GEOSTATISTICS AND EPIDEMIC MONITORING: SPATIO-TEMPORAL ANALYSIS OF COVID-19 IN A SMALL-MEDIUM-SIZED BRAZILIAN CITY

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ABSTRACT: With the phenomenon of COVID-19, which devastated society at a global level, several challenges were posed to different classes of social players, such as researchers, managers and decision makers. The use of classic Geomatics methods, such as geoestatistics and spatiotemporal data processing using digital maps, performed in Geographic Information Systems (GIS), is of great value in the processes of analysis, description and monitoring of epidemic outbreaks, aiming at environmental health. Therefore, these methods constitute, especially in the current pandemic world scenario and its consequences at the municipal level, an important contribution to the planning of future actions and strengthening of decision-making, based on solid space-time scientific evidence, on the part of their Health Authorities, in connection with the territory under analysis. Therefore, the working method of this research consisted of the survey, systematization and geolocation of confirmed cases of COVID-19, with which, based on the development on the GIS platform, allowed, as a result, the generation of spatiotemporal maps from geostatistical processes with several visualization methodologies (point data maps, stratified maps and heat maps or Kernel maps) of the data reviewed, obtained from the Municipality of Tubarão, This set of visual information at the territorial level will be of

great potential for the generation of different analyses and descriptions of the characteristics of the geographic development, during the years 2020 and 2021, of confirmed cases of COVID-19, aiming at understanding the spatiotemporal characteristics of that epidemic outbreak and thus collaborating with the Municipal Health System.

KEYWORDS: COVID-19; Geostatistics; Geoprocessing; Geolocation; Public health.

1 I INTRODUCTION

In December 2019, the initial wave of COVID-19 disease, caused by the SARS-CoV-2 virus appeared in Wuhan, China (Yang et al., 2020). The SARS-CoV-2 virus is an RNA virus of the beta subfamily coronavirus (Xu et al., 2020) that can cause mild symptoms such as dry cough, olfactory and gustatory dysfunctions (HU et al., 2020). But also SARS-CoV-2 can lead to severe clinical manifestations such as acute respiratory distress syndrome (Ards), respiratory failure and thrombotic events (Wiersinga, et al., 2020).

On January 30, 2020, the World Health Organization declared an international public health emergency and, on March 11, declared a Pandemic (Contini et al, 2020). Brazil declared a public health emergency on February 3 and on February 25 the first case of COVID-19 in Brazil was confirmed, in a traveler returning from Italy to São Paulo, and Brazil began experiencing an epidemic of COVID-19 disease as one of the fastest-spreading in the world (de Souza, 2020). Until April 2, 2022, Brazil counted 29,992,227 confirmed cases, accruing a total of 660,108 deaths from COVID-19, with a case fatality rate of 2.2%[1]. In this scenario, the Southern Region of the country had 6,376,760 confirmed cases, and accrued a total of 103,688 deaths, and the State of Santa Catarina had 1,678,615 confirmed cases and 21,669 deaths[2].

As a result, mechanisms for analysis, prevention and monitoring have become extremely necessary to face this pandemic and to promote strategies to mitigate or reduce the rapid contagion of Covid-19. From this perspective, georeferenced spatiotemporal analysis and geostatistics are traditionally used in Environmental Sciences, for example, to verify the dispersion of soil contamination, extension of mineral deposits, diseases in crops and variations in geoenvironmental characteristics of regionalized data (Landim, 2003).

Currently, in health sciences, due to the resurgence of many infectious diseases, as well as the frequent epidemics in different regions and with the COVID-19 pandemic, which was followed in our work, the epidemiological theory of John Snow, dated 1854, is resumed. This theory emerged to explain environmental contamination and its association with the cholera epidemic in London, and is considered the first Geographic Information System in history (Cerda & Valdivia, 2007; Ramsey, 2006).

One of the best ways to understand in detail the health conditions of the population is

1 https://covid.saude.gov.br/

2 https://www.saude.sc.gov.br/index.php/noticias-geral/13447-coronavirus-em-sc-estado-confirma-1-678-615-casos--1-652-873-recuperados-e-21-669-mortes

through the use of maps and cartograms that allow observing the spatiotemporal distribution of the risk situations and the distribution of health problems, for which the use of Geomatics and Geostatistics methods are fundamental (Lagrotta, 2006).

Souza-Santos and Carvalho (2000) stated that the use of spatial analysis techniques (or georeferenced or geolocated analysis) to assess the distribution of diseases has increased in recent years, providing important surveillance and control tools. Its biggest advantage lies in treating the municipality as composed of several realities deserving different approaches, contrary to what usually happens.

Problems associated with endemics and epidemics are considered to be characteristic of interconnected ecosystems. Thus, problems associated with outbreaks, endemics, epidemics, health surveillance, particular situations in primary health care centers, emergency care, but not limited to, are inherently dependent on each other, which imply the need for a joint analysis of the determinants of their occurrence. The geographic location of such occurrences for example or of their risk factors, together with environmental components and other characteristics specific to each situation, have great potential for the analysis, description and monitoring processes, provided they are evaluated by tools that incorporate the typical complexity of the events assessed (Souza-Santos & Carvalho, 2000).

Geographic epidemiology or spatial epidemiology have been mentioned in the literature as synonyms "...to describe a dynamic set of theories and analytical methods associated with the study of spatial patterns of disease incidence and mortality." (Waller & Gotway, 2004). Today, georeferenced epidemiological analyses have become increasingly important to review the spatial relationship that the facts present with each other.

Thus, the use of classic theories, including the ecological one (Rouquayrol & Almeida, 2003) focused on multicausality, highlights the importance of using analysis techniques that find the causality of diseases or the way in which they are spread in geolocation.

It can be said that the disease is a manifestation of the individual, thus, it can be deduced that the health situation is a manifestation of the place. The tendency of the health-disease process is managing to overcome the dichotomy between collective practices (epidemiological and sanitary surveillance) and individual practices (ambulatory and hospital care), by incorporating the processes of patients geolocation and Geostatistical analyses, which, in this way, can be made, allowing better strategic planning to combat disease outbreaks and epidemics through the understanding of the spatial relationships that these processes allow (Kitron, 2000).

In turn, in the field of Public Health, studies have shown that individuals occupy the territorial and social space in a non-random way, forming relatively homogeneous conglomerates from the point of view of their living conditions (Castellanos, 2021).

The social space, as a convergence category of expression of the processes involved in the populations' living conditions, environment and health, assumes importance in the investigation of inequality and determination of the occurrence of epidemics (Barcellos, et al., 2002).

The incorporation of indicators that show the social representation and occupation of the territory of population groups, their health situation and living conditions, allows the recognition of inequity in the health profiles of different groups and the advancement of Health Surveillance (Paim, 2014). The use of information with such details in the planning of health services, especially in the case of COVID-19, allows the reorientation of health practices, identification of areas of greater occurrence and definition of different strategies of situations that can be georeferenced.

Therefore, from the spatialization of data related to the geolocation of COVID-19 cases, during the years 2020 and 2021, with their corresponding date of occurrence, maps of different temporal outbreak cuts were created, which will allow the specialists of the medical field generate new theories as to where, how and why the outbreak progressed.

Therefore, this research was focused on the development of an analytical platform with processes of georeferencing health and environmental data that facilitate the description and analysis, aiming at the monitoring of outbreaks and epidemics, currently focused on COVID-19, from the generation of spatiotemporal disease distribution maps.

These space temporal cuts are accompanied by data on urban facilities, such as water systems, road systems, green areas, sewage systems, etc., and population density data according to the last *Instituto Brasileiro de Geografia e Estatística* (IBGE, Brazilian Institute of Geography and Statistics) census.

In this connection, the use of technological platforms based on GIS (Geographic Information Systems) allows a different way of organizing epidemiological data, taking into account the geographic location and temporality of confirmed cases of the disease, health infrastructures (health centers, emergency care and hospitals), sewage network, urban equipment that are centers of potential agglomerations, schools, community centers and other urban equipment, which can contribute to a better description of the facts assessed aiming at strategic planning and management in the Municipality in the Healtharea. All the data used were official data obtained from different municipal, state and national bodies.

