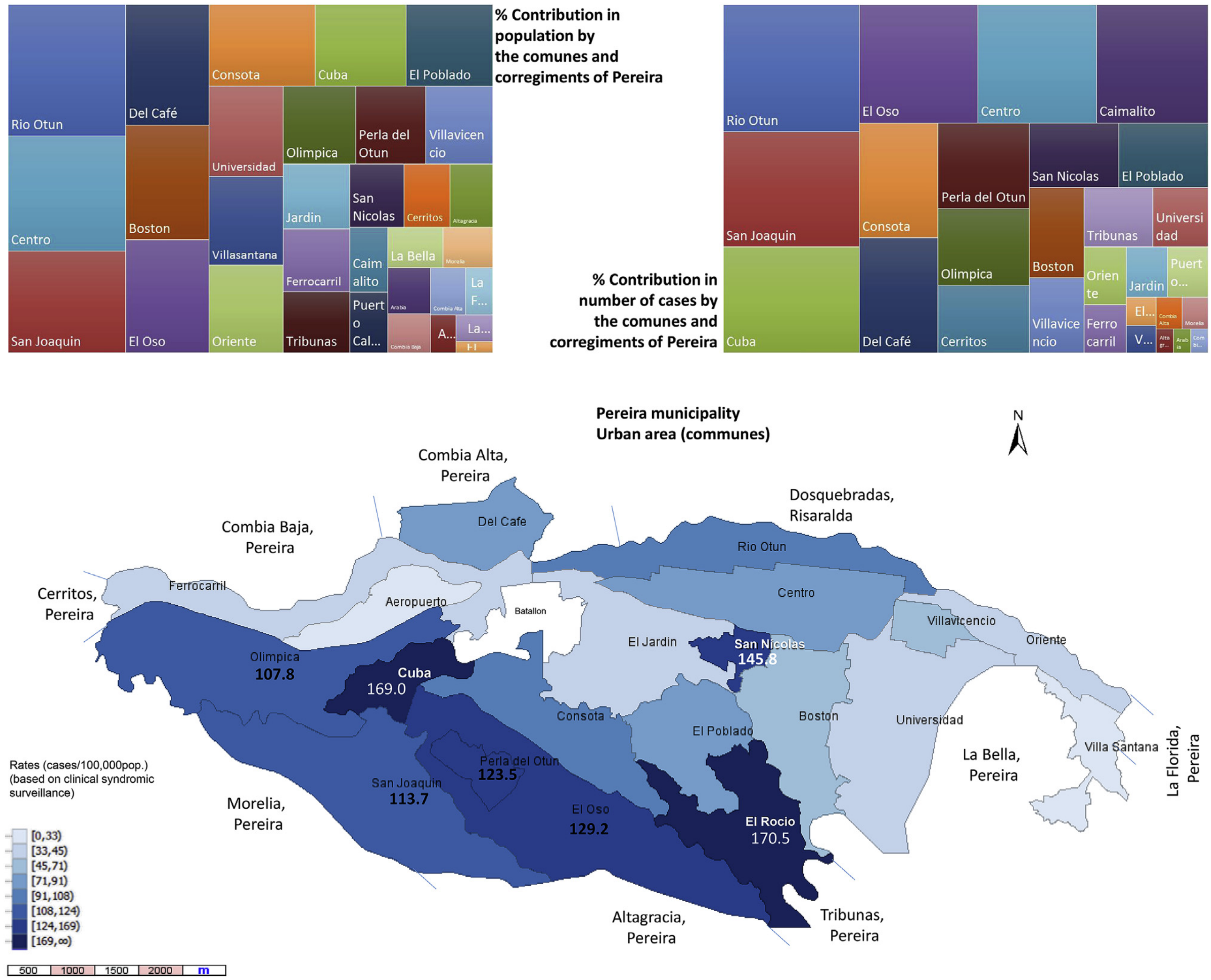

Fig. 2. Distribution of population and cases by communes and corregiments of the Pereira municipality and the GIS-based map of ZIKV incidence rates (cases/100,000pop) in the urban area (communes) of Pereira, Risaralda, Colombia, 2015–2016. (*Up to epidemiological week 40th, October 8, 2016).

Surveillance case data (2015–2016) by Colombia's National Institute of Health were used to estimate the cumulative incidence rates based on 2016 reference population data on ZIKV infections (cases/100,000) and to develop the first maps in Pereira and its communes (urban area) and corregiments (rural area). As described before [3], data processed for this study originated from the primary notification units (healthcare institutions) at communes and corregiments (32), and were later grouped and consolidated at the municipality level. Determination of ZIKV infection included syndromic and/or laboratory surveillance (clinical definition of fever, rash, conjunctivitis and arthralgias in a place with previously ZIKV circulation; at least one case confirmed by RT-PCR). This clinical definition has been recommended by the World Health Organization, the Pan American Health Organization, as well as the US Centers for Disease Control and Prevention. The total number of cases also included those in which clinical diagnostic criteria, i.e. the case definition was met; but which were reported in a municipality without RT-PCR confirmation. After single case confirmation by RT-PCR in a municipality, patients not classified as risk groups (pregnant women, children <1 y-old, people >60 y-old and patients with comorbidity) were diagnosed per clinical definition [3].

