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Towards Defining the Global Surgical Workforce for Children: A Geospatial Analysis in Brazil

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ABSTRACT

Objectives: The optimal size of the health workforce for children's surgical care around the world remains poorly defined. The goal of this study was to characterize the surgical workforce for children across Brazil, and to identify associations between the surgical workforce and measures of childhood health.

Design: This study is an ecological, cross-sectional analysis using data from the Brazil public health system (*Sistema Único de Saúde)*.

Settings and Participants: We collected data on the surgical workforce (pediatric surgeons, general surgeons, anesthesiologists, and nursing staff), perioperative mortality rate (POMR), and under-5 mortality rate (U5MR) across Brazil for 2015.

Primary and Secondary Outcome Measures: We performed descriptive analyses, and identified associations between the workforce and U5MR using geospatial analysis (Getis-Ord-Gi analysis, spatial cluster analysis, and quadratic regression models).

Findings: There were 39,926 general surgeons, 856 pediatric surgeons, 13,243 anesthesiologists, and 103,793 nurses across Brazil in 2015. The U5MR ranged from 11-26 deaths/1,000 live births and the POMR ranged from 0·11-0·17 deaths/100,000 children across the country. The surgical workforce is inequitably distributed across the country, with the wealthier South and Southeast regions having a higher workforce density as well as lower U5MR than the poorer North and Northeast regions. Using quadratic regression, we found an inverse relationship between the surgical workforce density and U5MR. An U5MR of 15 deaths/1,000 births across Brazil is associated with a workforce level of 5 pediatric surgeons, 200 surgeons, 100 anesthesiologists, or 700 nurses/100,000 children.

Conclusions: We found wide disparities in the surgical workforce and childhood mortality across Brazil, with both directly related to socioeconomic status. Areas of increased surgical workforce are associated with lower U5MR. Strategic investment in the surgical workforce may be required to attain optimal health outcomes for children in Brazil, particularly in rural regions.

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ARTICLE SUMMARY

STRENGTHS AND LIMITATIONS OF THIS STUDY

Strengths

- Use of geospatial analysis allows precise definition of associations between the surgical workforce and under-5 mortality rate (U5MR) across Brazil.
- Analysis can demonstrate an inverse relationship between the surgical workforce and U5MR, allowing for location of areas of increased workforce which are associated with lower U5MR levels.
- Geospatial tools can confirm disparities in the surgical workforce as well as U5MR across Brazil, and support modeling to define relationship between the surgical workforce and U5MR.

Limitations

- Analysis of a one-year dataset does not allow for examination of the dynamics of workforce migration or growth.
- Although our findings of an association between surgical workforce and U5MR does not demonstrate causation.

INTRODUCTION

Health care is workforce intensive, and an adequate level of human resources is essential to maintain strong health systems. Discrepancies between local health needs and the health workforce leads to clinical errors, wastage of resources, and increased patient mortality and morbidity.[1] For surgical care, the workforce is grossly inadequate and inequitably distributed in many low- and middle-income countries (LMICs), with rural areas disproportionately affected.[2,3]

Studies from the Lancet Commission on Global Surgery (LCoGS) have proposed a density of 20-40 specialist physicians (surgeons, anesthesiologists, or obstetricians, SAO) per 100,000 general population to attain desired health outcomes, such as perioperative mortality rate.[2-4] However, the surgical care for children is fundamentally different from adult care, with surgical resources provided through multiple tiers in a national health system in proportion to population needs and surgical complexity required.[5] In these complex health systems, the optimal surgical workforce for children remains poorly defined.

Brazil offers a rich environment to closely examine the health workforce, as it has extremely heterogeneous geography, health infrastructure, and socioeconomic status across the country (GINI index 53·3 in 2017).[6,7] Brazil has a large public health system (*Sistema Único de Saúde, SUS)* and maintains several publicly available datasets (DATASUS).[6,8] Efforts to reduce health disparities across the five Brazil regions (North, Northeast, Midwest, Southeast, and South) have made great strides in recent years, particularly though workforce expansion in primary care.[9]

Previous geospatial analysis by ourselves and others have identified wide disparities in surgical care across Brazil.[10,11] Facilities providing surgical care for children are inequitably distributed across the country, with higher density of infrastructure and surgical access associated with areas of higher socioeconomic status.[10] Spatial cluster analysis demonstrated a higher under-5 mortality rate (U5MR) in the poorer North, Northeast, and Midwest regions compared to the wealthier Southeast and South regions, although perioperative mortality rate (POMR) for a proxy set of children's conditions does not vary across the country.[10] Increased access to surgical care is associated with a lower U5MR, and access to surgical care differs by geographic region independent of socioeconomic status.

The goals of this study are to characterize the surgical workforce for children in the public health system in Brazil using geospatial analysis and to identify associations between the surgical workforce and childhood mortality rates. Through this analysis, we hope to provide an assessment of Brazil's surgical workforce, identify disparities in workforce distribution, and estimate the required surgical workforce to obtain desired health outcomes for children.

Methods

This study is an ecological, cross-sectional, geospatial analysis using data from the Brazil public health system. Brazil is composed of 5,570 municipalities across the union of the Federal District and 26 states, which are distributed across five regions (Midwest, North, Northeast, South, and Southeast). We collected data on all children < 15 years of age undergoing a surgical procedure from 2010 to 2015 across Brazil using datasets from DATASUS (see Table 1 for all datasets and study timeframes). Auxiliary data were collected from databases from the World Bank and the Brazilian Institute of Geography and Statistic (IBGE).[8] We used several tools of geospatial analysis to explore relationships between surgical workforce, POMR, and U5MR. All health estimates were summarized in line with the GATHER statement.[12]

We extracted demographic and socioeconomic indicators from Brazilian Institute of Geography and Statistics (IBGE).[13] We used this data along with the Brazilian gross domestic product (GDP) to classify municipalities according to income groups as high income, upper-middle income, or lower-middle income as defined by the 2017 World Bank criteria of gross national income (GNI) per capita adjusted to US dollars (low income: GNI per capita $1,005 or less; lower middle-income: GNI per capita between $1,006 and $3,955; upper middle-income: GNI per capita between $3,956 and $12,235; high-income > $12,235) (Fig 1).[14]

Surgical workforce density

We summarized data on the surgical workforce at the municipality, state, and regional levels. We summarized several workforce roles, including general surgeons, pediatric surgeons, anesthesiologists, obstetricians, and nurses, using professional role definitions from the CNES. The CNES keeps a record of the appointment of all health providers at public health facilities. The density of each profession was weighted per 100,000 children. For comparison to common surgical workforce metrics used in the Lancet Commission on Global Surgery,[2-4] we also summarized the density of surgeons, anesthesiologists, and obstetricians (SAO).

Under-5 child mortality rate (U5MR) and perioperative mortality rate (POMR)

We summarized annual all-cause under-5 pediatric mortality rates (U5MR) at the regional and municipality level using data from the Brazilian Mortality Information System database (SIM), which collects data on all deaths by age, sex, cause, and residence.[8] The U5MR was calculated using methods of the Inter Agency Group for Mortality Estimation (IGME), and was expressed as deaths per 1,000 live births.[15]

We collected procedure-based perioperative mortality rate (POMR) from the DATASUS Hospitalization Information System database (SIH) using the procedure codes for a proxy set of general surgical procedures. This set was based on the Optimal Resources for Children's Surgery (OReCS) document of the Global Initiative for Children's Surgery, which specifies representative surgical procedures to assess the delivery of surgical care within a national health system.[5] These five procedures included appendectomy, colostomy, hernia repair, laparotomy, and abdominal wall reconstruction for gastroschisis, omphalocele, or other indication. The SIH defines perioperative mortality as any death occurring during any surgical procedure. We summarized procedure-specific POMR at the regional level across the country.

Note that due to differences in the patterns of POMR and U5MR across the country,[10] we limited analysis of the surgical workforce to use of U5MR as the outcome metric. We chose not to use POMR, as the SIH dataset only records deaths occurring during operative procedures and thus likely underestimates the true POMR, which is generally accepted as within 30 days of surgery.[16] In light of this data quality limitation, we used U5MR for subsequent analysis of associations between the surgical workforce and measures of childhood health.

Data analysis

All analyses were performed using the municipality as the main observation unit. We summarized descriptive outcomes at the municipality, state, and regional levels. The density of the surgical workforce and U5MR were displayed using geospatial chloropleth maps.

To further identify potential associations between the surgical workforce and U5MR, we performed Getis-Ord Gi analysis.[17] This measure of spatial heterogeneity uses autocorrelation and hot spot techniques to assess associations within spatial random variables. For our study, we identified hot spots (red areas) depicting clusters of municipalities with adjacent municipalities with high values for a given indicator (workforce density or U5MR), and cold spots (blue areas) depicting areas of adjacent clusters with low values for each indicator. Yellow areas mark locations where no clustering was observed. Geographic mapping was used to identify the distribution of each indicator within a spatial area.[17]

To summarize geographic relationships between the surgical workforce density and U5MR, we plotted data using scatter plot graphs and created a series of quadratic regression models to define associations between the workforce density and U5MR, considering the U5MR at the state level as the primary outcome. We also used cubic spline plots to analyze these data, although quadratic regression models showed higher goodness of fit and were used for further analysis. The line resulting from each regression model was plotted using bivariate scatterplots. Each point in the graphic was proportional to the average U5MR (per 1,000 live births), with display by state as well as by region level.

Patient and public involvement

As an ecological study, there was no direct patient involvement with this research. However, there is public interest in addressing challenges with the surgical care of children in Brazil. We used anonymized publically available datasets to address these research questions. All research findings will be disseminated to the public and health community in Brazil through publication, academic meetings, and social media.

Data sharing statement

All data used for this analysis were obtained from the open access DATASUS system, from the Brazilian Ministry of Health. Data can be obtained, freely, from: http://tabnet.datasus.gov.br/.

RESULTS

We found that there were 39,926 general surgeons, 856 pediatric surgeons, 13,243 anesthesiologists, 103,793 nurses, and 9,674 obstetricians across Brazil in 2015. During the same year, there were 43,045 reported deaths in children under five years of age in Brazil, with the U5MR ranging between 11-26 deaths/1,000 live births across states. The POMR for the proxy set of surgical procedures ranged from 0·11-0·17 deaths/100,000 children across regions.

Disparities in the surgical workforce and U5MR across Brazil

The surgical workforce for children in Brazil is unequally distributed across the country, with the South and Southeast regions having a higher density of all professional roles, while the North and Northeast regions have a lower density of each role (Fig 2). We found disparities in U5MR across the country, with wide variations across states and regions. The South and Southeast regions had the lowest U5MR and had the highest socioeconomic status. In contrast, the North and Northeast regions had higher U5MR as well as lower areas of socioeconomic status (Fig 3).

