Spatial Distribution of Ischemic Heart Disease Mortality in Rio Grande do Sul, Brazil

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ABSTRACT
The aim of this study was to analyze the spatial distribution of mortality Ischemic Heart Disease (IHD) in 497 municipalities of the state of Rio Grande do Sul, Brazil, in year 2010. Geoda™ and QGIS 1.8 were used to perform Exploratory Spatial Data Analysis of the 7,821 deaths. The results showed a positive spatial autocorrelation regarding IHD mortality ($I = 0.16236$, $p = 0.001$) with the formation of three clusters of type High-High. Also occurred a significant positive association for three socioeconomic and demographic indicators and IHD mortality rate: School Index ($I = 0.0901944$, $P = 0.001$), GINI Index ($I = 0.0695551$, $p = 0.001$), and Geographic Distance ($I = 0.0901944$, $P = 0.001$). One indicator presented significant negative association with IHD mortality rate: City Development Index Human ($I = -0.130376$, $P = 0.001$). We conclude that high rates of IHD mortality in some regions of Rio Grande do Sul, is potentially determined by socioeconomic, demographic disparities and geographic distances between patients' city of residence and their corresponding Interventional Cardiology Reference Centers.

Categories and Subject Descriptors
H. Information Systems

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General Terms
Measurement

Keywords
Spatial Analysis, Myocardial Ischemia, Epidemiology.

1. INTRODUCTION
Ischemic heart disease (IHD) caused approximately 7 million deaths in 2010, representing the leading cause of death worldwide. In developing countries, the disease is responsible for about 12.8% of all deaths annually [1]. In Brazil, IHD caused almost 100,000 deaths in 2010, and was responsible for about 222,000 hospital admissions. In addition, more than 37,000 people died from IHD prior to accessing care at a hospital [2].

In developing countries, IHD patients rarely receive the appropriate and timely emergency treatment. In Brazil, despite recent socioeconomic improvements, high IHD mortality rates due to lower socioeconomic and demographic conditions is still observed in some regions [3]. Additionally, a recent study published on factors contributing to morbidity and mortality from IHD demonstrated that the long travel distances and a prolonged prehospital care time to primary and referral cardiology centers are common, and represent important risk factor for mortality in Brazil [4].

Low-income populations with low levels of education, who reside in locations distant from the large urban centers, are observed to have difficulty accessing health care services [5-10]. In this context, studies have shown that making reference cardiology centers more accessible could potentially reduce IHD mortality rates [11 - 14]. In Brazil, the southern region is the smallest land area, and has the second highest socioeconomic conditions in the country. However, there are still disparities in health care access, especially when it comes to interventional cardiology services, and will directly affect the IHD mortality rates. The aim of this study is to describe the socioeconomic, demographic and geographic characteristics of patients who died from IHD in 497 cities in Rio Grande do Sul state, in Brazil.

2. METHODS

This is an cross-sectional observational ecologic study using spatial analysis techniques based on data of mortality by IHD in 2010 in the state of Rio Grande do Sul, Brazil. The state is bordered to the north by the brazilian state of Santa Catarina, to the east by the Atlantic Ocean, on the south by Uruguay, and to the west by Argentina. It occupies 108.784 square miles, with the north coordinates Latitude: -27 04 '48" and Longitude: -53 ° 01' 53"; and South Latitude: -33 ° 45 '06 "Longitude: -53 ° 23' 48' (Figure 1) [15-16]. According to the 2010 Brazilian Census, Rio Grande do Sul state has 10,693,929 inhabitants, making it the 5th most populated in Brazil. Most inhabitants (85.1%) live in urban areas [15]. Rio Grande do Sul state has 497 cities administratively grouped into 19 Regional Health Units (RHU) responsible for health care management [2].

