MULTIVARIATE GEOVISUALIZATION OF DENGUE, ZIKA AND CHIKUNGUNYA CASES IN BRAZIL: A DIDACTIC EXPERIENCE

GEOVISUALIZAÇÃO MULTIVARIADA DOS CASOS DE DENGUE, ZIKA E CHIKUNGUNYA NO BRASIL: UMA EXPERIÊNCIA DIDÁTICA

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ABSTRACT

In recent decades, the *Aedes aegypti* mosquito, the vector of dengue, Zika, chikungunya and other diseases, has become an increasing concern in Brazil and other tropical countries. However, the spatial distribution of these diseases in Brazil is not homogeneous, implying that there are distinct risk levels and various guiding strategies for fighting these diseases. This paper presents a didactic exploratory multivariate spatial data analysis of dengue, Zika and chikungunya cases in Brazil in 2016 in the context of an undergraduate course. The students elaborated, interpreted and discussed multivariate maps using techniques such as proportional symbols, hachure density, bivariate and trivariate choropleth composition, contiguous cartograms, conditional maps and matrices of maps and graphs. The students investigated the various interpretative possibilities based on the intrinsic and extrinsic combinations of multivariate geovisualizations. Through their interpretations of the spatial representations, the students were able to identify that the states of Rio Grande do Norte, Paraíba and Alagoas are experiencing the most critical situations for these three diseases, while the state of Minas Gerais has a serious situation only for dengue. In contrast, the maps clearly revealed that the states of Rio Grande do Sul, Santa Catarina and the Northern Region of the country experienced fewer cases of the diseases. It can be concluded that the undergraduate course improved the students' abilities to build and interpret spatial representations using geotechnologies.

Keywords: *Aedes aegypti*. Dengue. Zika. Chikungunya. Geovisualization. Exploratory Spatial Data Analysis. Geotechnology. Geographic Information Systems. Didactics.

RESUMO

A transmissão de Dengue, Zika, Chikungunya e outras enfermidades pelo mosquito *Aedes aegypti* tem se tornado, no decorrer das últimas décadas, uma preocupação cada vez mais relevante no Brasil e em outros países tropicais. Todavia, a distribuição espacial dos casos dessas doenças no Brasil não é homogênea, implicando diferentes graus de risco e estratégias de combate às doenças. Este artigo apresenta uma experiência didática de análise exploratória espacial multivariada dos dados de ocorrência de Dengue, Zika e Chikungunya no Brasil, em 2016, no contexto de uma disciplina de graduação. Foram elaborados, interpretados discutidos, em conjunto com os estudantes, mapas multivariados utilizando técnicas de símbolos proporcionais, densidade de hachuras, composição coroplética bivariada e trivariada, cartogramas contíguos, mapas condicionais e matrizes de mapas e gráficos. Investigaram-se as diversas possibilidades de interpretação a partir das combinações intrínsecas e extrínsecas de geovisualização multivariada. As representações espaciais permitiram aos estudantes identificar como Rio Grande do Norte, Paraíba e

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Alagoas apresentam situações mais críticas quanto à ocorrência das três enfermidades, ao passo que Minas Gerais apresenta uma situação mais grave apenas para a Dengue. Rio Grande do Sul, Santa Catarina e a Região Norte, por sua vez, foram destacados nos mapas por apresentarem menor ocorrências das doenças. Considera-se que a disciplina contribuiu com o aprimoramento da capacidade dos alunos em elaborar e interpretar representações espaciais com o uso de geotecnologias.

Palavras chave: *Aedes aegypti.* Dengue. Zika. Chikungunya. Geovisualização. Análise Exploratória de Dados Espaciais. Geotecnologias. Sistemas de Informação Geográfica. Didática.

INTRODUCTION

The Spread of Dengue, Zika and Chikungunya in Brazil

The *Aedes aegypti* mosquito originated in Africa but has spread to most of the continental regions in the world that have tropical and subtropical climates (Womack, 1993), especially the most populated areas. This mosquito is a transmission agent for the dengue, Zika, and chikungunya viruses, as well as yellow fever, Mayaro, and other diseases.

In Brazil, the registered number of annual dengue cases has increased from 40,000 in 1990 (Ministério da Saúde, 2015) to more than 1,667,000 in 2015 (Secretaria de Vigilância da Saúde, 2017). During this same period, annual deaths from hemorrhagic dengue rose from 8 to 629 (Ministério da Saúde, 2014, Secretaria de Vigilância da Saúde, 2017). A significant expansion of chikungunya and Zika cases in Brazil occurred during the rainy season from the end of 2015 to the beginning of 2016 (Secretaria de Vigilância da Saúde, 2017). After the association was made between Zika and microcephaly in human fetuses (Schuler-Faccini et al., 2016), initially reported in Brazil, it is estimated that approximately 50% of Brazilian women have opted to postpone pregnancy (Diniz et al. 2017). With the Olympic Games taking place in Rio de Janeiro in 2016, these concerns have become global because of the possibilities of international spread through tourism related to sporting events.

In response to this situation, many actions have been carried out to control dengue, chikungunya and Zika. Government programs in Brazil have focused on the control of possible reproductive outbreaks of the *Aedes aegypti* mosquito, especially on public awareness programs for residential actions (Picinato et al., 2015). The development of medical diagnostic technologies integrating the three diseases (FIOCRUZ, 2016), dengue vaccination (Durbin, 2016) and biological control using genetically modified mosquitoes (Carvalho et al., 2015) has also advanced. Preventive action may also include the use of repellents, mosquito traps, screens on doors and windows to seal homes, similar to programs already in place to combat malaria and other mosquito-borne diseases in tropical countries.

The life cycle stages of *Aedes aegypti* and the associated viruses can tolerate temperatures above 10ºC, and the viruses spread faster in areas with high temperatures and low altitudes (Donalísio et al., 2002). These and other climatological variables foster optimal *Aedes aegypti* development in the coastal areas of Northeast and Southeast Brazil, especially during rainy periods (Braga and Valle, 2007). However, *Aedes aegypti* is also present in the interior of Brazil, especially in the Southeast. In contrast, the cold periods characteristic of extreme southern Brazil hamper the development of *Aedes aegypti* in that area. Areas with severe droughts and dry seasons also disrupt the reproductive cycle of the mosquito. Thus, *Aedes aegypti* and the associated diseases are unequally distributed among the different Brazilian states.

Multivariate Geovisualization

Geovisualization can be conceptualized as an area of knowledge dedicated to the visualization of spatial information (Jiang and Zhiling, 2013), and it is often combined with research on human cognition, data exploration and decision support processes (MacEachren and Kraak, 1997). Therefore, multivariate geovisualization can be conceived as the visual representation of more than one variable in a spatial visualization model or more than one contiguous model (Gahegan, 2008).

Two important concepts for understanding the application context of geovisualization are "maps to see" and "maps to read" (Bertin, 1988). "Maps to see" aim for simplicity, involving few variables, classes and elements, to allow fast and easy understanding and memorization by the general public; in contrast, "maps to read" are aimed at specialists who have the time to examine the diverse variables, classes and elements of the map and explore complex spatial patterns. There is no clear division between these two map types; instead, they exist on a continuum. Multivariate geovisualization, however, is more commonly used in the context of "maps to read".

An initial concern when designing a multivariate representation model is selecting which variables to display on the same map (i.e., multivariate map) or whether to present several maps in series, each presenting one of the variables or employing different visualization methods. This last option (a series of maps) is conceptualized by Tufte (2001) as "small multiples".

Another relevant theoretical framework for multivariate geovisualization is that it can use both intrinsic and extrinsic multivariate techniques (Slocum et al., 2009). Extrinsic techniques use different types of visualization elements (colored polygons, lines, hachures, dots and other symbols) on the same map, and each type represents a different variable. Because readers perceive each element type differently, it is possible to selectively focus on the spatial distribution of each variable.

