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Applying spatial decision support for maternal mortality analysis in a Brazilian state

Thiago Poleto[1], Victor Diogho Heuer de Carvalho[2]*, Rodrigo Cleiton Paiva de Oliveira[1]

[1] Business Management School, Institute for Applied Social Sciences, Federal University of Pará, Belém, Brazil
Email: thiagopoleto@ufpa.br and ro.wright09@gmail.com
[2] Technologies Axis, Campus do Sertão, Federal University of Alagoas, Delmiro Gouveia, Brazil
Email: victor.carvalho@delmiro.ufal.br
* Corresponding author: victor.carvalho@delmiro.ufal.br

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Abstract

The interface between Decision Support Systems (DSS) and Geographical Information Systems (GIS) generates Spatial Decision Support Systems (SDSS) which aid in the decision-making process, particularly in situations where spatial attributes play a pivotal role in achieving accurate conclusions. By integrating conventional decision criteria with spatial criteria and visualization through the adoption of SDSS and geographic information systems technologies, a comprehensive analysis is ensured. The primary aim of this research is to exemplify an application of SDSS to support analyses and decisions on a specific issue in Public Health. The focus lies on assessing cities within the state of Pernambuco (Brazil) that exhibit the highest rates of maternal mortality. This approach promises to offer valuable in-sights and aid in making informed decisions to address critical maternal health issues in the region.

Keywords

Spatial Decision Support Systems; decision-making; public health; maternal mortality; Pernambuco; Brazil.

1. Introduction

Maternal mortality stands as a paramount determinant among governmental health indicators, exerting a profound impact. According to the World Health Organization (WHO), it refers to the death of a woman during pregnancy or within 42 days after its conclusion, irrespective of the pregnancy's duration or location, and caused or worsened by factors related to pregnancy, excluding accidental or incidental causes. Recognizing its immense social significance and relevance to public health, the Brazilian government has underscored this critical issue. Moreover, maternal mortality serves as a significant marker of social development (Alves, 2007). It can also be considered as an indicator to help analyze the performance in terms of efficiency (Nepomuceno et al., 2022a) of childbirth and maternity services offered by hospitals and by public health services.

The primary causes and risk factors leading to maternal mortality during pregnancy, childbirth, and the postpartum period stem from a comprehensive understanding of medical, biological, and social influences. Many of these tragic deaths can be prevented through regular and thorough monitoring by healthcare specialists (Simão and Almeida, 2011). In a proactive effort to enhance maternal mortality data and take direct action, the State Health Department of Pernambuco established State Decree No. 087/95 in September 1995. This decree mandated the investigation of all deaths involving women of reproductive age (between 10 to 49 years) by municipal epidemiology departments. By implementing this measure, the authorities aimed to gain valuable insights into the circumstances surrounding maternal deaths and implement targeted interventions to reduce their occurrence.

However, health systems have a limited ability to achieve strategic outcomes in public health because the information generated by the maternal mortality system is not part of a dynamic process; it acts only as a case-control register. According to Joyce (2009), it is important to consider new computational tools to generate better care in the health sector and to make better strategic decisions.

Within this context, Geographic Information Systems (GIS) emerge as a powerful tool to address health-related challenges by utilizing advanced geospatial methods. GIS is a comprehensive software system that facilitates data input, storage, and retrieval, enabling mapping and spatial analysis based on location and geographical attributes. This capacity empowers organizations to make well-informed decisions. Moreover, GIS offers the unique ability to integrate and overlay diverse datasets, enhancing spatial analysis and modeling operations, thereby deepening our comprehension of geographic relationships (Sugumaran and DeGroote, 2010). By leveraging GIS, health professionals can gain valuable insights into the spatial distribution of health issues, identify potential hotspots, and devise targeted interventions to improve healthcare outcomes effectively.

This paper aims to investigate the application of decision support in public health, focusing on the maternal mortality issue in the state of Pernambuco, Brazil. Its key contribution lies in demonstrating how Geographic Information Systems (GIS) and Decision Support Systems (DSS) combined can be harnessed to devise effective health strategies and enhance the decision-making process in healthcare, composing a SDSS.

