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SPATIAL EXPLORATORY ANALYSIS OF THE EXISTENCE OF EQUIPMENT FOR CANCER DIAGNOSIS IN BRAZILIAN MICROREGIONS IN 2019

ANÁLISE EXPLORATÓRIA ESPACIAL DA EXISTÊNCIA DE EQUIPAMENTOS PARA DIAGNÓSTICO DE CÂNCER NAS MICRORREGIÕES BRASILEIRAS PARA O ANO DE 2019

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ANÁLISE EXPLORATÓRIA ESPACIAL DA EXISTÊNCIA DE EQUIPAMENTOS PARA DIAGNÓSTICO DE CÂNCER NAS MICRORREGIÕES BRASILEIRAS PARA O ANO DE 2019

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ABSTRACT

Access to healthcare and adequate infrastructure are essential for cancer diagnosis and treatment. This study aims to analyze the spatial distribution of cancer diagnostic equipment in Brazilian microregions for the year 2019. It was used data from the National Register of Health Establishments (CNES), made available by the Informatics Department of the Unified Health System (DATASUS). The methodology used in this work was an Exploratory Spatial Data Analysis (ESDA), which verifies the existing spatial associations in Brazilian microregions that have cancer diagnostic equipment. The study results presence of positive spatial autocorrelation in the data. Note the formation of high-high clusters of cancer diagnostic devices in the South and Southeast of Brazil, indicating that these regions have a high concentration of devices. However, the results also indicate that in the North and Northeast regions there is a strong presence of low-low clusters, indicating an agglomeration of micro-regions lacking these medical equipment. Thus, a regional inequality was found in the country regarding the availability of equipment for cancer diagnosis, highlighting the need for investments and public policies focused on regions with lack of equipment.

Keywords: Exploratory Analysis of Spatial Data, cancer diagnostic equipment, health.

RESUMO

O acesso à assistência médica e à infraestrutura adequada é essencial para o diagnóstico e tratamento do câncer. O objetivo deste estudo é mapear a disponibilidade dos equipamentos de detecção de câncer e identificar possíveis áreas de carência, assim como padrões de associação espacial da oferta da estrutura de equipamentos de diagnóstico de câncer nas microrregiões brasileiras para o ano de 2019. Para isso, foram utilizados dados do Cadastro Nacional de Estabelecimentos de Saúde (CNES), disponibilizados pelo Departamento de Informática do Sistema Único de Saúde (DATASUS). A metodologia utilizada neste trabalho foi uma Análise Exploratória de Dados Espaciais (AEDE), que permite verificar as associações espaciais existentes nas microrregiões brasileiras que possuem equipamentos de diagnóstico de câncer. Os resultados apontam a presença de autocorrelação espacial positiva nos dados, com uma formação de clusters do tipo Alto-Alto de aparelhos de diagnóstico de câncer no Sul e Sudeste do Brasil, indicando que estas regiões possuem uma alta concentração de aparelhos. Em contraste, os resultados também indicaram que nas regiões Norte e Nordeste há uma forte presença de clusters do tipo Baixo-Baixo, apresentando uma aglomeração de microrregiões com falta destes equipamentos médicos. Assim, constatou-se uma desigualdade regional presente no país com relação à disponibilidade de equipamentos para diagnóstico de câncer, ressaltando a necessidade de investimentos e políticas públicas focados nas regiões com maior carência de equipamentos.

Palavras-chave: Análise Exploratória de dados espaciais, equipamento de diagnóstico de câncer, saúde.

INTRODUCTION

According to the definition provided by the National Cancer Institute (INCA), cancer is the name given to a group of more than 100 diseases that share the characteristic of uncontrolled cell growth, which tends to be highly aggressive and unmanageable, leading to the formation of tumors that may spread to other regions of the body. According to the Ministry of Health, cancer identification in its early stages can be achieved through early diagnosis or screening (Brazil, 2019).

As stated by Silva and Hortale (2012), two strategies can be adopted for early cancer detection: early diagnosis and screening. Early diagnosis involves raising awareness among the population and healthcare professionals about the early signs and symptoms of cancer through consultations conducted in healthcare services for symptomatic individuals. Screening, on the other hand, consists of identifying cancer in its early stages among asymptomatic populations, thereby enabling a change in its prognosis.

Early cancer diagnosis allows treatments to begin sooner and be more effective (Kowalski, 2021), as late-stage diagnosis reduces the chances of a cure and is one of the factors responsible for high mortality rates. It may also lead to other negative consequences such as loss of workplace productivity, emotional repercussions, and increased healthcare expenses with medical costs (Rodrigues et al., 2015). For early diagnosis to be feasible, appropriate equipment must be available, and healthcare services must be accessible to the population, with a less unequal spatial distribution of cancer diagnostic equipment to enable faster diagnosis. Studies such as those by Dejardin et al. (2005), Huang et al. (2003), and Oliveira et al. (2011) have pointed out that in rural areas, small towns, regions with limited budgets, and those lacking transportation infrastructure, the absence of adequate facilities and equipment near patients directly influences population access to healthcare. Thus, a healthcare structure with a higher concentration of available equipment ends up benefiting those who live near this type of facility.

Access to medical care and adequate infrastructure is essential for cancer diagnosis and treatment, which may include surgery, chemotherapy, radiotherapy, or bone marrow transplantation, potentially combined in more than one procedure. This study holds great relevance as the patient's health depends on a timely diagnosis, which requires accessible equipment for the entire population without the need for significant travel. In this context, the study aims to address these gaps, enabling the identification of areas lacking diagnostic equipment and facilitating the mapping of regional disparities in the availability of healthcare infrastructure. This information can serve as a basis for the development of public policies to reduce these inequalities.

According to the cancer report published by the World Health Organization (WHO) in 2020, if current global trends persist, there will be a 60% increase in cancer incidence over the next twenty years. Data from the Department of Informatics of the Unified Health System (DATASUS) show that in 2019, 510,032 cancer surgeries or treatments were recorded in Brazil. However, even with the presence of highly qualified hospitals, this does not guarantee easy access for the entire population.

The distance between hospitals and the patient's residence can be a barrier both to the treatment of the disease and to the initial medical consultation, as the first contact with an oncologist is crucial for a favorable prognosis. Therefore, the location of specialized facilities plays a vital role.

Given the influence of the location of healthcare facilities on the speed of cancer diagnosis, treatment, and patient health, this study aims to map the availability of cancer detection equipment and identify potential underserved areas, as well as spatial association patterns in the distribution of cancer diagnostic equipment in Brazilian microregions for the year 2019. The availability of imaging and optical diagnostic equipment was analyzed using exploratory spatial data analysis (ESDA) in Brazilian microregions in 2019.