Thus, the objective of this work was to model georeferenced municipal infrastructure data, urban and public health equipment, together with the spatiotemporal mapping of confirmed cases of COVID-19, with data from public bodies, and using geomatics for the description of the disease distribution, aiming at monitoring the Pandemic in the Municipality of Tubarão, Santa Catarina, Brazil.

2 I MATERIAL AND METHOD

This research arises from a relationship between three basic elements, that is, area of study, phenomenon studied (Covid-19), and methodologies used under the nuances of geotechnologies and geomatics. As a result, the structuring of this research was characterized as applied research, using inductive reasoning (Martins & Theóphilo, 2018).

Considering the particularities of the subject, of the object of the study and of the techniques, this research should beacknowledged as a case study, within the boundaries of the study area and its peculiarities (Martins & Theóphilo, 2018).

2.1 Study area

As spatial delimitation, the study area covers the city of Tubarão located in the southern region of Santa Catarina, in the Federative Republic of Brazil, with an official area of 301,485 Km^2 (Figure 1). Tubarão had an estimated population of 107,143 inhabitants in 2021, and the last census, in 2010, counted 97,235 inhabitants (IBGE, 2021). The municipality's population has, therefore, grown approximately 11% in ten years.

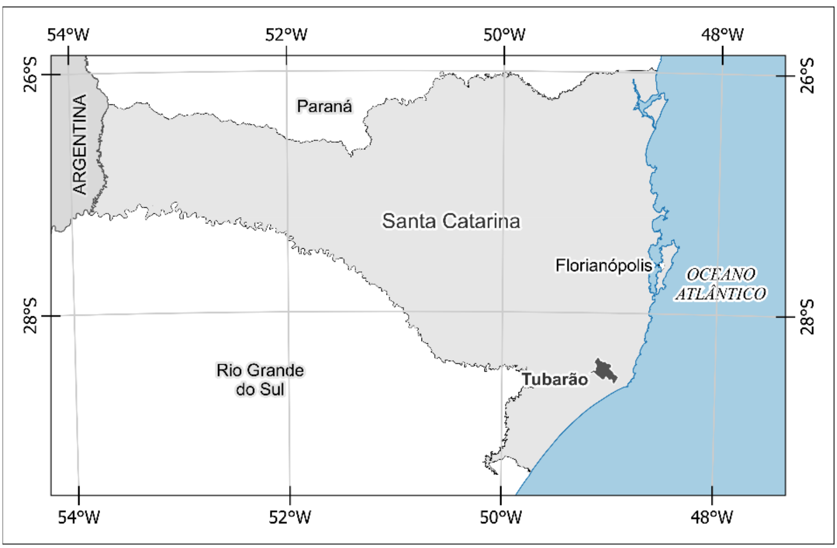


Figure1: Location of the Municipality of Tubarão in the State of Santa Catarina, Brazil.

2.1.1 Characterization of the municipality

With approximately 150 years, from pre-settlement and urbanization, the city of Tubarão, SC, officially began its municipal dynamics in 1870, with Law No. 635 that created the municipality of Tubarão, a territory that was separated from Laguna, another municipality in the south of Santa Catarina (Tubarão, 2021).

It is noteworthy that the city of Tubarão is part of one of the metropolitan regions of Santa Catarina, established by law between 1999 and 2007, further supported as a metropolitan region in 2010 by virtue of a new law (Moraes et al., 2018). As a metropolitan region, Tubarão begins to adapt to a form of regional organization, characterized by a dynamic that interconnects the socioeconomic and urban activities of the municipalities that make up the metropolitan region (Moraes et al., 2018).

The Municipality had a per capita GDP of BRL 37,487 for the year 2019 (IBGE, 2021). From the perspective of socio-environmental aspects, the municipality of Tubarão has approximately 91% of households with adequate sanitation, 44% of urban households on wooded public streets and 44% of urban households on public streetswith adequate urbanization, considering the basic and necessary equipment, such asculverts, sidewalk, paving, curb, etc. (IBGE, 2021).

From the description perspective of the physical-environmental aspects of Tubarão municipality, it is worth mentioning that the main river in the municipality, which also has the same name, Tubarão, crosses the city. According to the data presented by the Municipality, the flow line of this river cuts through the city with a section of 115 meters in width, a depth that varies from 2 meters to 10 meters and a flow of 5 m^3/sec (Tubarão, 2021).

From the climatic perspective, Tubarão has a subtropical climate, with an average maximum temperature of 24°C and a minimum average of 15°C, varying, in general, between 12ºC and 28ºC and with an average annual rain fall of 1500 mm, with a general range from 70mm to 125mm (Tubarão, 2021).

In addition, the city of Tubarão stands out as a regional trade and services hub. It is also a city characterized by its university and higher education trend, which consequently attracts diverse people from different locations (Schuelter-Trevisol et al., 2020). From this perspective, it should be noted that the city has been experiencing a dense growth of its urban area, expanding to several non-specific areas, which raises different problems, especially linked to land use (Heidemann, 2014).

In this context, it is noteworthy that the urban growth that occurred in recent decades in the city of Tubarão, culminated in a total of 104,937 inhabitants, spatially distributed by the area of 301.705 km² of the municipality (Rosa, 2020). Highlighting this data is necessary to the extent that, in Brazil, the sizes of cities are analyzed from the population density rather than the total area.

Thus, it appears that tubarão, under the prism of the Brazilian concept, permeates the dynamics of a medium-sized city, insofar as it has a population of over 100 (one hundred) thousand inhabitants. It is noteworthy that cities with this population size, mainly linked to rapid growth, promotes inefficiency for the public service from the perspective of socio-spatial organization, as well as the distribution of services offered by the public entity, thus making observation and analysis difficult. of urban phenomena (Pereira-Clemente, 2013).

Although it is not the focus of this work, it is also necessary to emphasize the socioeconomic role of the rapid process of population growth, since with the urban growth also occurs the process of expansion of the urban area. The consequence of these processes is that certain actions of the public entity will depend on the budget, which consequently depends on an adequate planning of both resources and urban space (BERNARDI, 2009).

From this thought, it is worth pointing out economic aspects of the studied area, Tubarão/SC, which has a per capita GDP of R$ 37,487 referenced by the year 2019 (IBGE, 2021). Moreover, the municipality assumes in a comparative level, the position of number 107th in the state of Santa Catarina (out of a total of 295 municipalities in the state), and consequently, the Brazilian global positioning in 878th, among the 5570 municipalities in the country, for the year 2019 (IBGE, 2021).

This dynamic is directly reflected by the collapse that occurred after Covid-19, since in previous years the city was more prominent in rankings of local, regional and national GDP. Therefore, in perspectives, correlated, under the contemporary prism, especially in the context of the pandemic lapse of COVID-19, the city has sought connections between public and private entities, especially from the academic context as a mechanism for treatment and overcoming in the fight against the pandemic (Schuelter-Trevisol et al., 2020).

2.2 Software, data and methods used

2.2.1 Software USED

Data processing was carried out with a Microsoft® Excel® spreadsheet for Microsoft 365 MSO (Version 2201) (https://www.microsoft.com/microsoft-365/) and, to manage the cartographic data, the Geographic Information Systems management software Quantum GIS was used: QGIS 3.22.0 (QGIS Development Team, 2022. QGIS Geographic Information System. Open-Source Geospatial Foundation Project. http://qgis.osgeo.org).

The QGIS add-on used for geolocation of the COVID-19 confirmed database cases, object of this study, was called "MMQGIS" in its stable version 2021.9.10 (by @Michael Minnhttps://michaelminn.com/linux/mmqgis/).

This QGIS plugin is a set of plugins programmed in the Python® language (https://www.python.org/) for manipulation of vector map layers in Quantum GIS, which can, among many other manipulations, geocode from a text file with pre-established fields, using some of the geolocation web services.

In this case, MMQGIS was used in combination with a Google Map© API (Application Programming Interface) (https://www.google.com.br/maps) so that the QGIS software itself could geolocate addresses from a data table with at least four basic fields: address (street name and number), city, state and country.

The API-key is managed from Google Cloud (https://cloud.google.com/e https://console.cloud.google.com/) with an account in Google Workspace environment. The web service is paid, but it has an initial credit as a test, which was sufficient to use in this investigation free of charge.

To edit and make compatible the vector files received in vector format ".dwg" from the Municipality of Tubarão with the basic register of the urban area of the municipality and its urban equipment, the Computer Aided Design (CAD) software was used (AutoCAD®

by Autodesk Inc® (Version 2022 S.51.0.0, with educational license. https://www.autodesk.com/education/).