Entomological data was also collected and considered for the analysis. Aedic (house), deposit (container) and Breteau indices for the municipality of Pereira by communes and corregiments were collected between 2013 and 2015 by the team of the Secretary of Health, led by two of the authors (PR and JT). The Aedic or house index (AI) is defined as the percentage of houses infested with larvae and/or pupae. The deposit or container index (DI) is defined as percentage of water-holding containers infested with larvae or pupae. The Breteau index (BI) is defined as the number of positive containers per 100 houses inspected [26].

Microsoft Access® software was used to design the spatial database to import incidence rates by communes and corregiments at Pereira to the GIS software. The Client GIS software open source used was Kosmo Desktop 3.0 RC1® (SAIG S.L., Madrid, Spain). For access to geographic data required and sharing results with institutions, support was provided by the spatial data infrastructure for the department by the Regional Information System of the Coffee-Triangle ecoregion (SIR) [3]. The shapefiles of communes and corregiments (.shp) were linked to a database through spatial joined operation to produce digital maps of the incidence rates for the Aedic index and the other thematic maps for the study area. The SIR provided also the shapefiles of regional ecosystems and hydrographical maps to be linked to the study area. An aerial photography of Pereira was obtained from the Geographical

Institute Agustin Codazzi, Colombia. Data of forest density, economical classification and economical activities for Pereira, was provided by the GIS system of the municipality of Pereira. Monthly satellite images for Total Rainfall and Surface Temperature were obtained from the Tropical Rainfall Measuring Mission (1 month - TRMM) imagery database NASA Earth Observations (NEO, NASA, USA) (http://neo.sci.gsfc.nasa.gov/) and analyzed for Pereira with the software Google Earth®, as described before [10].

Non-linear Poisson simple and multiple regression models were used for determining potential associations between the 2013–2015 mean entomological indexes and the incidence rates of ZIKV infection. Statistical significance was defined as $p < 0.05$. Statistical analyses were performed on Stata 14.0®.

3. Results

Up to October 8, 2016, 439 cases of ZIKV were reported in Pereira (33.85% of Risaralda department), for cumulated rates of 93/100,000 (Table 1). Of the total number of cases, 50 (11.4%) were laboratory confirmed by RT-PCR.

From the total number of cases, 77.7% occurred in the urban area, with a global incidence rate of 85.5 cases/100,000 (Table 1) (Fig. 1), and 94.1/100,000 in the rural area (1.1 times higher). Rates differed from 0 to 460/100,000 (Caimalito, rural, 7.3% of the municipality cases), followed by Cerritos (rural, 184.2 cases/100,000; 3.4%) (Fig. 1), El Rocio (urban, 170.5 cases/100,000; 0.5%) (Fig. 2), Cuba (urban, 169.0 cases/100,000; 8.0%) and San Nicolas (146/100,000; 3.2%) (Table 1, Fig. 1). These five territories (out of 32), reported 22.3% of cases of the municipality (Table 1) (Fig. 2).

Burden of ZIKV infection in the city has been concentrated in its South-West area, where communes have reported >100 cases/100,000 (Fig. 2). In the case of the corregiments of Pereira, Caimalito, which borders with La Virginia, a municipality of Risaralda with high transmission of ZIKV infection (1043 cases/100,000) and Cerritos, which borders with the urban area of Pereira, concentrated 10.7% of the cases (Fig. 1) (Fig. 2). This rural area had a higher rainfall pattern with very dense vegetation ecosystems (pastures and cultures) (Fig. 1). The densely populated, low economic level (level 3) (Fig. 3) and mainly residential area of Cuba and it has 169 cases/100,000 (Fig. 4); this is close to the airport, the military field of the city and the major soccer stadium (Fig. 1), as well with the highest Aedic index of the urban area (9.1%) (Fig. 5).

Eight of the communities and two of the corregiments have rates that are higher than the incidence rate of the municipality (incidence rates ratio) (Table 1). Among these, three communes and the two corregiments have rates higher than the incidence rate of the department (Table 1). The incidence rate ratio between Pereira and Risaralda is 0.69.

Table 1
ZIKV incidence rates (cases/100,000pop) by communes and corregiments in the Pereira municipality, Risaralda department, Colombia, 2015–2016.[a]