This work is divided into five sections: in addition to this introduction, the second section presents a literature review on inequality in access to oncology in Brazil; the third section outlines the methodology applied in the study; the fourth section presents the results of the spatial distribution of cancer diagnostic equipment in Brazilian microregions; and finally, the concluding remarks.

SPATIAL INEQUALITY IN ACCESS TO ONCOLOGY

According to Oliveira (2021), one of the key aspects of regional development within the context of Myrdal's cumulative causation theory is the provision of healthcare infrastructure in a given region. This is a factor that contributes to an increase in the availability of skilled labor and subsequent improvement in the region's business environment.

According to Gadelha et al. (2011), health plays a central role in the development process, including its territorial aspects. In the Brazilian context, the health sector acts as a driver of regional development, and healthcare infrastructure is a significant factor contributing to regional inequalities in the country. Miranda et al. (2023) highlight substantial disparities in health indicators and resource allocation for healthcare infrastructure across the national territory.

Access to healthcare services is influenced by geographical factors such as distance, travel time, region, and service availability, as well as demographic factors including rurality, race/ethnicity, income, and health insurance status. Guimarães et al. (2020) emphasize the importance of developing healthcare strategies that address the real needs of the population, particularly focusing on preventive actions to tackle cancer within primary healthcare networks, which serve as the gateway to the broader healthcare system. Onega et al. (2008) state that travel time to healthcare services significantly affects access and utilization, especially for cancer patients.

In addition to the limited availability of cancer treatment centers in low-income countries, Sharma et al. (2012) state that in developing countries, personal, sociocultural, and economic factors contribute to delays in patients seeking their first medical consultation. Identifying these challenges is crucial for implementing interventions to address such delays.

According to Stopa et al. (2017), access to healthcare is directly related to the availability of services to the population. Challenges in this access, in turn, are linked to the specific characteristics of healthcare systems, services, and population groups. Dejardin et al. (2005) further highlight the lack of mobility, particularly among women and the elderly, as a factor that can influence the preference for proximity to treatment centers.

Huang et al. (2003) state that the distance between a patient's residence and the nearest hospital also affects the staging of the disease: advanced-stage diagnoses are associated with a greater average distance compared to early-stage diagnoses. The likelihood of more advanced breast cancer diagnoses was significantly higher for women living more than 15 miles from an oncology facility compared to those residing within 5 miles.

In Brazil, regional inequalities are also reflected in disparities in access to healthcare services. One way to measure regional inequality is through the ratio of healthcare professionals to the population (Bastos; Gomes, 2014). Pinto (2015) further observed the relationship between the presence of these professionals and other factors, such as higher population density, per capita income, and the concentration of hospitals, which are predominantly located in the South and Southeast regions of the country.

Scheffer et al. (2018) report significant inequalities in the distribution of physicians across Brazil. In 2018, while the national average was 2.18 physicians per 1,000 inhabitants, some capitals had more than 12 physicians per 1,000 inhabitants, whereas cities in the Northeast had less than one physician per 1,000 inhabitants. This disparity was also evident among oncologists, with some states having up to four times more oncologists per 100,000 inhabitants compared to others in the North and Northeast regions.

Even in areas where physicians and hospital infrastructure are available, access difficulties impose barriers that compromise the quality of patient care. Oliveira et al. (2011) state that even when treatment is accessible, there is evidence of its spatial concentration: half of the total volume of care in the country occurred in a few capitals, particularly Rio de Janeiro and São Paulo, which accounted for about one-fifth of the national cancer care, mostly for their own residents.

According to a study conducted by the National Cancer Institute (INCA), the South and Southeast regions had the highest cancer incidence rates per 100,000 inhabitants by federal unit in 2006, while the North and Northeast regions had the lowest rates (Brazil, 2006). Additionally, INCA projections estimate

625,000 new cancer cases in Brazil each year during the 2020–2022 period. The Southeast and Northeast regions lead in the number of new cases, accounting for 48.3% and 21.78%, respectively. However, when analyzing the crude incidence rate per 100,000 men and women, the Southeast and South regions stand out (Brazil, 2019).

Stopa et al. (2017) assert that residents of the South and Southeast regions of Brazil have greater access to healthcare services compared to those living in other regions. This disparity is also observed among individuals with higher education levels, better living conditions, and those residing in areas with higher Human Development Index (HDI) scores. Similarly, Travassos, Oliveira, and Viacava (2006) associate the greater access to healthcare in the South and Southeast with the socioeconomic development of these regions.

Grabois, Oliveira, and Carvalho (2013) highlight that large distances between residences and hospital infrastructure are particularly notable in the North of Brazil. For chemotherapy or radiotherapy treatments, approximately 58% of residents had to travel more than 1,000 km to reach specialized healthcare facilities. This underscores the lack of adequate access to healthcare services for these populations.

According to Viacava et al. (2019), an analysis of mammography coverage in the 438 Brazilian health regions between 1998 and 2013 revealed cases of low coverage despite sufficient equipment availability. This indicates an abundance of mammography machines in some regions, while others face shortages or lack these services entirely.

In addition to reflecting cancer incidence, mortality from the disease is also influenced by disparities in access to, utilization of, and performance of healthcare services (Brazil, 2006). Barbosa et al. (2016) argue that the spatial distribution of cancer mortality rates in Brazil reveals significant inequality, with higher rates often correlated with the country's more developed areas. Between 2010 and 2012, the highest mortality rates were recorded in regions with better-structured healthcare services for patients (Melo, 2018).

This is corroborated by the Oncology Observatory's study *Cancer Mortality Patterns in Brazilian Regions*. From 2000 to 2015, the risk of dying from cancer (age-adjusted crude mortality rate per 100,000 inhabitants) was highest in the economically developed South and Southeast regions. This suggests potential underreporting of incidence and/or mortality in other regions.

Medici and Beltrão (2015) highlight limitations in DATASUS data, as it only registers individuals who received some form of treatment or whose cause of death underwent medical evaluation. This could exclude a significant number of individuals without regular access to healthcare or chronic disease detection and management.

According to INCA's report *The Cancer Problem in Brazil*, the quality of death registration due to cancer is compromised by the identification of the cause of death as ill-defined. This is often linked to the lack of prior diagnosis, meaning the individual did not access healthcare services during their lifetime. In 1998, ill-defined causes accounted for 24% and 30% of deaths in the North and Northeast regions, respectively. By 2001, only 4% and 19% of hospitals accredited as High-Complexity Oncology Care Centers (CACON) in Brazil were located in the North and Northeast, respectively. Thus, the geographic pattern is heavily influenced by the quality of data in the Mortality Information System (SIM) (Brazil, 2002).