Intrinsic techniques, in turn, use the same technique to represent more than one variable. For example, a proportional symbol map can be transformed into a pie chart to represent more than one variable at a time. Readers tend to perceive variables represented through intrinsic techniques as a whole set, making it easier to compare the variables at each map location (Slocum et al., 2009). A single map can employ both intrinsic and extrinsic techniques of multivariate geovisualization.

A standard context for multivariate geovisualization is Exploratory Spatial Data Analysis (ESDA), which is defined as a collection of interactive techniques that describe and visualize spatial distributions, spatial association patterns, outliers, groupings, and spatial homogeneity/heterogeneity patterns (Anselin, 1998). ESDA computational environments support the rapid design of spatial and graphic models with different visualization techniques. Users can easily switch their view between various visualizations, perform queries, and make selections that propagate between the different models (Slocum et al., 2009). ESDA is intended to allow researchers to become familiar with complex multivariate spatial patterns so they can formulate hypotheses that can be further tested with more specific spatial analysis models (Leu et al., 2009).

Rationale and Purpose

Due to the spread of dengue, Zika and chikungunya in Brazil, it is relevant to investigate the different spatial patterns formed by the occurrences of these diseases in Brazil. These spatial patterns facilitate understanding of the different risk levels in different regions of Brazil. This article aims to discuss a didactic experience that explores the possibilities for analyzing these spatial patterns through different multivariate geovisualization techniques. Geovisualization techniques were incorporated into an undergraduate course, and this paper presents the students' opinions on the utility, reproducibility, aesthetics and complexity of the visual representation models they used during the course.

METHODOLOGY

Pedagogical Context:

The case study presented in this article was developed for the course Informatics Applied to Territorial Planning offered at the Federal University of ABC (UFABC), from September to December 2016. The course is part of the curriculum for a Territorial Planning bachelor’s degree, and seeks to give students an overview of various spatial data representation tools (UFABC, 2017). The main course objective is to demonstrate how to use different models of spatial representation to reveal patterns and regularities in regional data. At the end of the course, students are expected to be able to select and use spatial representation models appropriate to research problems applied to territorial planning. The class of 2016 had 16 students, of whom 8 were studying for the Territorial Planning bachelor’s degree program and 8 were pursuing other programs, primarily bachelor's degrees in Environmental and Urban Engineering. The students had previously completed a Cartography and Geoprocessing course.

As specified in the course syllabus, several different multivariate geovisualization techniques were studied. Each class block presented a single technique as follows:

i. Present the theoretical concepts of the spatial visualization technique;

ii.Present and discuss case studies that used these techniques;

iii.Conduct practical activities in the laboratory, using tutorials with guidance by the teacher;

iv.Collectively discuss the results obtained by the students;

v.As an out-of-class activity, each student also applied the technique using other spatial data of their choice;

vi.During the course, the students collectively developed an applied project using a combination of at least 3 geovisualization techniques from the course.

During the course, the students used the dengue, chikungunya and Zika data to develop visualization models in the laboratory. These models are presented in the present article and use the following techniques:

- Univariate, bivariate, and trivariate choropleth maps
- Small multiples (matrices of maps and graphics)
- Univariate and multivariate proportional symbols
- Hachure density
- Cartograms
- Conditional maps

In addition to the occurrence maps for dengue, Zika and chikungunya, which are the focus of this article, demographic density, migration, crop yield, election result, water use and climatological data were also used throughout the course. The techniques included density maps, flow maps, kernel maps, proximity maps, interpolation, geostatistics, three-dimensional visualization, integration with computer-aided design (CAD), Building Information Modeling (BIM), geographic information systems (GIS) and photography.

At the end of the course, the students held a collective discussion to reflect on the obtained results. Each student also completed an anonymous self-assessment. The self-assessment form consisted of open-ended questions through which students could express their perceptions of the teaching method, learning level, utility, ease or difficulty of learning and reapplication, and perceived future utility in relation to both each individual subject and the entire course.

The classes were recorded and made available on YouTube in the playlist "*Informática Aplicada ao Planejamento Territorial* - Informatics Applied to Territorial Planning" (available at https://www.youtube.com/playlist?list=PLBvhnPO-uwWIkXCCh_bY6jGaQO6mjTP9f, in Portuguese). The description field of each video contains a link for accessing the lesson slides on the Slideshare.net repository.

Multivariate Geovisualization Products

During the course, the main data sources were the monthly epidemiological bulletins of the Brazilian Health Surveillance Secretariat (Secretaria de Vigilância da Saúde), which monitors dengue, chikungunya and Zika records in Brazil, and the maps produced during the course were updated with the latest bulletin data. The totals for 2016, made available by Secretaria de Vigilância da Saúde (2017), are used in this article. The GIS database containing the data compiled for each state can be accessed at https://app.box.com/s/hutyfqilubmrnnoeg853x8as44pin. The programs used for mapping were ArcGIS, Geoviz Toolkit, Geoda and ScapeToad.

The first cartographic product was a matrix of small multiples, with the univariate data of each disease and the cases of all three diseases grouped together. For each disease, a map was generated for total cases, cases/km^2, and cases per 100,000 inhabitants. The maps showing these total cases used point density visualization, following the mapping guidelines of Archella and Thery (2008) and Dent (2009).

The cases per km^2 and per 100,000 inhabitants were represented by choropleth maps, using a uniform color legend to allow comparison between the 3 diseases.

A first multivariate proportional symbol map in pie chart form (each of the three diseases - dengue, Zika, and chikungunya) was superimposed on a univariate choropleth map of total cases per square kilometer in ArcGis 10.4 software. The aesthetic pattern of this map was based on the guidelines of Archella and Thery (2008). In proportional symbols, the circle size adjustment method of Flannery (1956) (i.e., perceptual scale) was used to compensate for psychological perception errors concerning the symbol sizes.

The second map used the density of perpendicular hachures to describe the cases of occurrence of two diseases, while the third was represented by a univariate choropleth map. The cartographic styles of bivariate hachures followed the recommendations of Slocum et al. (2009), and the classification of hachure intervals on choropleth maps followed the standard of Francis et al. (2015).

A "Matrix of Maps and Scatter Plots" (DAI, 2007) was developed using the Geoviz Toolkit 0.8.5 application by pairing the variables and using a combination of bivariate choropleth maps, histograms and scatter plots. The matrix strategy was also used to elaborate a matrix of conditional maps (Anselin, 2005) using the GEODA 1.8 application.

Trivariate maps were developed using both subtractive (RGB: red, green, and blue) and additive (CMY: cyan, magenta, and yellow) color schemes to visualize the occurrences of each disease using ArcGis 10.4. The color schemes were developed by transforming the polygon maps to raster format for each disease and then overlapping the three layers to form the trivariate color scheme.

Finally, a contiguous cartogram of the total cases of the three diseases was developed with ScapeToad software, using the diffusion algorithm of Gastner and Newman (2004). The cartogram was displayed with a sequential bivariate choropleth layer representing the number of cases per 100,000 inhabitants and per square kilometer, based on the bivariate cartographic composition guidelines of Brewer (1994) and Stevens (2015). The multivariate choropleth overlap on the cartogram aligns with the perspective of Tobler (2004) and Hennig (2013) in that the cartogram becomes a cartographic projection for demographic data in a final view that "humanizes" cartography. To facilitate identifying and locating deformed states, the recommendations of Dent et al. (2009) and Slocum et al. (2009) were followed, presenting the deformation grid together with the cartogram, a non-deformed map in the same color pattern, and a toponymy of state acronyms in bold.

RESULTS AND DISCUSSION

Cartographic Products

Figure 1 contains a matrix of small multiples with univariate spatial representations. Dengue has a much greater occurrence density than the other two diseases; therefore, it exerts a greater influence in the maps that group all the occurrences. In Brazil, dengue cases are concentrated primarily in the Northeast and Southeast, while Zika is concentrated in the Northeast. Chikungunya cases are more dispersed, especially between the range of 10° and 20° south latitude. Mato Grosso do Sul has the highest number of occurrences of dengue per 100,000 inhabitants, followed by Minas Gerais, Rio Grande do Norte and Goiás. The highest concentrations of dengue per km^2 occur in the Distrito Federal and in Rio de Janeiro.