2.2.2 Mapping data and processing methods

One of the basic cartographic data sets used were those from the online *Sistema de Informações Geográficas de Santa Catarina* (SIGSC, Santa Catarina Geographic Information System, http://sigsc.sc.gov.br/) generated by the Government of the State of Santa Catarina and managed by the *Secretaria de Estado do Desenvolvimento Econômico Sustentável* (SDE, State Secretariat for Sustainable Economic Development). Using these data source, the state and municipalities borders were approached in SIG vector format ("Shapefiles" https://ceweb.br/guias/dados-abertos/capitulo-41/) made by SEPLAN (Planning Secretariat of the State of SC) in 2013 and updated by SDE, in 2018, with the new municipalities created by several laws in the State of SC. We also worked with the area of orthophotomosaic (official high resolution aerophotogrammetric survey of the State of SC, 2010/2012) corresponding to the Municipality, object of this study. This last set of raster images was used, fundamentally, to control the georeferencing of the other data used, given its high quality.

The vector data, from the SDE, were already in the appropriate computational format and with a geographic datum consistent with the cartography to be created for this work. Likewise, the orthophotomosaic data were properly georeferenced and with a datum consistent with the aforementioned cartography.

From the Brazilian Institute of Geography and Statistics (IBGE, 2021) the mapping of census sectors was obtained (https://ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/) and basic data on the total population by census sector (https://censo2010.ibge.gov.br/) to calculate population density. In this case, the cartography of the census sectors was already in a GIS "shapefile" format with a datum compatible with the cartography being executed and the census data in MS-Excel© table format.

For this last process of calculating the population density, the area of the census sectors was first calculated (in SIRGAS 2000 UTM zone 22 South cartographic plane projection), then this mapping of the census sectors was linked to the database containing the basic census data (Excel table), to finally calculate the population density from the field containing the "Number of permanent residents" and the area calculated in hectare, thus obtaining the density in Residents per Hectare of each census sector.

The municipal cadastral data used were obtained from the Cadastral Map of the Urban Area of the Municipality of Tubarão, showing the streets, roads, squares and main urban equipment, health infrastructure (UBSs, UPAs, hospitals, etc.), in addition to the system of sewer grates, water system, but not limited to, which were created and managed by the Department of Urbanism of Tubarão (https://www.tubarao.sc.gov.br/governo/index/

codMapaItem/16673) and had their use granted exclusively for the performance of this Research.

Said registration data were processed to make them compatible with the vector format used in GIS ("shapefiles") and, for that, each layer of specific information was individually imported into another "dwg" file. Subsequently, these files were edited to verify and correct, if necessary, typical editing errors that can cause problems in GIS: presence of double lines, lack of vector polygons closure, existence of gaps in polygon crossings, among the most common to be found in many AutoCAD©-type files, used in cadastral mappings. This editing was carried out with the indicated CAD software and then imported into QGIS as layers in "shapefiles" format".

In turn, the Municipal Health Foundation of the Municipality of Tubarão (https://www.tubarao.sc.gov.br/governo/index/codMapaItem/16673) made available the database of confirmed cases from 2020 to 2021, exclusively for this research and without any type of personal identification of the cases, only with addresses, sometimes approximate; these data were used in the spatial and temporal analysis for this investigation. They were made available in MS-Excel© table format and required extensive editing work to allow making the table compatible with the needs of the cartography developed.

In this case, the major work was to systematize the addresses to be able to geolocate, and to systematize the content of each field to carry out future statistical and geostatistical analyses. The biggest problems were the different ways of writing the same facts by the administrative assistants of the patients, since the same data sheet, in several copies, was used by several people in the different places of assistance in the Pandemic (UBS, UPAS, Hospitals, etc.).

In the case of some worksheet fields, it was decided to replace the fully written answer by Yes/No and in other cases, to systematize the answers for each field, for example, difference in lower-case and upper-case letters and comments from the professional who made the register, where there are no new data to be reviewed.

In the case of addresses, this was a task that was done in combination with online mappings to verify the existence of streets and addresses. Many of the original addresses did not have the building number and others had extra data, such as the building name, block and apartment numbers, data that were eliminated in order to be able to geolocate, since they were not necessary for this purpose. The spelling of street names was also systematized and a single field was created with the street name and number, separated by a comma, when appropriate, since this is the format required by the online mappings in order to be able to georeference. All this editing work was carried out using formulas, pivot tables and programming routines in Excel© itself.

The original database presented data from the beginning of the Pandemic (March 2020) to the end of November 2021, when the processing for this project was initiated.

The database in question had, originally, 24477 records to be geolocated, of which, with all the editing done in it and with Google Cloud and Google Map's own problems of being able to find the concordance of the streets registered in the map online with those indicated in the database, resulted in 23877 definitively georeferenced records, which meant an overall loss of less than 2.5% of the cases of the original database to the georeferenced cartographic database.

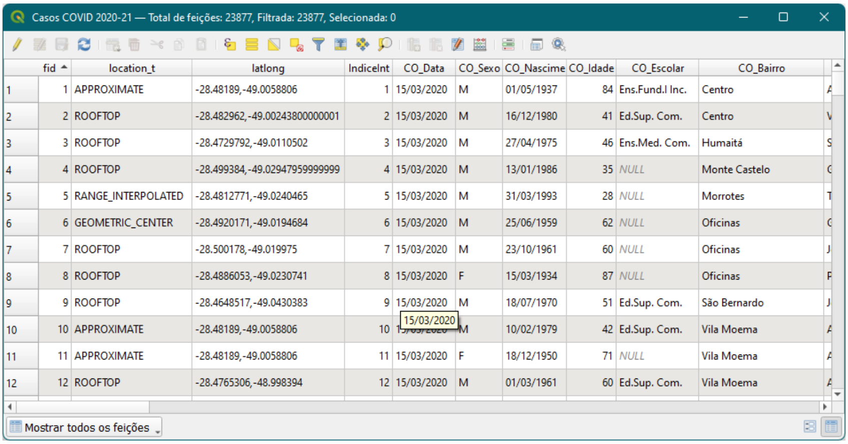
The most common problems during editing were the aforementioned table of COVID-19 cases: Cases with indecipherable addresses, without address or neighborhood and cases from other municipalities. The cases that had only street names without a number, the system found them at the midpoint of the street geometry.

The cases where only the Municipality was cited were located in the central point of the municipality (the one defined as the City Hall point) which could have been a limiting factor in the geographical analyses; however, taking into account the spatial distribution presented (see map in Results), it was decided to leave these points. Another flaw of MMQGIS, Google Maps and Google Cloud was to confuse some addresses when they had the name of states or cities of Brazil and the World, or were addresses that led to a certain mileage from a Federal highway (due to the differences in how the mileage of a road is identified by the States in Brazil and on the map online). These problems affected less than 2.5% of addresses.

3 I RESULTS

The results are divided into two large groups: table results and cartographic results. The COVID-19 table cases displayed the following edited and systematized fields: index (key field); type of location (whether it was approximated, interpolated, geometric center, etc., according to the process carried out at the time of geolocation); Latitude and longitude of the address; date of registration of the active case; gender; birth date; age; schooling; district; workspace; kind of exam performed; exam date; exam laboratory; situation (if cured or death); type of hospitalization (ward, ICU, etc.); if smoker; if vaccinated; first dose date; second dose date; which vaccine was applied; whether or not the patient used certain drugs (a total of six drugs was analyzed); if the patient had comorbidity; symptoms he/she had (questions about 17 symptoms in total) and whether the vaccine was positive post or pre-COVID-19 exam. In Figure 2, one can see a sample of the table already incorporated in the QGIS project. The data, although not necessary for this research, were kept for future analyses that may derive from the present work.

As for the cartographic results, in Figure 3, one can observe the listing of data layers and cartographic information used definitively in the GIS project for this investigation. It is observed in the figure that there is the identification of types of buildings inpoint data format and special buildings in polygon format; this discrimination will allow future geostatistical analyses to verify if close to the buildings, where there may be agglomerations of people, the distribution is different from the average distribution, for example, among other potential analyses to be made in future research works from the data presented here.