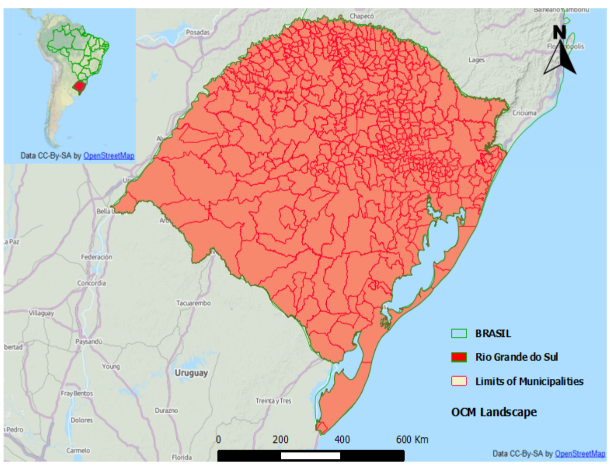


Figure 1: Map of Rio Grande do Sul.
Source: OpenStreetMap (OSM), 2013 (17).

2.1 Data Sources

We obtained data from the Mortality Information System of the Ministry of Health (SIM/MS) [18], and from the Brazilian Institute of Geography and Statistics (IBGE) [15].

To calculate the population per city, we used the total number of citizens over the age 20 years. Social and economic data were obtained online at IBGE and the DATASUS websites [15 - 18]. The geo-referenced map of Rio Grande do Sul with Political-Administrative Divisions from 2010 was obtained online from the IBGE.

To assemble a death profile related to IHD, we analyzed five socioeconomic and demographic indicators for each city, the GINI Index, Education, Municipal Human Development Index (HDI), population size over age 20. The GINI Index is a number between 0 and 1, where 0 corresponds to perfect equality (where everyone has the same income) and 1 corresponds to perfect inequality (where one person has all the income and everyone else has zero income) [19]. Scholarity - Illiterate people over 15 years old or that had not completed fundamental cycle (< 8 years of education) [15]. The HDI measures the cities' performance and quality rating of three service areas: employment and income, health, and education [20]. We selected IHD cases using the International Statistical Classification of Diseases and Related Health Problems –10th Revision (ICD-10) [21], specifically the codes I20 to I25.

We used an empirical Bayes spatial estimator to minimize variance in mortality rates by city, due to the variability associated with rates expressing the likelihood of a given event when the rate and population are both small. The global empirical Bayes estimator calculates a weighted average of the gross rate of the local and the region's global rate (which is a ratio between the total number of cases and the total population) [22]. Specific mortality rates per 100,000 inhabitants were obtained for each of the 497 cities in Rio Grande do Sul state. These values were divided by class intervals and aggregated according with the quantiles calculated.

2.2 Spatial Analysis

We analyzed spatial data grouped by geographic areas (polygons) to evaluate whether the presence of spatial aggregation was associated with socioeconomic, demographic, and/or geographic variables [23 - 24].

To Exploratory Spatial Data Analysis (ESDA) we used the softwares Quantum GIS (QGIS - Open GIS software)[25], GeoDaTM version 0.9.5-i (Spatial Analysis Laboratory, University of Illinois, UrbanaChampaign, IL, USA)[26] and R package (R Core Team 2013)[27] to determine measures of global spatial autocorrelation and local spatial autocorrelation [28].

To evaluate the existence of spatial autocorrelation, we defined a spatial weight matrix (W). This matrix allows for the measurement of nonrandom association between the value of a variable observed in a given geographical unit and the value of variables observed in neighboring units. Furthermore, we used the binary matrix-type Queen, which attributes the value of one for neighbors in any spatial locations within the analyzed region [29].

We calculated spatial autocorrelation evaluating mortality rates, socioeconomic, and demographic indicators for each city using the (I) Global Moran index for univariate and bivariate analysis [29-30].