Communes or corregiments	Cases	%	Population	%	Incidence Rates (/100,000pop)	Rates compared to the Department	Rates compared to the Municipality
Whole Department	1297	–	957,250	–	135.5	–	–
Whole municipality	439	100.0	472,023	100.0	93.0	0.69	–
Urban Area (Communes)							
El Rocio	2	0.5	1173	0.2	170.5	1.26	1.83
Cuba	35	8.0	20,714	4.4	169.0	1.25	1.82
San Nicolas	14	3.2	9599	2.0	145.8	1.08	1.57
El Oso	34	7.7	26,311	5.6	129.2	0.95	1.39
Perla del Otun	19	4.3	15,381	3.3	123.5	0.91	1.33
San Joaquin	38	8.7	33,420	7.1	113.7	0.84	1.22
Olimpica	17	3.9	15,775	3.3	107.8	0.80	1.16
Rio Otun	42	9.6	43,107	9.1	97.4	0.72	1.05
Consota	22	5.0	24,205	5.1	90.9	0.67	0.98
Centro	34	7.7	37,927	8.0	89.6	0.66	0.96
Del Café	22	5.0	28,016	5.9	78.5	0.58	0.84
El Poblado	14	3.2	19,723	4.2	71.0	0.52	0.76
Villavicencio	10	2.3	14,595	3.1	68.5	0.51	0.74
Boston	12	2.7	26,787	5.7	44.8	0.33	0.48
Ferrocarril	5	1.1	11,636	2.5	43.0	0.32	0.46
Universidad	8	1.8	18,897	4.0	42.3	0.31	0.46
El Jardin	5	1.1	11,991	2.5	41.7	0.31	0.45
Oriente	6	1.4	18,300	3.9	32.8	0.24	0.35
Villasantana	2	0.5	18,424	3.9	10.9	0.08	0.12
Aeropuerto	0	0.0	2732	0.6	0.0	0.00	0.00
Subtotal urban area	341	77.7	398,713	84.5	85.5	0.63	0.92
Rural Area (Corregiments)							
Caimalito	32	7.3	6952	1.5	460.3	3.40	4.95
Cerritos	15	3.4	8143	1.7	184.2	1.36	1.98
Tribunas	10	2.3	11,374	2.4	87.9	0.65	0.95
Puerto Caldas	5	1.1	6451	1.4	77.5	0.57	0.83
Combia Alta	2	0.5	4644	1.0	43.1	0.32	0.46
Morelia	2	0.5	5588	1.2	35.8	0.26	0.38
Combia Baja	1	0.2	4680	1.0	21.4	0.16	0.23
Arabia	1	0.2	5527	1.2	18.1	0.13	0.19
Altagracia	1	0.2	7481	1.6	13.4	0.10	0.14
La Bella	0	0.0	6240	1.3	0.0	0.00	0.00
La Florida	0	0.0	3505	0.7	0.0	0.00	0.00
La Estrella	0	0.0	2726	0.6	0.0	0.00	0.00
Subtotal rural area	69	15.7	73,310	15.5	94.1	0.69	1.01
Unknown	29	6.6	–				

[a] Up to epidemiological week 40th, October 8, 2016.

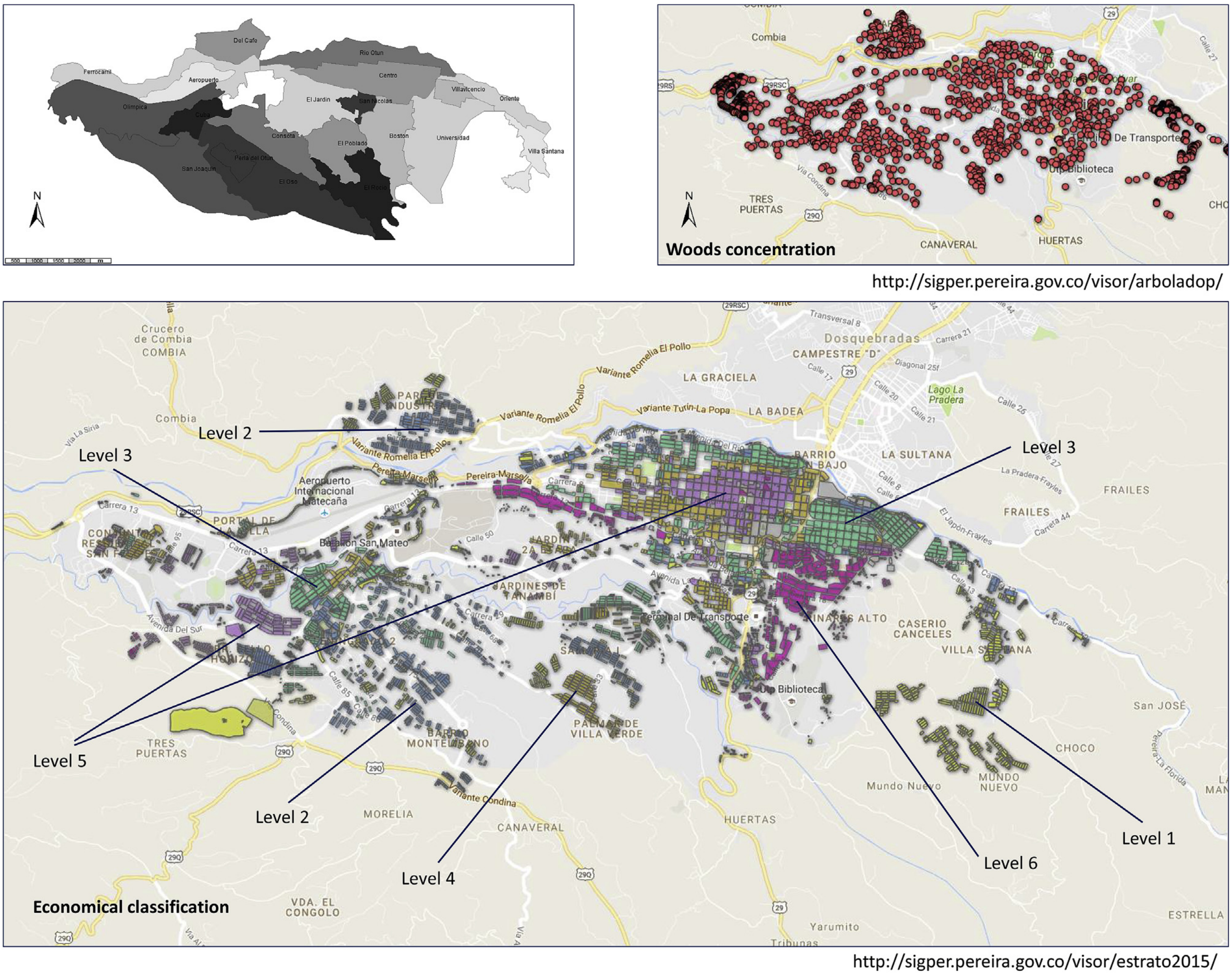

Fig. 3. GIS-based map of woods concentration and economical classification of the communes (urban area) of Pereira, Risaralda, Colombia, 2015–2016.

