Potential expansion of Zika virus in Brazil: analysis from migratory networks [1]

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Abstract

The second decade of the 21st century marked the moment when Zika virus became a worldwide concern. South American countries have been the most hit by this infectious disease, and between them Brazil registered the majority of the cases. The main goal of this study was to present the pathways or trajectories through which Zika infections tend to expand in Brazil. We proposed to map the network of cities that are linked to two important points of occurrence and distribution of cases of the disease, the municipalities of Recife and Rio de Janeiro. Recife for being an initial point of distribution of the Zika cases to the country, whereas the analysis of Rio de Janeiro can present the paths that the virus tends to follow after 2016. As data sources, we used the Brazilian Population Census (IBGE, 2010) and the National System of Notifiable Diseases (SINAN). From the Census it was possible to analyze the main migratory flows between Brazilian cities that presented dengue epidemics between 2008 and 2012 (the mosquito vector of this disease is the same as Zika, *Aedes aegypti*). The results indicate the possible path that led to the distribution of the Zika virus from Recife to other locations in the Brazilian Northeast, reaching Rio de Janeiro, Brasília (the national capital) and, from there, spreading to the other states of the country.

Key-words: Zika virus, South America, Brazil, networks, migration.

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Introduction

Dengue is present in American countries for at least sixty years. Transmitted by the same vector – the *Aedes aegypti* –, Zika virus has arrived in the continent during the year 2013 through Brazil. Since then, the disease has spread rapidly (FARIA et al., 2016).

According to the World Health Organization report, until March 2017, autochthonous cases of Zika (i.e., those resulting from local transmission) have already been reported in more than 45 countries or territories in the Americas (WHO, 2017). This virus has aroused worldwide attention due to its association with the expressive growth, especially in Brazil, of cases of microcephaly and other malformations of newborns, what is currently known as congenital Zika virus syndrome (FRANÇA et al., 2016). Until December 2015, 2,975 suspected microcephaly cases related to Zika infection were reported in the country (BRASIL, 2016). Another consequence of the disease is the increasing incidence of Guillain-Barré syndrome, which affects the central nervous system, generating muscle weakness and paralysis that can lead to death (MLAKAR, 2016).

The most recent Epidemiological Bulletin launched by the Ministry of Health (BRAZIL, 2017) affirms that Zika autochthonous cases have been reported in all 27 Brazilian Federal Units. In terms of number of reported cases, since the beginning of the epidemic, the state of Pernambuco stands out and in this, its capital, the municipality of Recife. In 2016, however, the state of Rio de Janeiro takes the lead in the number of Zika cases (70,539), presenting also the highest incidence rate of the country (424 cases per 100,000 inhabitants). In this state, its capital, the municipality of Rio de Janeiro, stands out in terms of notifications of this infectious disease.

The purpose of this paper was to analyze specifically these two municipalities: Recife and Rio de Janeiro. This research is based on previous work, which was dedicated to understanding other diseases also transmitted by *Aedes aegypti*: dengue and chikungunya (CARMO et al., 2015).

The main goal of this study was to present the pathways or trajectories through which Zika infections tend to expand in Brazil. Therefore, we proposed to map the network of cities that are linked to two important points of occurrence and distribution of cases of the disease, the municipalities of Recife and Rio de Janeiro. Recife for being an initial point of distribution of the Zika cases to the country, whereas the analysis of Rio de Janeiro can present the paths that the virus tends to follow after 2016.

The assumptions that guide this analysis are that this network: 1) tends to establish the spatial expansion structure of the disease in the Brazilian territory; 2) is based on the mobility of the population; and 3) has a propensity to establish itself especially among municipalities that have already presented dengue epidemics in recent years and, therefore, present the necessary conditions for the development of the mosquito vector of these two diseases.

The analysis of the migration allows us to identify localities between which there are significant population exchanges, establishing flows that are important for the disease spread.

Methods

As data sources, we used the Brazilian Population Census (IBGE, 2010) and the National System of Notifiable Diseases (SINAN).

From the Population Census it was possible to analyze the main migratory flows (change of residence). We used specifically the question that investigates in which municipality the interviewee lived 5 years before the date of application of the survey (“fixed date” criterion).

Thus, it was possible to elaborate two networks of municipalities. We depart from the centers of the Zika epidemic, the cities of Recife and Rio de Janeiro. The five municipalities that received the most migrants from each of them are selected. Then the five related to the first five are searched. And finally, the process is repeated one more time. The network is then structured into three levels of hierarchy. Example: 1 municipality (Recife) ⇨ 5 municipalities ⇨ 25 municipalities ⇨ 125 mun. Thus, the total number of municipalities in each network would be 156. As there are two networks, one departing from Recife and another from Rio de Janeiro, there would be 312 municipalities covered in this investigation. However, the representation on the map shows repeated municipalities only once. This is because each locality, when it first appears in the analysis, is already part of the probable "path" of the disease.