The paper's structure is as follows: Section 2 comprises a comprehensive literature review; Section 3 introduces a decision support framework that incorporates ideas from both SDSS and GIS; Section 4 outlines the materials and methods employed in the investigation that serves as the foundation for this article; in Section 5, the results obtained from applying the methodology are discussed; lastly, Section 6 offers a conclusion, summarizing the key findings and implications of the study.

2. Literature Review

2.1. Spatial Decision Support Systems (SDSS)

Decision support systems (DSS) are defined as a "set of procedures for data processing and judgments based on models to help managers in the decision-making process" (Little, 1970). The term DSS has its origin in studies by Simon, who defined the "intelligence-design-choice" model in the late 1950s and the early 1960s. A DSS normally consists of three subsystems: data management, model management, and user interactive user interface, all combined to support organizational learning to ensure proper decisions (Poleto et al, 2017). These are interactive, computer-based systems and subsystems intended to assist decision-makers in using communication technologies, data, documents, knowledge, and/or models to identify and solve problems and make decisions (Li et al., 2004).

Spatial decision support systems (SDSS) are a special type of DSS that uses geographic or spatial data. Sugumaran and DeGroote (2010) define SDSS as integrated computer systems that support decision makers in solving semi-structured or unstructured spatial problems interactively with functionality to handle bases of spatial and non-spatial data, analytical modeling resources, public services of decision support such as scenario and effective data analysis and utilitarian information presentation. The implementation of such systems becomes even more critical in the Health area, where ensuring a secure decision-making process is of utmost importance. It is essential to safeguard sensitive and confidential data, ensuring that only authorized decision-makers have access to them (Poleto et al., 2021). This approach also supports the analysis of the efficiency of health services, offering valuable assistance to decision-makers in visualizing variations in efficiency across different areas. For instance, it allows decision-makers to identify more and less efficient regions when analyzing specific healthcare services provided (Nepomuceno et al, 2022b).

The vast majority of SDSS applications developed previously had GIS as a main component of their architecture. The architectures of SDSS have varied, with some being fully developed within GIS software (embedded), some having a strong coupling (a common user interface) between GIS and other software assessment models or multicriteria analyses, and others having a weak coupling between GIS and other components through the formatting and exchange of data files. In a literature review of SDSS that focused on the theme of GIS and multicriteria decision analysis (GIS-MCDA) techniques, Malczewski (2006) found that loose coupling was the most common method of integration.

In Brazil, SDSS applications can be found across various domains. For instance, de Carvalho et al. (2016) utilized a SDSS approach with MCDA to support Public Education management. In a similar vein, de Carvalho et al. (2022) employed Machine Learning and Natural Language Processing techniques in a SDSS framework to analyze public opinion about COVID-19 vaccination in the country. Additionally, de Lima et al. (2019) applied SDSS with MCDA to map epidemiological data concerning tuberculosis in a Brazilian Municipality. Furthermore, Horita et al. (2015) employed SDSS for flood risk management. Overall, the development and application of SDSS in these contexts often necessitate the acquisition of GIS software and expertise in its utilization.

2.2. GIS in Healthcare

As previously established, Geographic Information Systems (GIS) utilize geospatial location data for georeferenced analysis, supporting decision-making processes. Geographic location is a crucial criterion in health services, leading to the development of various studies applying GIS in health and hospital contexts.

In a study analyzing accessibility to hospital services in the state of Kentucky, United States, researchers found that mortality rates vary geographically due to differences in accessibility. Individuals residing in rural areas must travel longer distances to reach hospital services, resulting in potential social and economic marginalization (Hare and Barcus, 2007). Similarly, researchers in Australia used GIS to assess geographical accessibility for patients with heart problems (Coffee et al., 2012).

In the United States, health systems focus on monitoring the aging population, with falls being a significant cause of hospitalization for adults over 65 years. A study in Pierce County,

Washington, utilized GIS to strategize site selection for fall-prevention programs (Carlson et al, 2011). GIS has also been employed in monitoring and evaluating programs for malaria elimination. A study proposed mapping the risks of malaria to support spatial decision-making processes (Clemens et al., 2013). Moreover, researchers developed an incidence grid map of observed rheumatoid arthritis cases using GIS and a georeferenced spherical variogram model (İnanır et al, 2013).
In a special epidemiological analysis, researchers provided ecological information on socioecological factors exposing the population to public health risks and proposed strategies to mitigate the risk (Kauhl et al, 2015).
Given GIS's importance in facilitating information availability, integration, and presentation, the research discussed here aims to explore the relationship between spatial behavior and maternal mortality. By incorporating new information, this study intends to enhance decision-making and contribute to the planning of actions aimed at reducing maternal mortality.