Figure 1 - Matrix of small multiples for the occurrences of dengue, chikungunya and Zika in Brazil in 2016 with univariate maps representing total cases, cases per square kilometer and cases per 100,000 inhabitants

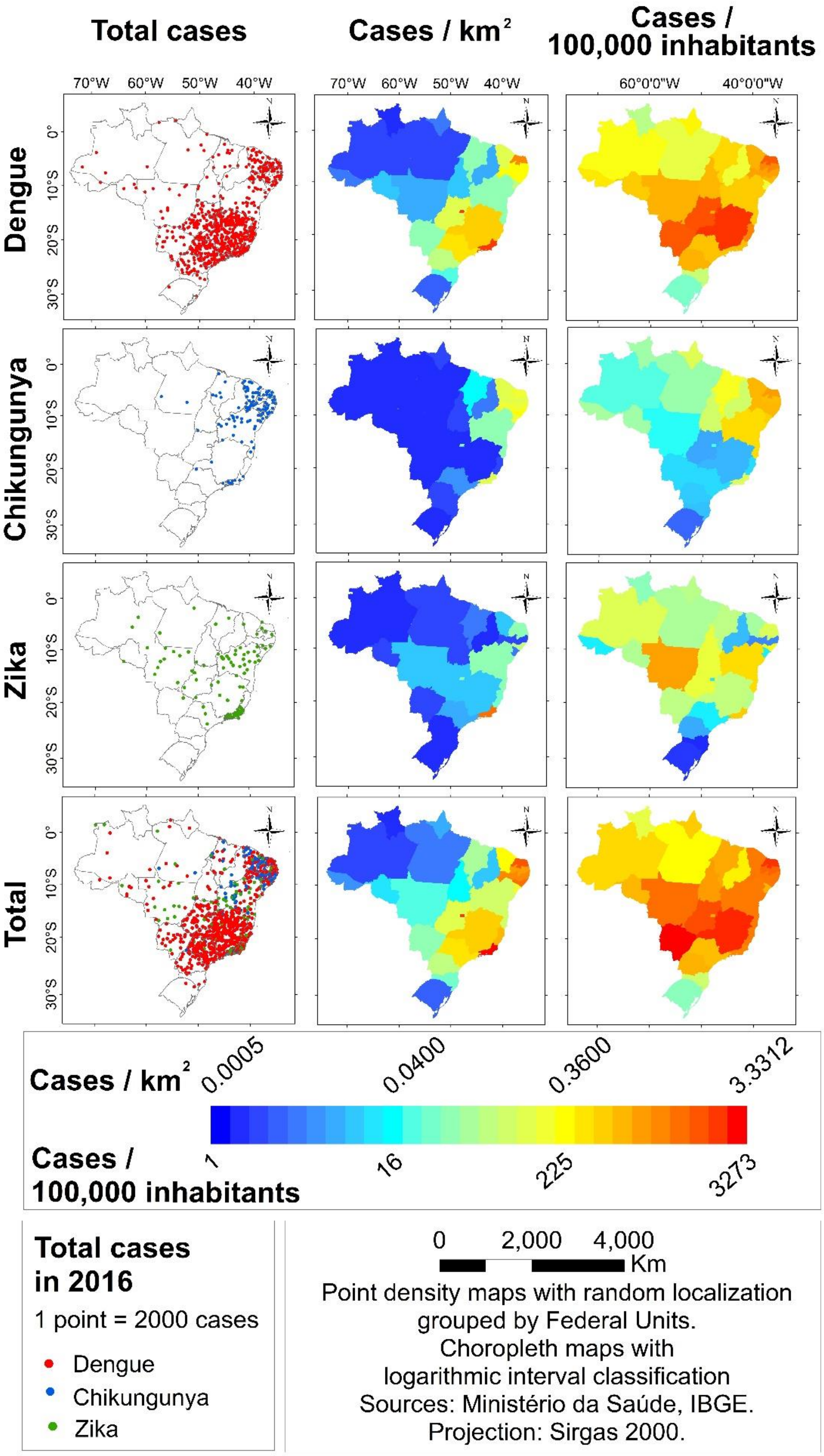


Figure 2 shows the proportional symbol and univariate choropleth map. Minas Gerais stands out by having the highest number of total cases (with dengue predominating), while Rio de Janeiro, Rio Grande do Norte and Alagoas have the highest number of total cases per km^2. The North and South regions stand out due to their low numbers of total cases. From a disease-proportion perspective, dengue cases predominate over those of Zika and chikungunya, although the latter two occur in substantial numbers in the Northeast and in Rio de Janeiro.

Figure 2 - Choropleth and proportional symbol map showing the occurrences of dengue, chikungunya and Zika in Brazil in 2016