Results

Figure 1 presents the results of the networks construction for Recife. Part (A) indicates the migration network between Recife and the other Brazilian municipalities that presented dengue epidemics between 2008 and 2012. Part (B), by its turn, is a fragment of the first map, showing in greater detail the connections of Recife with the Southeast and Central-West regions of Brazil. The thick black line indicates to the first level links of the hierarchy, that is, those municipalities connected more directly with Recife in terms of the volume of migratory exchanges. The dashed dark gray line, the second level, and the dashed light gray, the third.

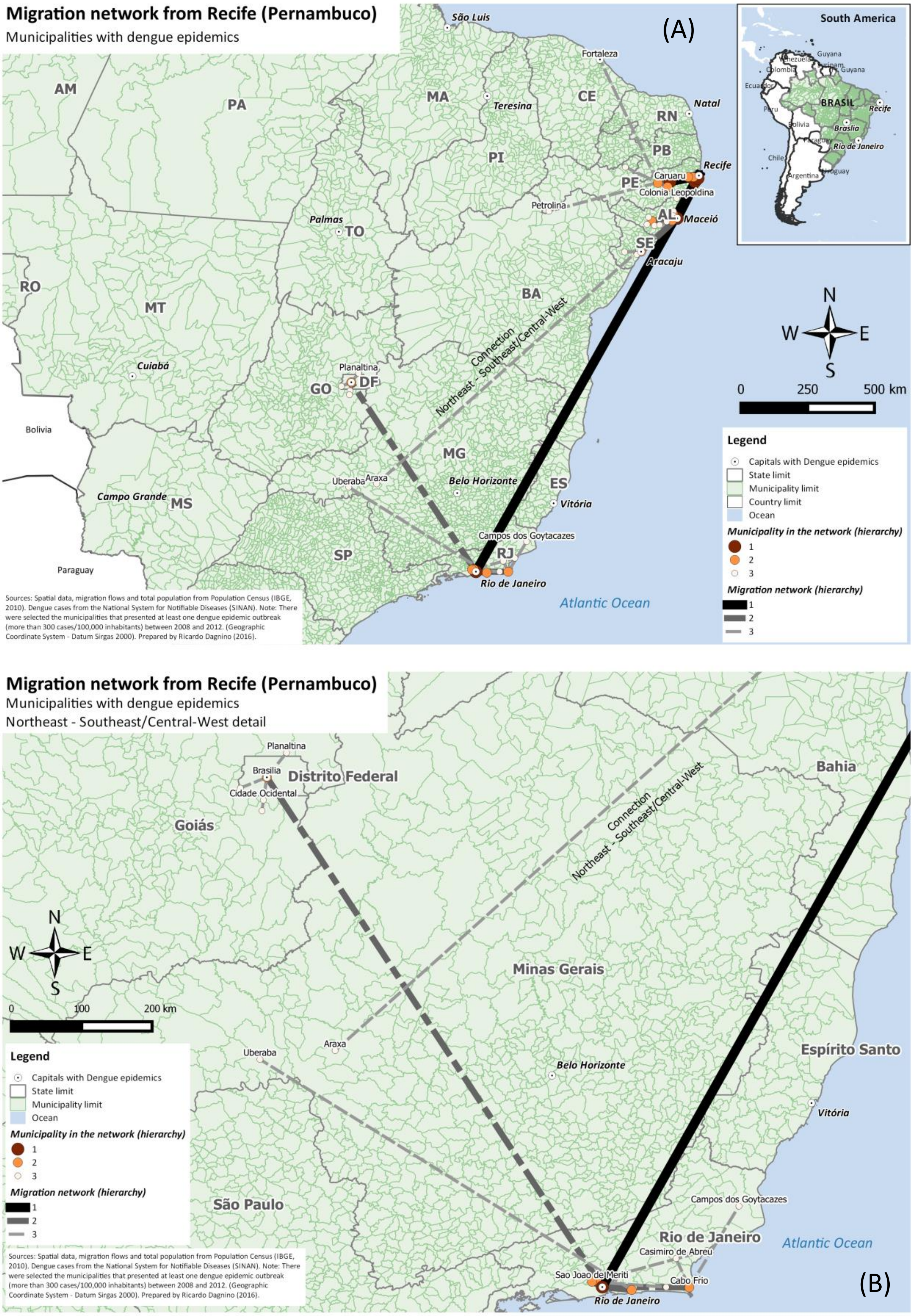
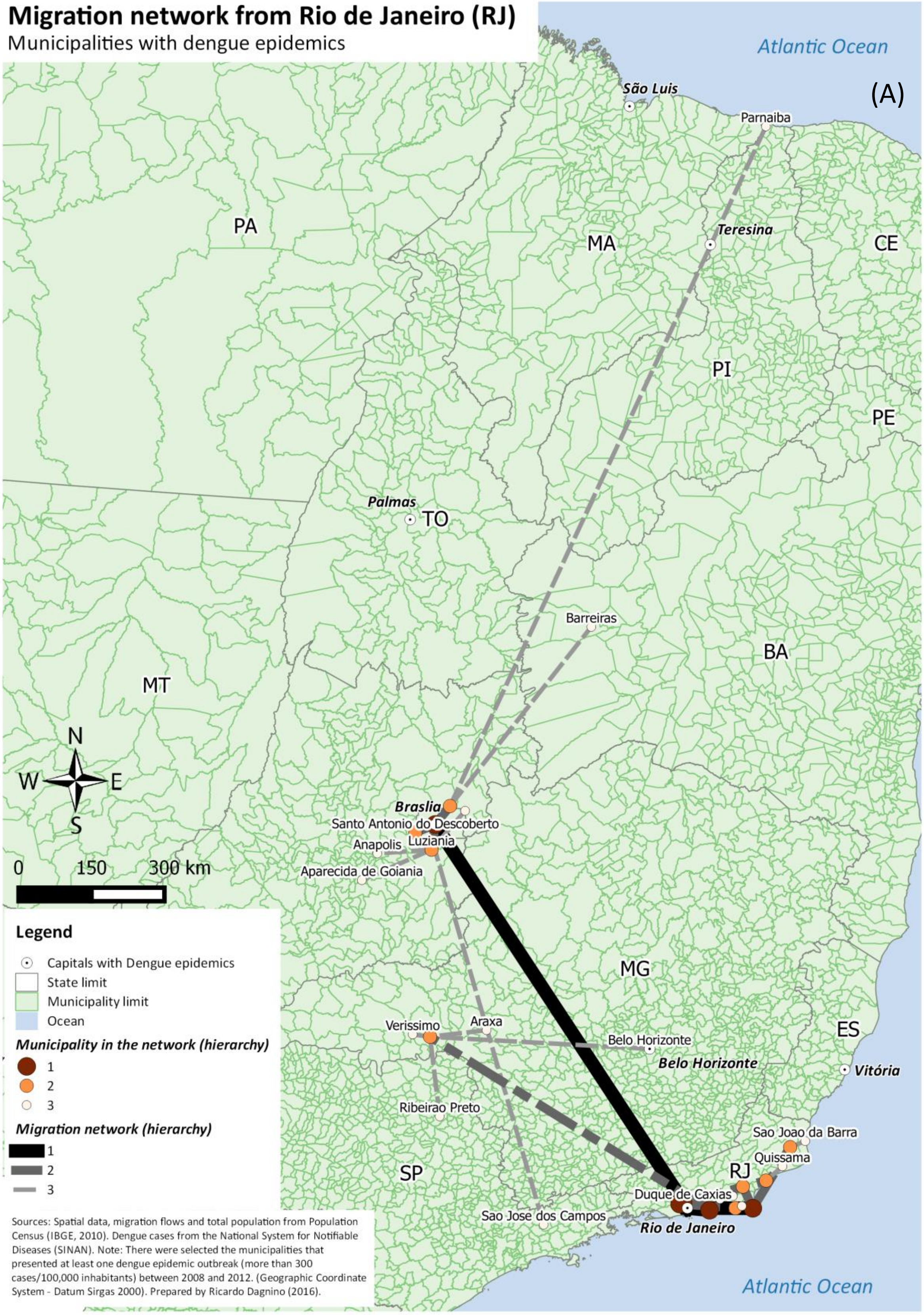