Souza (2004) found that the Southeast region accounted for half of all high-complexity hospital services in Brazil, while the North and Northeast regions represented only 4% and 15%, respectively. This disparity is also evident in high-complexity oncology services, where only 4 out of the 179 oncology care centers in Brazil were located in the North region. In contrast, the Southeast had 91 centers, the South had 41, the Northeast had 29, and the Midwest had 14 oncology hospitals.

Rodrigues, Amaral, and Simões (2007) highlight that Brazil's healthcare network is non-inclusive, overlapping, and widely unequal in regional distribution. With the concentration of services in the Southeast and South regions, large areas of deficiency were observed in other regions, particularly in the North and Northeast, consistent with their lower economic development. In the Northeast, nearly all municipalities have limited healthcare services and are surrounded by others in similar conditions. The presence of healthcare professionals, equipment, and physical facilities follows a similar pattern.

Gadelha (2002) notes that while the Brazilian high-complexity oncology system is sufficient in terms of registered units, it becomes inadequate due to the low output of these facilities. This means that despite a sufficient number of oncology centers, they fail to perform a number of procedures adequate to meet the total demand of cancer patients in Brazil. Amaral et al. (2017) report similar findings regarding the spatial distribution of mammography machines across the country.

Silva et al. (2024) analyzed the allocation of mammography machines between 2014 and 2019 in municipalities that lacked them until 2013. The authors found that the availability of equipment led to an increase in the number of exams performed among women aged 50 to 69 years but did not significantly impact diagnoses in the short term. This underscores the need to optimize resource use and enhance service availability for cancer screening and detection.

Dias et al. (2024) conducted an analysis of breast cancer detection procedures offered by the SUS in Brazil's macroregions in 2019. Their findings revealed a widespread deficit in procedures across the country, within an already regionally unequal healthcare structure. This emphasizes the urgent need to plan and adapt the healthcare network, balancing the requirements for early diagnosis and breast cancer screening in Brazil.

Inequality in access to healthcare in Brazil is notable and widely discussed in national literature. Studies such as those by Oliveira et al. (2011), Stopa et al. (2017), and Grabois, Oliveira, and Carvalho (2013) examine the challenges faced by residents in regions lacking hospital infrastructure, particularly concerning high-complexity services required for cancer care. This study seeks to advance research on cancer detection in Brazil by addressing the spatial distribution of diagnostic equipment—a topic not specifically covered in the existing literature.

METHODOLOGY

DATABASE AND SELECTED VARIABLES

The data were extracted from the National Registry of Health Facilities (CNES), available through the Department of Informatics of the Unified Health System (DATASUS). The CNES has nationwide coverage, operationalizing information from all healthcare facilities in Brazilian municipalities. The data collected from DATASUS are found in the *Assistance Network* section and filtered under *Physical Resources* in the *Equipment* category. The data were aggregated by Brazilian microregions, and the analysis year is 2019.

The variable selected for this study considers the availability of cancer diagnostic equipment in both public and private healthcare networks, without assessing the operational condition of these devices. The data reflect the equipment available in December 2019 to represent the healthcare network structure at the end of the year. The use of microregions as the geographical unit was defined because travel between municipalities within the same microregion or to nearby microregions with available equipment facilitates access to healthcare infrastructure.

To utilize this data as a statistical indicator, the two existing categories of equipment—imaging diagnostics and optical methods—were grouped. **Table 1** presents the definition of the selected variables.

Table 1 | Selected Aggregate Variables.

Aggregate Variable	Equipment	Description
Imaging Diagnostic Equipment (IMG)	Gamma camera	Device used to capture the radiation emitted by radioactive tracers/markers. Used for the dynamic evaluation of patient metabolism.
	Simple Command Mammography Unit	X-ray device used for breast examinations. Used for preventive screenings and early diagnosis of breast cancer.
	Stereotactic Mammography Unit	X-ray device equipped with a stereotactic apparatus to determine the precise location of tumors. Used for preventive screenings and early diagnosis of breast cancer.
	X-ray with Fluoroscopya	X-ray device with an imaging system for internal organs, allowing dynamic examination of their function.
	Computed Tomography Scanner	X-ray device providing video visualization and computerized reconstruction of images obtained through successive radiological slices (tomography).
	Magnetic Resonance Imaging (MRI)	Device used to perform imaging diagnostic tests obtained through magnetic resonance.
	Color Doppler Ultrasound	Device used to visualize and evaluate blood flow in veins and arteries.
	Ultrasound Scanner	Device used to generate images of organs and regions of the human body.
	Conventional Ultrasound	Device using high-frequency sound waves to detect abnormalities in internal organs.
	Film Processor Exclusively for Mammography	Supports the simple command mammography unit.
	Computerized Mammography Unit	Similar to conventional mammography units. Produces digitized images with computer assistance.
	PET/CT Scanner	Device used to produce images of organs after injecting a chemical compound. The reaction is tracked and reconstructed via computer.
	Respiratory Tract Endoscope	Device used to visualize the respiratory tract.
Optical Method Equipment (OPT)	Urinary Tract Endoscope	Device used to visualize the urinary tract.
	Digestive Endoscope	Device used to visualize the digestive system. It can be divided into the upper digestive system (stomach, esophagus, duodenum) and the lower digestive system (rectum, intestines).
	Laparoscope/Video	Device used to visualize internal cavities of the human body through artificial openings (incisions).

Source: Adapted from DATASUS and *Encyclopedia Britannica*

EXPLORATORY SPATIAL DATA ANALYSIS (ESDA)

This study is a descriptive and exploratory research. According to Bivand (2010), Exploratory Spatial Data Analysis (ESDA) focuses on exploring data in relation to their spatial association. It is important to consider that this analysis is more suitable for investigating spatially dense or intensive variables—variables divided by some intensity indicator (Almeida, 2012). Total equipment, imaging diagnostic equipment, and optical method equipment per thousand inhabitants (EQP_HAB; IMG_HAB; OPT_HAB) were analyzed.

Anselin (1999) defines ESDA as a set of techniques for describing and visualizing spatial distributions, identifying outlier locations (spatial outliers), uncovering patterns of spatial association, and other forms of spatial or non-spatial instability. The core concept of ESDA is spatial autocorrelation, which refers to the phenomenon where local similarity (observations in spatial proximity) is compared to value similarity (correlation).