At a municipality level, we found wide disparities in the workforce density as well as U5MR across Brazil, with inequities even within states (Fig 4). Several municipalities did not have even one general surgeon, pediatric surgeon, obstetrician, or anesthesiologist. Even within the wealthier North and Northeast regions, there are inequities in workforce distribution, with the workforce preferentially localized in areas around the state capitals. This distribution was similar to the U5MR at the municipality level.

We found a direct association between the surgical workforce and U5MR across Brazil, with higher density of each professional role associated with lower U5MR across regions (Fig 5). This pattern is consistent across workforce roles (surgeon, anesthesiologist, nursing, etc.), although there are some variations in the distribution patterns across the country. For example, in the South and Southeast, we found the highest density of pediatric surgeons as well as the lowest levels of U5MR, although this pattern was not seen in the Federal District, where there was a high density of all workforce roles as well as higher levels of U5MR compared to surrounding regions. The Federal district is where the Brazilian government is located, and the density of the surgical workforce in this state-city was higher than in all other states.

Relationship between surgical workforce density and U5MR

By use of scatter plots, we developed a set of quadratic regression models to define the association between the density of surgical workforce at the state level and U5MR (Fig 6A-F). We found that although the slope of each curve varied across professional roles, all professional roles had a direct relationship between workforce density and U5MR. Regression analyses supported the trends highlighted in the maps.

Discussion

As surgical care is an essential component of functioning health care systems, there is a need to improve our understanding of the surgical workforce for children. Brazil has wide disparities in socioeconomic status and health care delivery.[18,19] Our previous work has shown disparities in delivery and infrastructure for surgical care for children across Brazil, with areas of higher socioeconomic status associated with increased delivery of surgical care.[10] Our current study demonstrates similar disparities in the surgical workforce across the country, with a higher workforce density related to areas of higher socioeconomic status. As well, increased surgical workforce is associated with areas of lower U5MR, suggesting that an adequate and equitable surgical workforce is essential for support of high-quality health care for children.

Disparities in surgical care for adults have been previously noted in Brazil as well as other countries, although systems to minimize disparities in the surgical care for children remain poorly understood. Reports from the Lancet Commission on Global Surgery have shown an association between the density of surgeons, anesthesiologists, and obstetricians (SAO) and the rate of surgical procedures or perioperative mortality rates.[2-4] Our data aligns with recent analyses of surgical care for adults in Brazil, which showed wide disparities in manpower and surgical care.[11,20] The Brazilian government has long recognized challenges with health care delivery across the country, and have implemented several programs to increase primary care access in rural areas.[6,9,21]

The perioperative mortality rate is often used to gauge the quality of a surgical system,[16] although we suggest that metrics of overall childhood health such as U5MR may offer an alternative, and potentially even more valuable metric to guide manpower planning. First, given the increasing emphasis on surgical care as an integral part of a comprehensive health system, associations between the workforce and overall population health may be the most appropriate measure of manpower across an entire health system, including the surgical workforce.[16] For example, care of neonates or children with cancer often require surgical care, and an adequate surgical workforce is essential to ensure high-quality outcomes for these children. Second, despite interest around the world for collection of perioperative mortality rates, data quality continues to be challenging.[22] Our previous work in Brazil suggests that data quality for POMR is too poor to allow for analysis of the surgical workforce.[10,16] Third, the United Nations and the World Health Organization have identified several indicators to evaluate health interventions in children, including the U5MR, rate of growth stunting, immunization coverage, and prevalence of common childhood diseases.[23] These metrics are routinely collected around the world, and our analysis suggests that strategic expansion of the surgical workforce can be guided by these metrics. Finally, we confirmed an association between the nursing workforce and U5MR, as few analyses have examined the nursing workforce requirements for surgical care.

To assist with policy development, geospatial analysis can identify priority regions of workforce needs. The sequence of steps in our analysis may be generalizable to other countries to guide scale-up of the surgical workforce to desired levels of health outcomes. For example, we found that U5MR of 15 deaths/1,000 births across Brazil is associated with an approximate workforce level of 5 pediatric surgeons, 200 surgeons, 100 anesthesiologists, or 700 nurses/100,000 children. Geospatial analyses has help guide health workforce expansion in Thailand,[24] as well as in some countries in sub-Saharan Africa.[25] However, we caution that the workforce associations in Brazil may not be applicable to other countries. As well, geospatial analysis requires access to high quality national datasets, which remains problematic in many countries around the world.

The areas of Brazil with lower socioeconomic status remain challenging environments for health care, where there is a long history of difficulties with retention of health care professionals.[18,19] Our findings align with studies of adult surgical workforce in Brazil, which have shown inequities in the density of SAO professionals across the country, with rural regions disproportionately affected.[26] Similar to many counties around the world, the rural areas in Brazil have high levels of poverty and a scarcity of health infrastructure.[27,28] Brazil has successfully increased access to the primary care workforce in rural areas through the *Mais Médicos* program,[29] and our findings suggest that similar expansion of the surgical workforce may improve the health of children.

As with any population-based study, our work has several limitations. The analysis of a one-year dataset does not allow for examination of the dynamics of workforce migration or growth. There is a lack of consensus in geospatial analysis about how the density of professionals should be weighted regarding different populations (i.e. overall population, child population, etc.), although we chose to weigh by child population. Although our findings of an association between surgical workforce and U5MR does not demonstrate causation and indeed many factors impact the U5MR, it does suggest that a robust surgical workforce is required for the provision of high-quality care for children. Analysis of the workforce of the Federal District in Brazil is particularly challenging, as the presence of the federal administrative structure might be responsible for the high density of surgeons in this location. Finally, we recognize that the surgical workforce includes many type of subspecialists that were not included in our analysis.

In conclusion, we found that the surgical workforce for children is inadequate and inequitably distributed across Brazil, suggesting that strategic investment in the surgical workforce is required to support high-quality and equitable health care for children. There is a direct relation between the surgical workforce and U5MR across Brazil, with higher levels of the surgical workforce associated with improved U5MR. These findings have several policy implications to improve the health of children in Brazil:

- Increased investment in the surgical workforce is required to support the health of children in Brazil, particularly in rural regions
- Identification of associations between the workforce and measures of population health (such as U5MR) may be a valuable tool to define surgical workforce levels in LMICs
- Definition of workforce indicators is particularly challenging for children's surgical care given the complexity of care across different levels of national health systems
- Geospatial analysis can help define the required surgical workforce to attain desired population health goals, and may be generalizable across other LMICs

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FOOTNOTES

CONTRIBUTORS

TAHR, JRNV, and HER had the initial idea for this analysis. TAHR, JRNV, NCS, and HER performed the initial analysis and wrote the first draft. The analysis and manuscript were completed and revised in collaboration with DP, MGS, and ERS. All co-authors read and approved the final manuscript.

DECLARATION OF INTERESTS

We declare no competing interests.

IRB APPROVAL

Not required.

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FIGURE LEGENDS

Figure 1-Income group distribution of Brazilian municipalities. Socioeconomic data were extracted from Brazilian Institute of Geography and Statistic (IBGE), and used with the Brazilian gross domestic product to classify municipalities according to income groups as defined by the World Bank as high-income, upper-middle-income, or lower-middle-income. The map of Brazil was freely obtained in shapefile format (SHP) through online access to the website of the Brazilian Institute of Geography and Statistics (https://mapas.ibge.gov.br/bases-e-referenciais/bases-cartograficas/malhas-digitais.html). Reprinted from Vissoci et al.[10]

Figure 2-The density (rate) of the surgical workforce for each professional role across Brazil as summarized by region. The density of each professional role is weighted per 100,000 children.

Figure 3-Under 5 mortality rates (U5MR, per 1,000 live births) across Brazil summarized by state as well as by region levels.

Figure 4-Spatial distribution of the surgical workforce density (weighted per 100,000 children) or under-5 mortality rate (U5MR, per 1,000 live births) at the municipality level.

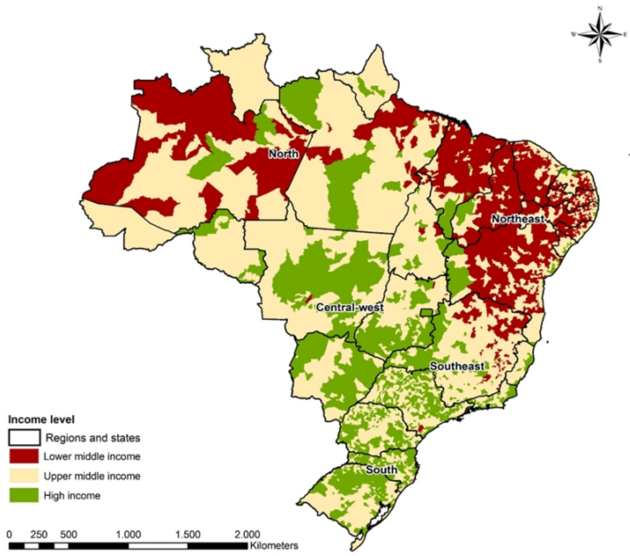
Figure 5-Hot spot cluster analysis of association between the surgical workforce density (weighted per 100,000 children) and under-5 mortality rate (U5MR, per 1,000 live births) across Brazil using Getis-Ord-Gi analysis.[17] Hot spots (red areas) depict clusters of municipalities with adjacent municipalities with high values for a given indicator (workforce density or U5MR), and cold spots (blue areas) depict clusters with an adjacent low values regarding each indicator. Yellow areas mark locations where no clustering was observed.

Figure 6 (A-F)-Association between the density of the surgical workforce (weighted per 100,000 children) and under-5 mortality rate (U5MR, per 1,000 live births) in each state across Brazil. Quadratic regression models were used to define associations between the workforce density and U5MR. The line resulting from each regression model was plotted using bivariate scatterplots. The size of each point in the graphic is proportional to the average U5MR for each state, with different colors used to summarize data by region.