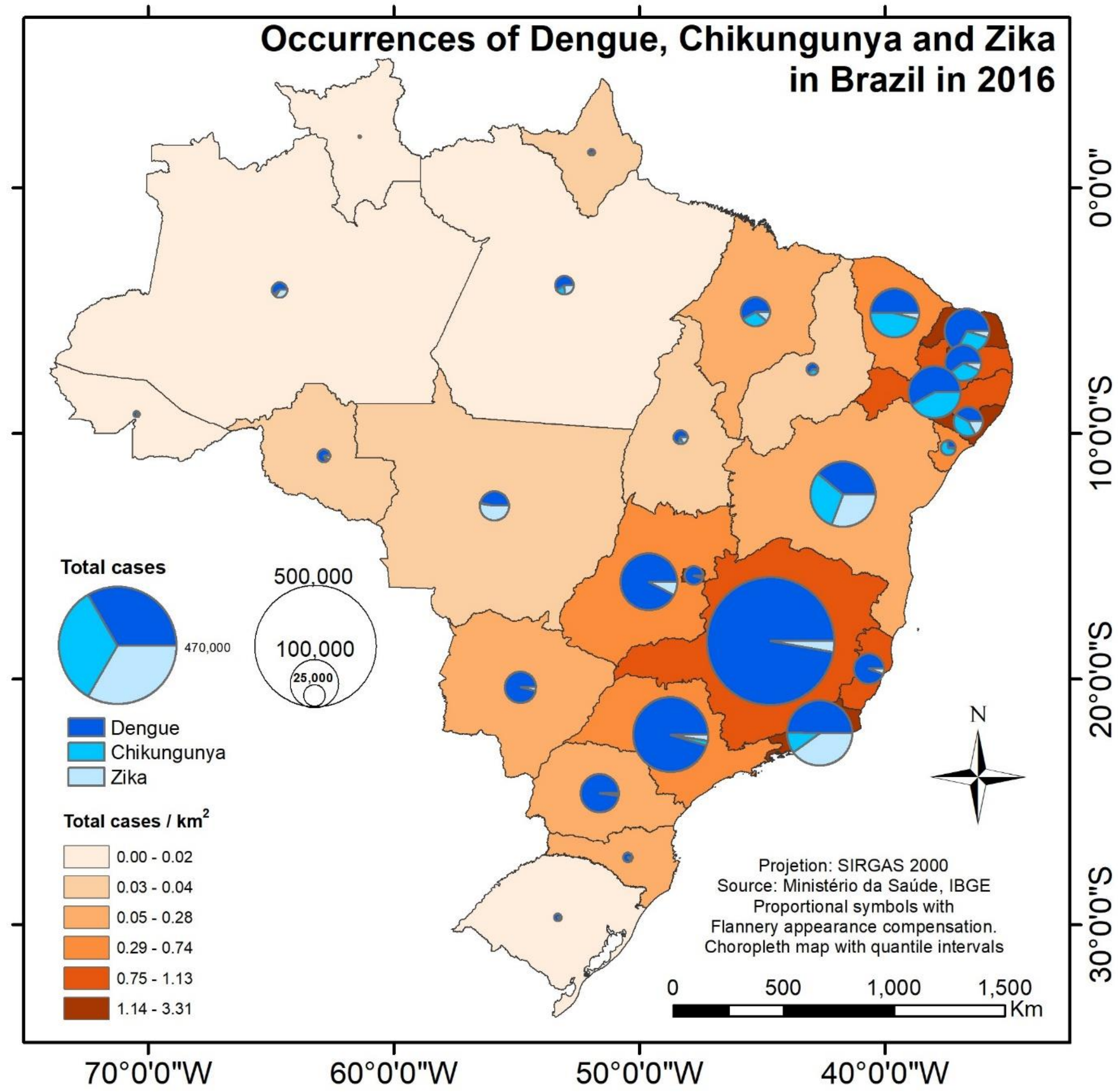


Figure 3 presents one of the trivariate maps (chikungunya and dengue in hachure and Zika in choropleth) showing the occurrences of cases per 100,000 inhabitants. The map makes it possible to visualize the higher density of cases per 100,000 inhabitants in the central latitude range (between 5° and 25° south latitude). Zika cases also occur in a central (but smaller) range, reaching 20º south latitude, although it also reaches Amazonas and Rio de Janeiro. Chikungunya cases are more concentrated in the Northeast and in Amapá.

Figure 3 - Bivariate hachure map on a choropleth map background representing the cases of dengue, chikungunya and Zika per 100,000 inhabitants in Brazil in 2016

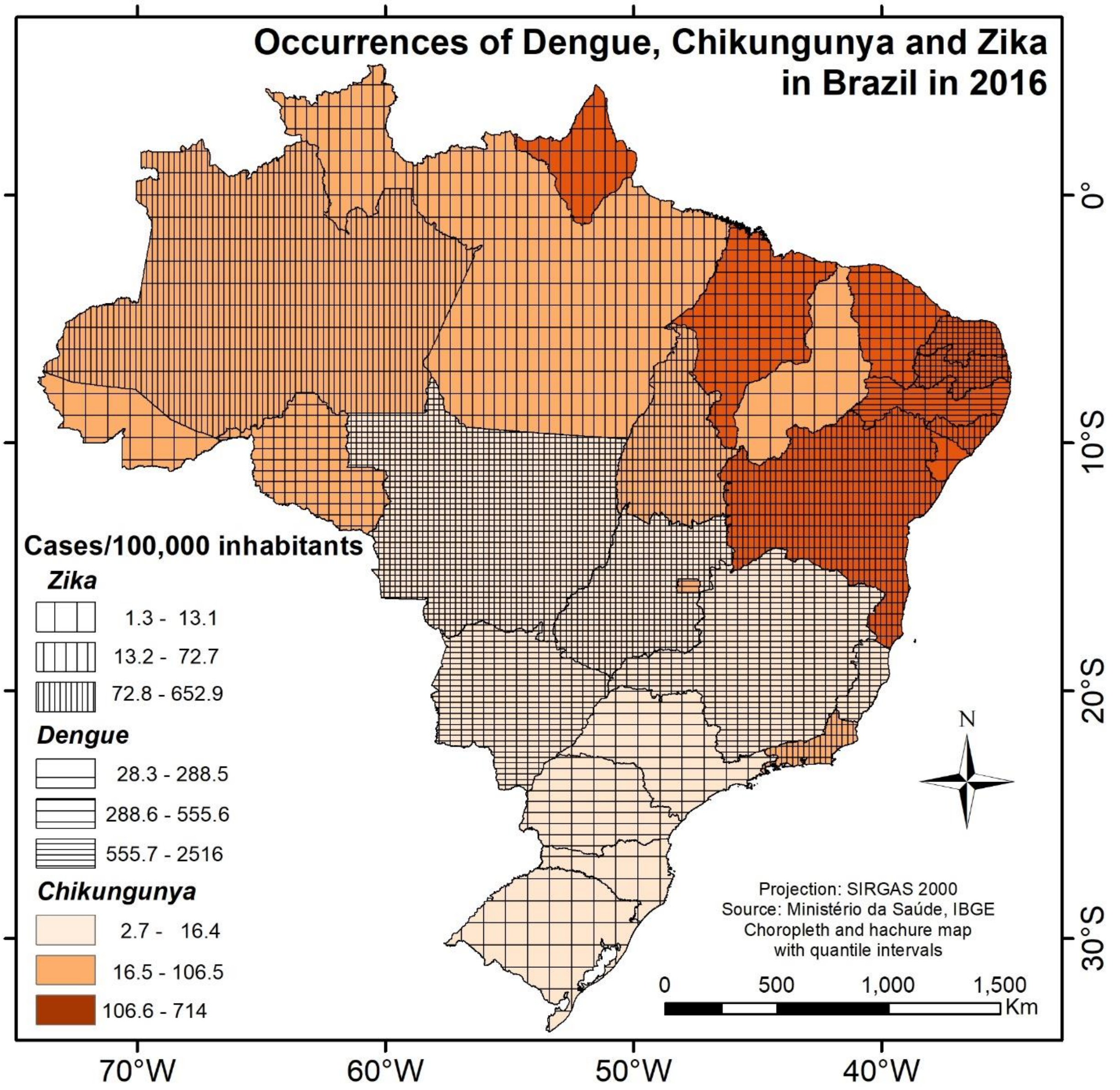


Figure 4 shows a matrix of maps and scatter plots. Where a variable intersects with itself, the frequency histograms appear as a negative asymmetric distribution with an elongated right tail, showing that only a few states present values that are much higher than others. The scatter plots, with their respective trend lines, Pearson correlations, and R^2 values, show that little correlation (although always positive) exists between the case occurrences of these three diseases. The bivariate map of dengue and chikungunya shows that the Southeast and Center-West regions have higher proportions of dengue than of chikungunya. The North and a large part of the Northeast present relatively higher values for chikungunya, except for Rio Grande do Norte, Paraíba and Pernambuco, which present high values for both diseases. The bivariate map of dengue and Zika also shows a transition from higher proportional dengue values in the Southeast and Mato Grosso do Sul to relatively higher values of Zika in the northern latitudes. The bivariate map of Zika and chikungunya shows a relatively higher occurrence of chikungunya in Northeast Brazil, and a relatively greater predominance of Zika in the Center-West.

Figure 4.- Matrix of maps and scatter plots for cases of dengue, chikungunya and Zika in Brazil in 2016. Bivariate choropleth maps with quantile classification, WGS84 projection