Entomological indexes (Table 2) were in general higher in the rural areas than in urban ones; however, in three corregiments data was not collected (Table 2). Those indices were significantly associated with ZIKV incidence, AI ($r^2 = 0.5370$; $p < 0.0001$), DI ($r^2 = 0.5304$; $p = 0.0001$) and BI ($r^2 = 0.5282$; $p = 0.0001$). In a multiple non-linear regression of those indices, a significant association with ZIKV was found ($r^2 = 0.2842$; $p = 0.0423$), being higher when applying AI and BI indices only ($r^2 = 0.2519$; $p = 0.0266$) (Fig. 6). In addition, in a detailed entomological follow-up at the corregiment of Caimalito, from 25 collection sites, in 24 *Culex* sp. was found and in 1 *Aedes albopictus* (Fig. 7).

4. Discussion

Colombia has reported a total of 104,724 cases of ZIKV infection during 2015–2016 (up to October 15, 2016), 8826 (8.4%) of them confirmed by RT-PCR [27,28]. From the total, 1298 have been from Risaralda (1.24%) and 439 from Pereira city. Although the Ministry of Health, through its National Institute of Health, have declared the end of the epidemic phase in the country (during epidemiological 28th, July 16, 2016), certainly ZIKV has become endemic with stable transmission in most of its territories [27]. Nevertheless, still, more than 230 cases per week (to >600) are reported during the last 9 weeks of the endemic phase of ZIKV infection in the country. Up to December 31, 2016, Colombia officially reported 106,659 cases (9799 [9.2%] confirmed by RT-PCR), and 1079 additional cases during the first 17 weeks of 2017 (up to April 29, 2017).

In view of the eco-epidemiological conditions in the region close to and of Pereira [10,25], a city located in the foothills of the Andes in a coffee-producing area of Colombia, there exist conditions for transmission of vector-borne and arboviral diseases, such as malaria [25], dengue [10] and chikungunya [29,30]. Significant rainfall patterns and warm temperatures during the whole year (Fig. 1), with high numbers of susceptible individuals and ample presence of vectors (Fig. 5), are prone for transmission in multiple areas of the municipality, urban and rural (Fig. 6), counting for almost 100 cases/100,000 during this epidemic. Unfortunately, only 11% of cases have been confirmed by RT-PCR, but this is higher than the proportion for the country, 8% [27,28], mainly for economic reasons. Consequently, the Pan American Health Organization (PAHO) utilizes surveillance cases that have been reported based on clinical case definition only.

Being the most populated city in the Coffee-Triangle [25] and the second-most populated city in the Paisa region, after Medellín, these results have significant implications for public health and particularly for focalization of interventions, which is one of the goal of this assessment in collaboration with the Secretary of Health of the city, as our research group has done before with other