Table 1: Data Sources for Analysis

Source	Variables	Date Range	Data entries	Scope
DATASUS - Hospitalization information system (SIH)	• Hospitalization procedures performed • ICD code • Age of patient • Location of residence • Costs associate to the procedure • Hospital	2008-2015	267,248 procedures	Appendectomy (ICD 10 0DTJ4ZZ, 0DTJ0ZZ) Laparotomy (ICD 10 0WJP0ZZ) Hernia (ICD 10 0YQ54ZZ, 0YQ64ZZ, 0YQ50ZZ, 0YQ60ZZ, 0WQF4ZZ, 0WUF07Z, 0WUF0KZ, 0BQR4ZZ,0BQS4ZZ, 0BQR0ZZ, 0BQS0ZZ) Colostomy (ICD 10 0WQFXZ2) Abdominal wall reconstruction (ICD 10 0WQF0ZZ)
DATASUS - Mortality information system (SIM)	• Deaths of patients under 14 years old • The municipality of residence and of death • Mortality rate by municipality	2010-2015	326,459 deaths	All deaths between 2010 and 2015
CNES - National registration of health establishments	• Geolocation • Type of care provided • Accreditation	2014	6,498 hospitals	District and referral level hospitals
World Bank	• Gross national income (GNI) • Atlas index • GNI per capita • Income level classification	2010-2013	5565 municipalities	-
IBGE - Brazilian institute of geography and statistics	• Pediatric population by municipality • Gross domestic product (GDP) • GDP per capita	2008-2014	5565 municipalities	-

Table 1. Primary datasets used for analysis derived from the Brazilian public health system (*Sistema Único de Saúde, SUS)*, which maintains several publicly available datasets (DATASUS). Auxiliary data collected from the World Bank and the Brazilian Institute of Geography and Statistic (IBGE).



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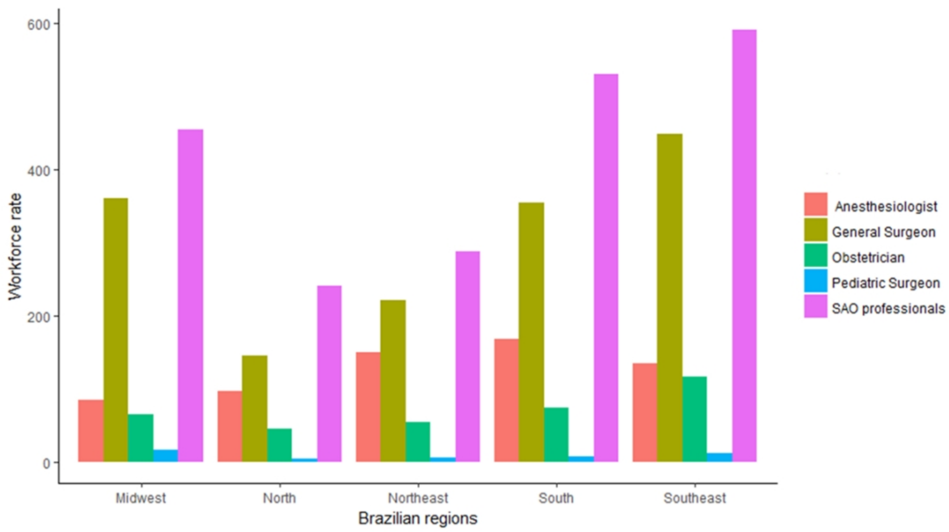

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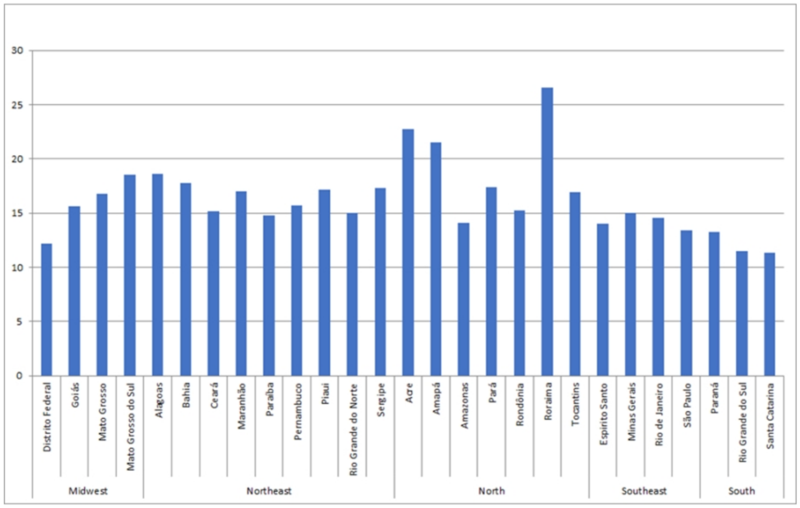

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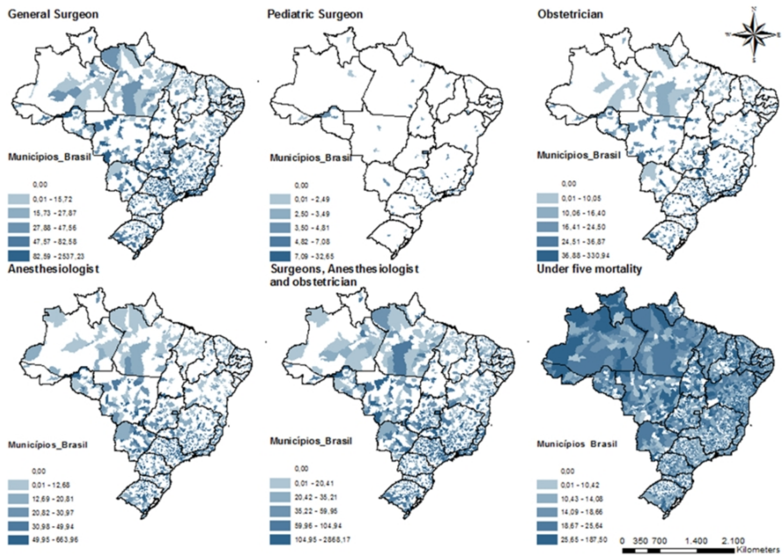

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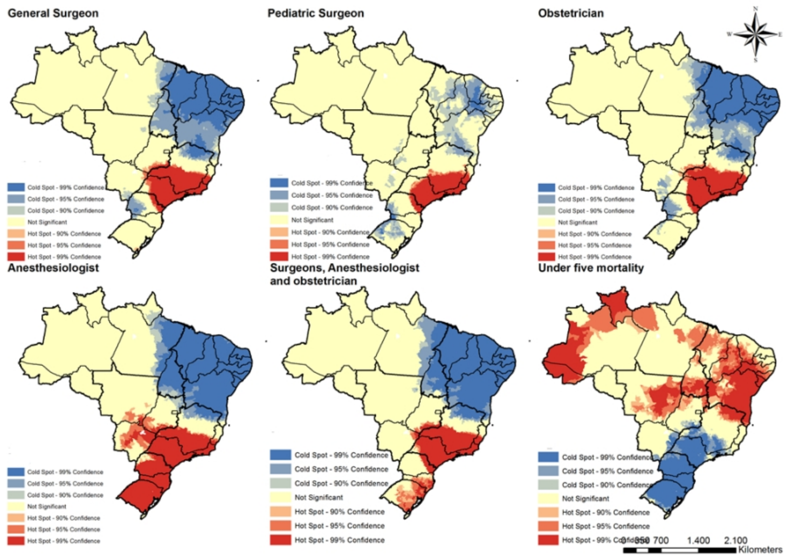

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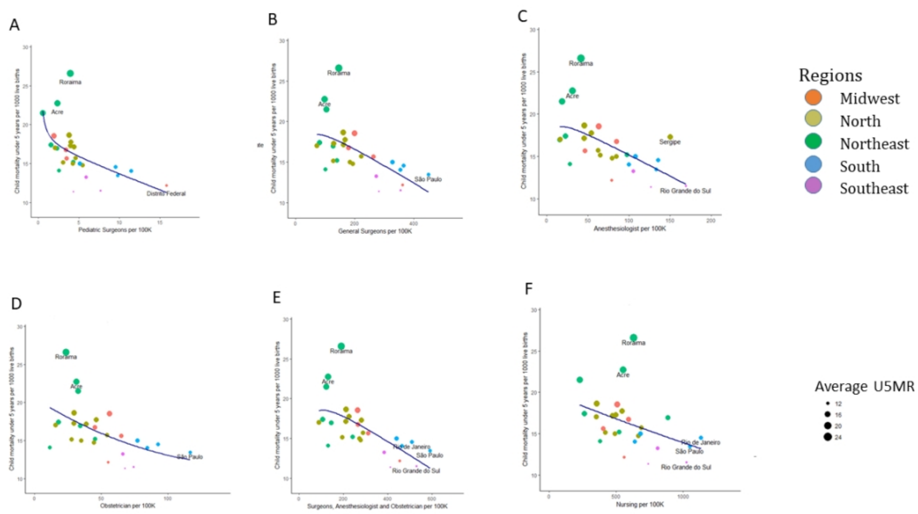

Fig6

338x190mm (96 x 96 DPI)

Checklist of information that should be included in new reports of global health estimates

Item #	Checklist item	Reported on page #
Objectives and funding		
1	Define the indicator(s), populations (including age, sex, and geographic entities), and time period(s) for which estimates were made.	5
2	List the funding sources for the work.	2
Data Inputs		
For all data inputs from multiple sources that are synthesized as part of the study:		
3	Describe how the data were identified and how the data were accessed.	5-6
4	Specify the inclusion and exclusion criteria. Identify all ad-hoc exclusions.	5-6
5	Provide information on all included data sources and their main characteristics. For each data source used, report reference information or contact name/institution, population represented, data collection method, year(s) of data collection, sex and age range, diagnostic criteria or measurement method, and sample size, as relevant.	5-7
6	Identify and describe any categories of input data that have potentially important biases (e.g., based on characteristics listed in item 5).	10
For data inputs that contribute to the analysis but were not synthesized as part of the study:		
7	Describe and give sources for any other data inputs.	NA
For all data inputs:		
8	Provide all data inputs in a file format from which data can be efficiently extracted (e.g., a spreadsheet rather than a PDF), including all relevant meta-data listed in item 5. For any data inputs that cannot be shared because of ethical or legal reasons, such as third-party ownership, provide a contact name or the name of the institution that retains the right to the data.	7
Data analysis		
9	Provide a conceptual overview of the data analysis method. A diagram may be helpful.	5-7
10	Provide a detailed description of all steps of the analysis, including mathematical formulae. This description should cover, as relevant, data cleaning, data pre-processing, data adjustments and weighting of data sources, and mathematical or statistical model(s).	5-7
11	Describe how candidate models were evaluated and how the final model(s) were selected.	5-7
12	Provide the results of an evaluation of model performance, if done, as well as the results of any relevant sensitivity analysis.	5-7
13	Describe methods for calculating uncertainty of the estimates. State which sources of uncertainty were, and were not, accounted for in the uncertainty analysis.	5-7
14	State how analytic or statistical source code used to generate estimates can be accessed.	5-7
Results and Discussion		
15	Provide published estimates in a file format from which data can be efficiently extracted.	7
16	Report a quantitative measure of the uncertainty of the estimates (e.g. uncertainty intervals).	7-9
17	Interpret results in light of existing evidence. If updating a previous set of estimates, describe the reasons for changes in estimates.	7-11
18	Discuss limitations of the estimates. Include a discussion of any modelling assumptions or data limitations that affect interpretation of the estimates.	10

This checklist should be used in conjunction with the GATHER statement and Explanation and Elaboration document, found on gather-statement.org

Towards Defining the Surgical Workforce for Children: A Geospatial Analysis in Brazil

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Towards Defining the Surgical Workforce for Children: A Geospatial Analysis in Brazil

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ABSTRACT

Objectives: The optimal size of the health workforce for children's surgical care around the world remains poorly defined. The goal of this study was to characterize the surgical workforce for children across Brazil, and to identify associations between the surgical workforce and measures of childhood health.