Casos COVID 2020-21 — Total de feições: 23877, Filtrada: 23877, Selecionada: 0

	fid	location_t	latlong	IndiceInt	CO_Data	CO_Sexo	CO_Nascime	CO_Idade	CO_Escolar	CO_Bairro
1	1	APPROXIMATE	-28.48189,-49.0058806	1	15/03/2020	M	01/05/1937	84	Ens.Fund.I Inc.	Centro
2	2	ROOFTOP	-28.482962,-49.00243800000001	2	15/03/2020	M	16/12/1980	41	Ed.Sup. Com.	Centro
3	3	ROOFTOP	-28.4729792,-49.0110502	3	15/03/2020	M	27/04/1975	46	Ens.Med. Com.	Humaitá
4	4	ROOFTOP	-28.499384,-49.02947959999999	4	15/03/2020	M	13/01/1986	35	NULL	Monte Castelo
5	5	RANGE_INTERPOLATED	-28.4812771,-49.0240465	5	15/03/2020	M	31/03/1993	28	NULL	Morrotes
6	6	GEOMETRIC_CENTER	-28.4920171,-49.0194684	6	15/03/2020	M	25/06/1959	62	NULL	Oficinas
7	7	ROOFTOP	-28.500178,-49.019975	7	15/03/2020	M	23/10/1961	60	NULL	Oficinas
8	8	ROOFTOP	-28.4886053,-49.0230741	8	15/03/2020	F	15/03/1934	87	NULL	Oficinas
9	9	ROOFTOP	-28.4648517,-49.0430383	9	15/03/2020	M	18/07/1970	51	Ed.Sup. Com.	São Bernardo
10	10	APPROXIMATE	-28.48189,-49.0058806	10	15/03/2020	M	10/02/1979	42	Ed.Sup. Com.	Vila Moema
11	11	APPROXIMATE	-28.48189,-49.0058806	11	15/03/2020	F	18/12/1950	71	NULL	Vila Moema
12	12	ROOFTOP	-28.4765306,-48.998394	12	15/03/2020	M	01/03/1961	60	Ed.Sup. Com.	Vila Moema

Mostrar todos os feições

Figure2: Partial example of the COVID-19 active cases table structure

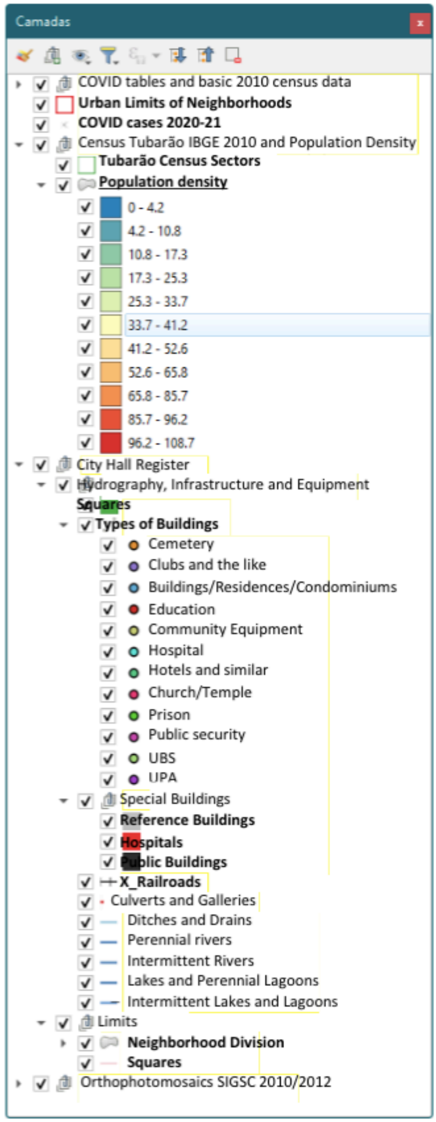


Figure3: List of used data and information layers

Next, a series of result maps are shown with summarized and disaggregated data in order to be able, based on these data, to discuss about them. Thus, Figure 4 (A) is an overview of data and information on infrastructure and urban equipment obtained from the SDE State Development Department and the Municipality of Tubarão: Municipality boundaries (black), Urban and neighborhood limits (red), squares (green), special buildings (cemeteries, clubs, schools, hospitals, community facilities, hotels, churches, prisons, public security, basic health units and emergency care units: black) and water systems (blue) and, in Figure 4(B), the boundaries of the urban area (red lines) and the census sectors and their population densities are shown (Blue: densities between 0 and 4 and dark red: between 96 to 109 in hab./ha). As it usually happens in all cities, the census sectors do not coincide with the division of the districts of the municipalities, since the logics of geographic division are different.

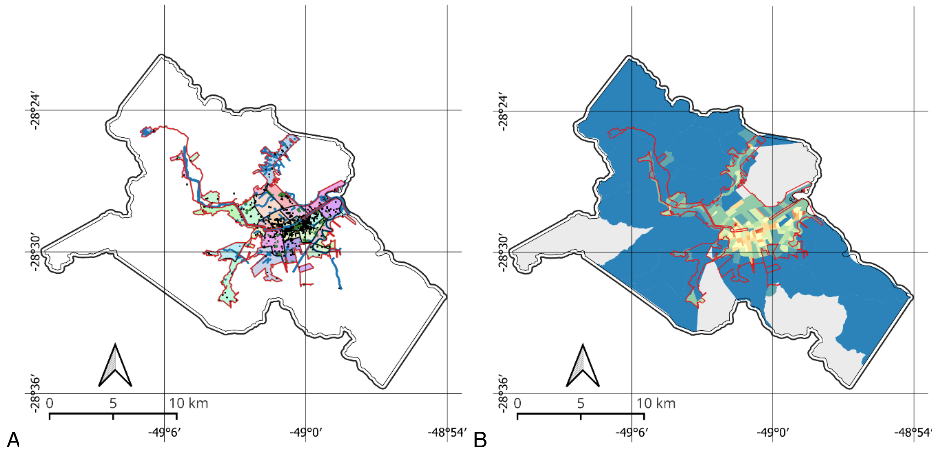


Figure4: (A) Structural data of the urban area; (B) Municipalities boundaries and census sectors with population densities.

From the point of view of geomatics, the investigation procedures are called "Spatial Analysis" in which, using geostatistical tools, one seek to analyze spatial patterns and verify whether they are random or not. The most basic form of this analysis for specific facts is their case-by-case mapping, through their coordinates, either in total or disaggregated by time unit. Also, cases can be mapped by smaller geographic units, such as census sectors and sometimes neighborhoods, by counting cases in each sector and using a color scale to identify different accumulations of cases. Another way of performing a spatial analysis, which usually allows for better analyses, is through an exploratory analysis of the specific study definition process, which should start by estimating the intensity of occurrences of the points in the analyzed region. This generates a surface whose value is proportional to the intensity of events per unit area, called a heat map or Kernel map.

The Kernel Map is an alternative for the geographic analysis of the behavior of punctual or accumulated distribution patterns by geographic sectors. The map is plotted using the interpolation method, showing the punctual intensity of a given phenomenon distributed throughout the study region. Thus, we have an overview of the intensity of the process in all sectors of the map (Souza et al., 2013). The Kernel estimator is an interpolator that allows the estimation of the intensity of the point event in the entire area, even in regions where the process has not generated any actual occurrence.

The use of the Kernel method has two advantages: the first one is the aid in visual analysis considering the extensive concentration of points under analysis and, the second, allows the representation not to be limited to pre-defined areas, as is the case with polygons of neighborhoods or census sectors, thus allowing a continuous visualization of the phenomenon throughout the area under study (Vieira et al.; 2019).

This heat maps analysis allows to study the superposition of the patients' addresses point data, represented by geographic coordinates (latitude and longitude) in the spherical model of the earth's surface and, for this reason, the bivariate estimation of the Kernel density will be used (Wand, Jones, 1993). The result of this estimation is a density function where its local maxima represent the regions with the highest concentration of point data recorded on the map. These locations of high concentration of points may indicate potential hotspots (regions of greater concentration of the fact under study) to be taken into accountin this work for the analysis of confirmed cases of COVID-19 distribution.

The etymology of the word Kernel is "core". In the framework of Geotechnologies, this term refers to a statistical method of estimating density curves, in which each of the observations is weighted by the distance in relation to a core value, the concentration core (Vieira et al.; 2019).

