Analysis of mobility network metrics in the spread of COVID-19 in the Metropolitan Region of Vale do Paraíba and Litoral Norte (RMVPLN)

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Abstract. *In 2019, a pandemic of the so-called new coronavirus (SARS-COV-II) began, which causes the disease COVID-19. In a short time after the first case appeared, hundreds of countries began to register new cases every day. Mapping and analyzing the flow of people, regardless of the mode of transport, can help us to understand and prevent several phenomena that can affect our society in different ways. Graphs are complex networks made up of points and edges. The (geo)graphs are graphs with known spatial location and, in the case of our study, the edges represent the flow between them. The (geo)graphs proved to be a promising tool for such analyses. In the study region, municipalities that first registered their COVID-19 cases are also municipalities that have the highest mobility indices analyzed: degree, betweenness and weight of edges.*

1. Introduction

The World Health Organization declared the SARS-COV-II virus a pandemic on March 11, 2020. Almost two months later, on April 30, 2020, the so-called new coronavirus, which causes the disease COVID-19, had already been identified in 180 countries. On February 26, 2020, the Ministry of Health confirmed the first case of the disease in Brazil, and currently, in August 2021, there are more than 200 million cases and 4 million deaths worldwide from COVID-19 [Sanarmed 2021].

The rapid spread of the virus has been accentuated by the ease with which people cross borders in the globalized world in which we live. Countries, states and cities around the world are strongly connected through different modes of transport, facilitating the spread of contagious diseases in an accelerated and uncontrolled way. Therefore, it is necessary to understand the mobility phenomena and adopt control measures to contain the flow of people, causing the transmission network to be interrupted [FREITAS 2020a].

The Metropolitan Region of Vale do Paraíba and Litoral Norte (RMVPLN) is made up of 39 municipalities divided into five sub-regions. Containing a population of approximately 2.5 million people [EMPLASA 2016], the region has a great connection with state and federal highways, airports and universities, factors that influence the displacement of people to the region and that end up influencing the dissemination of COVID-19

[PERES]. In addition, there is the pendulum movement that occurs from home to work and can occur intercity, being of great importance in the study of the displacement of people [JARDIM].

There is strong social interaction between the cities of the RMVPLN with the urban network of the state of São Paulo, with the capital and other cities such as Campinas, which is currently considered one of the 15 metropolises in Brazil [IBGE 2020].

Recent works in the literature demonstrate that there are patterns between mobility and the spread of COVID-19. It is possible to notice that the disease diffusion model in the state of São Paulo occurred from the largest to the smallest cities, characterizing a cascade effect in which, hierarchically, the propagation walked from the large metropolises to the regional capitals and other cities in the countryside of São Paulo [FORTALEZA 2020]. In [FREITAS 2020b], topological indices are used to represent their relationship with the spread of the disease.

Mathematical graphs have several applications [BOAVENTURA Netto 2012]. Complex networks are a type of graph with topological properties. The use of complex networks in the study of mobility provides analysis of important indices for the understanding of local dynamics. The (geo)graphs [SANTOS 2017] are defined as graphs composed of nodes of known geographic location and edges that connect pairs of nodes and represent their spatial dependence.

2. Methodology

For the elaboration of the (geo)graphs, two codes were executed in the Google Collaboratory platform in the Python language, previously written and provided to this study. The input data used were the coordinates of the centroids of the study region, a flow matrix and a threshold, which defines which edges are strong enough to appear in the (geo)graph.

In addition to the longitude and latitude of the extracted centroids, a flow matrix was used as input for the first code. It was prepared from an Origin-Destination matrix generated with 2014 year flow data from Sao Paulo Metropolitan Transport Department. The matrix contains flow data by the individual mode and by the work reason of the RMVPLN connected and also to the municipalities of Belo Horizonte/MG, Campinas/SP, Rio de Janeiro/RJ and São Paulo/SP. As input data for the second code, we used the same flow matrix and a file with the threshold, which for this study was defined as 1 (one), what means that edges with a flow bigger than or equal to one are strong enough to appear in the (geo)graph.

During the pre-processing of the matrix, we removed the rows and columns with data from 'other municipalities', as these did not have a defined spatial location, being not consistent with the definitions of a (geo)graph. In the execution of the code, the matrix was symmetrized by the sum of the values above and below the main diagonal, in order to obtain the total flow of the connection pair, either the origin or destination municipality of the displacement.

As output data of the two codes, the metrics of the nodes and the shapefile with the nodes and edges of the (geo)graph were obtained and used for the elaboration of three maps of the RMVPLN. In each map, a different index was used in the symbology, namely degree centrality, betweenness and edge weight. The first two are given by the node

metrics and the last one is provided by the edge attribute table. In all three indices, a color scale was applied in the symbology, representing the highest indices in red and the lowest in green gradually.