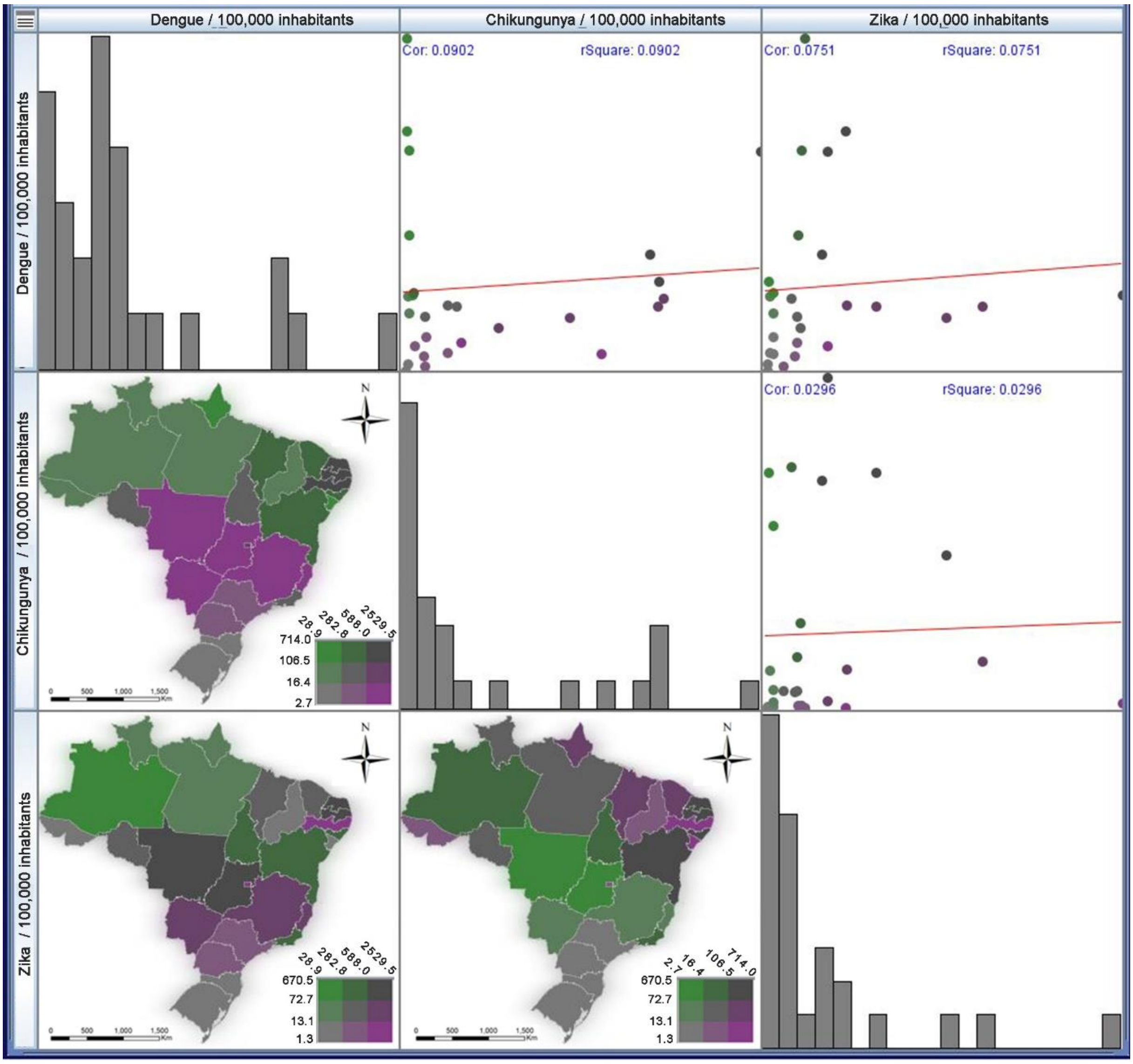


Figure 5 shows a conditional choropleth map of the occurrence of the three diseases. The map shows that the highest quantiles of dengue and Zika per 100,000 inhabitants coincide in the central-western region of Brazil. Rio Grande do Norte, Paraíba and Pernambuco are again distinguished by the high occurrence of dengue and chikungunya per 100,000 inhabitants, and Bahia by its combination of Zika and chikungunya.

Figure 6 shows the trivariate choropleth maps that represent the cases per 100,000 inhabitants of the three diseases, in both additive (RGB) and subtractive (CMY) compositions. The spatial patterns in the two maps are the same because the additive composition is simply the inverse of the subtractive composition. From a general perspective, the low occurrences of the three diseases per 100,000 inhabitants in Rio Grande do Sul and Santa Catarina, and their high occurrences in Rio Grande do Norte, Paraíba and Alagoas are evident. The maps show that Rio de Janeiro, Bahia and Alagoas have high joint occurrences of Zika and chikungunya. Mato Grosso and Goiás show high joint occurrences of Zika and dengue. Pernambuco shows a high joint occurrence of dengue and chikungunya. São Paulo and Paraná show high occurrences of dengue, but low occurrence of the other diseases.

Compared to the rest of Brazil, the northern states, ranging from Piauí to Roraima, have proportionally higher rates of chikungunya per 100,000 inhabitants than of dengue and Zika.

Figure 5 - Conditional map of the occurrences of dengue, chikungunya and Zika in Brazil in 2016