The first step in an ESDA study is testing the hypothesis that spatial data are randomly distributed. Intuitively, spatial randomness means that the values of an attribute in one region do not depend on the values of that attribute in neighboring regions (Almeida, 2012).

The index used in this study was Moran's I, which calculates the correlation of a variable in a given space with the value of the same variable in neighboring areas. In this study, the index was used to analyze whether there is a tendency for clustering of cancer diagnostic equipment in space.

According to Almeida (2012), Moran's I provides three types of information:

- The significance level reinforces the information about whether the data are randomly distributed or not;
- A positive sign of Moran's I statistic, provided it is significant, indicates that the data are clustered across regions. Conversely, a negative sign indicates data dispersion.
- The magnitude of the statistic provides the strength of spatial autocorrelation: the closer it is to 1, the stronger the autocorrelation; the closer it is to -1, the more dispersed the data.

Moran's I is the most commonly used specification test for spatial autocorrelation (Anselin, 2001). According to Almeida (2012), it is a coefficient that uses the measure of autocovariance in a cross-product form. Algebraically, this statistic is expressed as:

$$I = \frac{n}{S_0}\frac{\sum_i \quad \sum_j \quad w_{ij}z_iz_j}{\sum_{i=1}^{n} \quad z_i^2} \tag{1}$$

Or in its matrix form:

$$I = \frac{n}{S_0}\frac{z'Wz}{z'z} \tag{2}$$

Where *n* is the number of regions, *z* denotes the standardized values of the variable of interest, and *Wz* represents the average values of the standardized variable of interest for neighboring regions, defined according to a spatial weighting matrix *W*. An element of this matrix, referring to region *i* and region *j*, is recorded as *wij*. *S0* equals the operation *wij*, meaning that all elements of the spatial weights matrix *W* must be summed.

The expected value of Moran's I is *I*=−[1/(*n*−1)]. Values greater than this expected value indicate positive spatial autocorrelation (spillover effect), while values lower than this indicate negative spatial autocorrelation.

According to Anselin (1999), combined with the Local Indicator of Spatial Association (LISA), the Moran's I test provides a basis for interpreting clusters (spatial association) or spatial outliers (atypical locations). However, as noted by Almeida (2012), indications of global spatial autocorrelation patterns may align with local patterns, though this is not necessarily the case, as global patterns can obscure or hide local patterns.

Thus, Anselin (1995) defines the LISA indicator as any statistic that meets two criteria: for each observation, it identifies spatial clusters with statistically significant values around the given observation; the sum of LISA indicators for all observations is proportional to the global spatial autocorrelation indicator used.

The local Moran's *Ii* coefficient is not necessarily an index but rather a map with clusters. It allows for the analysis of the spatial association pattern of variables and potential cluster groupings. According to Almeida (2012), the LISA or local Moran's *Ii* coefficient for a standardized variable *y*, observed in region *i*, *zi*, can be expressed as:

$$I_i = z_i \sum_{j=1}^{J} w_{ij} z_j \quad (3)$$

Where the computation of *Ii* only includes the neighbors of observation *i*, defined according to the spatial weights matrix. The local Moran's *Ii* coefficient decomposes the global autocorrelation indicator into the local contribution of each observation across four categories: High-High (HH), Low-Low (LL), High-Low (HL), and Low-High (LH) (Almeida, 2012).

Spatial Weights Matrices and their degree of dependency are key characteristics of spatial data, manifesting across various fields of study such as the environment, criminology, economics, and health, as in this study. However, a fundamental aspect in determining spatial autocorrelation is the consideration of the degree of neighborhood for which spatial dependency analysis is conducted. Once a neighborhood criterion is established, a spatial weights matrix can be constructed (Marconato, 2015).

Spatial weights matrices are based on contiguity, which can be defined by proximity, either geographic or socioeconomic, or a combination of both. Many results in spatial econometrics are sensitive to the choice of the spatial weights matrix (Marconato, 2015).

In this study, the Queen contiguity matrix was used, where all regions that share a direct border are considered neighbors. Its Moran's I values were higher compared to the Rook contiguity matrix.

RESULTS AND DISCUSSION

This section presents the results of the spatial distribution of cancer diagnostic equipment across Brazilian microregions in 2019. The variables were analyzed in their entirety and within two categories: imaging diagnostic equipment and optical method equipment.

Table 2 shows the absolute number of equipment by Brazilian macroregion within its two groupings. It is evident that there is more imaging diagnostic equipment than optical method equipment, yet the proportions are approximately the same across macroregions: optical method equipment represents between 26% and 33% of the total cancer diagnostic equipment.

The data in Table 2 indicate an unequal spatial distribution of cancer diagnostic equipment among Brazilian macroregions in 2019. Nearly half (48.18%) of all equipment is located in the Southeast region, while the North and Central-West regions together account for only 13.7% of the total.

Table 2 | Quantity of Equipment by Brazilian Macroregion in 2019

Macroregion	Imaging Diagnostic Equipment	Number of Optical Method Equipment	Total	Total per Thousand Inhabitants
North	3.686	1.302	4.988	0.271
Northeast	13.546	5.104	18.650	0.327
Southeast	29.739	13.669	43.408	0.491
South	10.554	5.138	15.692	0.523
Central-West	5.315	2.046	7.361	0.452
Total	62.840	27.259	90.099	0.429

Source: CNES/DATASUS (2019).

Table 3 presents the absolute quantity of each type of equipment by macroregion in Brazil.

From Table 3, it is evident that the types of equipment with the highest availability are color Doppler ultrasound and conventional ultrasound, while the types of equipment with the lowest availability across all regions are PET/CT scanners and gamma cameras.

Table 3 | Quantity of Equipment by Brazilian Macroregion in 2019, Disaggregated by Equipment Type

Equipment Type	Macroregion				
	North	Northeast	Southeast	South	Central-West
Gamma Camera	59	141	379	124	74
Simple Command Mammograph	238	897	2077	650	317
Stereotactic Mammograph	56	225	404	159	87
X-ray with Fluoroscopy	55	209	1192	310	94
Computed Tomography	296	929	2464	910	566
Magnetic Resonance Imaging	158	484	1377	494	264
Color Doppler Ultrasound	855	3360	8316	2882	1460
Ultrasound Scanner	550	2325	4156	2160	935
Conventional Ultrasound	1145	4041	7692	2213	1198
Film Processor for Mammography	199	704	1208	491	204
Computerized Mammograph	71	216	436	145	105
PET/CT Scanner	4	15	38	16	11
Respiratory Endoscope	245	858	2573	1052	373
Urinary Endoscope	101	464	1419	529	206
Digestive Endoscope	733	2811	7161	2489	1083
Laparoscope/Video	223	971	2516	1068	384

Source: CNES/DATASUS (2019).