Kernel maps (Wand et al.; 2020) are based on two factors: the radius that defines the neighborhood of the point to be interpolated and controls the degree of smoothing or granulation of the heat surface obtained; and the interpolation function, which differ in the way the interpolation model assigns weights to existing points within the pre-defined radius and that will be used to estimate the intensity within the area of interest of each point.

There are several kernel interpolation functions among which, but not limited to, we can mention the normal, uniform, quartic and triangular. The normal function weights the points inside the circle so that closer points are weighed more intensely compared to those farther away (Figure 5). The uniform function weighs all points within the circle equally. And the quartic function, weighs points that are near rather than distant, but the decrease is progressive. Finally, in the case of the triangular function, it weighs near points more than distant points inside the circle, but the decrease is faster (Wand et Al.; 2020).

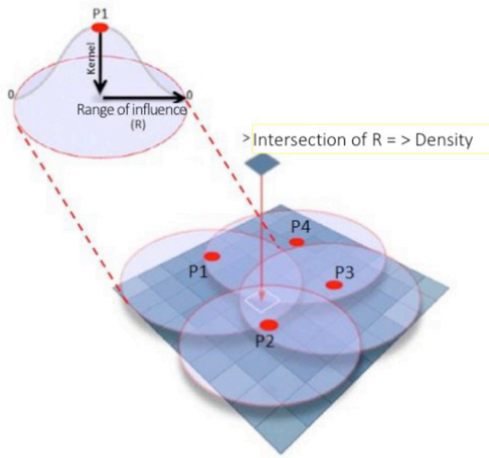


Figure5: Kernel density estimation principle: here presented with a normal distribution.

Source: adapted from Wand et al; 2020.

The radius and the interpolation function are defined in order to obtain a continuous map, smoothed (smooth or soft), without granularities and presenting continuities throughout the region under study. In the case of this work, the density maps of the hotspots (Kernel) were performed using the Kernel density estimation in the QGIS software already indicated and a radius of 1,000 meters and cells of 10 x 10 m were used, with a quartic interpolator, which allowed the development of continuous surfaces, smoothed, non-granulated and without discontinuities.

Thus, in Figure 6, the geolocated data of the total positive COVID-19 cases are exhibited, in the years 2020 (A), 2021 (B) and the total 2020-21 (C) and in Figure 5 (D), the bar chart corresponding to the spatial distribution of figures (A), (B) and (C) is shown. In this chart, we observe that the difference between the cases of 2020 and 2021 are not statistically significant, and it can mean that the cases that occurred in the two years were significantly the same.

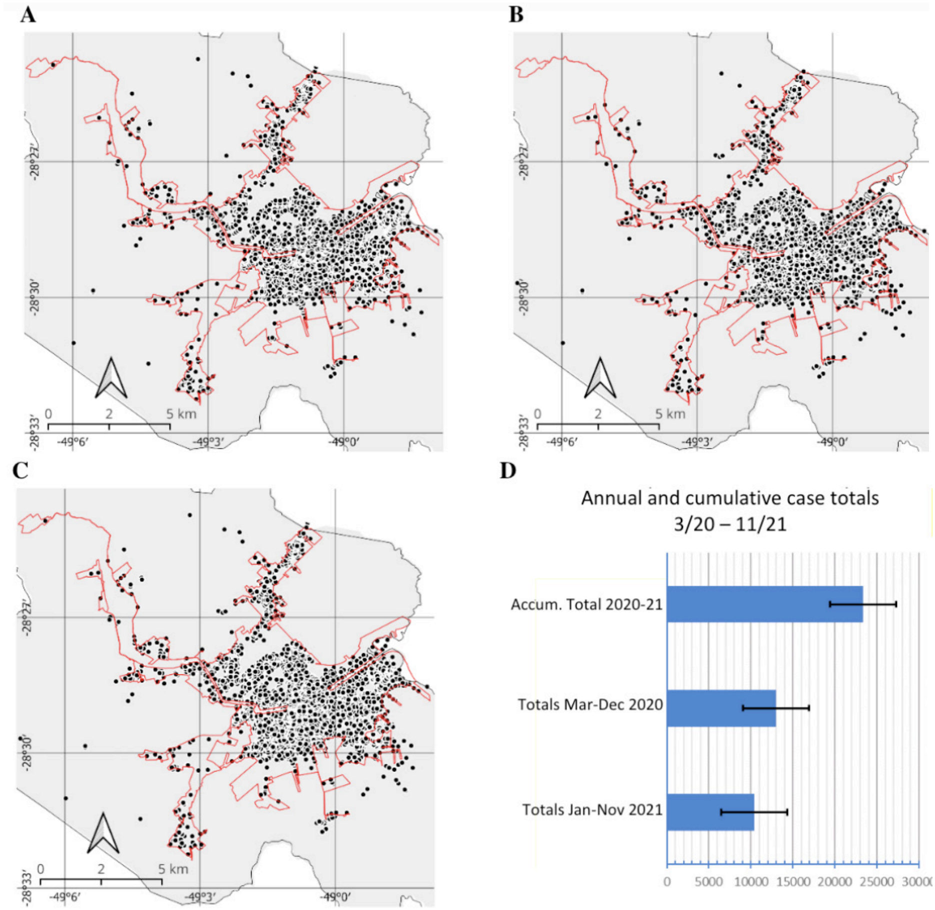


Figure6: Spatial and statistical distribution of total cases per year and accumulated in the period.

In turn, in Figure 7, one can observe the punctual distribution of COVID-19 cases totaled for each year and accumulated for the review period; these are maps that allow a better reading than those in Figure 6, although representing the same fact, only stratified by census sectors (smallest geographic region available): Totals 2020 Figure 7 (A), Totals 2021 Figure 8 (B), Totals 2020-2021 Figure 7 (D) and to improve the interpretation by neighborhoods, in Figure 7 (D) the distribution of neighborhoods in the Tubarão urban area is reported.