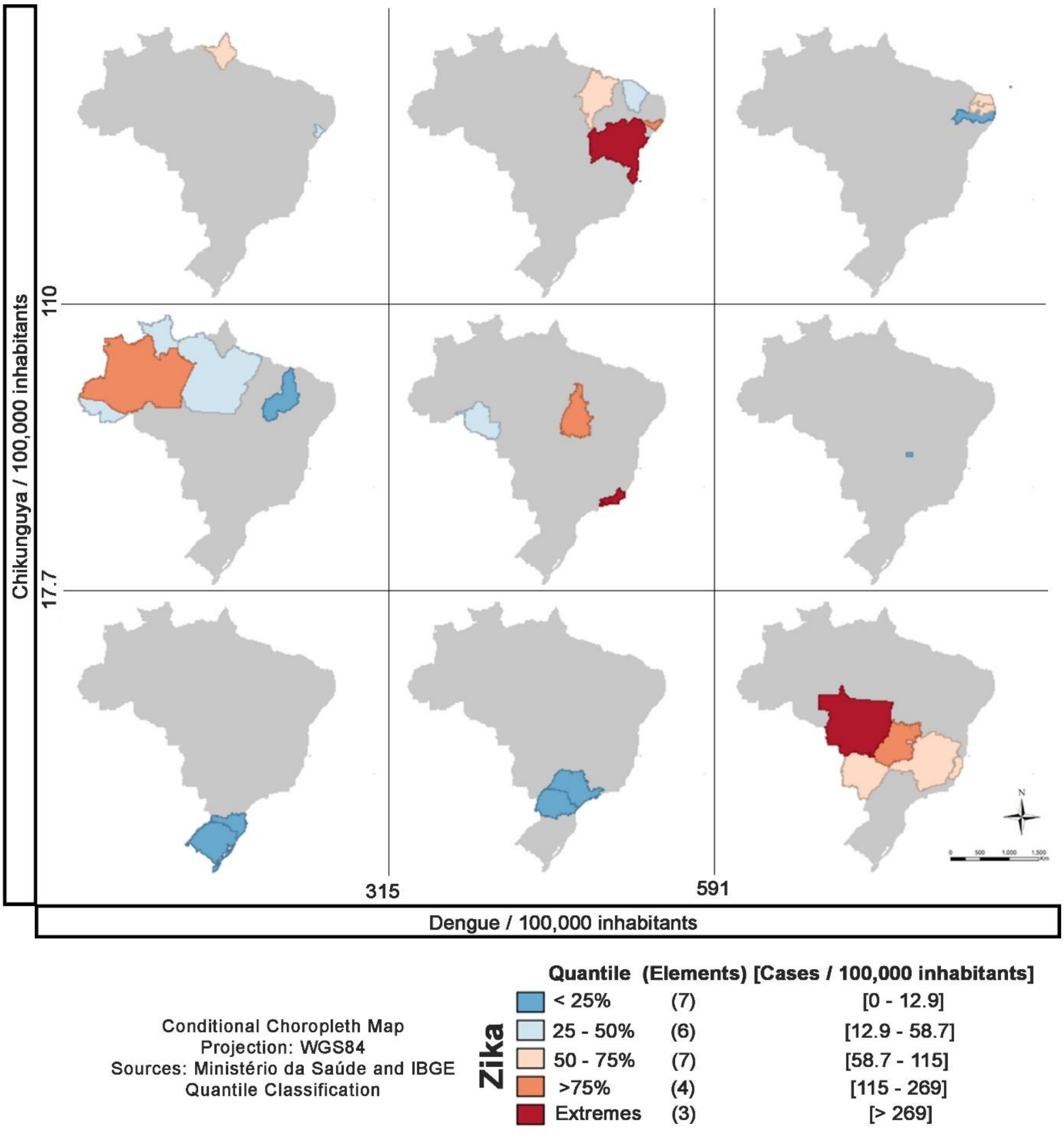
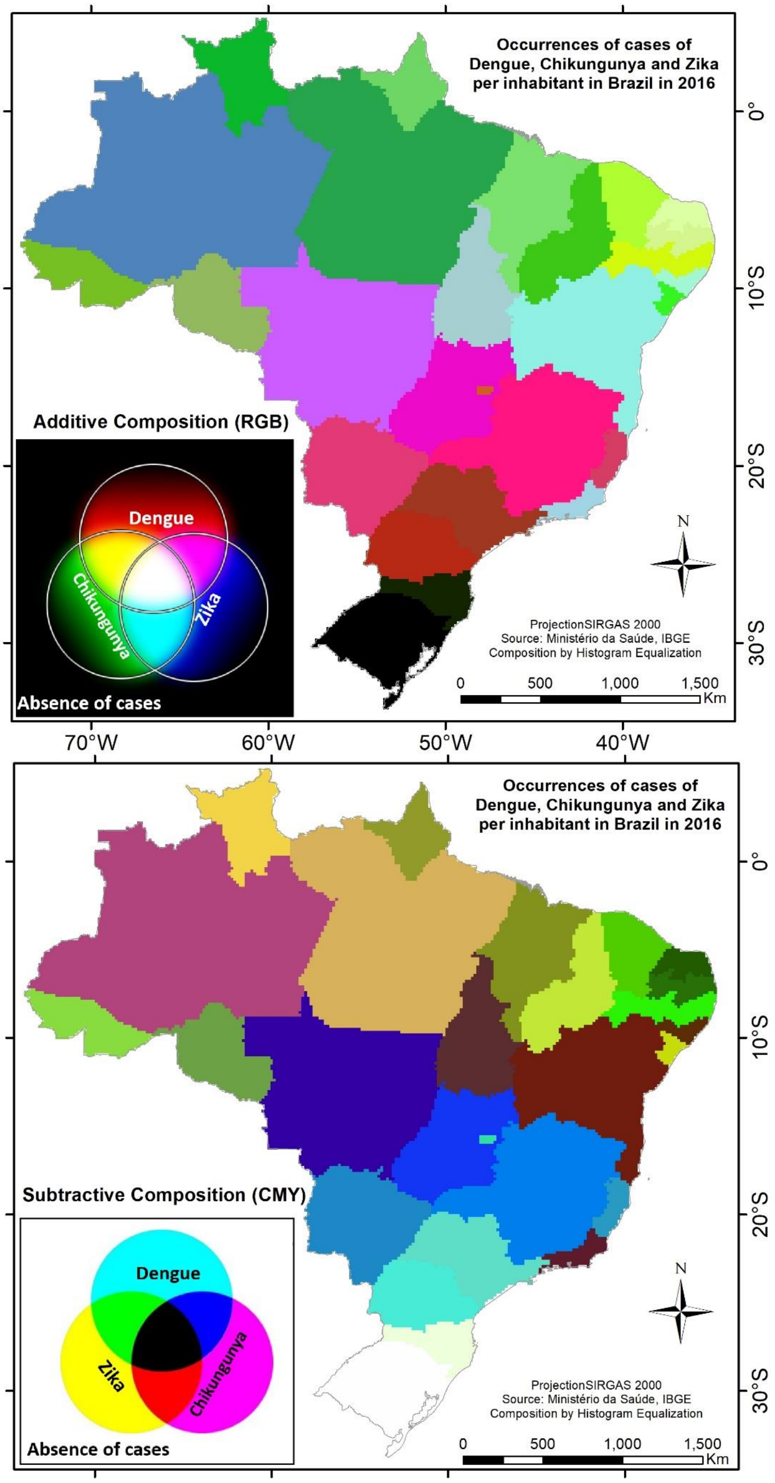
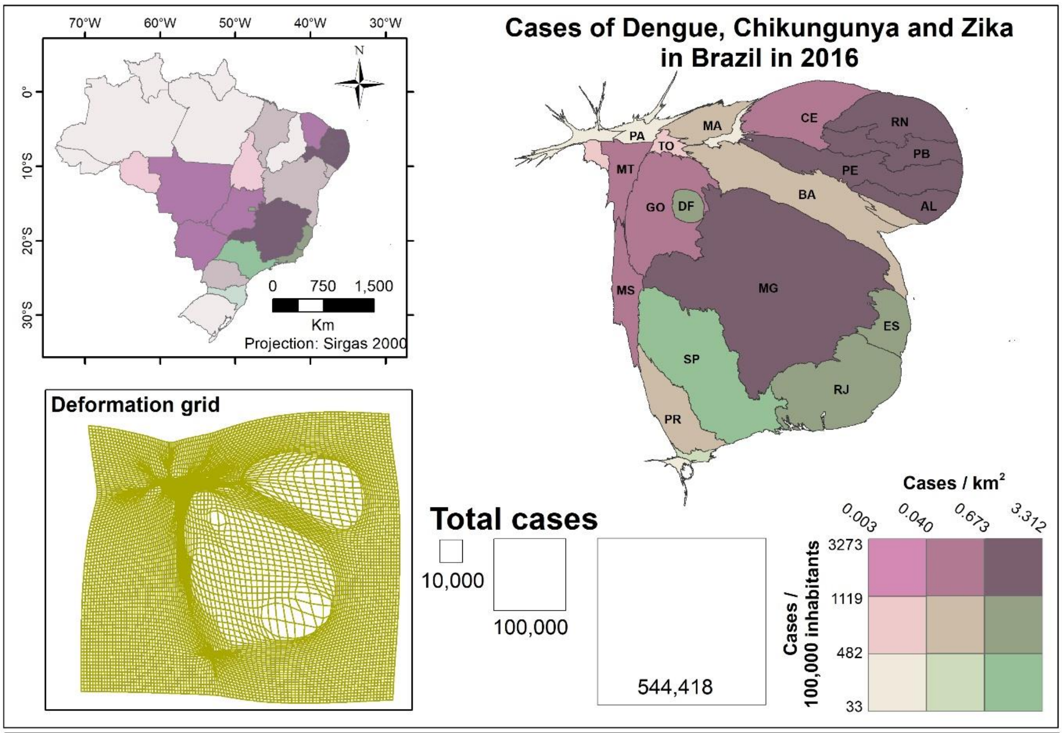


Figure 6 - Trivariate choropleth maps of dengue, Zika and chikungunya cases in Brazil in 2016, in additive (above) and subtractive (below) compositions



The cartogram in Figure 7 shows the sizes of the Brazilian states in proportion to the total number of cases of the three diseases, while the bivariate choropleth classification reflects the number of cases per 100,000 inhabitants and per square kilometer. Corroborating the interpretations already made on the proportional symbol map (Figure 2), the cartogram shows the large number of total cases in the Southeast and, secondarily, in the Northeast. The deformation grid indicates that Rio de Janeiro and Distrito Federal were the federal units that were most enlarged in the cartogram, while there was a significant reduction in the North and South. The choropleth information indicates that Minas Gerais, Alagoas, Pernambuco, Paraíba and Rio Grande do Norte have a high concentration both per 100,000 inhabitants and per square kilometer. The Northern Region of Brazil and Rio Grande do Sul present low densities, both per 100,000 inhabitants and per square kilometer.

Figure 7 - Cartogram of total cases and cases/km^2 of dengue, chikungunya and Zika in Brazil in 2016



Contiguous cartogram by total cases, using the diffusion algorithm of Gastner and Newman (2004).
Sequential bivariate map with quantile classification, with subtractive composition (CMY)
Source: Ministério da Saúde, IBGE

Pedagogical Dialogue

Students considered the proportional symbol map to be both aesthetically pleasing and easy to read, as well as easily replicable. The proportional symbol map and the cartogram were the only ones that treated the total data more specifically. The hachure map was noted as being aesthetically the worst, although it allowed the students to better identify the spatial patterns of each variable, and they found it easier to reuse this technique[2]. The polarization between the proportional symbol map and the hachure map fits well in the theoretical perspective of "maps to see versus maps to read" (Bertin, 1988).