The data presented in Table 3 reinforce the unequal distribution of equipment already observed in Table 2, where the highest availability of all types of equipment is concentrated in the Southeast region of the country.

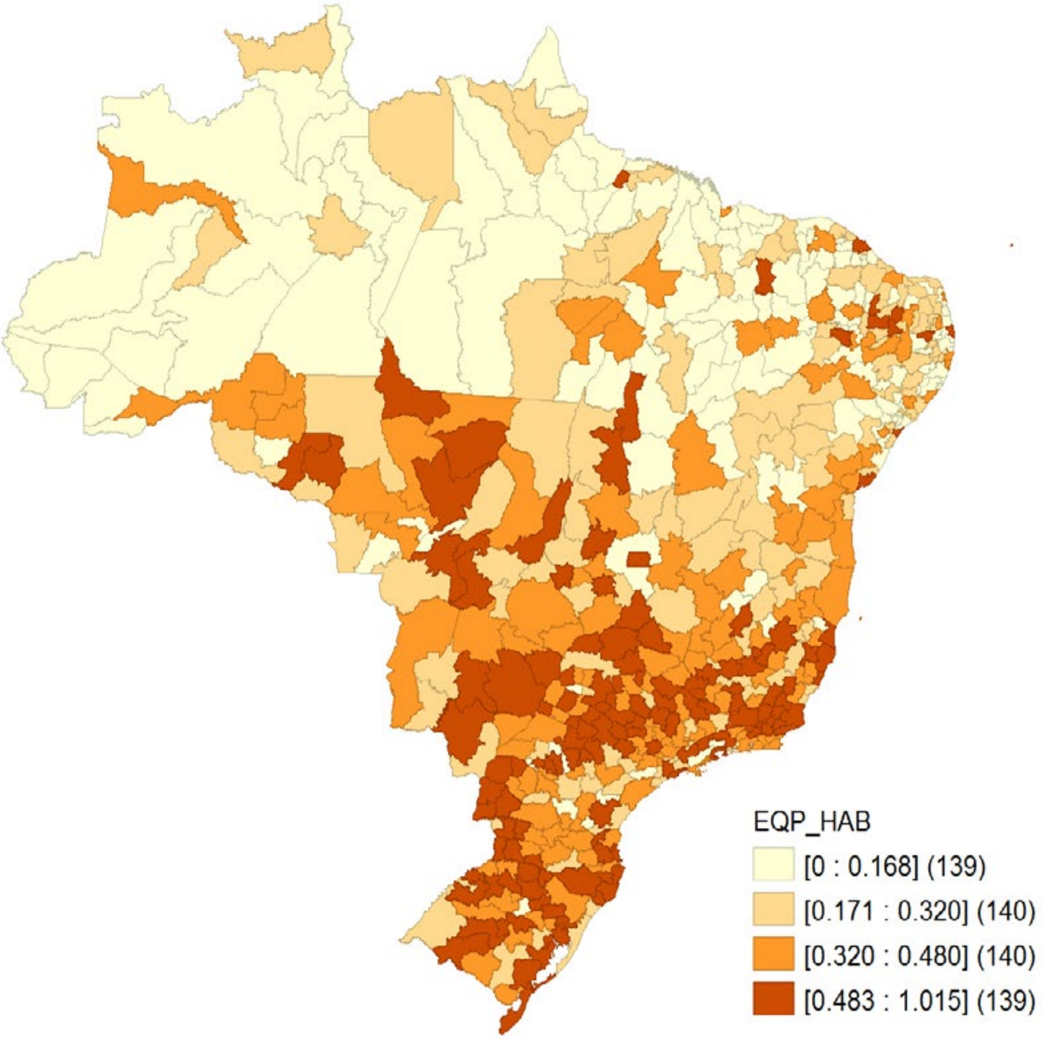
Figure 1 shows the distribution of diagnostic equipment per thousand inhabitants, divided into quartiles. It is evident that the two highest quartiles are predominantly concentrated in the Southeast and South regions. In other words, the microregions with the highest numbers of equipment per thousand inhabitants are mostly located in these two regions.

The quartile with the lowest values is predominant in the Northern region of Brazil. Complementing Table 2, it can be concluded that this region has not only the lowest number of equipment in absolute terms but also the lowest proportion of equipment per thousand inhabitants.

The Central-West region has a relatively low quantity of equipment, as observed in Table 2. However, when considering the proportion per thousand inhabitants (Figure 1), it becomes apparent that more microregions fall into the two highest quartiles (with the largest numbers of equipment per thousand inhabitants) than into the two lowest quartiles (with the smallest numbers). In other words, despite having a low absolute number of diagnostic equipment, the Central-West region does not stand out for a lack of infrastructure for cancer detection when analyzed proportionally.

This scenario is the opposite of that in the Northeast region, which is the second region with the highest number of equipment in absolute terms. However, when considering the proportion per thousand inhabitants, most of its microregions fall into the lowest quartiles.

Figure 1 | Quantile Distribution of Diagnostic Equipment per Thousand Inhabitants in Brazil in 2019



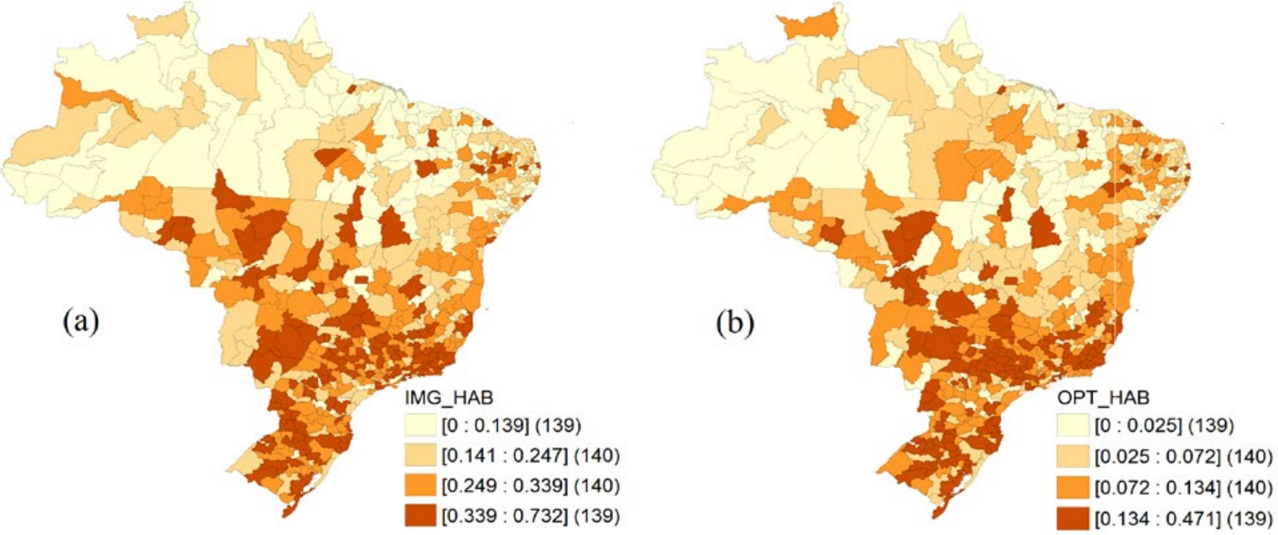
Source: Prepared by the author.