Design: This study is an ecological, cross-sectional analysis using data from the Brazil public health system (*Sistema Único de Saúde)*.

Settings and Participants: We collected data on the surgical workforce (pediatric surgeons, general surgeons, anesthesiologists, and nursing staff), perioperative mortality rate (POMR), and under-5 mortality rate (U5MR) across Brazil for 2015.

Primary and Secondary Outcome Measures: We performed descriptive analyses, and identified associations between the workforce and U5MR using geospatial analysis (Getis-Ord-Gi analysis, spatial cluster analysis, and linear regression models).

Findings: There were 39,926 general surgeons, 856 pediatric surgeons, 13,243 anesthesiologists, and 103,793 nurses across Brazil in 2015. The U5MR ranged from 11-26 deaths/1,000 live births and the POMR ranged from 0·11-0·17 deaths/100,000 children across the country. The surgical workforce is inequitably distributed across the country, with the wealthier South and Southeast regions having a higher workforce density as well as lower U5MR than the poorer North and Northeast regions. Using linear regression, we found an inverse relationship between the surgical workforce density and U5MR. An U5MR of 15 deaths/1,000 births across Brazil is associated with a workforce level of 5 pediatric surgeons, 200 surgeons, 100 anesthesiologists, or 700 nurses/100,000 children.

Conclusions: We found wide disparities in the surgical workforce and childhood mortality across Brazil, with both directly related to socioeconomic status. Areas of increased surgical workforce are associated with lower U5MR. Strategic investment in the surgical workforce may be required to attain optimal health outcomes for children in Brazil, particularly in rural regions.

Funding: None

ARTICLE SUMMARY

STRENGTHS AND LIMITATIONS OF THIS STUDY

Strengths

- Use of geospatial analysis allows precise definition of associations between the surgical workforce and under-5 mortality rate (U5MR) across Brazil.
- Analysis can demonstrate an inverse relationship between the surgical workforce and U5MR, allowing for location of areas of increased workforce which are associated with lower U5MR levels.
- Geospatial tools can confirm disparities in the surgical workforce as well as U5MR across Brazil, and support modeling to define the relationship between the surgical workforce and U5MR.

Limitations

- Our findings of an association between surgical workforce and U5MR does not demonstrate causation, as many confounding factors and modifiers other than surgical disease impact the U5MR
- Although our findings of an association between surgical workforce and U5MR does not demonstrate causation.

INTRODUCTION

Health care is workforce intensive, and an adequate level of human resources is essential to maintain strong health systems. Discrepancies between local health needs and the health workforce leads to clinical errors, wastage of resources, and increased patient mortality and morbidity.[1] For surgical care, the workforce is grossly inadequate and inequitably distributed in many low- and middle-income countries (LMICs), with rural areas disproportionately affected.[2,3]

Studies from the Lancet Commission on Global Surgery (LCoGS) have proposed a density of 20-40 specialist physicians (surgeons, anesthesiologists, or obstetricians, SAO) per 100,000 general population to attain desired health outcomes, such as perioperative mortality rate (POMR).[2-4] However, surgical care for children is fundamentally different from adult care, with surgical resources provided through multiple tiers in a national health system in proportion to population needs and surgical complexity required.[5] In these complex health systems, the optimal surgical workforce for children remains poorly defined.

Brazil offers a rich environment to closely examine the health workforce, as it has extremely heterogeneous geography, health infrastructure, and socioeconomic status across the country (GINI index 53·3 in 2017).[6,7] Brazil has a large public health system (*Sistema Único de Saúde, SUS)* and maintains several publicly available datasets (DATASUS).[6,8] Efforts to reduce health disparities across the five Brazil regions (North, Northeast, Midwest, Southeast, and South) have made great strides in recent years, particularly through workforce expansion in primary care.[9]

Previous geospatial analysis by ourselves and others have identified wide disparities in surgical care across Brazil.[10,11] Facilities providing surgical care for children are inequitably distributed across the country, with higher density of infrastructure and surgical access per population unit associated with areas of higher socioeconomic status.[10] Spatial cluster analysis demonstrated a higher under-5 mortality rate (U5MR) in the poorer North, Northeast, and Midwest regions compared to the wealthier Southeast and South regions, although the POMR for a proxy set of children's conditions does not vary across the country.[10] Increased access to surgical care is associated with a lower U5MR, and access to surgical care differs by geographic region independent of socioeconomic status.

The goals of this study are to characterize the surgical workforce for children in the public health system in Brazil using geospatial analysis and to identify associations between the surgical workforce and childhood mortality rates. Through this analysis, we hope to provide an assessment of Brazil's surgical workforce, identify disparities in workforce distribution, and estimate the required surgical workforce to obtain desired health outcomes for children.

METHODS

This study is an ecological, cross-sectional, geospatial analysis using data from the Brazil public health system. Brazil is composed of 5,570 municipalities across the union of the Federal District and 26 states, which are distributed across five regions (Midwest, North, Northeast, South, and Southeast). We collected data on all children < 15 years of age undergoing a surgical procedure from 2010 to 2015 across Brazil using datasets from DATASUS (see Table 1 for all datasets and study timeframes). Auxiliary data were collected from databases from the World Bank and the Brazilian Institute of Geography and Statistic (IBGE).[8] We used several tools of geospatial analysis to explore relationships between surgical workforce, POMR, and U5MR. All health estimates were summarized in line with the GATHER statement.[12]

We extracted demographic and socioeconomic indicators from Brazilian Institute of Geography and Statistics (IBGE).[13] We used this data along with the Brazilian gross domestic product (GDP) to classify municipalities according to income groups as high income, upper-middle income, or lower-middle income as defined by the 2017 World Bank criteria of gross national income (GNI) per capita adjusted to US dollars (low income: GNI per capita $1,005 or less; lower middle-income: GNI per capita between $1,006 and $3,955; upper middle-income: GNI per capita between $3,956 and $12,235; high-income > $12,235) (Fig 1).[14]

Surgical workforce density

We summarized data on the surgical workforce at the municipality, state, and regional levels. We summarized several workforce roles, including general surgeons, pediatric surgeons, anesthesiologists, obstetricians, and nurses, using professional role definitions from the CNES. The CNES keeps a record of the appointment of all health providers at public health facilities. The density of each profession was weighted per 100,000 children. For comparison to common surgical workforce metrics used in the Lancet Commission on Global Surgery,[2-4] we also summarized the density of surgeons, anesthesiologists, and obstetricians (SAO).

Under-5 child mortality rate (U5MR) and perioperative mortality rate (POMR)

We summarized annual all-cause under-5 pediatric mortality rates (U5MR) at the regional and municipality level using data from the Brazilian Mortality Information System database (SIM), which collects data on all deaths by age, sex, cause, and residence.[8] The U5MR was calculated using methods of the Inter Agency Group for Mortality Estimation (IGME), and was expressed as deaths per 1,000 live births.[15]

We collected procedure-based perioperative mortality rate (POMR) from the DATASUS Hospitalization Information System database (SIH) using the procedure codes for a proxy set of general surgical procedures. This set was based on the Optimal Resources for Children's Surgery (OReCS) document of the Global Initiative for Children's Surgery, which specifies representative surgical procedures to assess the delivery of surgical care within a national health system.[5] These five procedures included appendectomy, colostomy, hernia repair, laparotomy, and abdominal wall reconstruction for gastroschisis, omphalocele, or other indication. The SIH defines perioperative mortality as any death occurring during any surgical procedure. We summarized procedure-specific POMR at the regional level across the country.

Note that due to differences in the data quality,[10] we limited analysis of the surgical workforce to use of U5MR as the outcome metric. We chose not to use POMR, as the SIH dataset only records deaths occurring during operative procedures and thus likely far underestimates the true POMR, which is generally accepted as within 30 days of surgery.[16] We recognize that U5MR measures both surgical and non-surgical causes of child mortality, although we chose to use it for analysis of associations between the surgical workforce and childhood health as it is a widely used measure of health system strength for children.

Data analysis

All analyses were performed using the municipality as the main observation unit. We summarized descriptive outcomes at the municipality, state, and regional levels. Descriptive statistics were used to report the mean and standard deviation of workforce variables. The density of the surgical workforce and U5MR were displayed using geospatial chloropleth maps. Geographic mapping was used to identify the distribution of each indicator within a spatial area.[17] We used a Getis-Ord Gi analysis to depict the spatial autocorrelation within each indicator (workforce density and U5MR). We identified hot spots (red areas) depicting clusters of municipalities with adjacent municipalities with high values for a given indicator (workforce density or U5MR), and cold spots (blue areas) depicting areas of adjacent clusters with low values for each indicator. Yellow areas mark locations where no clustering was observed. Geographic mapping was used to identify the distribution of each indicator within a spatial area.

To identify potential associations between the surgical workforce and U5MR, we used linear regression on the aggregated data on the state level, adjusting for regional distribution. Scatter plots were built to graphically depict the association between workforce and U5MR. Each point in the graphic was proportional to the average U5MR (per 1,000 live births), with display by state as well as by region level. We also performed quadratic and splines regression analysis, but the linear models showed better fit to the data, assessed in comparison using ANOVAs and residual evaluation.

Further analysis evaluated the association between workforce and U5MR accounting for the spatial heterogeneity, using Moran's I bivariate spatial autocorrelation between each indicator. For our study, we identified High-High spots (red areas) depicting clusters of municipalities with high workforce adjacent municipalities with high values for a U5MR, and Low-Low spots (blue areas) depicting areas of adjacent clusters with low values for each indicator. High-Low (light red areas) and Low-High (light blue areas) marked locations cluster of high in one indicator was adjacent to a low in the other.