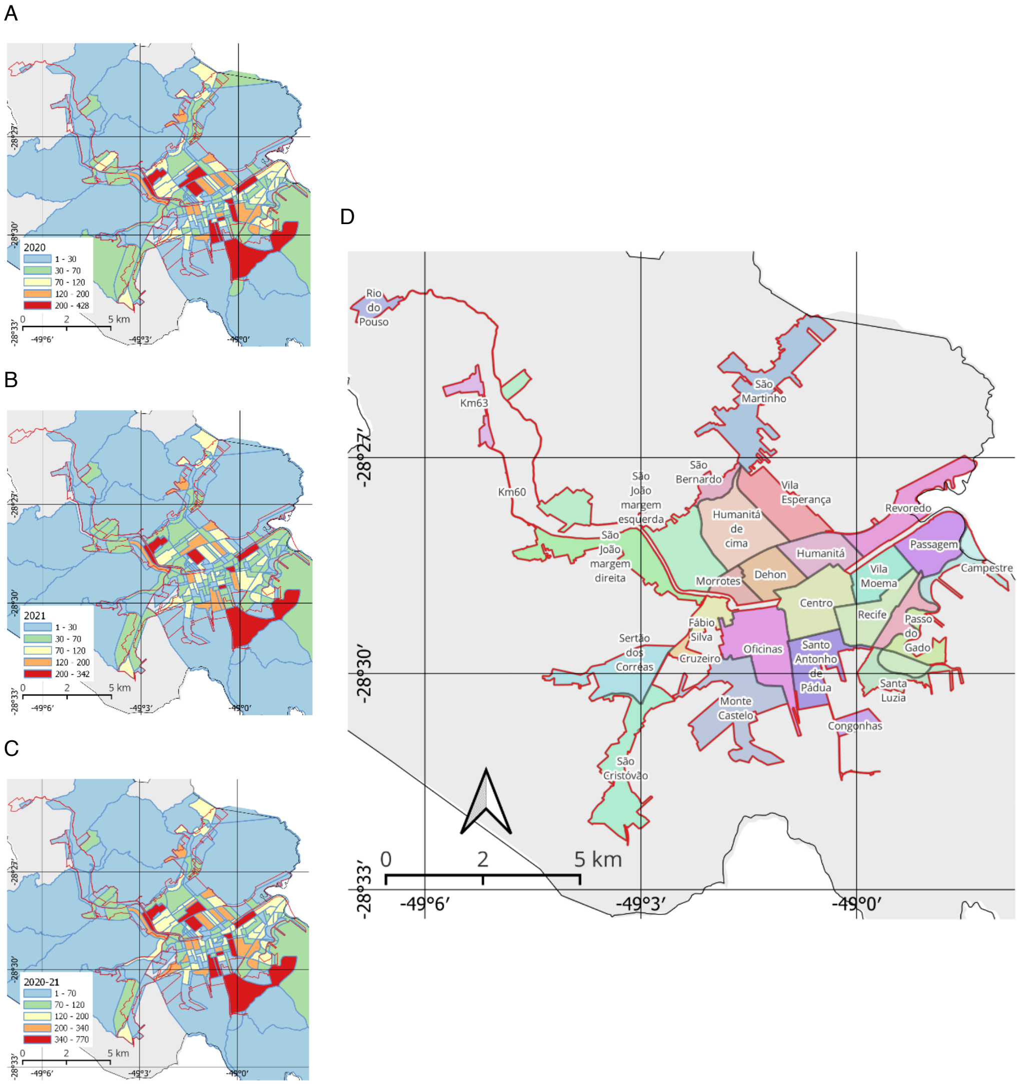


Figure 7: Spatial distribution sectors of total cases per year stratified by census (A): 2020, (B): 2021, accumulated in the study period (C): 2020-2021 and neighborhood division map (D)

To complete the review of the summarized/accumulated data, Figure 8 presents the Kernel maps of the COVID-19 cases accumulated data for the periods assessed i.e. the years 2020 in Figure 8 (A), 2021 in Figure 8 (B) and the accrued total for the years 2020-2021, in Figure 8 (C).

In order to statistically follow the monthly disaggregated maps, which will be detailed hereafter, and thus be able to associate the peaks of monthly cases, in Figure 9 an evolution chart of the monthly cases can be found for the period reviewed i.e. from March 2020 to November 2021.

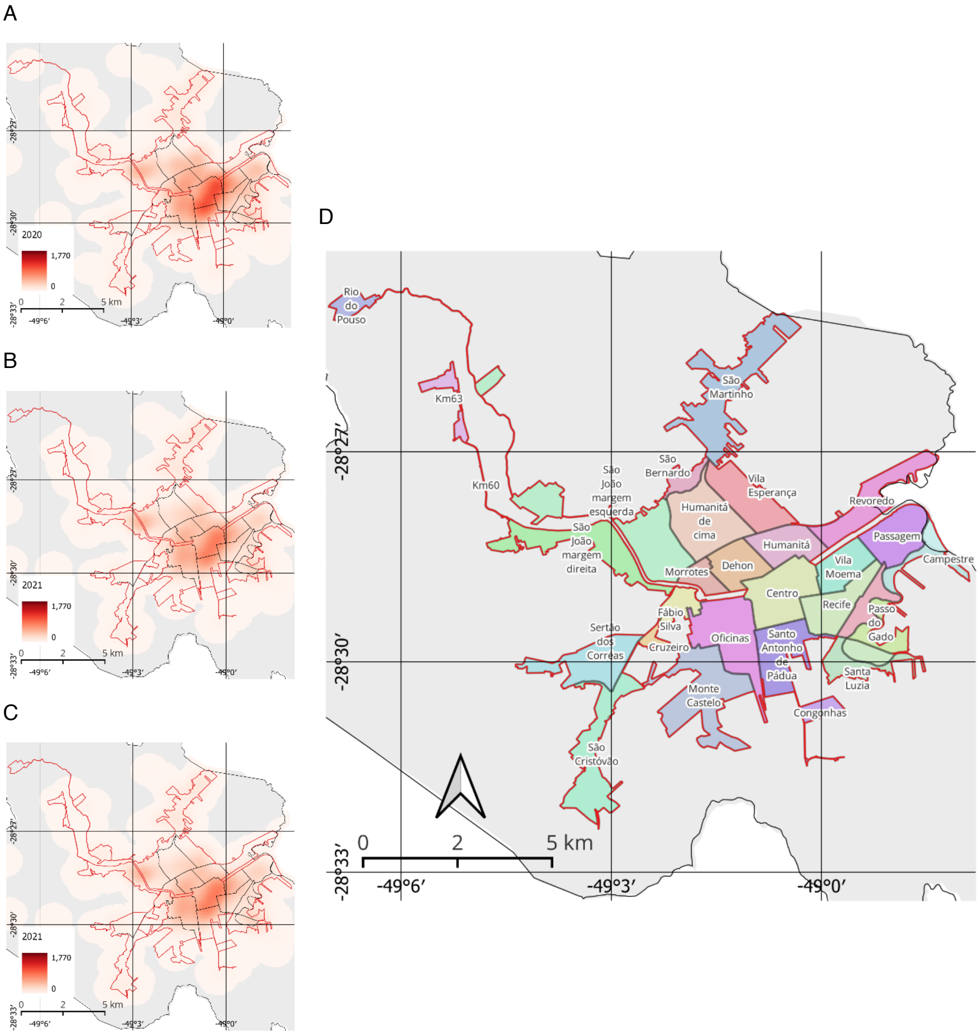


Figure8: Spatial distribution of the intensity of punctual occurrence by Kernel interpolation of total cases per year (A): 2020, (B): 2021, accumulated in the study period (C) and neighborhood division map (D)

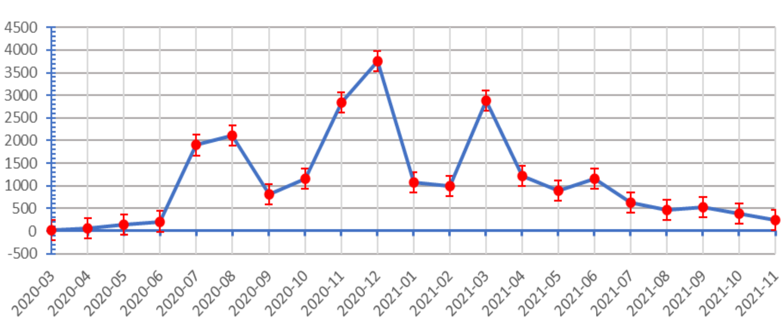
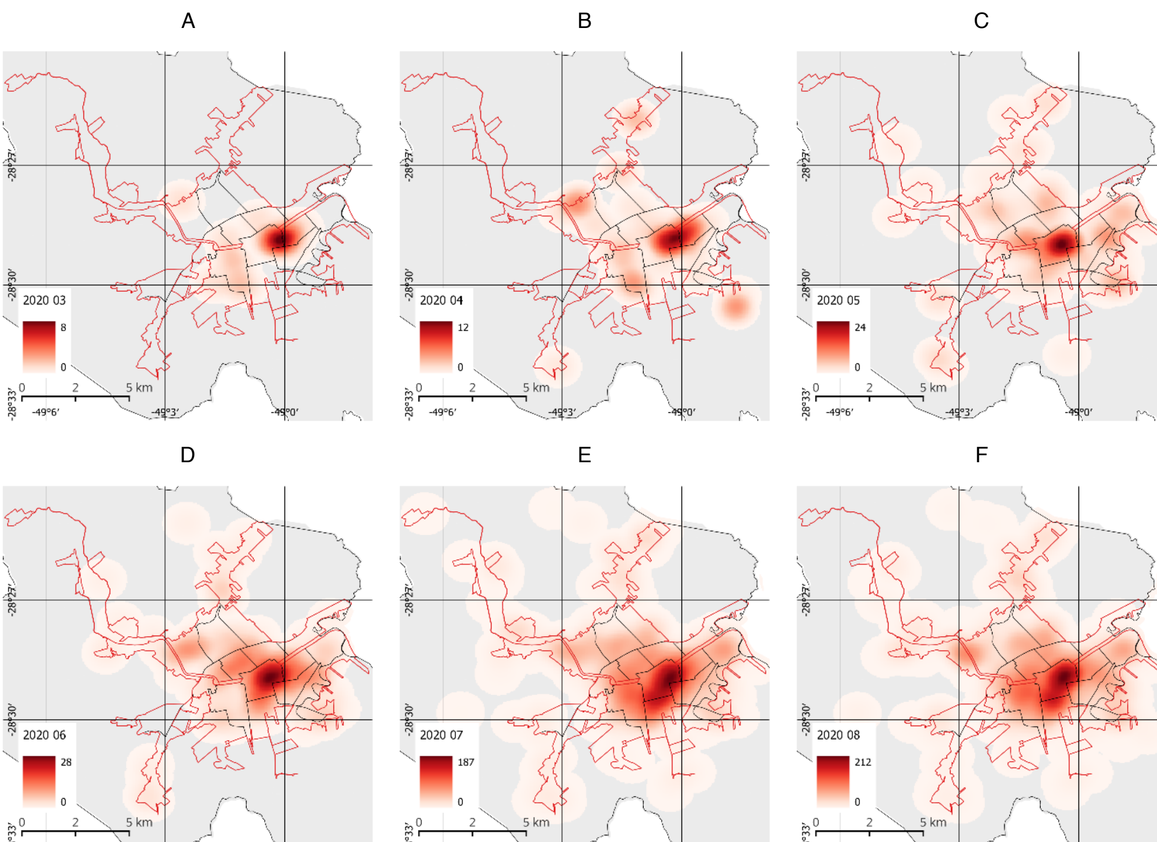