Figure 2 presents quantile maps of the distribution of diagnostic imaging equipment (a) and optical method equipment (b) per thousand inhabitants.

It is noticeable that, in addition to being similar to Figure 1, the distributions of both types of equipment are also similar to each other, suggesting the presence (or absence) of both medical instruments in the same microregion.

This result aligns with the pattern reported by Scheffer et al. (2018), who analyzed the unequal distribution of physicians and oncology specialists across Brazil. As shown in the figure below, Scheffer et al. (2018) indicated that the Northeast and North regions of Brazil are the most underserved in terms of the availability of clinical oncologists. In other words, the location of oncologists may be associated with the distribution of cancer diagnostic equipment.

Figure 2 | Quantile Distribution of Diagnostic Imaging Equipment and Optical Method Equipment per Thousand Inhabitants in Brazil in 2019



Source: Own elaboration.

Table 4 presents the results of the univariate Moran's I for cancer diagnostic equipment per thousand inhabitants in Brazilian microregions for the year 2019.

The Queen and Rook contiguity matrices were used to test the null hypothesis of spatial randomness. All results were statistically significant; however, the results indicate that the Queen matrix yielded the highest Moran's I value. In this case, it can be concluded that this configuration is more suitable for capturing the spatial autocorrelation of the variable "cancer diagnostic equipment" in Brazilian microregions for the year 2019. Therefore, all subsequent analyses were conducted using the Queen contiguity matrix.

Table 4 | Moran's I Index of Spatial Autocorrelation for Cancer Diagnostic Equipment Variables per Thousand Inhabitants in Brazilian Microregions – 2019

Variables	Moran's I (p-value)	
	Queen Matrix	Rook Matrix
EQP_HAB	0.371 (0.001)	0.370 (0.001)
IMG_HAB	0.357 (0.001)	0.354 (0.001)
OPT_HAB	0.309 (0.001)	0.302 (0.001)

Source: Own elaboration.

The results of Moran's I indicate a similarity in the studied variables, i.e., they reveal positive spatial autocorrelation. The high positive spatial correlation suggests a spatial concentration of cancer diagnostic equipment (both imaging and optical methods) in Brazilian microregions, as well as clusters of microregions lacking these diagnostic devices. Microregions with a high quantity of equipment tend to be located near each other, just as microregions with low quantities are spatially grouped.

This aligns with the regional asymmetries highlighted by Viacava et al. (2019) in their study on mammography machines, a device used for breast cancer diagnosis. The authors stated that, despite having a sufficient number to meet the needs of the Brazilian population, the uneven distribution of the devices hinders or prevents access for many individuals, leading to regional inequalities. Similarly, some regions concentrate a large share of mammography machines in Brazil, while others are affected by a low supply of this medical device, resembling the scenario observed here for cancer diagnostic equipment in general.

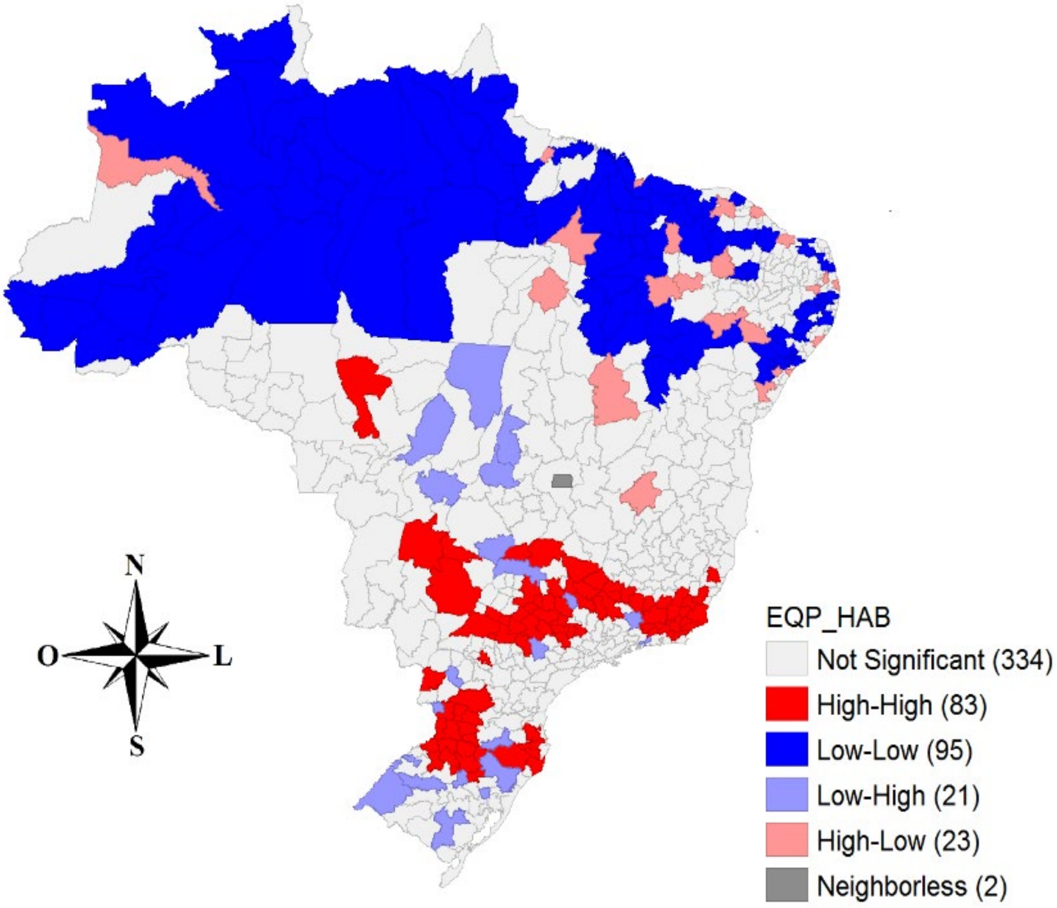
Regarding local Moran's I, the spatial distribution of cancer diagnostic equipment per thousand inhabitants is presented in Figure 3. The disparity in the distribution of High-High and Low-Low clusters on the map suggests an uneven distribution of equipment across the national territory, with the North and Northeast regions characterized by low availability, while the South and Southeast regions stand out for their abundance of devices.