Patient and public involvement

As an ecological study, there was no direct patient involvement with this research. However, there is public interest in addressing challenges with the surgical care of children in Brazil. We used anonymized publically available datasets to address these research questions. All research findings will be disseminated to the public and health community in Brazil through publication, academic meetings, and social media.

Data sharing statement

All data used for this analysis were obtained from the open access DATASUS system, from the Brazilian Ministry of Health. Data can be obtained, freely, from: http://tabnet.datasus.gov.br/.

RESULTS

We found that there were 39,926 general surgeons, 856 pediatric surgeons, 13,243 anesthesiologists, 103,793 nurses, and 9,674 obstetricians across Brazil in 2015. During the same year, there were 43,045 reported deaths in children under five years of age in Brazil, with the U5MR ranging between 11-26 deaths/1,000 live births across states. The POMR for the proxy set of surgical procedures ranged from 0·11-0·17 deaths/100,000 children across regions.

By use of scatter plots, we developed a set of linear regression models to define the association between the density of surgical workforce at the state level and U5MR (Fig 2A-F). Using linear regression, we e found all professional roles had a direct relationship between workforce density and U5MR (Table 2). However, when adjusting the models by the interaction of workforce density and region of the country, we noticed that some of the associations had lower coefficients and were not significant, suggesting that the association between workforce and U5MR is dependent on the geographic and social context.

Disparities in the surgical workforce and U5MR across Brazil

The surgical workforce for children in Brazil is unequally distributed across the country, with the South and Southeast regions having a higher density of all professional roles, while the North and Northeast regions have a lower density of each role (Fig 3). We found an inverse pattern of disparities in U5MR across the country,. The South and Southeast regions had the lowest U5MR. In contrast, the North and Northeast regions had higher U5MR (Fig 4).

At a municipality level, we found wide disparities in the workforce density as well as U5MR across Brazil, with inequities even within states (Fig 5). Several municipalities did not have even one general surgeon, pediatric surgeon, obstetrician, or anesthesiologist. Some wealthier parts of the North and Northeast regions showed high inequities in workforce distribution, with the workforce preferentially localized in areas around the state capitals. The high areas of workforce distribution was similar to the patterns of low U5MR seen at the municipality level.

Relationship between surgical workforce density and U5MR

We found a direct association between the surgical workforce and U5MR across Brazil, with higher density of each professional role associated with lower U5MR across regions (Fig 6, Table 2). This pattern is consistent across workforce roles (surgeon, anesthesiologist, nursing, etc.), although there are some variations in the distribution patterns across the country. For example, in the South and Southeast, we found the highest density of pediatric surgeons as well as the lowest levels of U5MR, although this pattern was not seen in the Federal District, where there was a high density of all workforce roles as well as higher levels of U5MR compared to surrounding regions. The Federal district is where the Brazilian government is located, and the density of the surgical workforce in this state-city was higher than in all other states.

Discussion

As surgical care is an essential component of functioning health care systems, there is a need to improve our understanding of the surgical workforce for children. Brazil has wide disparities insocioeconomic status and health care delivery.[18,19] Our previous work has shown disparities in the density of delivery and infrastructure for surgical care for children per population unit across Brazil, with areas of higher socioeconomic status associated with increased delivery of surgical care.[10] Although Brazil does have widely variable geography, these disparities are corrected for population density, and therefore reflect underlying disparities in health access. Our current study demonstrates disparities in the surgical workforce across the country, with a higher workforce density per population unit found in areas of higher socioeconomic status. As well, increased surgical workforce density is associated with areas of lower U5MR, suggesting that an adequate and equitable surgical workforce is essential for support of high-quality health care for children.

Disparities in surgical care for adults have been previously noted in Brazil as well as other countries, although disparities in the surgical care for children remain poorly understood. Reports from the Lancet Commission on Global Surgery have shown an association between the density of surgeons, anesthesiologists, and obstetricians (SAO) and the rate of surgical procedures or perioperative mortality rates.[2-4] Our data aligns with recent analyses of surgical care for adults in Brazil, which showed wide disparities in manpower and surgical care.[11,20] The Brazilian government has long recognized challenges with health care delivery across the country, and have implemented several programs to increase primary care access in rural areas.[6,9,21]

The POMR is often used to gauge the quality of a surgical system,[16] although we suggest that metrics of overall childhood health such as U5MR may offer an alternative, and potentially even more valuable metric to guide manpower planning. First, given the increasing emphasis on surgical care as an integral part of a comprehensive health system, associations between each aspect of the health workforce and overall measures of population health may be the most appropriate measure of manpower across an entire health system, including the surgical workforce.[16] For example, neonates or children with cancer often require surgical care, and an adequate surgical workforce is essential to ensure high-quality outcomes for these children. Second, despite interest around the world for collection of perioperative mortality rates, data quality for POMR continues to be challenging in many settings.[22] Our previous work in Brazil suggests that data quality for POMR is too poor to allow for analysis of the surgical workforce.[10,16] Third, the United Nations and the World Health Organization have identified several indicators to evaluate health interventions in children, including the U5MR, rate of growth stunting, immunization coverage, and prevalence of common childhood diseases.[23] These metrics are routinely collected around the world, and our analysis suggests that strategic expansion of the surgical workforce can be guided by these widely collected metrics. Finally, we confirmed an association between the nursing workforce and U5MR, as few analyses have examined the nursing workforce requirements for surgical care.

To assist with policy development, geospatial analysis can identify priority regions of workforce needs. The sequence of steps in our analysis may be generalizable to other countries to guide scale-up of the surgical workforce to desired levels of health outcomes. For example, we found that U5MR of 15 deaths/1,000 births across Brazil is associated with an approximate workforce level of 5 pediatric surgeons, 200 surgeons, 100 anesthesiologists, or 700 nurses/100,000 children. Geospatial analyses has help guide health workforce expansion in Thailand,[24] as well as in some countries in sub-Saharan Africa.[25] However, we caution that the workforce associations in Brazil may not be applicable to other countries. As well, geospatial analysis requires access to high quality national datasets, which remains problematic in many countries around the world.

The areas of Brazil with lower socioeconomic status remain challenging environments for health care, where there is a long history of difficulties with retention of health care professionals.[18,19] Our findings align with studies of adult surgical workforce in Brazil, which have shown inequities in the density of SAO professionals across the country, with rural regions disproportionately affected.[26] Similar to many counties around the world, the rural areas in Brazil have high levels of poverty and a scarcity of health infrastructure.[27,28] Brazil has successfully increased access to the primary care workforce in rural areas through the *Mais Médicos* program,[29] and our findings suggest that similar expansion of the surgical workforce may improve the health of children.

As with any population-based study, our work has several limitations. First, our findings of an association between surgical workforce and U5MR do not demonstrate causation. We recognize that many confounders other than surgical workforce impacts the U5MR (such as non-surgical disease, non-surgical workforce, etc.). However, we view surgical care as a core component of a functional health system, and therefore association between the surgical workforce and U5MR can help guide workforce planning. Although our analysis did not account for detailed study of the confounding and modifying variables which impact the U5MR, further discernment of which components of a health workforce are most important for childhood health is a critical question that merits further analysis. Second, there is a lack of consensus in geospatial analysis about how the density of professionals should be weighted regarding different populations (i.e. overall population, child population, etc.), although we chose to weigh by child population. Finally, we recognize that the surgical workforce includes many type of subspecialists that were not included in our analysis.

In conclusion, we found that the surgical workforce for children is inadequate and inequitably distributed across Brazil, suggesting that strategic investment in the surgical workforce is required to support high-quality and equitable health care for children. There is a direct relation between the surgical workforce and U5MR across Brazil, with higher levels of the surgical workforce associated with improved U5MR. These findings have several policy implications to improve the health of children in Brazil:

- Increased investment in the surgical workforce is required to support the health of children in Brazil, particularly in rural regions

- Identification of associations between the workforce and measures of population health (such as U5MR) may be a valuable tool to define surgical workforce levels in LMICs
- Definition of workforce indicators is particularly challenging for children's surgical care given the complexity of care across different levels of national health systems
- Geospatial analysis can help define the required surgical workforce to attain desired population health goals, and may be generalizable across other LMICs

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FOOTNOTES

CONTRIBUTORS

TAHR, JRNV, and HER had the initial idea for this analysis. TAHR, JRNV, NCS, and HER performed the initial analysis and wrote the first draft. The analysis and manuscript were completed and revised in collaboration with DP, MGS, and ERS. All co-authors read and approved the final manuscript.

DECLARATION OF INTERESTS

We declare no competing interests.

IRB APPROVAL

Not required.

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FIGURE LEGENDS

Figure 1-Income group distribution of Brazilian municipalities. Socioeconomic data were extracted from Brazilian Institute of Geography and Statistic (IBGE), and used with the Brazilian gross domestic product to classify municipalities according to income groups as defined by the World Bank as high-income, upper-middle-income, or lower-middle-income. The map of Brazil was freely obtained in shapefile format (SHP) through online access to the website of the Brazilian Institute of Geography and Statistics (https://mapas.ibge.gov.br/bases-e-referenciais/bases-cartograficas/malhas-digitais.html). Reprinted from Vissoci et al.[10]

Figure 2 (A-F)-Association between the density of the surgical workforce (weighted per 100,000 children) and under-5 mortality rate (U5MR, per 1,000 live births) in each state across Brazil. Linear regression models were used to define associations between the workforce density and U5MR. The line resulting from each regression model was plotted using bivariate scatterplots. The size of each point in the graphic is proportional to the average U5MR for each state, with different colors used to summarize data by region.

Figure 3-The density (rate) of the surgical workforce for each professional role across Brazil as summarized by region. The density of each professional role is weighted per 100,000 children.

Figure 4- Under 5 mortality rates (U5MR, per 1,000 live births) across Brazil summarized by state as well as by region levels.

Figure 5- Spatial distribution of the surgical workforce density (weighted per 100,000 children) and under-5 mortality rate (U5MR, per 1,000 live births) at the municipality level. Hot spot cluster analysis of association between the surgical workforce density (weighted per 100,000 children) and under-5 mortality rate (U5MR, per 1,000 live births) across Brazil using Getis-Ord-Gi analysis.17 Hot spots (red areas) depict clusters of municipalities with adjacent municipalities with high values for a given indicator (workforce density or U5MR), and cold spots (blue areas) depict clusters with an adjacent low values regarding each indicator. Yellow areas mark locations where no clustering was observed. Note that the scatterplots are not adjusted for spatial autocorrelation.

Figure 6- Association between the surgical workforce density (weighted per 100,000 children) and under-5 mortality rate (U5MR, per 1,000 live births) across Brazil using spatial correlation analysis. High-High areas (red areas) depict clusters of municipalities with high values for workforce adjacent municipalities with high values for a U5MR, and Low-Low areas (blue areas) depict clusters with an adjacent low values regarding each indicator.