Figure 1. Migration network between Recife (Pernambuco) and other Brazilian municipalities with dengue epidemics between 2008 and 2012.

Figure 2, on its turn, presents the migratory networks departing from the municipality of Rio de Janeiro.



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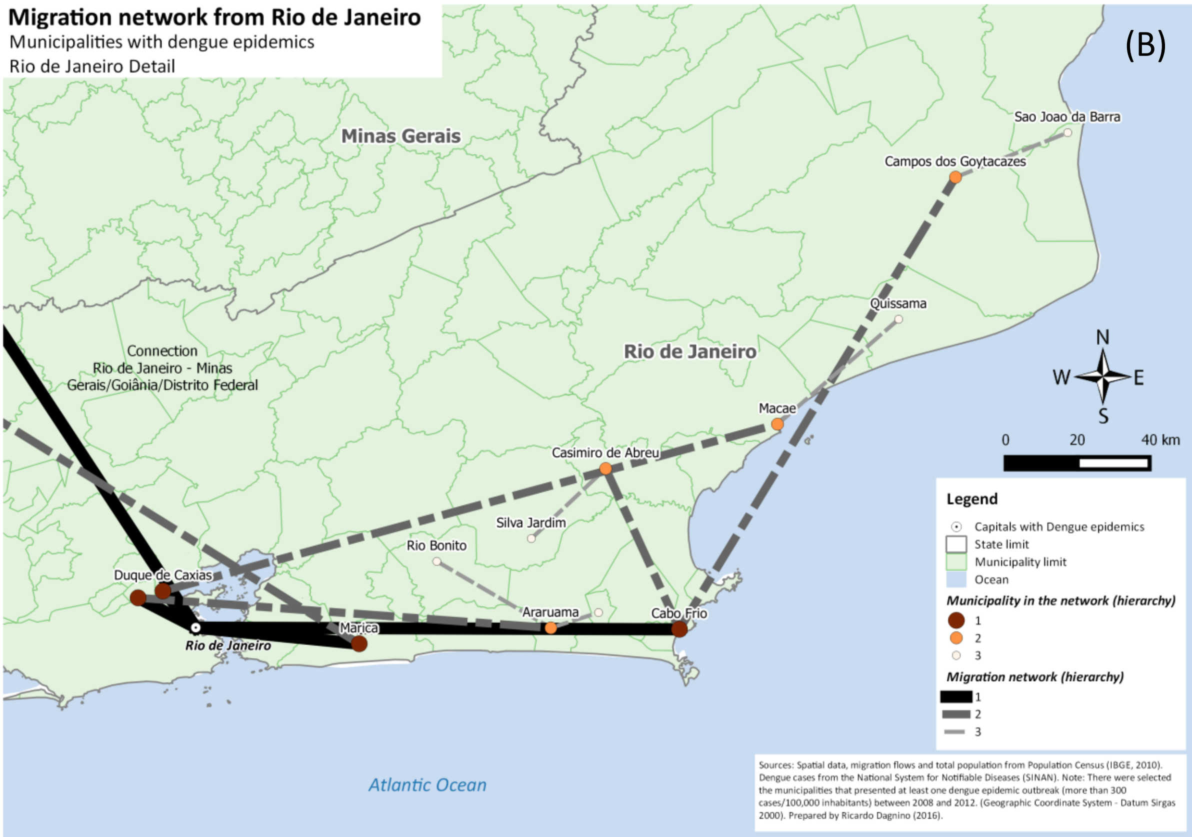

Figure 2. Migration network between Rio de Janeiro (RJ) and other Brazilian municipalities with dengue epidemics between 2008 and 2012.

It is not always possible to observe all the "nodes" of the network, i.e., all the municipalities involved in migratory exchanges between the central point (Recife and Rio de Janeiro) and the sites that presented dengue epidemics between 2008 and 2012 (Figures 1 and 2). This is because it is common for the main migratory exchanges to take place between neighboring municipalities, making it difficult to be seen in the map in this scale, even in the most detailed frames. See, for example, the case of Recife, in Figure 1-A. It is impossible to see that, besides Rio de Janeiro, in this first level of the hierarchy are also the following municipalities of the state of Pernambuco: Jaboatão dos Guararapes, Caruaru and Cabo de Santo Agostinho. The line that indicates the population flows between Recife and Maceió (capital of the state of Alagoas), also in the first level of the hierarchy, can be confused with the representation of the vector between Recife and Rio de Janeiro.

Thus, the migratory networks are also presented in the form of organograms (Figures 3 and 4). The information is fundamentally the same, what changes is the mode of representation. It is intended that these four figures complement each other and enhance the comprehension of the methodology and the results.