This reflects health access inequalities, as noted by Travassos, Oliveira, and Viacava (2006), which result from the socioeconomic development of certain regions. Residents of the South and Southeast of Brazil have greater access to healthcare infrastructure compared to those in other regions. In Figure 3, it is clear that cancer diagnostic equipment is predominantly located in the South and Southeast regions, with High-High clusters concentrated primarily in São Paulo, Rio de Janeiro, and Minas Gerais.

All Low-Low clusters are located in the North and Northeast regions. This means that the microregions represented by dark blue on the map have a low number of cancer diagnostic devices per thousand inhabitants and are also surrounded by other microregions with similarly low quantities of these devices.

This finding supports the study by INCA (Brazil, 2002) on the scarcity of high-complexity oncology hospitals in the North and Northeast regions of Brazil (at the time, only 4% and 19% of CACONs in Brazil were located there, respectively). In other words, the distribution of cancer diagnostic equipment is closely related to the location of high-complexity oncology centers.

Figure 3 | Spatial Distribution of Cancer Diagnostic Equipment per Thousand Inhabitants in Brazil – 2019



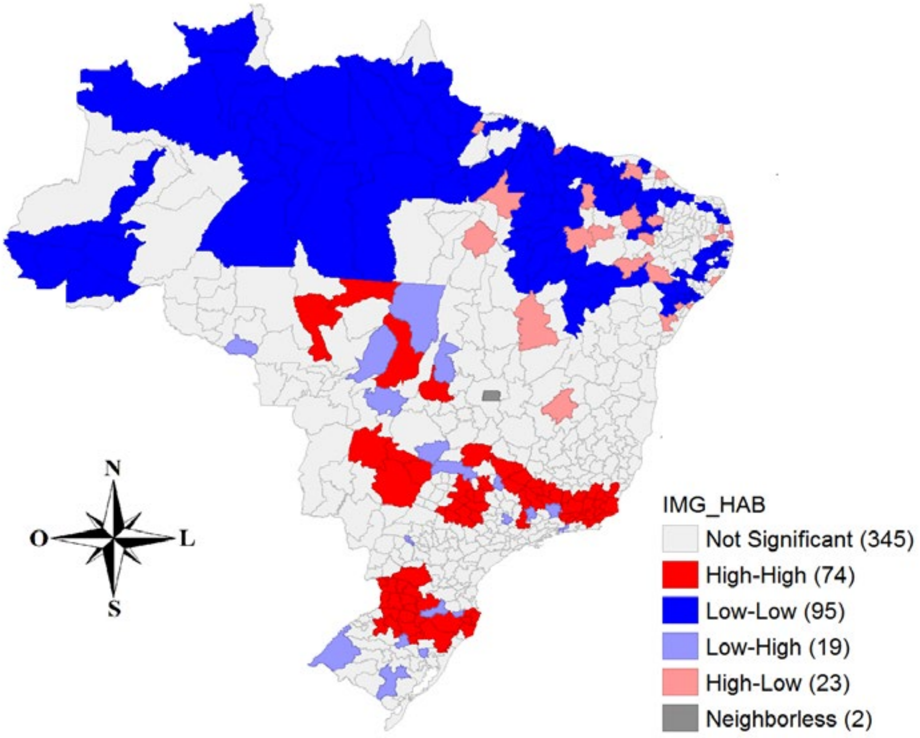
Source: Own elaboration.

These findings align with the health indicators presented by Miranda et al. (2023), who identified the Northern region of Brazil as the most vulnerable and, therefore, a priority for resource allocation. This is particularly important for improving healthcare infrastructure to support the development of this region.

In Figure 4, which illustrates the spatial distribution of imaging diagnostic equipment per thousand inhabitants, a strong similarity with Figure 3 is evident. High-High clusters are predominantly present in the South and Southeast regions, while the North and Northeast regions are mainly characterized by Low-Low clusters.

This disparity in the spatial distribution of cancer diagnostic equipment per thousand inhabitants is consistent with the data presented by Souza (2004) on high-complexity hospital services. The Northern region of Brazil stood out as having the lowest number of hospital services and certified units for cancer treatment. According to Souza (2004), in 2002, the North accounted for only 2.23% of the total high-complexity hospital services in Brazil.

Figure 4 | Spatial Distribution of Imaging Diagnostic Equipment per Thousand Inhabitants – Brazil – 2019



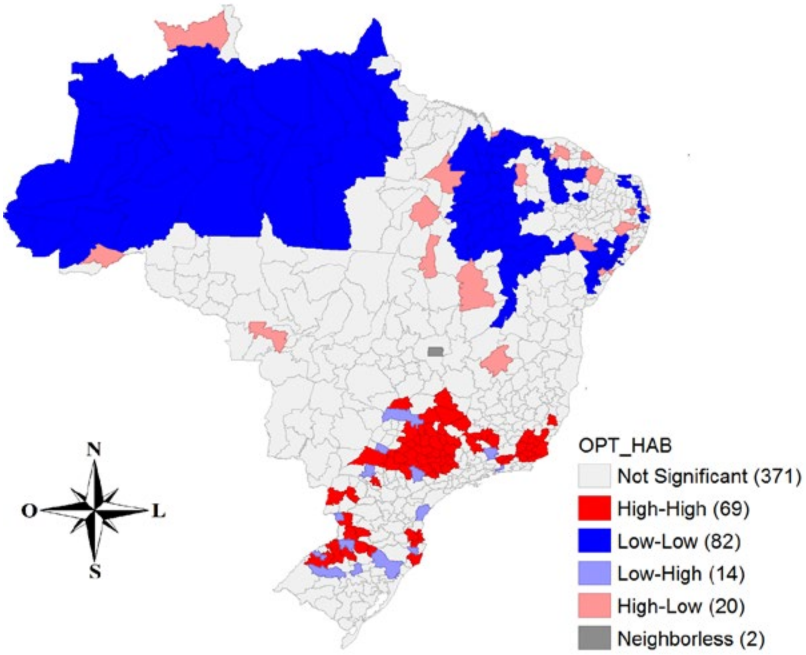
Source: Own elaboration.