3. A Comprehensive Framework Incorporating SDSS and GIS Concepts and Functionalities

The presented framework aims to leverage the potential of GIS and geostatistics as decision support tools, fostering the seamless integration of information from diverse sources, including data acquired through space sensors (remote sensing). The information can be gathered using various means, such as global positioning system (GPS) technology or conventional methods like surveys and data sheets. Figure 1 illustrates the integration of these tools with the decision-making process.

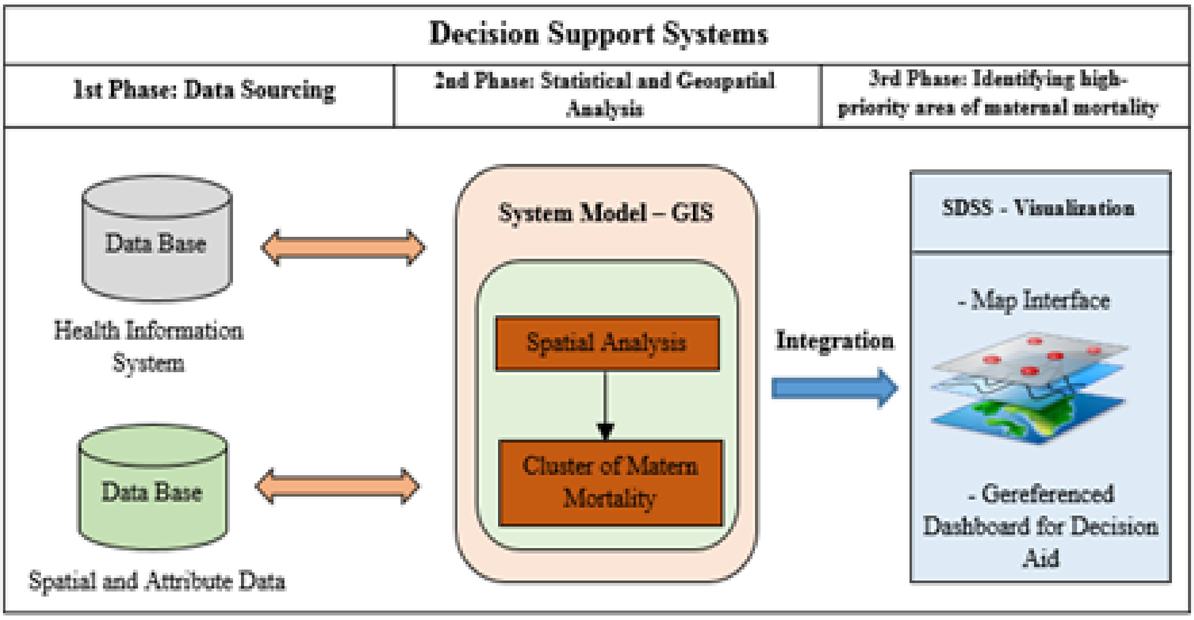


Figure 1. Integration of GIS and SDSS with the Decision-Making Process.

The three phases depicted in Figure 1 are:

1st Phase: In this initial stage, descriptive attributes are adopted, which can be represented in a conventional database, such as a hospital information system. Additionally, the geographic space is considered based on its coordinates, including altitude and relative position. This approach enables the localization of the geographic area, facilitating the identification of maternal and child hospitals.

2nd Phase: The second phase involves the analysis of the public health system, wherein spatial dependence in a set of geodata is utilized to identify priority areas for maternal mortality in Pernambuco. This analysis reveals spatial associations and the overall Moran indices are employed for an exploratory analysis, assessing spatial dependence by comparing sample values with their neighbors. The indicators used in this process are based on spatial proximity matrices. Furthermore, clustering is applied to classify areas with the highest maternal mortality incidence.

3rd Phase: In the final phase, GIS is leveraged for data integration, spatial analysis, queries, and image processing. These tools are employed to generate geographic visualizations and plots, aiding in the identification of priority areas for maternal mortality in Pernambuco. Visualization tools play a vital role as technology products, synthesizing information from complex and dynamic data, thus supporting evaluation. This visual analysis becomes integral to the decision-making process, improving interaction with the user (decision-maker). It enables the analysis of large datasets and provides valuable support in achieving the desired outcomes.