The students considered the three-color maps to be better for comparing the proportions between variables. The fact that it was the only type of map with continuous color classification (the others had interval classification) allowed observation of more nuances between the variations among states, according to the reflections of Dent et al. (2009). Students who had previous experience with remote sensing preferred the additive composition (RGB), while those who did not have such experience considered the subtle (CMY) method more intuitive. The greater intuitiveness of trivariate choropleths maps with a subtractive scheme (CMY) for laypersons was also defended by Slocum et al. (2009). The state of Goiás, which had average values for the cases of the three diseases, appeared as a

[2] Complementarily, one of the anonymous reviewers of this article expressed that the hachure map could confuse readers as to the symbology for each variable. We agree that such a case could likely occur in a rapid reading in the context of “maps to see”, because this map requires more prolonged and focused attention from the reader to differentiate spatial patterns (i.e., it falls into the "maps to read" context).

grayish color that was not presented directly in the trivariate legend because of the visual limitation to represent a three-dimensional color scheme using a two-dimensional legend.

Some students reported that the multivariate maps were more difficult to interpret than the univariate maps. Comparatively, the students had more difficulties and required more time to interpret the conditional choropleth maps and the matrices of bivariate maps and scatter plots. In contrast, some students expressed higher interest, particularly in the the cartograms and trivariate choropleth maps, due to their curiosity to explore the spatial patterns, consistently with the arguments of Dent et al. (2009) and Hennig (2013). However, some environmental engineering students expressed concern about the acceptability of cartograms in technical reports, due to their spatial distortions.

The students agreed that the joint evaluation of the various maps representing the same variables allowed an analysis of patterns that would not be clear if only one map were used. From this perspective, one can conceive that the set of maps presented in this paper may form a series of small multivariate multiples. As a group, the students discussed how each of the maps used the intrinsic and extrinsic multivariate combinations differently (Table 1) to provide complementary perspectives of spatial analysis.

Table 1 - Possibilities for interpreting the intrinsic and extrinsic multivariate combinations in the developed maps

Map	Intrinsic Combination	Extrinsic Combination
Figure 2. Univariate choropleth and proportional symbol (pie chart) map	Representation of the total cases for each disease, allowing a comparison of the total values within each state, but increasing the difficulty of comparing each type of disease occurrences among states.	Contrasting proportional symbols (circles) with the choropleth background of total cases/100,000 inhabitants. Contrasting colors made it possible to alternate focus between the circles and the choropleth background.
Figure 3. Bivariate hachure map on a univariate choropleth map background	The reader can focus on one of the hachure types (horizontal or vertical) at a time or analyze their correlations (sizes and lengths of the resulting rectangles).	The reader can also alternate focus between the choropleth background and the hachures.
Figure 4. Matrix of bivariate maps, scatter plots and histograms	The bivariate maps and scatter plots facilitate pairwise analysis of the relationships among variables. Readers must focus on one panel at a time. The interpretation limit is bivariate rather than trivariate.	Statistical plots provide additional information for understanding the data displayed on the maps.
Figure 5. Conditional choropleth map	The vertical and horizontal axes that divide the 9 maps facilitate relating two types of disease (dengue and chikungunya).	After focusing on the axes, the reader subsequently analyzes the element colors (the third variable), first for each variable on one axis (vertical or horizontal) and then on the two axes simultaneously.
Figure 6. Trivariate choropleth maps	These maps allowed a better comparison of the proportions of disease occurrences in each state through the final combination of colors.	There is no extrinsic combination. Therefore, it is more difficult to visualize each of the three variables independently.
Figure 7. Cartogram with bivariate choropleth map	The size of the state conveys an intuitive notion of its relevance, even when the reader is focused on the color classes. It is possible to read the bivariate legend diagonally (from lower left to upper right), interpreting the interaction of doubly low values (light colors) or doubly high values (dark colors).	The reader can alternate focus between the sizes of the states or the basic color sequence of each choropleth variable.

Discussion

From the interpretation of the multivariate representations, the students concluded that Rio Grande do Norte, Paraíba and Alagoas present the most critical situations because of their high concentrations of cases of the three diseases. Minas Gerais also has a high concentration of dengue cases (total, per capita and per square kilometer), but it does not yet present high proportions of chikungunya and Zika. However, if the chikungunya and Zika epidemics were to spread over the next few years to the areas with the highest concentrations of the *Aedes aegypti* mosquito, these diseases could become a major concern in Minas Gerais. Rio Grande do Sul and Santa Catarina have few cases because they are below the minimum reproductive temperature range of the transmitting mosquito. The spatial representations allowed the students to recognize that the Northern Region of Brazil presents a relatively smaller proportion of cases than the proportions in the Northeast, Southeast and Center-West.

The data used in this study could also be spatially represented by other multivariate geovisualization techniques such as Chernoff Faces (Chernoff, 1973), Interlinked Micro-Maps (Carr et al., 1998), Universal Data Maps (Durham et al., 2006), fusion of bivariate choropleth legend with scatter plot (Leonowicz, 2007) and Ring Maps (Huang et al., 2008). However, the automated deployment of these techniques in GIS software is still experimental.

Because Zika and chikungunya are undergoing epidemic expansion, the continuity of spatial monitoring may be useful in assessing the spread of disease over time. Multivariate geovisualization techniques such as map time series, space-time cube (Carlstein, 1978), time line graph legends (Slocum et al., 2009), Scan (Chen and Glaz, 1996) and Emerging Hotspots (Gudes and Varhol, 2015) may be useful for such analyses.

CONCLUSIONS

From a didactic aspect, this study revealed how students gradually developed the ability to create and interpret the intrinsic and extrinsic geovisualization combinations as they learned and reflected on the different techniques used. The students agreed that the Informatics Applied to Territorial Planning course expanded their ability to work with GIS for data representation. They also emphasized this topic's relevance to their labor market aspirations. Some of the students also expressed an interest in publishing their final papers at academic events. It is concluded that the course fulfilled its didactic objectives.

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REFERENCES

ANSELIN, L. Exploratory spatial data analysis in a geocomputational environment. In: LONGLEY, P.A, BROOKS, S.M., MCDONNELL, R., MACMILLIAN, W. (ed.). **Geocomputation**: A Primer. New York: Wiley and Sons. 1998, p. 77–94

ANSELIN, L. **Exploring Spatial Data with GeoDa: A Workbook**. Spatial Analysis Laboratory. Department of Geography, University of Illinois, Urbana-Champaign, 2005. Available at: https://s3.amazonaws.com/geoda/software/docs/geodaworkbook.pdf, access on 31/jan/2017

ARCHELA, Rosely Sampaio; THÉRY, Hervé. Orientação metodológica para construção e leitura de mapas temáticos. **Confins**, v. 3, 2008.

BERTIN, J. Ver ou ler: um novo olhar sobre a cartografia. **Seleção de textos**, AGB, São Paulo, v. 18, p. 45-62, 1988.

BRAGA, Ima Aparecida; VALLE, Denise. Aedes aegypti: histórico do controle no Brasil. **Epidemiol. Serv. Saúde**, Brasília , v. 16, n. 2, p. 113-118, jun. 2007.

BREWER, C. A.. Color use guidelines for mapping. In: MACEACHREN, A. M., TAYLOR, D.R.F. (ed.) **Visualization in modern cartography**, Tarrytown, NY: Elsevier Science, 1994, p. 123-148. https://doi.org/10.1016/B978-0-08-042415-6.50014-4

CARR, D. B., OLSEN, A. R., COURBOIS, J. P., PIERSON, S. M., CARR, D. A. Linked micromap plots: named and described. **Statistical Computing & Graphics Newsletter**, v. 9, n. 1, p. 24-32, 1998.