In the constructed (geo)graph, there are nodes, which represent the centroid of the municipalities in the study area, connected by edges, which represent the inter-municipal flow between them. Degree centrality represents the number of connections of each node of the (geo)graph, that is, how many different municipalities a given municipality connects to. The intermediation (betweenness) indicates how central a node is within the network, that is, how much a municipality acts as an intermediary in the shortest path between two other municipalities. And, finally, the weight of the edges (weight) represents the intensity of the flow between the municipalities.

In addition, we prepared maps with the representation of the occurrence of the first case in each municipality according to the epidemiological week. For this, we used data downloaded from the Wesley Cota website containing the cases of each municipality. Only the first case of each one was filtered and using the epidemiological week of the occurrence as an attribute in the symbology, it was possible to apply a color scale and represent the municipalities that had the first case registered first in red and those that had the first case registered finally in light green gradually.
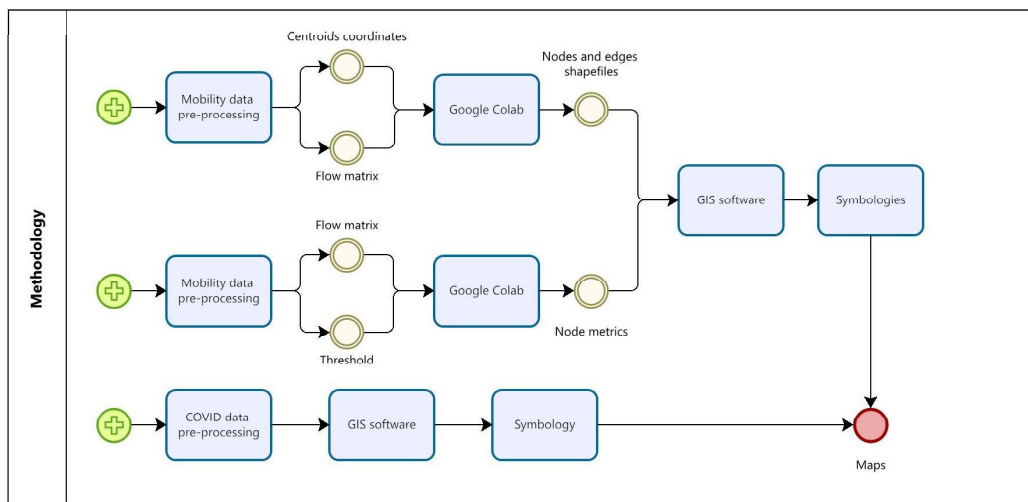
Figura 1. Flowchart of the applied methodology

3. Results

The municipalities of Taubaté and São José dos Campos were the first municipalities to register a case of COVID-19 in the region, in the epidemiological week 12, as can be seen from the representation in Figure 2, followed by the municipalities gradually represented in dark orange and orange. medium. The municipalities of Lagoinha, Queluz, Areias and São José do Barreiro registered their first case between 15 and 19 weeks after the first case registered in the region.

For the distribution of data in classes in the symbology, natural breaks were used. The lowest values of the indexes used are represented in green, with the colors gradually varying up to the highest values, which are represented in red. To represent the occurrence of the first case of COVID-19, the same color scale was used, but oppositely, representing the municipalities that had the first case registered before in red, gradually until the registration of the last first case in green.

The color scale of the indicators represents in red which ones are stronger, highlighting the centroids of the municipalities that have the highest indices. The color scale of the representation of the municipalities highlights in red those municipalities that had the first case registered before.

Even with the geographic proximity between the municipalities of Lagoinha and Taubaté, which share the border, the registration of the first case in each of these cities occurred 15 weeks apart, with Lagoinha registering its first case in epidemiological week 30. if the hypothesis that mobility was one of the factors that led to this large time interval between the first occurrence of the municipalities, since only the physical connection (roads) is not enough for the scattering to occur, requiring a flow of contaminated people.
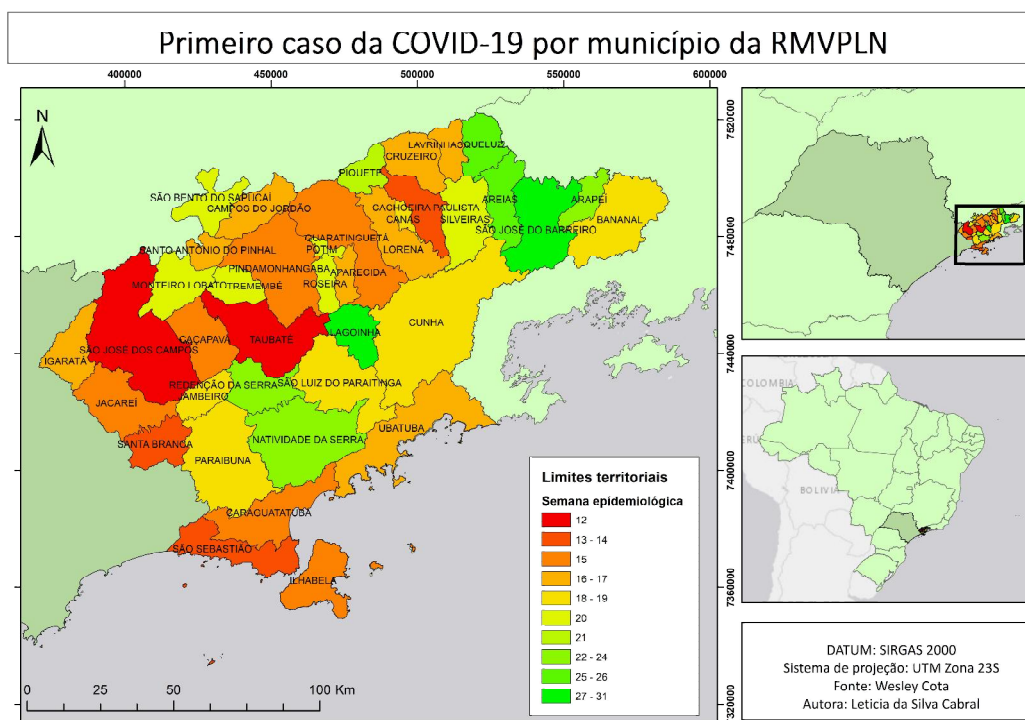