4. Material and Methods

The study was carried out in the northeastern Brazilian state of Pernambuco, which is home to a population of 8,796,448 inhabitants, residing across an area of 98,149.119 km^2. The population density is approximately 89.62 inhabitants per square kilometer (inhabitant/km^2). The state of Pernambuco is subdivided into 185 municipalities. As depicted in Figure 2, the study area encompasses these municipalities, which are further grouped into 12 health regions: Afogados de Ingazeira, Arco Verde, Caruaru, Garanhuns, Goiana, Limoeiro, Ouricuri, Palmares, Petrolina, Recife, Salgueiro, and Serra Talhada.

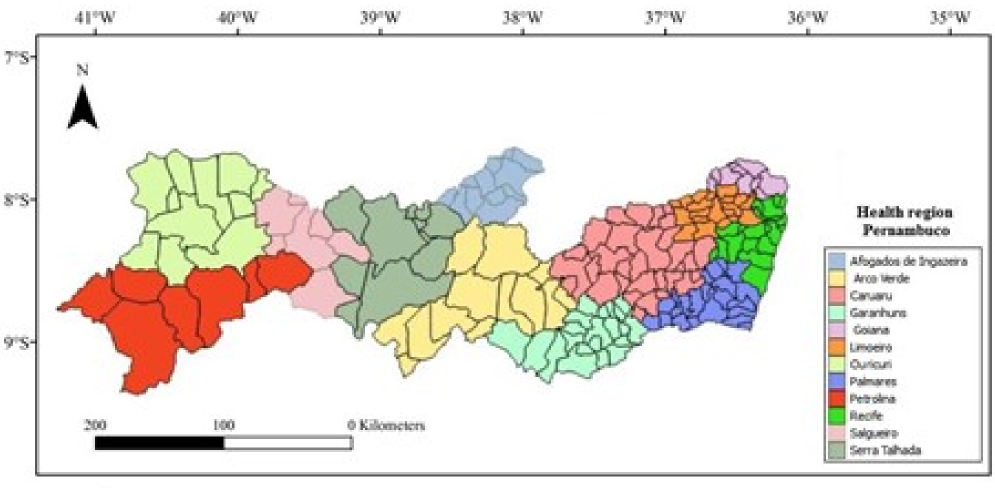
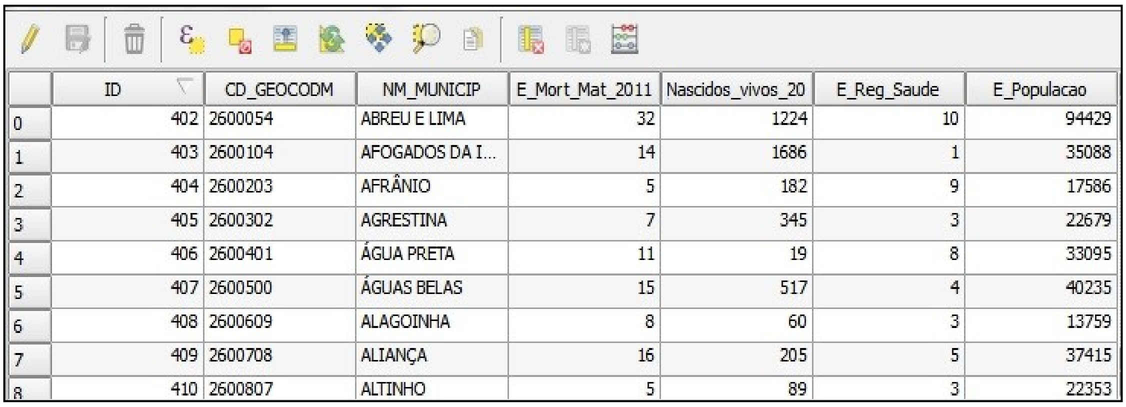


Figure 2. General health regions in Pernambuco.

The spatial distribution of maternal mortality was derived from secondary data sources, specifically the Hospital Information System (HIS) and Mortality Information. The study accessed the database of the Department of Informatics of the Brazilian Unified Health System (DATASUS) provided by the Brazilian government.