This index measures both the spatial autocorrelation and the weighted neighborhood matrix, indicating that the IHD mortality rates of a given region might be similar to those of neighboring regions. Values of Moran I vary between -1 and +1. Values greater or smaller than the expected value of Moran I [E (I) = -1/(N - 1)] indicate a positive or negative autocorrelation, respectively. If the value of Moran's I is 0 (zero), the region is considered to have spatial independence. Moran I values between 0 and +1 indicate positive spatial association (direct) [29 - 30].

This indicates that regions with high Moran I values for the variable in question are surrounded by regions that also have high variable values (high/high). Similarly, regions with low variable values are surrounded by neighbors who also have low variable values (low/low). Negative values of Moran I (from 0 to -1) represent negative spatial association (reverse). Therefore, regions with high Morans I values are surrounded by regions with low variable values, while regions with low Morans I variable values are surrounded by neighbors with high variable values [23,29-30].

Local indicators of spatial association (LISA) allowed us to identify the existence of spatial clusters significant and specific to each analyzed area, with high or low values for the analyzed variables contributing to spatial autocorrelation [23,29]. Choropleth maps were generated to investigate the presence of specific mortality rate clusters. Coefficients of global and local spatial autocorrelation were considered significant at $p<0.05$. These coefficients were analyzed by pseudo significance levels [30].

The distance between centroids (geometric coordinate that determine the geometric center) of the municipalities and the Interventional Cardiology Center closest to the center was calculated through Euclidean distance (straight-line) [25] and to determine the percentage of the population that resides there less of 25 km, of 26-50 km, of 51-75 km, of 76-100 km or 100 km or more distance and mortality rate respective, were visualized in a heat map. The list with the host cities where the hemodynamic laboratories are located is publicly available in the Datasus [18].

3. RESULTS

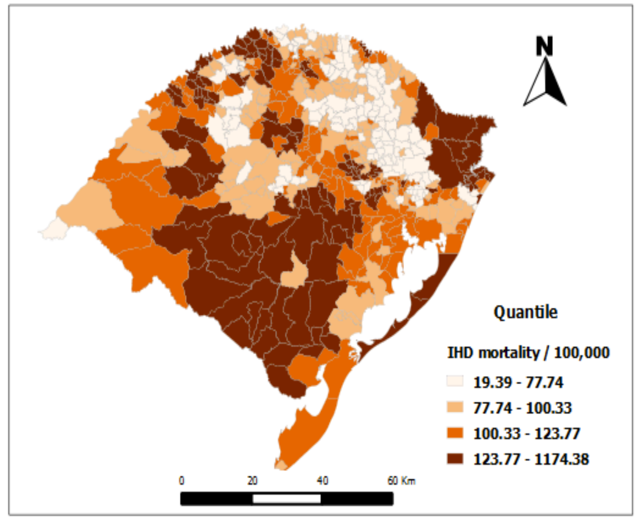
During the studied period, there were 7,821 deaths due to IHD in Rio Grande do Sul state. Of those, 54.11% were men and 45.89% were women of which 31.33% were over 80 or more years old while 26.6% of patients were 70 -79 years of age. The population was mostly white (89.44%), married (48.91%), and with educational level of up to seven years in school (53.43%), of total data of education 34.90% were missings.

Regarding spatial patterns of death distribution from IHD in the 497 cities in Rio Grande do Sul, on average 73.13 per 100,000 inhabitants over the age of 20 years died from IHD. Out of 497 cities, 58,95% presented IHD mortality rates between 74.58 and 130.49 per 100,000 inhabitants. Rates above 131.09 per 100,000 inhabitants were identified in 103 (19,52%) cities located in all regions of the state (Figure 2A).

Univariate analysis (Figure 2B) regarding specific mortality rates by IHD indicated the existence of a positive spatial autocorrelation ($I = 0.16236$, $p = 0.001$). Thus demonstrating that cities with high mortality rates by IHD tend to be surrounded by neighboring towns with similar high mortality rates by IHD.