Figure 9: Evolution chart of total monthly cases in the period under study

The history of patients infected with COVID-19, as soon as they were geolocated, allowed to obtain the hotspots: these are regions that require greater attention from the public health and epidemiological surveillance agencies (CARDOZO, 2018). The task of finding these regions, through geolocated data from the addresses of infected patients and by applying Kernel density estimation techniques or point clustering (heat map) is important because regions with greater densities can represent shared infection sites.

It can be seen that the Kernel density estimation, with the radius and distribution method of selected points, performed a distribution density analysis, identifying and representing the areas with the highest concentration of infected patients by neighborhoods of the municipality. This procedure allows the recognition of areas of greater concentration or hotspots.

Finally, working with the disaggregated data, maps were drawn month by month, based on the cases distributed punctually (Figures 10) and using Kernel interpolation to obtain the spatial distribution of occurrences or heat maps of COVID-19 cases under study (Figure 11).



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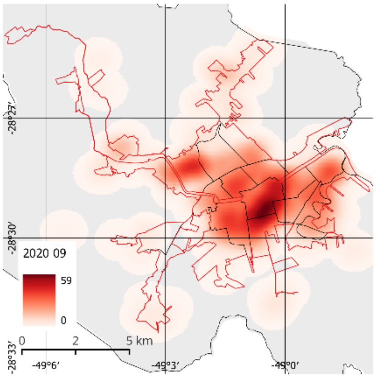

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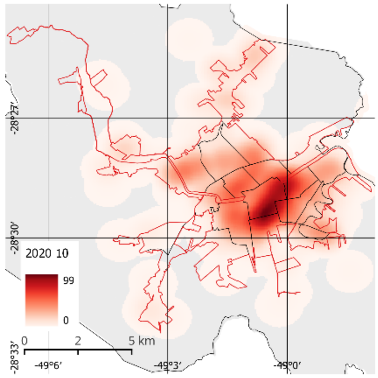

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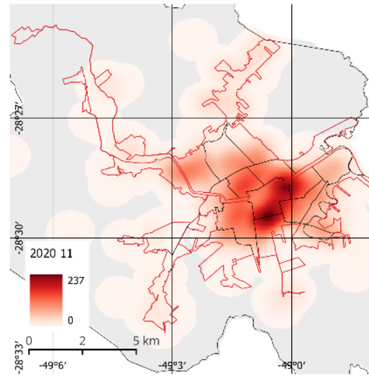

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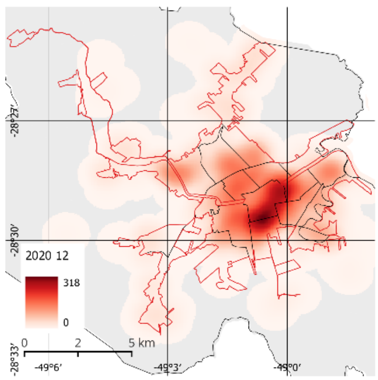
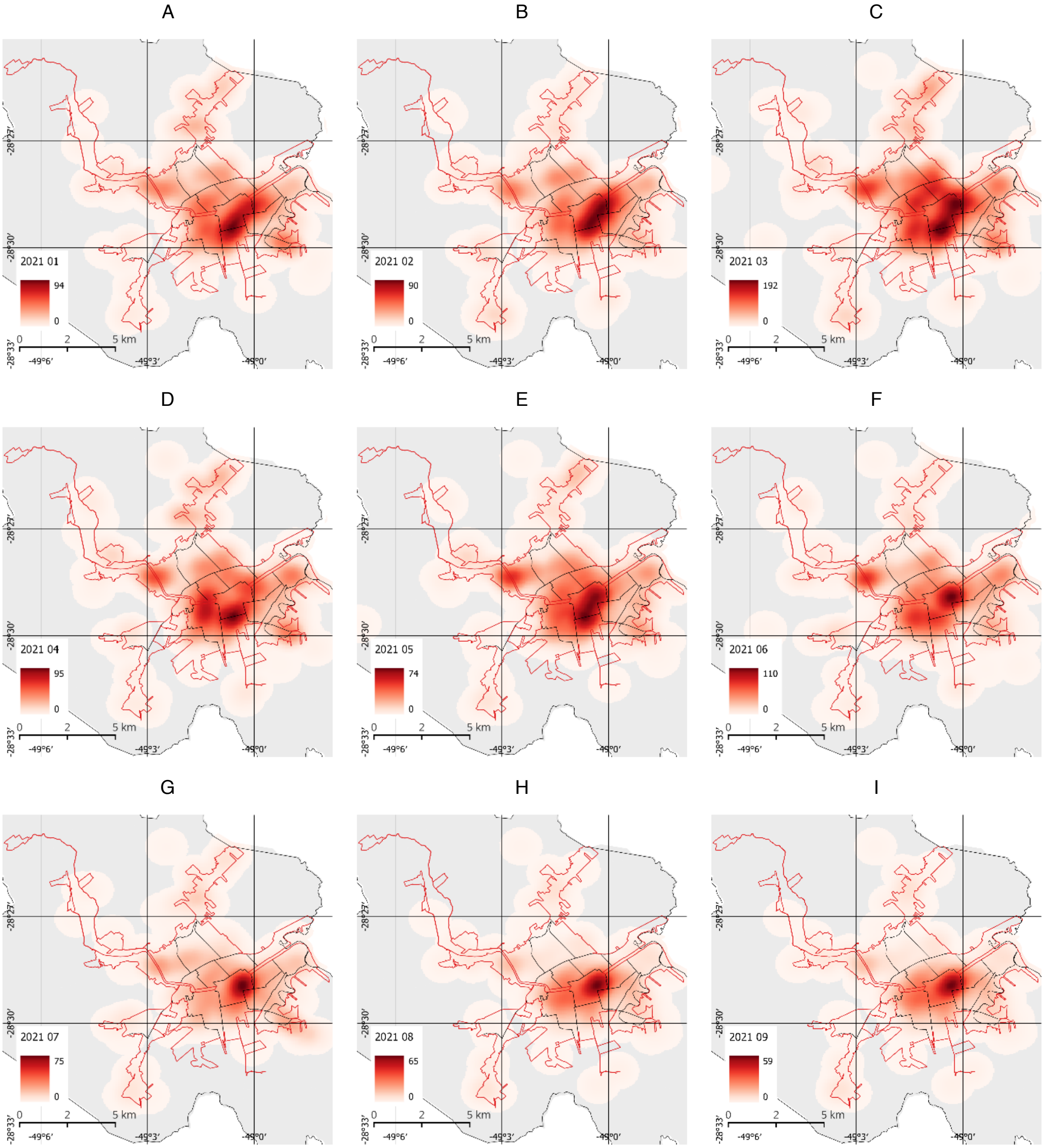


Figure 10: Kernel maps (hotspot)March to December 2020: March (A), April (B), May (C), June (D), July (E), August (F), September (G), October (H), November (I), December (J) (Density scales maximized each month to check hotspots and compare different densities)