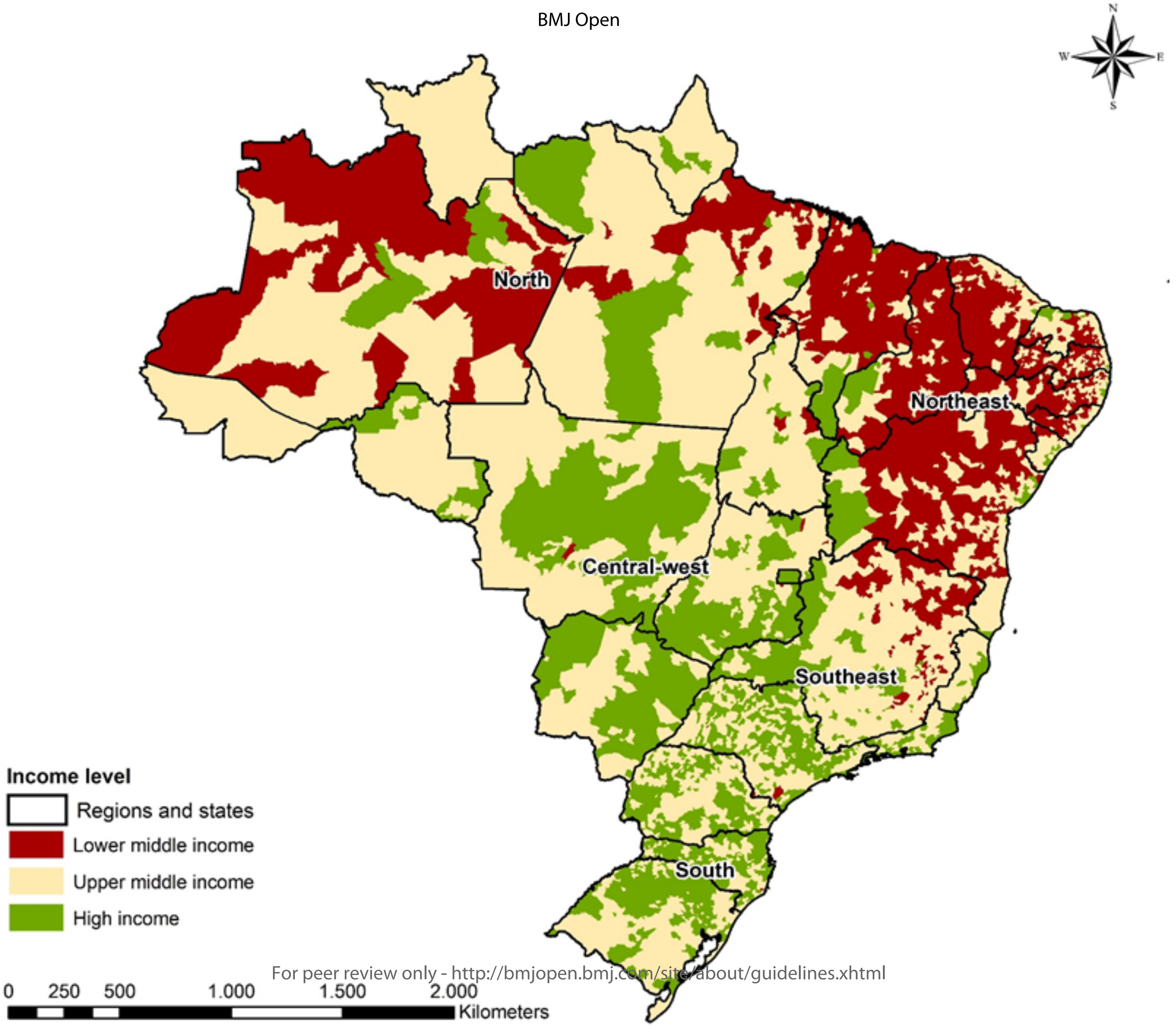
Table 1: Data Sources for Analysis

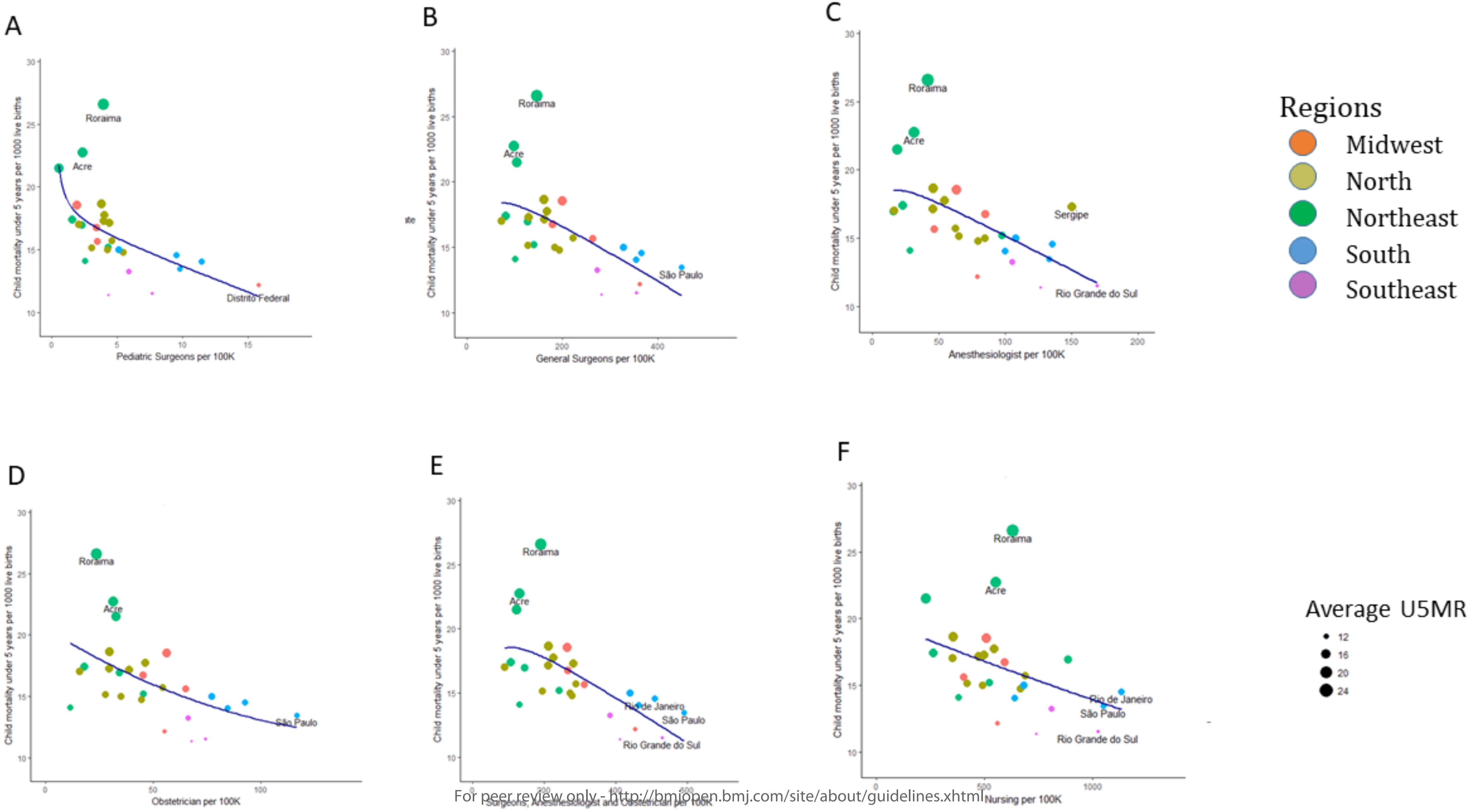
Source	Variables	Date Range	Data entries	Scope
DATASUS - Hospitalization information system (SIH)	• Hospitalization procedures performed • ICD code • Age of patient • Location of residence • Costs associate to the procedure • Hospital	2008-2015	267,248 procedures	Appendectomy (ICD 10 0DTJ4ZZ, 0DTJ0ZZ) Laparotomy (ICD 10 0WJP0ZZ) Hernia (ICD 10 0YQ54ZZ, 0YQ64ZZ, 0YQ50ZZ, 0YQ60ZZ, 0WQF4ZZ, 0WUF07Z, 0WUF0KZ, 0BQR4ZZ,0BQS4ZZ, 0BQR0ZZ, 0BQS0ZZ) Colostomy (ICD 10 0WQFXZ2) Abdominal wall reconstruction (ICD 10 0WQF0ZZ)
DATASUS - Mortality information system (SIM)	• Deaths of patients under 14 years old • The municipality of residence and of death • Mortality rate by municipality	2010-2015	326,459 deaths	All deaths between 2010 and 2015
CNES - National registration of health establishments	• Geolocation • Type of care provided • Accreditation	2014	6,498 hospitals	District and referral level hospitals
World Bank	• Gross national income (GNI) • Atlas index • GNI per capita • Income level classification	2010-2013	5565 municipalities	-
IBGE - Brazilian institute of geography and statistics	• Pediatric population by municipality • Gross domestic product (GDP) • GDP per capita	2008-2014	5565 municipalities	-