A LISA analysis allowed the detection of clusters based on similarities between cities (Figure 2C). We could therefore classify these groups of cities using the following categories: **(1) high-high**, i.e., cities with high rates of death from IHD with surrounding neighbors also with high rates of death from IHD; **(2) low-low**, i.e., cities with low rates of death from IHD with neighbors with low rates of IHD mortality; **(3) low-high**, i.e., cities with low rates of death from IHD with neighbors with high rates of IHD mortality, and **(4) high-low** i.e., cities with high rates of death from IHD with neighbors with low rates of IHD mortality (Figure 2C). We identified 6 clusters high high involved sixty-four cities, these 45 cities located in the Mid-east, southwest and southeast; 12 cities in the Midwest and Northwest; 7 cities in the northeastern region of the state.

A)



B)

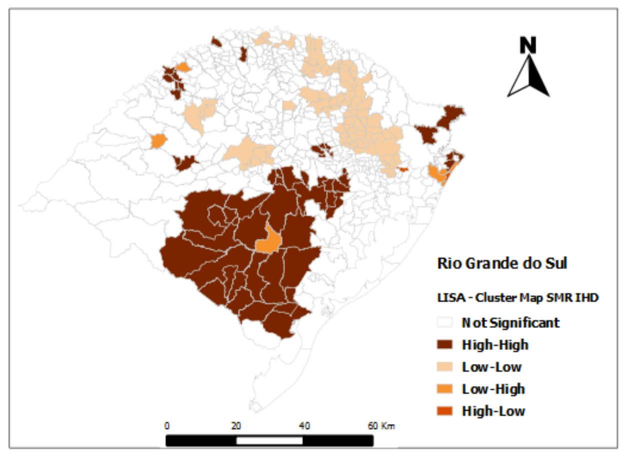
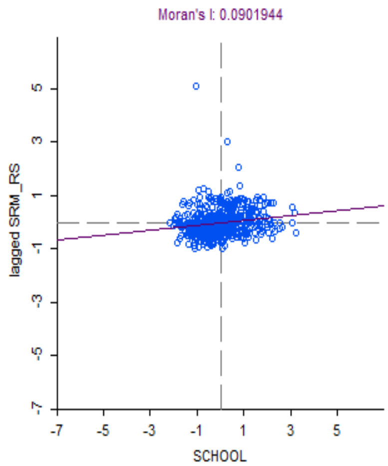


Figure 2. Exploratory spatial analysis of specific mortality rate by IHD in state of Rio Grande do Sul, Brazil, 2010. **A)** Spatial distribution of cities' specific mortality rate (SMR) by IHD, with ranges of Natural Breaks for the delimitation of class intervals; the number of cities is in parenthesis. **B)** LISA univariate analysis: cluster formation according to specific mortality rate (SMR) by IHD (Types of cluster: high-high; low-low; low-high, high-low).

All four socioeconomic and demographic indicators used for analysis in this study were significantly associated with mortality rates by IHD ($p < 0.05$). The correlation was positive for the School Index ($I = 0.0901944$, $P = 0.001$), GINI index ($I = 0.0695551$, $p = 0.001$), and for the Geographic Distance ($I = 0.0901944$, $P = 0.001$)

These positive correlations indicated that cities with a high level of these variables were surrounded by cities with high rates of IHD mortality. However, specific mortality rates by IHD correlated negatively with City Development Index Human ($I = -0.130376$, $P = 0.001$), suggesting that cities with high values of City Development Index Human were surrounded by cities with low rates of mortality by IHD and vice-versa. Thus, socioeconomic and demographic factors significantly influence the number of deaths by IHD in these cities (Figure 3).