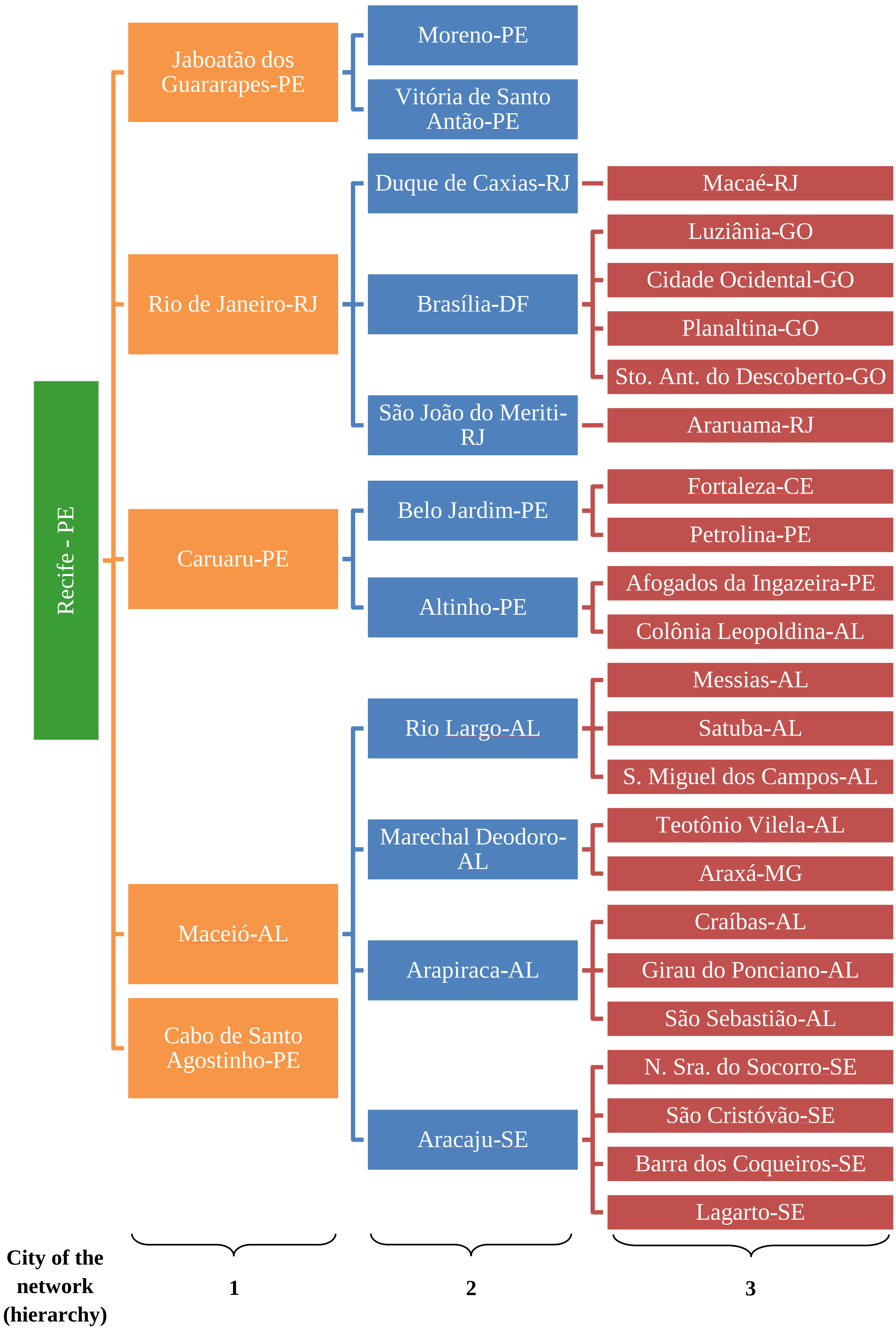

Figure 3. Organogram - Migration network between Recife (Pernambuco) and other Brazilian municipalities with dengue epidemics between 2008 and 2012 (total: 39 municipalities)

Source: Population Census (IBGE, 2010).