Geographic Information System (Quantum GIS) was utilized to categorize the health regions based on this information. Additionally, spatial analysis was performed using the GeoDA

software to analyze the variable "Maternal Mortality" during the 2011 period. This analysis aimed to identify municipalities with the highest rates of maternal death and determine the intensity of spatial correlation at both global and local levels among these regions.
The results of the geospatial analysis identified regions with the highest prevalence of maternal mortality in comparison to other areas within Pernambuco. The study intends to provide valuable insights for decision-making, contribute to health planning, especially in reducing maternal mortality, and investigate the causes and events specific to each municipality in the state. Figure 3 displays the prepared database for the Geographic Information System application.



	ID	CD_GEOCODM	NM_MUNICIP	E_Mort_Mat_2011	Nascidos_vivos_20	E_Reg_Saude	E_Populacao
0	402	2600054	ABREU E LIMA	32	1224	10	94429
1	403	2600104	AFOGADOS DA I...	14	1686	1	35088
2	404	2600203	AFRÂNIO	5	182	9	17586
3	405	2600302	AGRESTINA	7	345	3	22679
4	406	2600401	ÁGUA PRETA	11	19	8	33095
5	407	2600500	ÁGUAS BELAS	15	517	4	40235
6	408	2600609	ALAGOINHA	8	60	3	13759
7	409	2600708	ALIANÇA	16	205	5	37415
8	410	2600807	ALTINHO	5	89	3	22353

Figure 3. General view of the mortality geodatabase created for the study

Figure 4 illustrates the number of deaths among women of childbearing age reported over the period between 2009 and 2015. This figure aims to demonstrate the results of the analysis for identifying the period with the highest maternal mortality rate in Pernambuco.

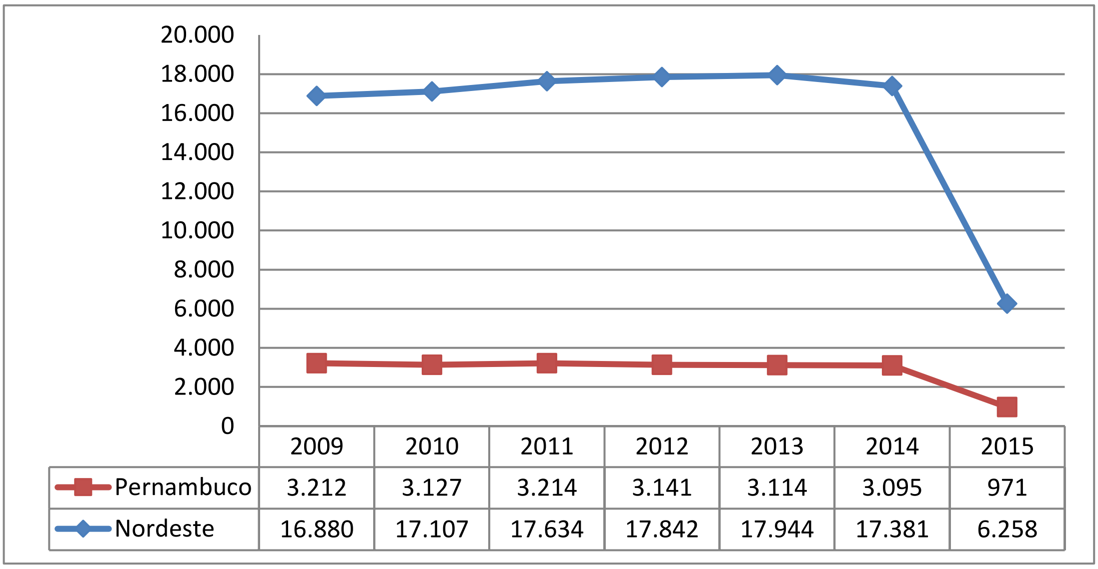


Figure 4. Breakdown of the number of deaths of women of childbearing age reported from 2009 to 2015.

The graph illustrates the number of deaths among women in the Northeast region. In 2009, there were 16,880 reported cases of death, which reached its peak in 2013 with 17,944 deaths. Specifically for Pernambuco, there were 3,212 deaths in 2009, which reached a peak in 2011 with 3,214 deaths, and then slightly declined to 3,095 deaths in 2014.