CARVALHO, D. O., MACKEMEY, A.R., GARZIERA, L., LACROIX, R., DONNELLY, C.A., ALPHEY, L., MALAVASI, A., CAPURRO, M.L. Suppression of a field population of Aedes aegypti in Brazil by sustained release of transgenic male mosquitoes. **PLoS Negl Trop Dis**, v. 9, n. 7, p. e0003864, 2015. https://doi.org/10.1371/journal.pntd.0003864

CHEN, Jie; GLAZ, Joseph. Two-dimensional discrete scan statistics. **Statistics & probability letters**, v. 31, n. 1, p. 59-68, 1996. https://doi.org/10.1371/journal.pntd.0003864

CHERNOFF, Herman. The use of faces to represent points in k-dimensional space graphically. **Journal of the American Statistical Association**, v. 68, n. 342, p. 361-368, 1973.

DAI, Xiping. **Integrated approach for the exploration of geospatial datasets: the interaction of concepts, methods and data**. PhD Thesis, The Pennsylvania State University, 2007.

DENT, Borden; TORGUSON, J.; HODLER, T. **Thematic map design**. New York: McGraw Hill. 2009

DINIZ, Debora; MEDEIROS, Marcelo; MADEIRO, Alberto. Brazilian women avoiding pregnancy during Zika epidemic. **Journal of Family Planning and Reproductive Health Care**, v. 43, n. 1, p. 80-80, 2017.

DONALISIO, Maria Rita; GLASSER, Carmen Moreno. Vigilância entomológica e controle de vetores do dengue. **Rev. bras. epidemiol.**, São Paulo , v. 5, n. 3, p. 259-279, dez. 2002 .

Durbin, A.P. A dengue vaccine. **Cell**, v. v. 166, n. 1, p.1, 2016.

DURHAM, H., DORLING, D. and REES, P. An Online Census Atlas for everyone, **Area**, v. 38, p. 336–341, 2006. https://doi.org/10.1111/j.1475-4762.2006.00700.x

FIOCRUZ. **Fiocruz obtém registro de teste para zika, dengue e chikungunya.** Online. 2016. Available at: http://portal.fiocruz.br/pt-br/content/fiocruz-obtem-registro-de-teste-para-zika-dengue-e-chikungunya, access on 04/jan/2017.

GAHEGAN, M., 2008. Multivariate geovisualization. In: Wilson, J.P., Fotheringham, A.S. (eds) **The handbook of geographic information science**. John Wiley & Sons, 2008, p.292-316.

FLANNERY, J. **The Graduated Circle**: A Description, Analysis and Evaluation of a Quantitative Map Symbol. PhD Thesis, University of Wisconsin-Madison, 1956.

FRANCIS, J., TONTISIRIN, N., ANANTSUKSOMSRI, S., VINK, J., ZHONG, V. (2015). Alternative strategies for mapping ACS estimates and error of estimation. In: HOQUE, M. Nazrul, POTTER, Lloyd B. (eds.) **Emerging Techniques in Applied Demography**, Netherlands: Springer, 2015, p. 247-273. https://doi.org/10.1007/978-94-017-8990-5_16

Gastner, M.T. and Newman, M.E., Diffusion-based method for producing density-equalizing maps. **Proceedings of the National Academy of Sciences of the United States of America**, v. 101, n. 20, pp.7499-7504, 2004. https://doi.org/10.1073/pnas.0400280101

GUDES, Ori; VARHOL, Richard. Using a spatial analysis approach to investigate Articulated Heavy Vehicle. **Journal of Transport Geography**, v. 31, p. 64-71, 2015.

HENNIG, Benjamin D. **Rediscovering the World**: Map Transformations of Human and Physical Space. Heidelberg / New York / Dordrecht / London: Springer, 2013. https://doi.org/10.1007/978-3-642-34848-8

HUANG, Guilan, GOVONI, S., CHOI, J., HARTLEY, D.M., WILSON, J.M. Geovisualizing Data with Ring Maps, **ArcUser**, v. 10, n. 2, p. 54–55, 2008.

JIANG, Bin, ZHILIN Li. Geovisualization: design, enhanced visual tools and applications. **The Cartographic Journal**, v. 42, n. 1, 2013.

LEU, E., JOOST, S., Häberling, C. **Geovisualisation Tools Applied to Landscape Genetics**. Online. 2009. Available at: http://www.ika.ethz.ch/teaching/bachelor_leu_bericht.pdf, access on 13/aug/2017

MACEACHREN, A.M., KRAAK, M.J.Exploratory cartographic visualization: advancing the agenda. **Computers & Geosciences**, v. 23, n. 4, p.335-343, 1997. https://doi.org/10.1016/S0098-3004(97)00018-6

MINISTÉRIO DA SAÚDE. **Casos de Dengue. Brasil, Grandes Regiões e Unidades Federadas, 1990 a 2014**. 2015. Online. Available at: http://portalsaude.saude.gov.br/images/pdf/2015/julho/29/Dengue-at---2014.pdf, access on 4/jan/2017.

MINISTÉRIO DA SAÚDE. **Óbitos por Febre Hemorrágica da Dengue. Brasil, Grandes Regiões e Unidades Federadas, 1990 a 2013**. 2014. Online. Available at http://portalsaude.saude.gov.br/images/pdf/2015/julho/29/--bitos-at---2014.pdf, access on 4/jan/2017.

PICINATO, M. A. C., GRISOLIO, A. P. R., CASELANI, K., Nunes, J. O. R., CARVALHO, A. A. B., FERRAUDO, A. S. Dengue: uma visão sobre o vetor urbano Aedes aegypti e a difícil interface do seu controle. **Veterinária em Foco**, v. 13, n. 1, 2015..

SCHULER-FACCINI L., RIBEIRO E.M., FEITOSA I.M.; HOROVITZ, D.D.G., CAVALCANTI, D.P., PESSOA, A., DORIQUI, M.J.R., NERI, J.I., PINA NETO, J.M., WANDERLEY, H.Y.C., CERNACH, M., EL-HUSNY, A.S., PONE, M.V.S., SERAO, C.L.C., SANSEVERINO, M.T., BRAZILIAN MEDICAL GENETICS SOCIETY – ZIKA EMBRYOPATHY TASK FORCE. Possible Association Between Zika Virus Infection and Microcephaly - Brazil, MMWR. **Morbidity and mortality weekly report**, v. 65, n. 3:1-4. Jan. 2016. DOI: 10.16/mmwr.mm6503e2

SECRETARIA DE VIGILÂNCIA DA SAÚDE. Monitoramento dos casos de dengue, febre de chikungunya e febre pelo vírus Zika até a Semana Epidemiológica 51, 2016. **Boletim Epidemiológico**. v. 48, n. 2, 2017.

SLOCUM, T. A., MCMASTER, R. B., KESSLER, F. C., HOWARD, H. H. **Thematic cartography and geovisualization**. New Jersey, NJ: Prentice Hall, 2009.

STEVENS, J. Bivariate Choropleth Maps: A How-to Guide. Online. 2015. Available at: http://www.joshuastevens.net/cartography/make-a-bivariate-choropleth-map/, access on 03/02/2017

TOBLER, W. Thirty five years of computer cartograms. **Annals of the Association of American Geographers**, v. 94, n. 1, p. 58-73, 2004. https://doi.org/10.1111/j.1467-8306.2004.09401004.x

TUFTE, E. **The visual display of quantitative information**. 2 ed. Cheshire, CT: Graphics Press, 2001.

WOMACK, Michael. The yellow fever mosquito, Aedes aegypti. **Wing Beats**, v. 5, n. 4, p. 4, 1993.

UFABC – UNIVERSIDADE FEDERAL DO ABC. **Projeto Político-Pedagógico do Bacharelado de Planejamento Territorial**. 53p. 2017. Available at: http://prograd.ufabc.edu.br/cg/2016/OD1_ppc_planej_territorial_rev_27_out_2016.pdf, access on 29/jan/2017.