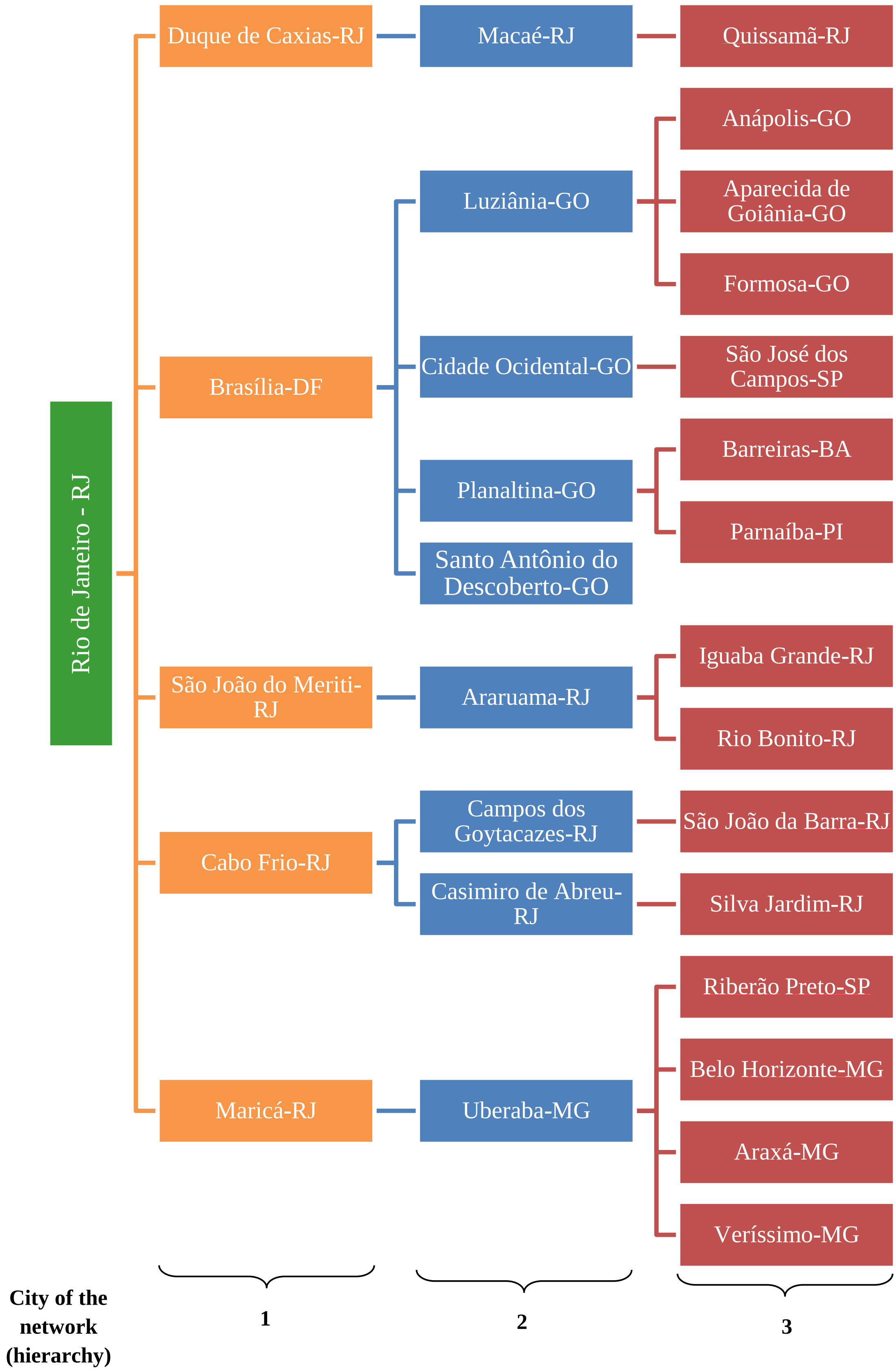

Figure 4. Organogram - Migration network between Rio de Janeiro (RJ) and other Brazilian municipalities with dengue epidemics between 2008 and 2012 (Total: 30 municipalities)

Source: Population Census (IBGE, 2010).

Besides these two forms of presentation of the methodology and results (figures and organograms), the maps were also made available online. In this way, each reader can access and use the zoom tools to observe the migration network established between the cities selected in this study. Thus, in this same map it is possible to visualize not only the names of the interconnected municipalities, but also characteristics of their own urban organization, such as distribution of streets, presence of green areas and proximity to lakes, rivers or ocean. The map with the networks from Recife and Rio de Janeiro is available at http://bit.ly/RedesRioRecife. To activate the visualization of the networks, select the layers in the Layer List, located in the upper right corner of the screen (Figure 5).

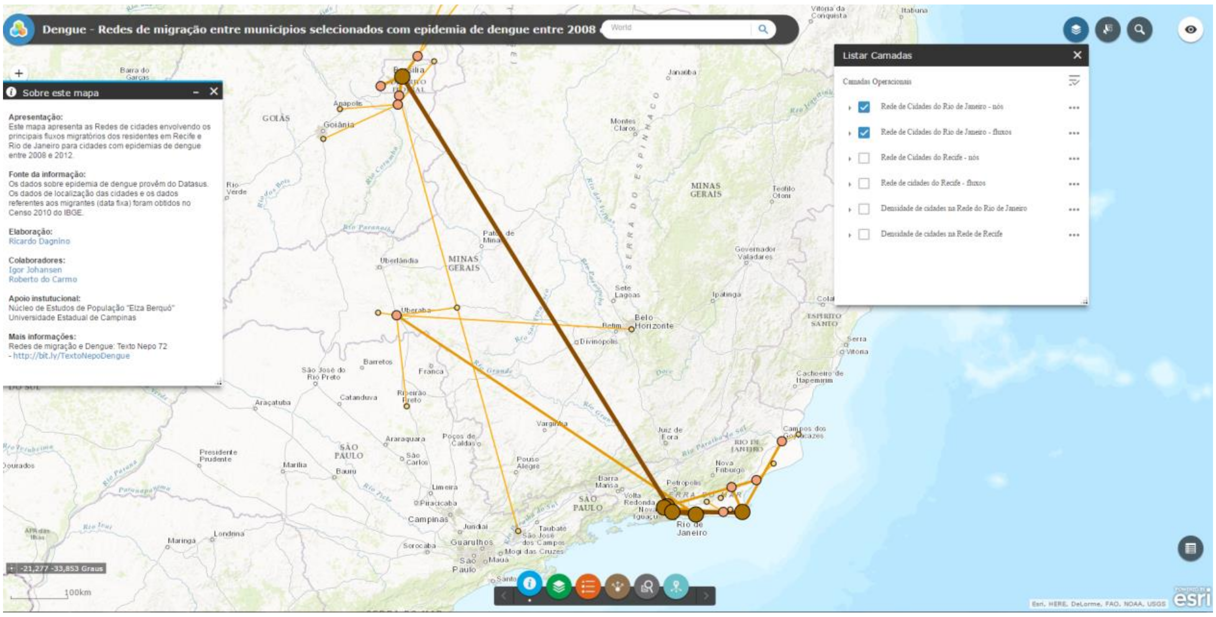

Figure 5. Online visualization tool of the Migration Network between Recife and Rio de Janeiro (RJ) with the other Brazilian municipalities with dengue epidemic between 2008 and 2012.

Source: Population Census (IBGE, 2010).

Note: Available in: http://bit.ly/RedesRioRecife

Discussion and Conclusions

Figure 1 (A) – complemented by Figure 3 and the online viewing tool – shows that in the Northeast, the initial tendency of the virus was to distribute to the municipalities of Maceió (capital of Alagoas), the first level in the hierarchy, then Aracaju (capital of Sergipe), second level, and reach Fortaleza (capital of Ceará) on the third level. Analyzing part (B) of Figure 1, the strong connection between Recife and Rio de Janeiro, at the first level, and from this one with Brasília, at the second level of the hierarchy, is evident. This shows a potential Zika virus distribution axis between the Northeast, Southeast and Central-West regions of Brazil.