5. Results and Discussion

Maternal mortality serves as a crucial health indicator for the female population and provides insights into inequities that can be addressed through targeted policies for specific groups. Reducing maternal mortality rates and conducting thorough investigations into such deaths are essential goals for comprehensive healthcare improvement. To achieve these objectives, maps were generated to analyze cluster formations of maternal mortality across 185 municipalities. The initial exploratory analysis involved constructing interval map percentiles, enabling the observation of various spatial distribution patterns of maternal mortality in 2011, as depicted in Figure 5.

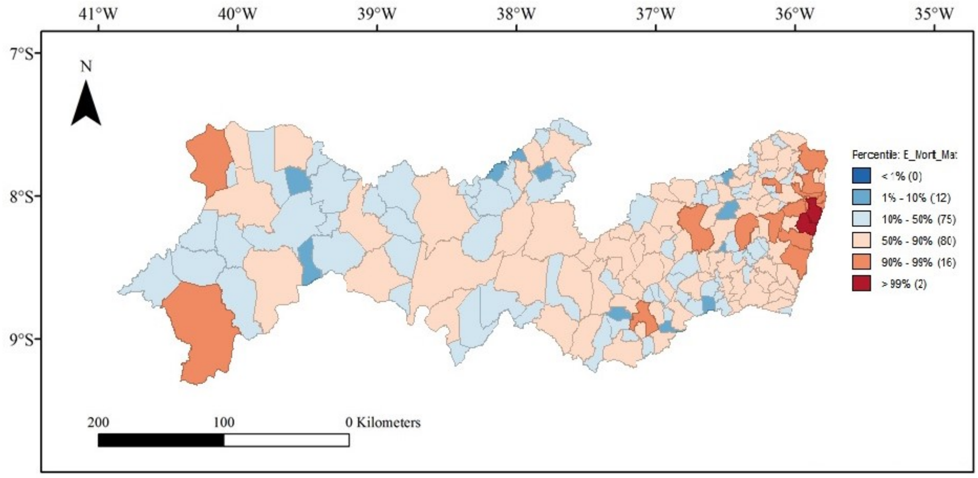


Figure 5. Percentage of maternal mortality in the state of Pernambuco.

In the subsequent step, an exploratory analysis of the dataset was conducted, focusing on determining the spatial dependence of the maternal mortality variable in the municipalities of Pernambuco. The analysis utilized the Moran Global Index to examine spatial relationships, as illustrated in Figure 6.

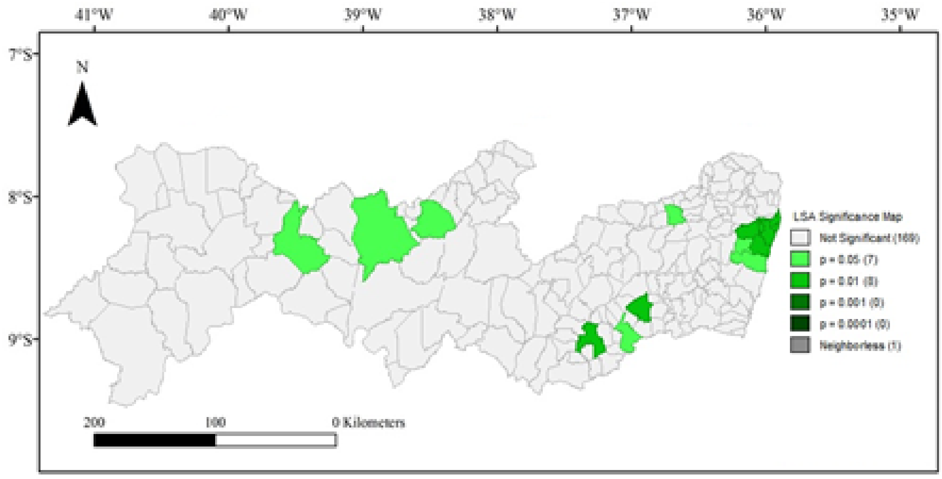


Figure 6. Map of significant variables for maternal mortality in Pernambuco.

To delve deeper into the relationships between maternal mortality in the municipalities, a thorough investigation was carried out using the local association index (LISA). The goal was to pinpoint local spatial associations within the data. Utilizing this local insight, a map classifying areas based on their characteristics was created, as depicted in Figure 7.