A)



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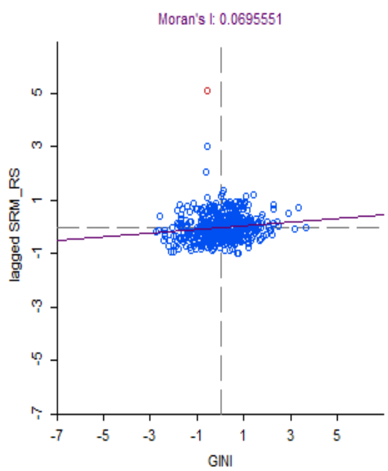
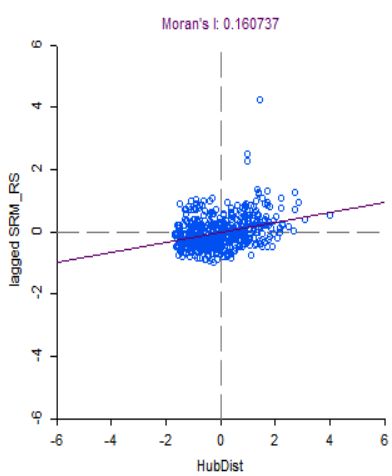


C)



D)

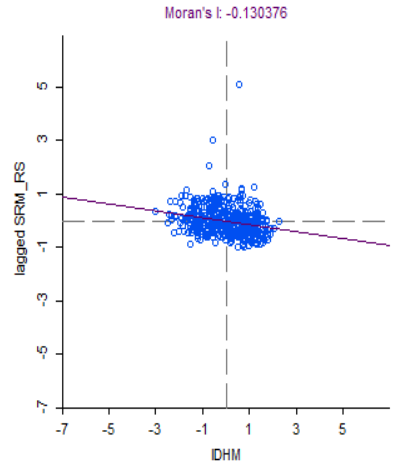
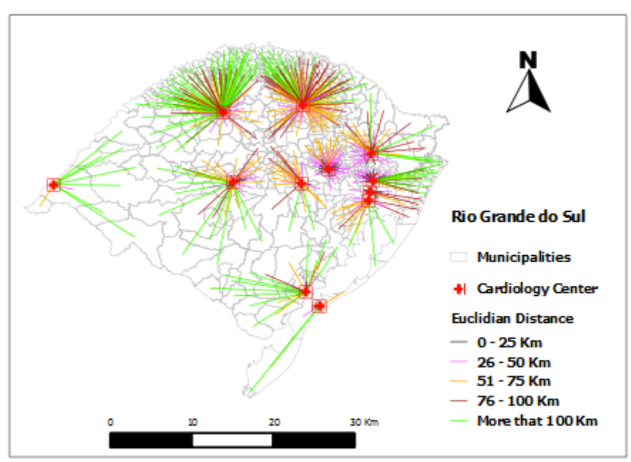


Figure 3. Moran’s diagram of dispersion (bivariate analysis). Analysis of socioeconomic or demographics variables of the city of residence of the patient (X axis) and the weighted average specific mortality rate by IHD of the neighbor cities (Y axis). A) Education Level. B) Gini Index. C) Geographic Distance (HubDist). D) Municipal Development Human Index (IDHM).

We further analyzed the influence of the existence of Referral Interventional Cardiology Centers on mortality rates by IHD among neighbor cities. In Figure 4 A, the distances between centroids of the municipalities and the nearest Reference Interventional Cardiology Center are depicted through Euclidean distance analysis. This analysis allowed the determination of five categories of distances: black lines (0 to 25 km range); pink lines (26 to 50 km range); orange lines (51 to 75 km range); red lines (76 to 100 km range) and more than 100 km by green lines. Furthermore the heatmap (Figure 4B) showed the distribution of values for four variables by using a table with colored represented by frequency of each intersection of values. The heat map shows that the highest percentage of the population lives within 25 km to the reference centers (yellow density), though the mortality rate (green density) is not significantly lower than those who live further away (p value: 0.13).