Observing the population flows from Rio de Janeiro (Figure 2A and B), new axes are observed. The connection with Brasília, in the Central-West, is at the first level of the hierarchy. This city, as the country's capital, enhance the virus spread potential, reaching states such as Goiás, Minas Gerais, São Paulo, Bahia and Piauí.

It is worth noting that Brasília appears in the first level of the hierarchy in the network of Recife and Rio de Janeiro. Therefore, a policy to control the spread of the Zika virus in Brazil must pay special attention to this city as a nodal axis of connection with the main capitals that already have ongoing circulation of the virus, potentializing its redistribution to naive portions of the country.

In addition, while the construction of the network was expected to show 156 municipalities in each one (or 312 in both), it was seen that the network of Recife had 39 municipalities, while that of Rio de Janeiro, 30, totaling 69 municipalities in the two networks. This difference of 243 municipalities (312 - 69) shows that, in reality, the municipalities involved in the main population exchanges often repeat themselves. This is clear, for example, in the Recife network which, at level 2 of the hierarchy, ends in Moreno-PE. At the third level of the hierarchy, Moreno presented his main migratory exchanges with Jaboatão dos Guararapes-PE, Recife-PE, Vitória de Santo Antão-PE, Cabo de Santo Agostinho-PE and Caruaru-PE, all of which had previously appeared in this network.

It is concluded that, once arrived at a certain place, Zika virus presents several channels of communication to be distributed to other municipalities, due to the strong circulation of people between the same municipalities. This finding also points out that public policies to control this infectious disease must necessarily be structured taking into account, in particular, the regional scale, in addition to the local one.

This work was inspired by the study by Carmo, Dagnino and Caparroz (2015), which indicated the potential of comparing population flows and distribution of chikungunya cases in Brazil. The authors built the networks from the two municipalities that had first autochthonous cases of chikungunya: Feira de Santana (Bahia) and Oiapoque (Amapá) (BRAZIL, 2014; FARIA et al, 2016a). Carmo, Dagnino and Caparroz (2015) verified the existence of two possible axes of chikungunya distribution throughout the country. The first axis was structured to the north of the Amazon, interconnecting Oiapoque with Macapá (Amapá), Belém (Pará), Manaus (Amazonas) and Boa Vista (Roraima). The second axis, on the other hand, connected the Northeast and Southeast regions of the country, organizing from Feira de Santana towards the capitals of São Paulo and Rio de Janeiro. Therefore, given the "starting" municipalities to structure the network are distinct from this work on Zika, none of the population flows reached Brasília, which, as we have seen, can potentialize the distribution of the disease across the territory.

On expanding the potential for disease distribution over time and across space, Fauci and Morens (2016) raise the question whether dengue, Zika and chikungunya viruses would follow distinct distribution processes or would otherwise be correlated, indicating the emergence of new standards. There is no definitive answer to this question.

It should be noted, however, that there is a set of studies that sought to verify if and how much the risk of emerging infectious diseases can be influenced by the migration and mobility of the population, both internally and internationally (WILDER-SMITH; SCHWARTZ, 2005; GUSHULAK et al., 2011; MONGE-MAILLO et al., 2014). The clues provided by such references will be essential for analyzing the present and emerging infectious diseases in Brazil.

Considering that in recent years Zika has gained global dimensions (WHO, 2016), there is still a lack of more studies to indicate more assertively how the relations between migratory flows and the distribution of this disease can be established – as well as its relation with the other infectious diseases already present in the territory.

The main research conducted so far on the Zika virus epidemic comprises efforts to highlight the cause of the increasing occurrence of microcephaly in infants and severe neurological impairment in children, especially from 2015 onwards. These investigations have occurred especially in the field of neuroscience, molecular biology and genetics (BRASIL et al., 2016; FARIA et al., 2016b; VENTURA et al., 2016).

The difficulties are immense while all the conclusions are partial, the studies still very recent and there are completely unknown aspects of the Zika epidemics, for example, why the congenital syndrome of Zika virus has more acute effects in the Northeastern Brazil. Precisely because of the dimensions of this challenge, more robust, consistent and perennial results will be generated only through the combination of efforts through a multidisciplinary approach.

The characteristics and dynamics of the population (sex, age, schooling, income, living conditions, mobility, etc.) may be playing an important role in this process. There is, therefore, a gap in the scientific knowledge to be supplied and the demographers are called upon to make their contribution.

The main goal of this study was to present the pathways or trajectories through which Zika infections tend to expand in Brazil. It was shown how, from Recife, migration data already indicated that the disease tended to reach Rio de Janeiro and, from there, the capital of the country, Brasília. From Brasília the distribution is pulverized to the other Brazilian states.