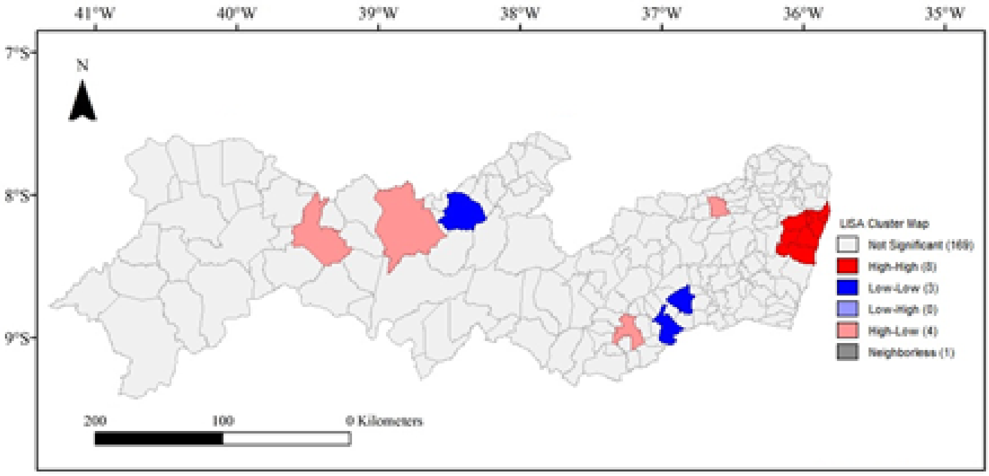


Figure 7. LISA map for maternal mortality.

The cluster map for the maternal mortality variable illustrates distinct patterns in the municipalities. The red color represents municipalities where both their own and their neighbors' maternal mortality rates for the year 2011 were higher than the average (positive deviation; high-high quadrant). The municipalities exhibiting this behavior include Cabo de Santo Agostinho, Camaragibe, Jaboatão dos Guararapes, Moreno, Olinda, Paulista, Recife, and São Lourenço da Mata. On the other hand, the blue color represents municipalities where both their own and their neighbors' maternal mortality rates were below the global average (low-low quadrant). This group includes Canhotinho, Flores, and Panelas.

There were no municipalities in the low-high quadrant, where the maternal mortality rates were below average, but their neighbors had above-average rates. However, the high-low quadrant consists of municipalities with above-average maternal mortality rates but whose neighbors had rates below the global average, including Garanhuns, Salgueiro, and Serra Talhada.

The present study focuses solely on the number of maternal mortality occurrences in each municipality of Pernambuco. Future research aims to analyze hospital infrastructure capacity and population migration from other municipalities with high maternal mortality rates in the region. Additionally, transportation conditions to the hospital are vital, as women may encounter pregnancy-related complications.

It is essential to acknowledge that one of the limitations of this work is the secondary sourcing of data from the Brazilian Unified Health System database on hospital admissions.

The findings of this study demonstrate the application of a decision support system in the health context. However, further consideration is necessary, especially regarding factors that could influence the indicator's values or hinder the monitoring of maternal mortality over time or in comparison to different locations in Brazil.

6. Conclusion

This work proposal culminated in a decision model based on GIS, seamlessly integrated with the existing government system's information. The study aimed to identify municipalities with the highest maternal mortality rates, addressing a critical public health issue in Brazil, particularly in Pernambuco. As such, a key challenge for the government is to effectively reduce maternal mortality. This study endeavors to consolidate state and federal programs, incorporating

regulations from all regions of Pernambuco, and secure enhanced funding for bolstering health surveillance teams. The application of this model was carried out in the municipalities of Pernambuco, providing valuable support to the decision-making processes in these regions.
The adoption of GIS as a decision support system (DSS) proves advantageous due to its capacity to work with spatial data. Integrating GIS tools with databases enhances decision support capabilities, allowing for improved interactions with other techniques, such as dynamic data exchange, given the ease of employing GIS functionalities.
For future work, a priority would be to geocode all the properties of the identified municipalities, including factors such as workforce capacity and access to hospitals, as these elements contribute significantly to decreasing maternal mortality rates in Pernambuco. Additionally, the development of systematic evaluation methods to measure institutionalized impact could offer insights into the health system's effectiveness and inform future priorities, aiding in the reorientation of action plans and activities.

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Conflict of Interest Declaration

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report

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