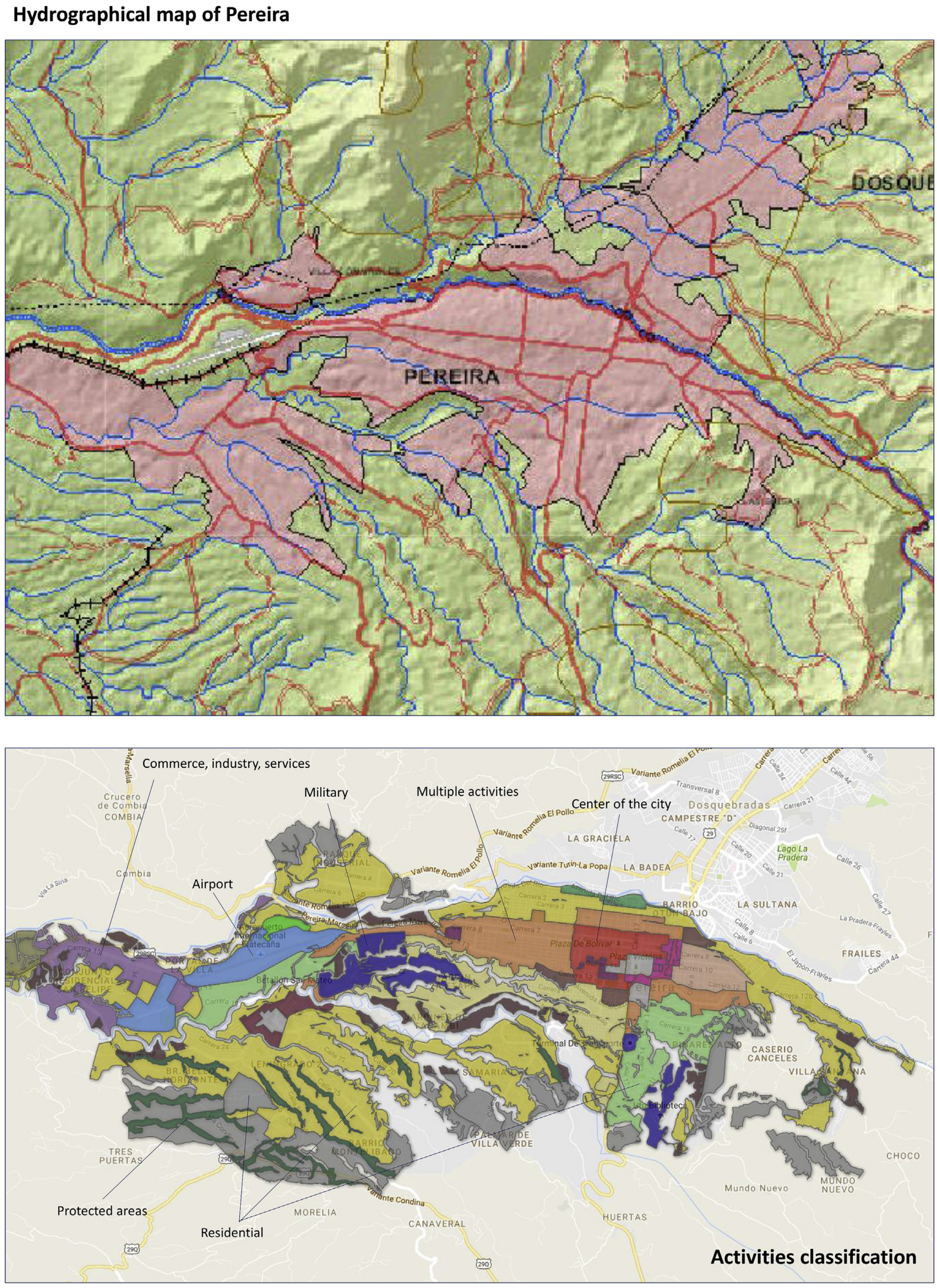

Fig. 4. GIS-based map of hydrography and activities classification of the communes (urban area) of Pereira, Risaralda, Colombia, 2015–2016.

infectious diseases such as tuberculosis and HIV [31,32]. As part of this study, activities for education and control will be focused in the commune of Cuba (for the urban area) and at Caimalito (for the rural area). Pereira is also part of the Central West Metropolitan Area, which has over 700,000 residents and is composed of Pereira and the neighboring cities of Dosquebradas (200,829 inhabitants in 2016) and La Virginia (32,114 inhabitants in 2016), also the implications would be extended to these other cities and municipalities,

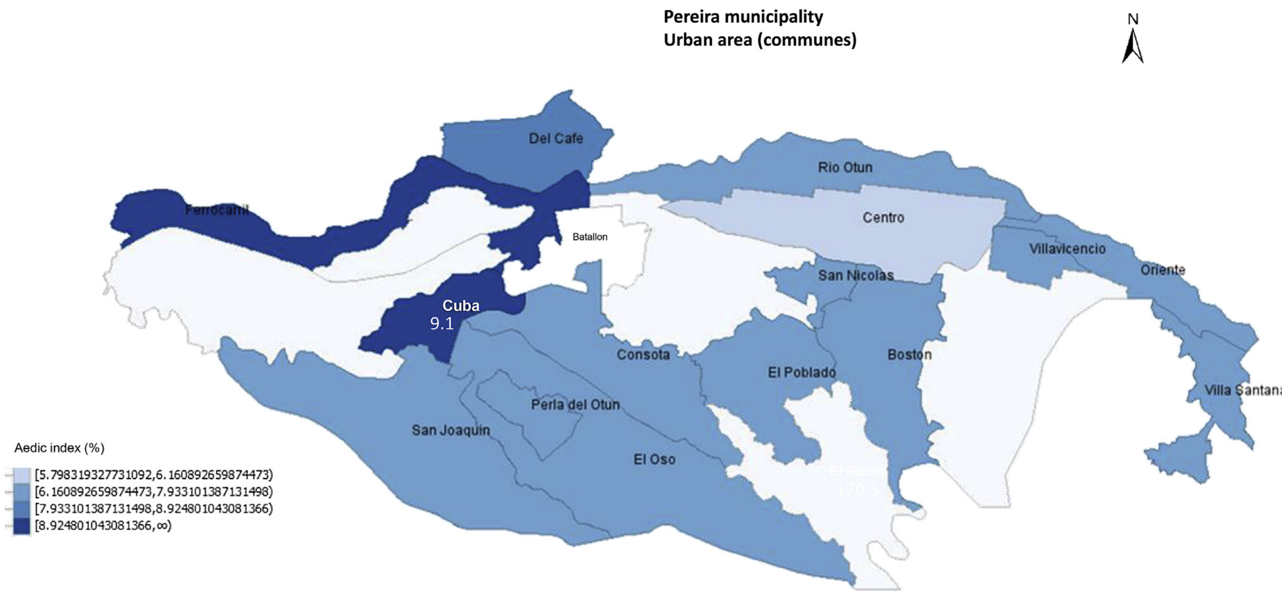

Fig. 5. GIS-based map of Aedic index (%) in the urban area (communes) of Pereira, Risaralda, Colombia, 2013–2015.

Table 2
Entomological indicators, Aedic index, Deposit index, Breteau Index, for the communes and corregiments in the Pereira municipality, Risaralda department, Colombia, 2013–2015.