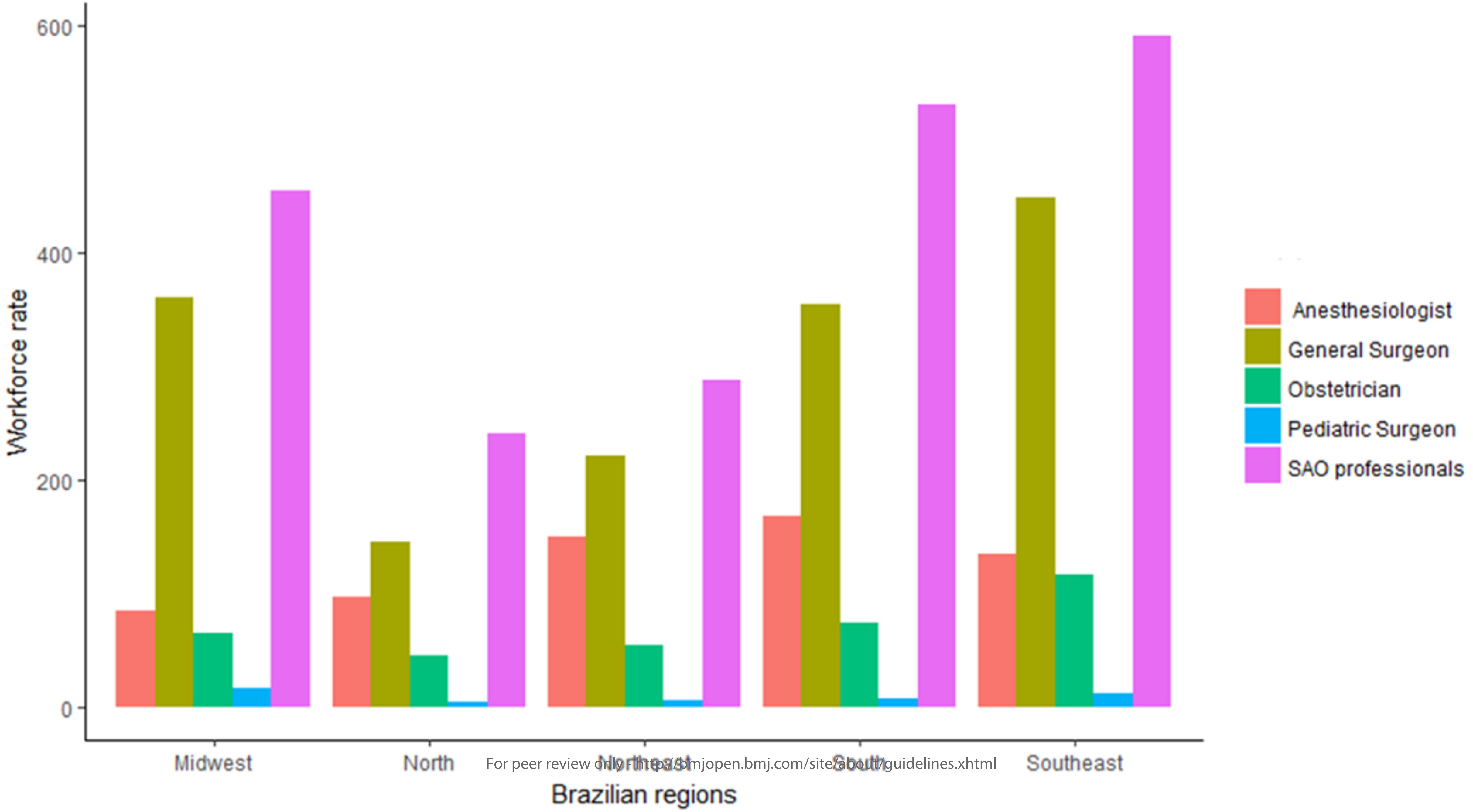
Table 1. Primary datasets used for analysis derived from the Brazilian public health system (*Sistema Único de Saúde, SUS)*, which maintains several publicly available datasets (DATASUS). Auxiliary data collected from the World Bank and the Brazilian Institute of Geography and Statistic (IBGE).

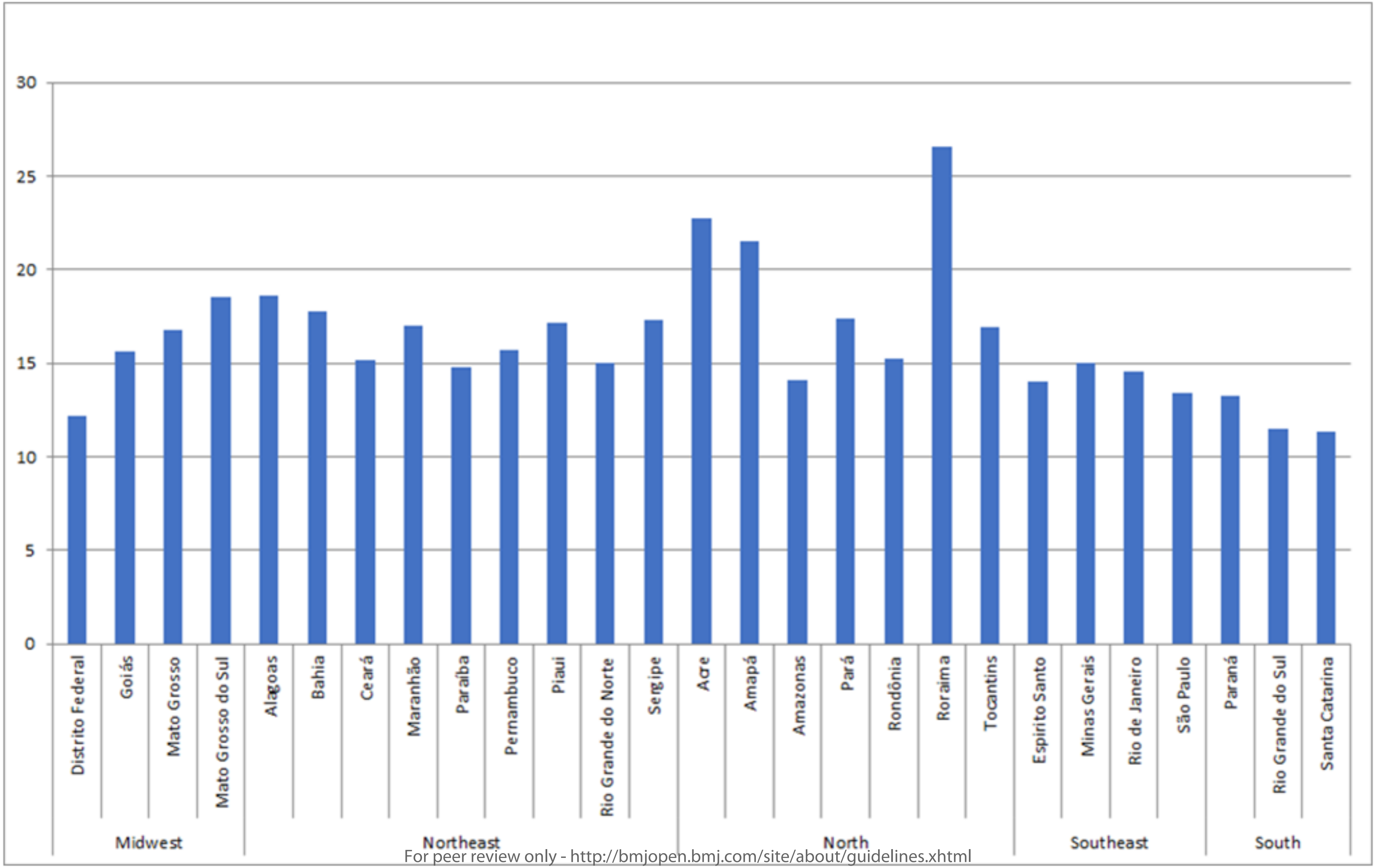
	Mean (SD)	Unadjusted coefficient (SE)	Adjusted coefficient (SE)
General surgeon rate	208.01 (103.93)	-0.02 (0.01)**	-0.01 (0.01)
Pediatric surgeon rate	4.86 (3.38)	-0.53 (0.17)**	-0.32 (0.20)
Obstetrician rate	48.95 (25.37)	-0.07 (0.02)**	-0.02 (0.05)
Anesthesiologist rate	74.34 (43.32)	-0.05 (0.01)**	-0.02 (0.02)
Surgeons, Anesthesiologists and Obstetrician rate	287.22 (140.70)	-0.02 (0.00)**	-0.01 (0.01)

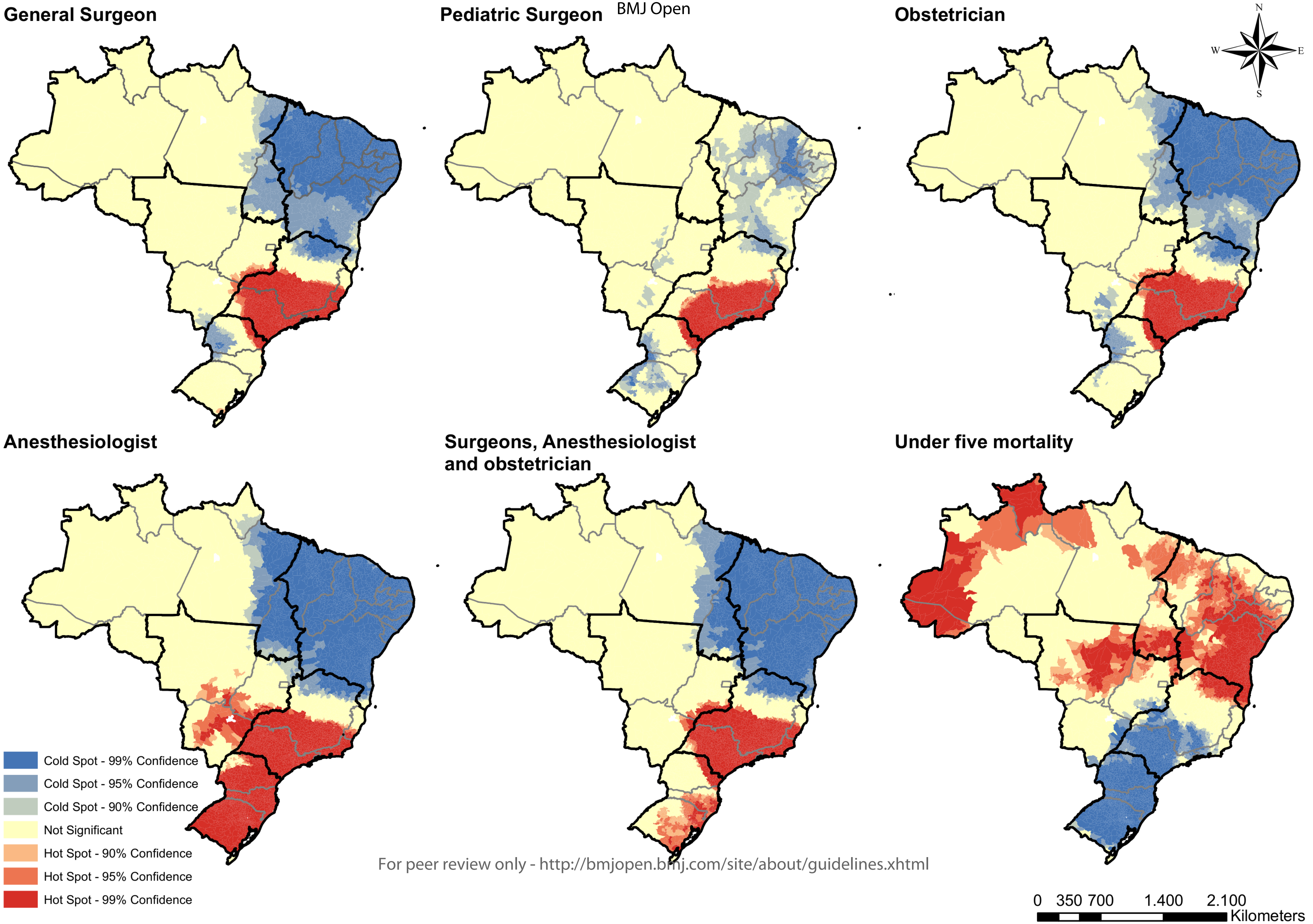
Table 2. Linear regression coefficients for the association between workforce and U5MR in Brazil, unadjusted and adjusted by region of the country. **P-value < 0.01)