This paper has also some limitations. The most important to mention is that we do not know if the population flows are composed by infected people. Our data sources for dengue cases and migration are provided by different institutions. Besides that, these data also come from different moments in time. The population flows are provided by the Population Census carried out in 2010, while the dengue cases, by SINAN from 2008 to 2012. Based on them, we are trying to identify possible paths of a disease that entered the country years later. Another limitation is the fact that the city of São Paulo did not appear in the analysis because it recorded no dengue epidemic during the period 2008-2012. However, as the biggest city of the country in terms of population volume, and an important center for economic dynamics and population mobility to and from all over the country (and abroad), future studies should dedicate special efforts to understand its role on Zika spread in Brazil. The scale of analysis is also a concern. We proposed an investigation of the entire country, that can contribute to the development of public policies in this broad context. However, Zika virus, as all other infectious diseases transmitted by *Aedes aegypti*, depends deeply on the local political, social and environmental settings to spread.

Thus, considering the limitations of this paper, we highlighted a couple of directions to concentrate the efforts for future studies based on the results we have found. They are:

- Assign weights to population flows between municipalities. In this study, the first five municipalities that received the most migrants from the previous municipality were selected for the analysis. However, considering Recife network, for example, while in the first level of the hierarchy was Jaboatão dos Guararapes-PE receiving more than 48 thousand people, at the same level of the hierarchy was Cabo de Santo Agostinho-PE, with less than 4 thousand people. That is, even municipalities on the same level of the hierarchy can present volumes of population flows quite different with the municipality of origin. This difference can be weighed in future studies, as larger volumes of population exchanges potentiate that axis of communication as more likely paths of transmission of the disease;
- Overlay the actual "flows" of the disease in the territory using official data from the Ministry of Health. This way it will be possible to verify where the disease

originated and how it spread throughout the Brazilian territory. Spatial analysis tools can be useful for this purpose. This strategy will make possible to verify more effectively if this "disease path" corresponds to the main migratory flows established between the municipalities;

- In case of continuing to use the municipalities that presented dengue epidemics to investigate the path of other diseases, update the epidemic data up to 2017 (in this study it was not possible given the most recent year available was 2012);
- Add to the analysis the indicators of larval infestation of *Aedes aegypti* in municipalities, such as Breteau Index and House Infestation Index;
- Collect information for environmental sanitation conditions in Brazilian municipalities (especially water supply and garbage collection information), fundamental aspects in the reproduction dynamics of *Aedes aegypti*;
- Depending on the scale of analysis, in the case of studies focused on specific regions, it is possible to analyze specificities in the municipal control programs of this vector. Variations in access to material resources, facilities and health professionals can trigger consequences on mosquito infestation and consequently reflect on the number of notifications;
- At the national level, consider more rapid population flows, such as population mobility for work or study (information available in the 2010 Brazilian Population Census) and the volume of people transported through domestic flights (using data from the National Civil Aviation Agency – ANAC – http://www.anac.gov.br/);
- At the international level, investigate population flows through air transportation between Brazil and other countries of the world (data available at the International Air Transport Association – IATA – http://www.iata.org/), highlighting which are the main vectors of mobility of population and, consequently, the potential distribution channels of Zika between Brazil and the world.

It is intrinsic in this work the goal to find out how demography as a field of studies can, with its data and tools, produce advances in understanding the dynamics of Zika virus in the Brazilian territory. Effective public policies from the point of view of disease control should necessarily consider the three links of the transmission chain: virus, vector (*Aedes aegypti*) and host (population). Furthermore, it is also important to consider the various scales of the problem and develop public policies focused on the characteristics of each one of them.

It is also worth remembering that, because it is transmitted by the *Aedes aegypti* mosquito, whose transmission process is directly related to the way of structuring the cities, understanding the configuration of the urban space is a fundamental aspect to defenestrate the invasion of this infectious disease.

Finally, we should note that in the context of Zika worldwide concern, much has been said in terms of the importance of sexual and reproductive health promotion and prevention policies. According to the World Health Organization Zika Strategic Response Plan (WHO, 2016), the use of emergency contraception is recommended as a strategy to prevent the spread of the most deleterious effects of the virus. Emergency contraception comprises birth control methods that prevent pregnancy after sex.

Our results showed Zika tended to spread to Central-West, results corroborated by the most recent epidemiological bulletin of the Ministry of Health (BRAZIL, 2017). The Demographic and Health Survey (DHS) carried out in Brazil in 2006 showed that in the Central-West emergency contraception is a viable strategy to focus on. Considering women from 15 to 49 years old (the reproductive period), the Central-West region had 31.6% of them in non-formal or non-union, while for the entire country the figure is 27.7%. Besides that, 39.9% of Central-West women had been married or ever married, with 29.4% at the national level. In this region also a higher percentage of women use emergency contraception (ARILHA et al., 2016).

So, given the importance of Zika virus in this region it is necessary to implement control strategies specially designed for its population. One of the most effective is certainly strengthening sexual and reproductive health policies, among which the guarantee access to emergency contraception to all women who opt for it.

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