Area	Level	Commune or corregiment	2013			2014			2015			Mean		
			Aedic Index	Deposit Index	Bretau Index	Aedic Index	Deposit Index	Bretau Index	Aedic Index	Deposit Index	Bretau Index	Aedic Index	Deposit Index	Bretau Index
		Mean municipality	10.1	10.0	13.1	7.2	6.9	8.3	6.1	6.6	7.6	8.1	8.2	10.2
		Mean urban area	8.4	8.5	11.6	6.6	6.2	7.6	4.5	4.7	5.4	6.3	6.2	7.9
Urban	Commune	Cuba	10.0	11.6	14.2	SD	SD	SD	8.2	8.1	10.0	9.1	9.9	12.1
		Ferrocarril	10.1	11.2	15.1	10.2	10.5	12.2	6.4	6.6	7.8	8.9	9.4	11.7
		Del Café	7.6	9.0	10.7	13.9	12.2	17.5	2.3	2.2	2.5	7.9	7.8	10.2
		San Nicolas	7.8	10.6	11.8	8.0	6.3	7.4	7.6	8.1	9.5	7.8	8.3	9.6
		Perla del Otun	10.8	9.7	13.7	10.2	7.8	10.2	1.8	1.5	1.8	7.6	6.3	8.6
		San Joaquin	12.6	11.8	16.1	5.0	4.6	5.7	4.3	4.5	4.9	7.3	7.0	8.9
		Villasantana	11.6	10.6	13.5	7.1	7.0	8.8	3.0	1.8	4.7	7.2	6.5	9.0
		El Poblado	12.9	8.1	24.7	5.8	6.6	7.8	2.1	2.3	2.6	7.0	5.7	11.7
		El Oso	8.3	8.3	10.4	4.0	4.6	5.1	8.0	8.5	9.8	6.8	7.1	8.5
		Villavicencio	10.8	11.3	15.4	2.1	2.8	3.1	7.0	6.7	7.3	6.6	6.9	8.6
		Boston	6.2	6.0	7.7	7.4	7.3	7.4	6.2	5.0	6.2	6.6	6.1	7.1
		Oriente	7.6	7.8	9.8	8.4	8.3	9.0	3.7	5.7	4.5	6.5	7.3	7.8
		Consota	9.8	9.2	12.4	6.5	6.1	7.5	3.0	3.1	3.5	6.4	6.1	7.8
		Rio Otun	7.3	8.8	11.1	6.8	7.0	9.2	4.4	6.5	6.8	6.2	7.5	9.0
		Centro	5.7	6.3	8.6	5.9	5.6	5.9	SD	SD	SD	5.8	5.9	7.2
		El Rocio	4.6	4.7	5.6	7.5	6.6	9.2	4.8	4.1	4.8	5.6	5.1	6.5
		Olimpica	SD	SD	SD	2.8	2.4	3.2	SD	SD	SD	2.8	2.4	3.2
		Universidad	7.5	7.1	7.5	0.3	0.4	0.3	0.0	0.0	0.0	2.6	2.5	2.6
		El Jardin	0.0	0.0	0.0	SD	SD	SD	SD	SD	SD	0.0	0.0	0.0
		Aeropuerto	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Mean rural area	13.8	13.5	16.6	10.0	9.5	11.3	10.2	11.6	13.5	11.9	12.5	14.9
Rural	Corregiment	La Estrella	23.4	21.5	31.1	N/A	N/A	N/A	N/A	N/A	N/A	23.4	21.5	31.1
		Morelia	14.1	15.6	16.9	N/A	N/A	N/A	20.0	19.0	26.7	17.0	17.3	21.8
		Caimalito	19.8	17.7	21.8	16.5	15.4	18.3	14.4	13.7	15.9	16.9	15.6	18.6
		Puerto Caldas	13.7	13.0	17.4	13.1	12.2	14.9	7.8	8.5	10.6	11.5	11.2	14.3
		Altagracia	14.4	13.7	18.4	N/A	N/A	N/A	6.4	7.6	9.8	10.4	10.6	14.1
		Arabia	8.4	13.8	8.4	N/A	N/A	N/A	N/A	N/A	N/A	8.4	13.8	8.4
		Cerritos	10.1	9.2	12.1	8.5	8.7	10.2	5.8	10.5	5.8	8.1	9.5	9.4
		Combia Baja	N/A	N/A	N/A	N/A	N/A	N/A	6.8	10.1	12.3	6.8	10.1	12.3
		Tribunas	6.2	3.6	7.1	1.8	1.8	1.8	N/A	N/A	N/A	4.0	2.7	4.4
		Combia Alta	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		La Bella	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		La Florida	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A = Not available/collected.

especially La Virginia, which has been also studied for ZIKV and chikungunya [29]. Pereira is a city with a high population mobility and located in an area of the country which serves for transit to multiple destinations by road in all directions, including also an