N
W
E
S
North
Northeast
Central-west
Southeast
South
Income level
Regions and states
Lower middle income
Upper middle income
High income
0 250 500 1.000 1.500 2.000
Kilometers

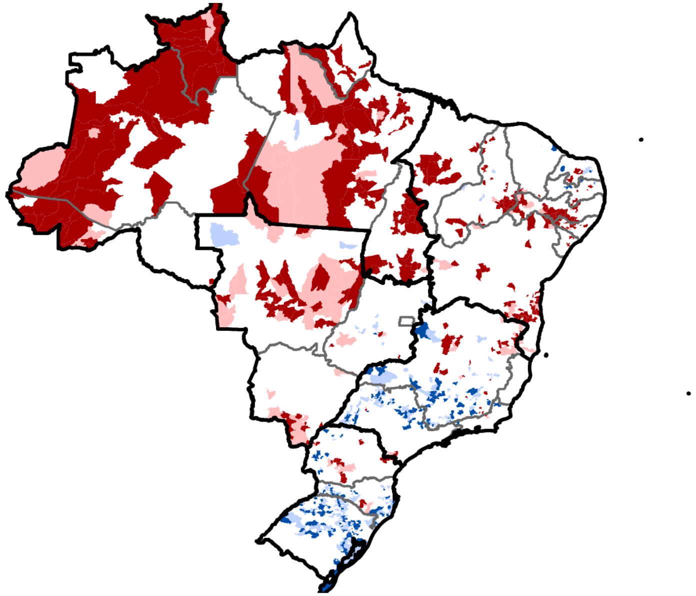

A
B
C
D
E
F
Roraima
Acre
Distrito Federal
São Paulo
Sergipe
Rio Grande do Sul
Rio de Janeiro
Child mortality under 5 years per 1000 live births
Pediatric Surgeons per 100K
General Surgeons per 100K
Anesthesiologist per 100K
Obstetrician per 100K
Surgeons, Anesthesiologist and Obstetrician per 100K
Nursing per 100K
Regions
Midwest
North
Northeast
South
Southeast
Average U5MR
12
16
20
24


600
400
200
0
Workforce rate
Midwest
North
Northeast
South
Southeast
Brazilian regions
Anesthesiologist
General Surgeon
Obstetrician
Pediatric Surgeon
SAO professionals

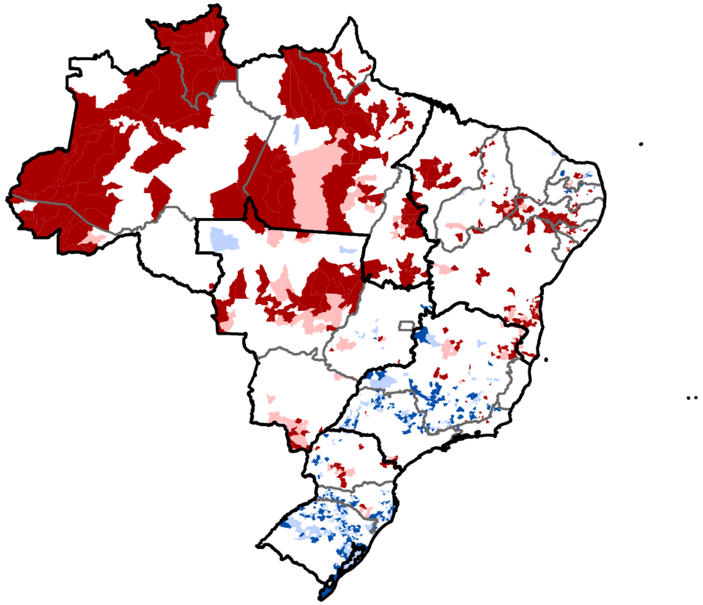

30
25
20
15
10
5
0
Distrito Federal
Goiás
Mato Grosso
Mato Grosso do Sul
Alagoas
Bahia
Ceará
Maranhão
Paraíba
Pernambuco
Piauí
Rio Grande do Norte
Sergipe
Acre
Amapá
Amazonas
Pará
Rondônia
Roraima
Tocantins
Espírito Santo
Minas Gerais
Rio de Janeiro
São Paulo
Paraná
Rio Grande do Sul
Santa Catarina
Midwest
Northeast
North
Southeast
South


General Surgeon
Pediatric Surgeon
Obstetrician
N
W
E
S
Anesthesiologist
Surgeons, Anesthesiologist and obstetrician
Under five mortality
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
0 350 700 1.400 2.100
Kilometers

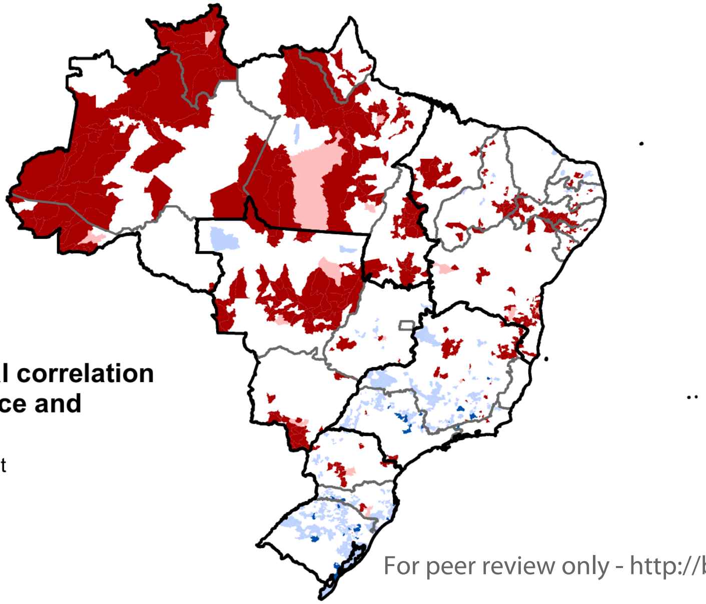
Anesthesiologist



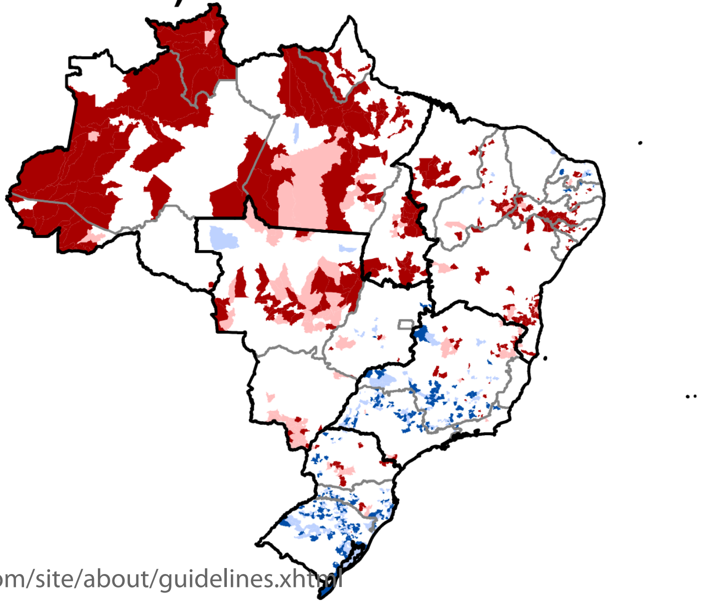
Surgeons



Obstetrician



SAP (Anesthesiologist, surgeons and obstetrician)



Legend

Bivariate spatial correlation among workforce and child mortality

- Not significant
- High-High
- Low-Low
- Low-High
- High-Low

GATHER
Guidelines for Accurate and Transparent Health Estimates Reporting

Checklist of information that should be included in new reports of global health estimates

Item #	Checklist item	Reported on page #
Objectives and funding		
1	Define the indicator(s), populations (including age, sex, and geographic entities), and time period(s) for which estimates were made.	5
2	List the funding sources for the work.	2
Data Inputs		
For all data inputs from multiple sources that are synthesized as part of the study:		
3	Describe how the data were identified and how the data were accessed.	5-6
4	Specify the inclusion and exclusion criteria. Identify all ad-hoc exclusions.	5-6
5	Provide information on all included data sources and their main characteristics. For each data source used, report reference information or contact name/institution, population represented, data collection method, year(s) of data collection, sex and age range, diagnostic criteria or measurement method, and sample size, as relevant.	5-7
6	Identify and describe any categories of input data that have potentially important biases (e.g., based on characteristics listed in item 5).	10
For data inputs that contribute to the analysis but were not synthesized as part of the study:		
7	Describe and give sources for any other data inputs.	NA
For all data inputs:		
8	Provide all data inputs in a file format from which data can be efficiently extracted (e.g., a spreadsheet rather than a PDF), including all relevant meta-data listed in item 5. For any data inputs that cannot be shared because of ethical or legal reasons, such as third-party ownership, provide a contact name or the name of the institution that retains the right to the data.	7
Data analysis		
9	Provide a conceptual overview of the data analysis method. A diagram may be helpful.	5-7
10	Provide a detailed description of all steps of the analysis, including mathematical formulae. This description should cover, as relevant, data cleaning, data pre-processing, data adjustments and weighting of data sources, and mathematical or statistical model(s).	5-7
11	Describe how candidate models were evaluated and how the final model(s) were selected.	5-7
12	Provide the results of an evaluation of model performance, if done, as well as the results of any relevant sensitivity analysis.	5-7
13	Describe methods for calculating uncertainty of the estimates. State which sources of uncertainty were, and were not, accounted for in the uncertainty analysis.	5-7
14	State how analytic or statistical source code used to generate estimates can be accessed.	5-7
Results and Discussion		
15	Provide published estimates in a file format from which data can be efficiently extracted.	7
16	Report a quantitative measure of the uncertainty of the estimates (e.g. uncertainty intervals).	7-9
17	Interpret results in light of existing evidence. If updating a previous set of estimates, describe the reasons for changes in estimates.	7-11
18	Discuss limitations of the estimates. Include a discussion of any modelling assumptions or data limitations that affect interpretation of the estimates.	10

This checklist should be used in conjunction with the GATHER statement and Explanation and Elaboration document, found on gather-statement.org