A
2021 01
94
0
B
2021 02
90
0
C
2021 03
192
0
D
2021 04
95
0
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2021 05
74
0
F
2021 06
110
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G
2021 07
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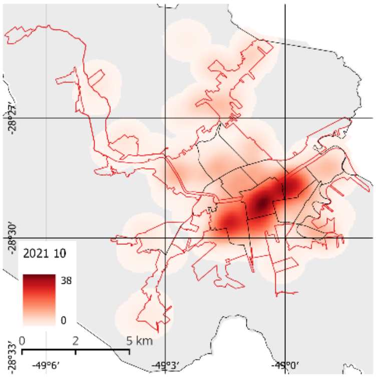

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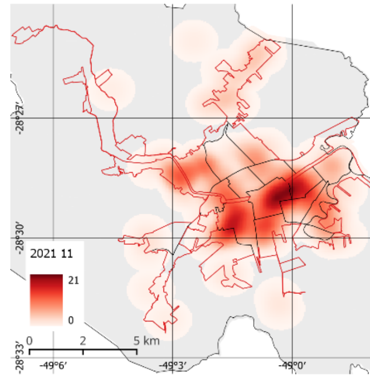

Figure 11: Kernel maps (hotspot) from January to November 2021: January (A), February (B), March (C), April (D), May (E), June (F), July (G), August (H), September (I), October (J), November (K) (Note: Density scales maximized each month to check hotspots and compare different densities)

4 I DISCUSSION AND CONCLUSIONS

After reviewing the work data and information, several considerations related to the data and the results can be discussed.

Regarding the geolocated data, the lack of a complete address and/or CEP (Postal Address Code), as well as typing errors, has posed a challenge dealing with the data in a computational setting. Typing errors implied a process of cleaning and systematizing the addresses and numbers in the database, which was time consuming. It should be noted that, due to usage and custom in managing the address database, street names, the relevant house numbers and additional data must necessarily be typed in separate fields/columns, a situation that did not occur in the database presented and was part of the cleaning and filtering processes that had to be performed for the geolocation of patients. On the other hand, systematizing the spelling of the municipality's street names based on computational routines for entering these data into the database would facilitate and avoid the writing errors indicated.

In turn, and taking into account the characteristics of the CEP (ZIP code) implemented in Brazil since 1971 and, considering that medium to large cities have their CEP distributed throughout the municipality, as is the case of Tubarão, with more than fourteen hundred active CEP, requesting, in addition to the street address and number, the patient's zip code, would facilitate geolocation analyses. In this case, it would not be necessary to use online geolocation systems, since the zip codes have their own geographic coordinates defined by the Brazilian Post Office.

The online geolocation systems proved to be efficient, although they have caused some errors for not being able to overcome the addressing knot when the street name is the same as a Municipality or a State; in this case the address was geolocated in the geographic center of these Administrations and not on the street of the municipality under study, in this case, in Tubarão.

In turn, the lack of numbering of some addresses only showing the street name, made the online geolocation systems place the data in the center of the street, which may affect the concentration of cases. These systems also have the problem of not having a continuous updating of street names (which would be almost impossible, considering that they are worldwide systems), which causes the loss of some addresses and these are geolocated in the geometric center of the Municipality under study. If these situations would occur on a large scale in a survey, they could create a geolocation bias, which could affect the investigation results. In the case under study, these addressing errors remained below 2.5% of the geolocated cases, being considered without significance for the purposes of the georeferenced analyses.

The first maps geolocating the cases, although necessary for the following analyses, by themselves proved to be visually inefficient to detect the shape and areas of the spatiotemporal distribution of the cases. Even the month-by-month distribution (not shown in this report) was not useful for the analyses, except for the analysis that detected in the first and second years, that the distribution of cases was consistent to a certain extent throughout the urban area of the municipality and, apparently, without specific concentrations, a situation that was reversed in the latest cartographic analyses presented (Kernel maps).

The next attempt of analysis was to use data from the IBGE census and the census sectors, stratifying the cases by sector, totaling them in each sector and calculating the density of cases per unit area. In this mapping process, some problems were found. The most evident problem is that the latest census data are from the years 2011/2012 (the so-called 2010 census) and are outdated in the years of the assessment, 2020/21, and that the update based on the city's population growth, data generated year by year by sampling and mathematical models used by the IBGE and published in the Official Gazette, in the months of July of each year, are useful for the municipality as a whole, but it is very uncertain to try to take this population variation to the census sectors, since it is not possible to evaluate if the housing and population growth was consistent throughout the urban area or if developments of properties in gated communities, new companies and factories, generated an uneven growth, in the different census sectors.

Another problem of the census sectors is the total lack of geographic coincidence with the neighborhoods and/or districts of the municipalities, since both geographic sectors have different purposes. This leads to a density map that is difficult to read, as the census sectors are, in general, smaller than a neighborhood and these neighborhoods can cross different census sectors. Thus, and for reasons similar to those indicated in the above paragraph, trying to extrapolate data from a census sector to the neighborhoods would also have an uncertain outcome. Therefore, the analysis of these maps stratified by census sectors and overlapping the limits of the neighborhoods also result in a difficult reading, both for mapping specialists and for Policy Managers, who must assess situations based on these maps.

Finally, we have the third form of spatio-temporal representation of active COVID cases: heat maps or Kernel maps.

In the annualized maps, it can be observed that the highest concentrations of cases occurred in the Centro and Santo Antonio de Pádua neighborhoods and, with a little less intensity, in the São João, Deão and Oficinas neighborhoods. In those maps, we can also see that the distribution over the months under study in the year 2020 and 2021, was similar, being higher in 2020 than in 2021 (more intense red). Hence, the totalizing map allows us to see the concentration of cases in the same neighborhoods, but with the highest intensity expected due to the sum of the two years reviewed.

When reviewed on a monthly basis, we can analyze the spatio-temporal variability of confirmed cases: starting in March 2020, on the edge of Vila Moema and Centro neighborhoods, with two outbreaks occurring in April in São João Margem Esquerda and Oficinas neighborhoods, in addition to a focus in the rural area south of the Santa Luzia neighborhood; concentrating again in the Centro in May 2020; and from July to December 2020, the cases are mainly concentrated in the Centro, Santo Antonio de Pádua and Vila Moema neighborhoods and, to a lesser extent, in the Oficinas, Dehon and Humanitá neighborhoods, although the massive distribution of cases throughout the urbanized area of the Municipality is already observed, with only the urbanized area in the south of the city (São Cristóvão, Monte Castelo and Congonhas, for example) remaining without significance.

In this spatial distribution, it is observed that, in the months of July/August and November/December 2020, there are two peaks of cases, higher at the end of the year, coinciding with the analysis of the line graph of the totalization of cases in Figure 9.

In the first two months of 2021, a decrease in cases in all neighborhoods is observed with the concentration always increasing in the city center (downtown) and, in March, coinciding with Figure 9, an accelerated increase in the number of cases can be seen, fundamentally in the limits of Centro and Santo Antonio de Pádua and Centro with Vila Moema and, secondarily, in São João, Oficinas, Dehon and Humanitá neighborhoods, as well as again, in the south and west neighborhoods of the urbanized area the concentration is minimal or null.

As of April 2021, it was found that the cases were decreasing, but always maintaining the highest concentration in the Centro, Vila Moema and Oficinas neighborhoods, also in line with the numerical data totaled in the line graph of Figure 9, mentioned above.

Therefore, in these last assessments the advantages of Kernel maps in relation to punctual or stratified representations are evidenced; the ease of observing concentrations and differences in the levels of concentrations of confirmed COVID-19 cases by month and by geographic region, represent the best way to analyze the situation under study.

However, for these heat maps to be used, the studies will always depend on properly geolocated data, which in the Health System databases will not always be available, having to definitely implement the habit of thinking of Geographic Health Databases and not just Health Databases.

In short, we perceive the importance of developing public health databases aiming at geolocation, in order to be able to carry out spatial and temporal analyses, which will be of great help in decision-making by Public Managers at different levels of the three health administrations: Municipalities, States and Union.

In view of the above, it is noteworthy that the Covid-19 Pandemic, analyzed from the perspectives of this study, shows that there is a continuous need to strategically monitor health situations. Therefore, it is essential to continue the work and studies that indicate alternatives and descriptions to allow explaining and evaluating the health-disease-care triad, aiming to evaluate and validate the decision-making by public health entities and agents.

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CONFLICT OF INTERESTS

None

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AUTHORS' CONTRIBUTIONS

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