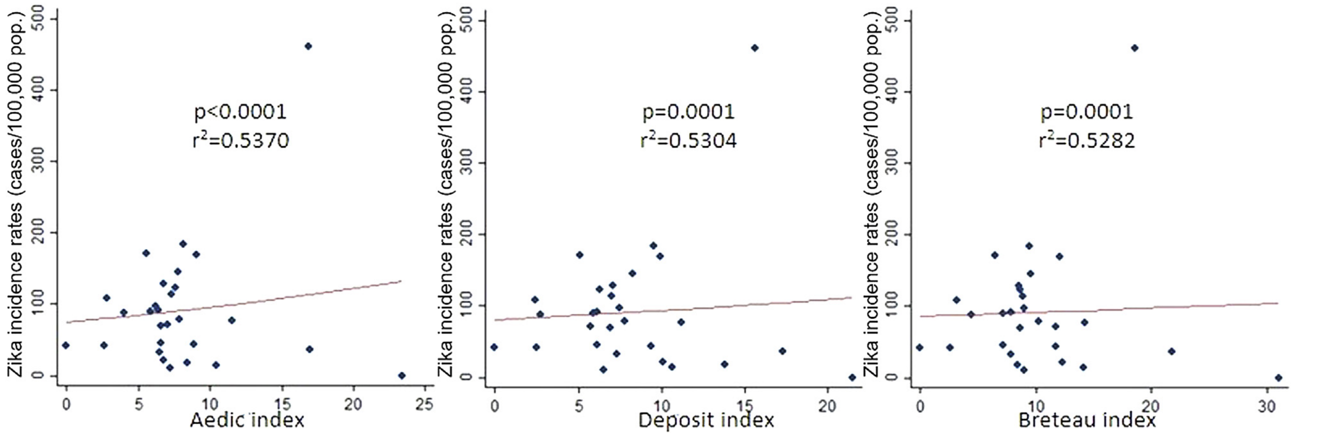

Fig. 6. Non-linear regression models between entomological indexes (mean, 2013–2015) and the ZIKV infection incidence in the Pereira municipality, Risaralda, Colombia, 2015–2016.

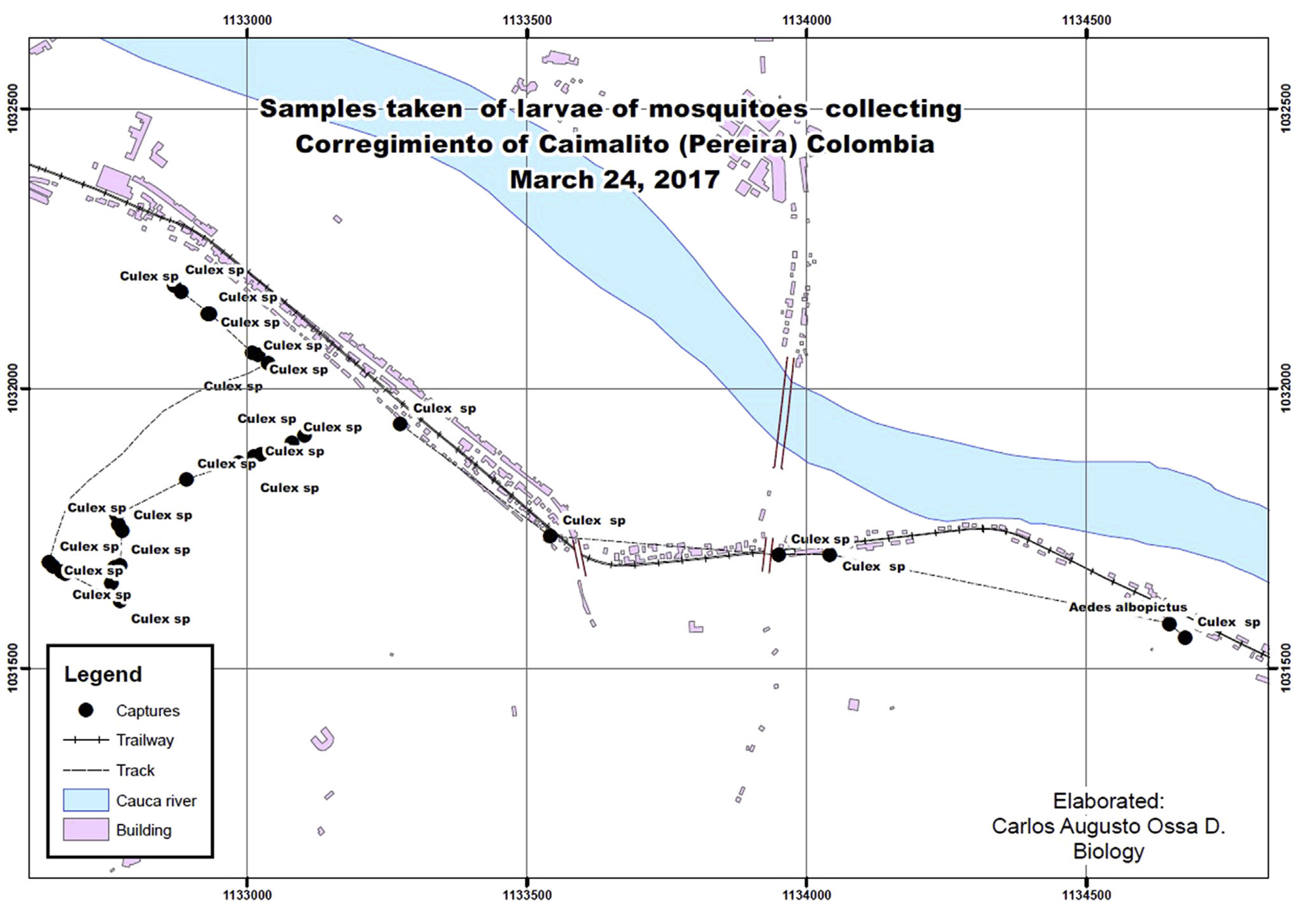

Fig. 7. Map of sites of entomological collection for potential vectors of ZIKV in the Corregiment of Caimalito, Pereira municipality, Risaralda, Colombia, March 2017.

international airport located in its own urban commune, the International Airport Matecaña (which moved 1,890,088 travelers in 2015, 11% directly from other countries), serving Pereira, but also being important for people with final destinations in the North of Valle del Cauca (department), such as Cartago (highly endemic for ZIKV infection) (>500 cases/100,000) or Toro, La Victoria, Roldanillo, Zarzal (all with >1000 cases/100,000) [3], and Armenia (capital of Quindio department), Manizales (capital of Caldas department) and south Antioquia and north Tolima [6]. This airport is the main in the Coffee-Triangle area of Colombia, including international flights to New York (JFK) (USA) (with a stop in Cartagena, Colombia) and Panama City (Panama). It has been officially announced by a US-based airline, that in the next few months there will be a new route, to Miami. Domestic flights include Bogota (capital of Colombia), Cartagena, Medellin, Quibdo and San Andres and Providencia islands. Implications for travel medicine should be considered when assessing the risk of international spread and measures related [1,8,21,30].