Figura 2. occurrence of the first case of COVID-19 in each municipality of the RMVPLN according to the epidemiological week

With the union of the mobility network and the map with the first case of each municipality, we correlated the occurrences and the calculated topological indices, as well as the flow between the municipalities. In Figure 3, it is possible to notice that the municipalities with many connections and very strong connections. The municipalities of São José dos Campos and Taubaté, which were the first municipalities in the region to register

the first case, have the highest levels of degree centrality and network intermediation. In addition, the largest flow occurs between SJC and Jacareí, followed by the number of trips between the municipality of Taubaté and Tremembé, Pindamonhangaba and São José dos Campos.

Modo de deslocamento: **Individual** - Motivo do deslocamento: **Trabalho**, RMVPLN
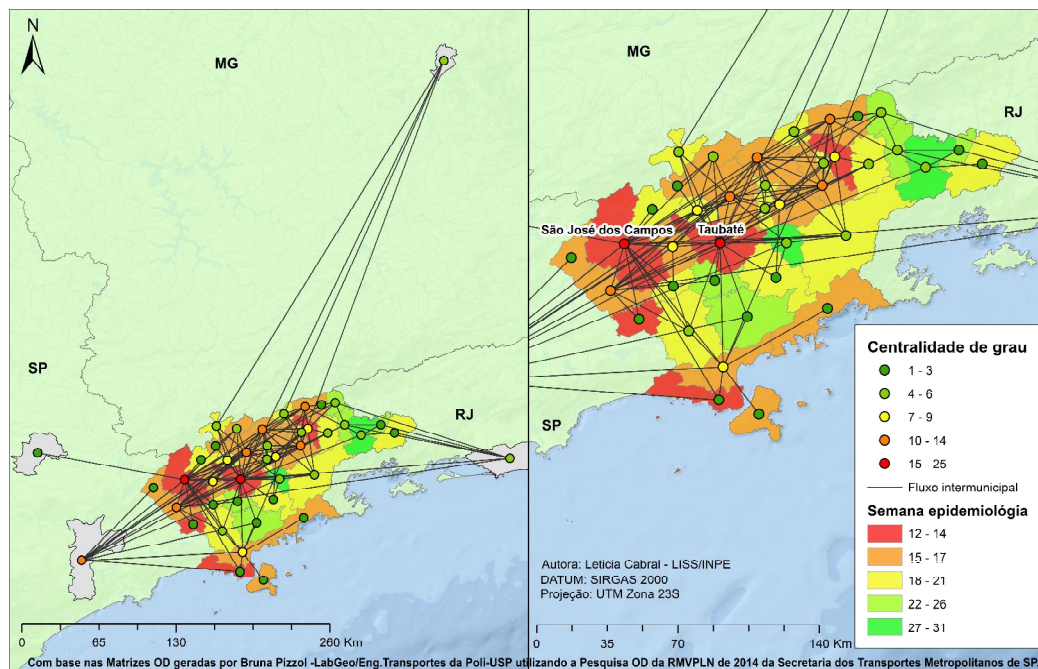
Figura 3. (geo)graph of mobility by individual travel mode for the work reason of the RMVPLN

As we can see, the municipalities with the highest mobility rates evaluated in this study were the ones that first recorded their first occurrence of COVID-19.

4. Conclusion

Given the current scenario, it is important to assess, quantify and analyze mobility and how it occurs, to relate it to the spread of contagious viruses that cause diseases such as SARS-COV-II. The use of the developed methodologies has shown to be promising for carrying out such analyses since it was possible to evaluate the mobility and transport networks in the region and relate them to the occurrences of the first case of COVID-19. In the next steps of the research, we aim to expand the analysis of the transport network, evaluating its impact in the presented context and how its presence and use can result in different scenarios of the spread of COVID-19 in Brazil.

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