A)



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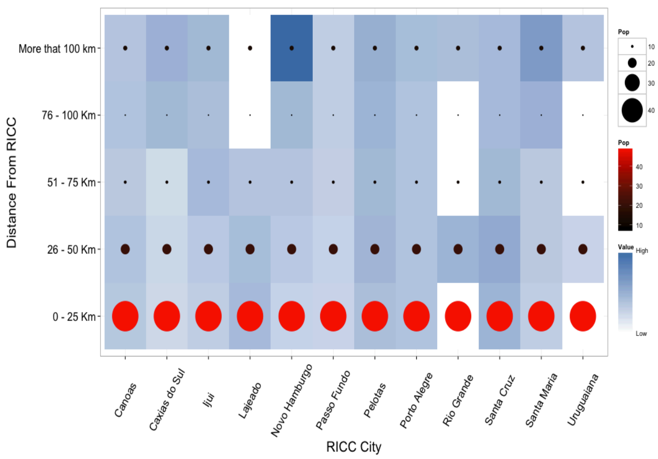

Figure 4: A) Map with Euclidian Distance between each municipality centroid and the respective nearest Reference Interventional Cardiology Center (red cross: total of 12 in the Rio Grande do Sul state): black lines (0 to 25 km range); pink lines (26 to 50 km range); orange lines (51 to 75 km range); red lines (76 to 100 km range) and more then 100 km by green lines. B) Heat map showed distribution of values for four variables represented by frequency of each intersection of values. Distance geographic (X axis) City of Reference Interventional Cardiology Center (Y axis). Percentual of population for each group of distance (yellow density). Specific mortality rate for each group (green).

4. DISCUSSION

To the best of our knowledge, there are few studies analyzing the interaction between distance from a Interventional Cardiology Referral Centers, socioeconomic and demographic conditions and IHD mortality rates in developing countries. This study showed a positive spatial association for IHD mortality rate in Rio Grande do Sul Brazil. Cities with high IHD mortality rates were surrounded by cities with high IHD mortality rates, determining a high-high pattern of clustering. Low-low, low-high and high-low types of clustering were also observed. Furthermore, there was an association between different socioeconomic, demographic and geographic indicators and higher IHD specific mortality rate. These data indicate that geographical distribution of Interventional Cardiology Referral Centers as well as socioeconomic and demographic characteristics of the cities influences specific mortality rate by IHD.

The distance or absence of a Interventional Cardiology Reference Center in a Regional Health District may be an important independent predictor of IHD mortality, especially for patients that live in cities with socioeconomic disparities. Studies have shown that socioeconomic and demographic disparities increase IHD mortality rates when combined with increased distance from a specialized treatment center [31 - 33]. Other studies have shown that higher rates of IHD mortality are frequently associated with greater distances from a patient's place of residence to a Interventional Cardiology Reference Center increasing the time delay to the treatment of IHD [34 - 36].

Previous studies have indicated that established policies of universal access to healthcare adopted by different countries do not necessarily lead to real universal access to healthcare for all population subgroups equally; specialized services can be difficult to access due to difficulties related with distance and availability of general practitioners, among other factors [37 - 38]. A possible solution to this problem could be the creation of new cardiology reference services [4].

In Brazil, many problems have been related the accessibility and equity of care provided by the different levels of health care levels of assistance [39,40]. Regarding patients with IHD, these problems seem to be related to inadequate management of health services mainly at the primary health care system level, but also at the secondary care level [4,40]. Thus, the majority of patients with risk factors for IHD are received in primary hospitals without adequate structure and trained health professionals, increasing the delay in the treatment of IHD.

The limitations of the study may be related the availability and quality of ambulance services in the different municipalities and infrastructure of the Referral Interventional Cardiology Centers. Similarly, further analysis is warranted including obtaining more database about logistics and infrastructure of the ambulance services and referral hospital, providing important information on the IHD mortality for Brazil.

5. CONCLUSION

We identified significant geographic differences in IHD mortality rates in the state of Rio Grande do Sul, Brazil. Higher IHD mortality rates are associated with lower socioeconomic status, higher demographic disparities, and longer travel distance to an ICC. Aside from targeting social inequalities, improving geographic access to ICC may result in improved IHD outcomes.

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