From this travel medicine point of view, it is important to mention that Pereira is in the center of the Golden Triangle (which consists of the cities of Bogotá, Medellín and Cali), and for that it has become especially important in the fields of trade and commerce, but also of tourism. Touristic places in the region (few kilometers away from Pereira) include the National Park of the Coffee, the National Natural Park of the Snow Mountains (*Los Nevados*), the Hot Springs of Santa Rosa de Cabal, Cocora Valley, and the BioPark Ukumari (former Matecaña Zoo), among others. For example, BioPark Ukumari is in the Cerritos corregiment, the second most important area in terms of transmission of Zika (incidence rate) at the rural area of Pereira, and located just 8 km far away from the International Airport Matecaña. This 110.5 acres park, since its inauguration in September 2015 considered the largest biopark in Latin America, received 80,000 visitors during its first year. In 2011, Pereira was one of the cities in Colombia for a mass gathering event, the FIFA Sub-20 Soccer World Cup (Stadium Hernan Ramirez Villegas, 30.297 seats), which brought thousands of international travelers and fans as well international sport teams to this city, from Ecuador, Costa Rica, Saudi Arabia, Nigeria, Cameroon, Mexico, Brazil and Spain (all these teams played in Pereira), with all the related implications [33]. In addition, a proportion of travelers (teams from Australia, Guatemala, Croatia, England and South Korea) going to Armenia and Manizales (other cities of the Cup) arrived via Pereira due to its airport's larger capacity. Then, public health policies and strategies for integral control of ZIKV in people living and visiting those areas, should be considered and urgently implemented. Particularly in Caimalito, where a free-trade commerce zone is being implemented, it is a neighboring town with La Virginia (just separated by the Cauca river, with a road bridge), which is highly endemic for ZIKV infection now (more than 1000/100,000), an effective control is needed. In Pereira, as well as Risaralda, Colombia and Latin America as a whole, other arboviruses, such as dengue and chikungunya are also co-circulating, then those measures will mitigate and reduce not just ZIKV [1]. In this setting, co-infections are possible and have reported in Colombia in such epidemiological scenarios [13,14], as well in other countries of Latin America & the Caribbean (e.g. Brazil, Ecuador, Haiti) [34–36].

Although ZIKV was isolated in 1947, only significant research has been done during the past months (ending 2015-beginning 2016) [24], in countries particularly such as Brazil and in Colombia, due to multiple negative potentially linked outcomes, including not just birth and adult neurological compromise, but even deaths [4,37–40].

In this setting, the use of GIS would be important to provide models on the impact and suitability of ZIKV containment measures in the context of environmental and social factors. Recent evidence indicates that the 2015 El Niño caused extreme climatic conditions in Northeastern South America during winter and spring in the Southern hemisphere [41] that might have contributed to the rapid dispersal of the Zika virus in Brazil and other countries in the region, possibly happening in Pereira, as we observed, but in other areas of Colombia, as has been evidenced for dengue in different regions of this country [9,10]. Also, entomological surveillance, in airports, such the one in Pereira, should be enhanced, given the associated risks for exporting infected mosquitoes to other regions and countries, but also importation of infected and non-infected mosquito vectors; particularly in this city, where still there a mean Aedic index >5% for most areas (Fig. 5).

Finally, maps provide relevant information to assess the risk of travelers to specific destinations in highly transmission areas allowing detailed prevention advices [3]. Use of GIS-based epidemiological maps allows to integrate prevention and control strategies, as well as public health policies, for joint control of this vector-borne disease in this and other areas of the country [21]. As other arboviruses are co-circulating (DENV, CHIKV) [1], maps of them as well for co-infections will be also needed [1,13,14,36]. Simultaneous or sequential arboviral infections occur and should be also assessed [42]. Preparedness in this setting should also consider the potential arrival of Mayaro and Yellow Fever in *Aedes* infested areas [43–46].

Combining entomological, environmental, human population density, travel patterns and case data of vector-borne infections, such as ZIKV, leads to a valuable tool that can be used to pinpoint hotspots also for infections such as dengue, chikungunya and malaria, among others [3,8,21,30]. Such a tool is key to planning mosquito control and the prevention of mosquito-borne diseases in local populations. Such data also enable microepidemiology and the prediction of risk for travelers who visit specific areas in a destination country.

In conclusion, GIS mapping appears as so far under-utilized tool to characterize (arboviral) disease outbreaks down to a detail which allows to interrupt the further spread early, targeted and hence cost-effectively.

Ethical approval

Not required.

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Author contributions

Study design: AJRM, Data collection: PR, JT, CAO, Data analysis: AJRM, COLR, PR, JT, Writing: All authors. All authors contributed to, and approved the final version submitted.

Data availability

Raw data for is available and will be provided on request.

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Conflicts of interest

The authors have no conflict of interest to disclose.

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