The results presented in Figure 4 support the findings of Stopa et al. (2017), who stated that the highest proportions of medical consultations in 2013 occurred in the South and Southeast regions of Brazil. These regions have better living conditions, higher Human Development Index (HDI) scores, and populations with higher levels of education compared to areas with lower levels. These factors likely explain the high concentration of Low-Low clusters in the North and Northeast regions, which have lower HDI scores and educational attainment levels.

Figure 5 shows the distribution of cancer diagnostic equipment using optical methods per thousand inhabitants in Brazilian microregions. As in the previous figures, Low-Low clusters are exclusively located in the North and Northeast regions, now spanning the entire state of Amazonas.

High-High clusters in the figure below are concentrated in the South and Southeast regions, primarily in São Paulo. These two regions not only stand out for their high concentration of diagnostic equipment per thousand inhabitants but also perform the majority of cancer treatments (especially in the capitals Rio de Janeiro and São Paulo), as observed by Oliveira et al. (2011). This analysis suggests that medical devices for cancer detection are spatially correlated with the locations providing treatment for the disease.

Figure 5 | Spatial Distribution of Optical Method Diagnostic Equipment per Thousand Inhabitants – Brazil – 2019



Source: Own elaboration.

The location of Low-Low clusters validates the findings of Medici and Beltrão (2015), who discussed the irregular coverage of healthcare services in certain Brazilian regions, such as the Northeast. The authors argued that, in recent years, the low cancer mortality rate in these areas has been linked to poor access to healthcare and limitations caused by the quality of death records. In other words, the lack of diagnosis or prior medical evaluation can lead to morbidity and mortality without awareness of the underlying disease. Thus, the shortage of cancer diagnostic equipment in neighboring microregions (Figures 3, 4, and 5) restricts opportunities for disease detection, potentially resulting in underreporting of cases and creating a false impression of low cancer incidence and mortality in certain regions.

Examining Figures 3, 4, and 5, it becomes clear that the inequality in the spatial distribution of cancer diagnostic equipment per thousand inhabitants aligns with the uneven distribution of physicians across Brazilian municipalities. This is consistent with the findings of Pinto (2015) and the disparities in equipment distribution noted by Silva et al. (2024) and Dias et al. (2024).

Pinto (2015) also analyzed other factors, such as population density, per capita income, hospitals, and hospital beds. These elements are correlated with the distribution of physicians and, consequently, the location of cancer diagnostic equipment. This suggests that the Northern region has a low population density and, among its residents, limited financial resources, which further hinders access to healthcare.

These results align with the pattern presented by Scheffer et al. (2018), who studied the unequal distribution of physicians and oncology specialists across Brazil. As shown in the following figure, Scheffer et al. (2018) stated that the Northeast and North regions are the most underserved in terms of clinical oncologists. In other words, the location of oncology specialists may be associated with the distribution of cancer diagnostic equipment.

In the last three analyzed figures, some High-Low clusters are also observed, primarily in the North and Northeast. These indicate a high number of cancer diagnostic devices in a microregion surrounded by others with low numbers of such equipment. Consequently, the few structures present in the North are likely very distant and difficult to access for residents. Additionally, the

North is the largest Brazilian region in terms of territorial size. Therefore, residents must often travel long distances to access healthcare services and obtain a cancer diagnosis, as noted by Grabois, Oliveira, and Carvalho (2013) regarding cancer patients in this region.

Residents of areas with many Low-Low clusters face significant challenges in finding cancer diagnostic facilities. Even when disease detection is possible, the distance between their residence and the nearest hospital structure can influence cancer staging, as pointed out by Huang et al. (2003). Greater distances are associated with more advanced diagnoses, whereas early-stage diagnoses occur closer to the nearest hospital. In other words, the distance to the nearest hospital may delay seeking healthcare services, which, in turn, can impact a patient's survival chances (Brasil, 2006).

The findings support the perspective of Gadelha et al. (2011), who argued that the lack of a strategic outlook and regional planning for healthcare infrastructure remains a barrier to overcoming regional inequalities in the healthcare sector.

FINAL CONSIDERATIONS

This study aimed to map the availability of cancer detection equipment and identify potential underserved areas, as well as to analyze spatial association patterns in the distribution of cancer diagnostic equipment in Brazilian microregions for the year 2019.

The findings reveal significant regional inequalities in the availability of cancer diagnostic equipment across the country. The North and Northeast regions stood out as areas of scarcity, with a high number of Low-Low clusters. In addition to the low availability of equipment per thousand inhabitants in the North, this region also faces accessibility challenges due to Brazil's vast territorial extension. Residents in the North often need to travel long distances to access cancer diagnostic facilities. These distances can delay medical consultations, leading to late-stage detection, complicating treatment, and reducing chances of survival or cure.

Identifying these underserved areas is crucial for the development of public health policies aimed at reducing regional disparities in access to diagnostic infrastructure. Targeted investments should focus on regions with the least availability of diagnostic equipment.

The North also experiences underreporting of cancer incidence and mortality, creating a misleading impression that the disease affects fewer people in the region. However, as shown in this study, the North has insufficient diagnostic equipment, both in absolute numbers and proportionally per thousand inhabitants. Meanwhile, the equipment in regions such as the South and Southeast may not be utilized to their full capacity.

Therefore, public policies to improve the spatial distribution of diagnostic equipment should be implemented based on the specific needs of each Brazilian region. These policies should aim to address the diagnostic equipment shortages identified in this study, enabling quicker and more accurate cancer diagnoses, reducing underreporting, and lowering mortality rates.

It is important to note that this study analyzed only the availability of cancer diagnostic equipment in Brazilian microregions without assessing whether the equipment was operational. Furthermore, cancer diagnosis and treatment extend beyond the availability of equipment, although this is a significant factor.

For future studies, it is recommended to explore the lack of cancer care centers in the North and Northeast regions in greater depth. These studies could focus on identifying the specific needs for diagnostic equipment and high-complexity infrastructure investments in these regions. Additionally, they could analyze the relationship between the underestimation of cancer incidence and mortality and the availability of infrastructure to record these cases.

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