https://doi.org/10.1590/1980-549720210007.supl.1

ORIGINAL ARTICLE / *ARTIGO ORIGINAL*

Spatial patterns of avoidable fetal mortality and social deprivation

Padrões espaciais da mortalidade fetal evitável e carência social

Indianara Maria de Barros Canuto[I], Vilma Costa de Macêdo[I], Paulo Germano de Frias[II], Conceição Maria de Oliveira[III], Heitor Victor Veiga da Costa[I], José Luiz Portugal[I], Cristine Vieira do Bonfim[IV]

ABSTRACT: ***Objective:*** To develop a social need index for stratification of municipalities and identification of priority areas for reducing fetal mortality. ***Methods:*** ecological study, carried out in the state of Pernambuco, between 2010 and 2017. The technique of factor analysis by main components was used for the elaboration of the social need index. In the spatial analysis, the local empirical Bayesian estimator was applied and Moran's spatial autocorrelation was verified. ***Results:*** The social deprivation index selected two factors that, together, explained 77.63% of the total variance. The preventable fetal mortality rate increased among strata of social need, with rates of 8.0 per thousand births (low deprivation), 8.1 per thousand (medium deprivation), 8.8 per thousand (high deprivation), and 10.7 per thousand (very high social deprivation). Some municipalities in the São Francisco and Sertão Mesoregions had both high fetal and preventable fetal mortality, in addition to a very high social deprivation rate. ***Conclusion:*** The spatial analysis identified areas with the highest risk for fetal mortality. The social deprivation index listed some determinants of fetal deaths in areas with worse living conditions. Priority areas for intervention in public policies to reduce fetal mortality and its determinants were detected.

Keywords: Fetal mortality. Vital statistics. Spatial analysis. Social inequity.

[I]Universidade Federal de Pernambuco – Recife (PE), Brazil.

[II]Instituto de Medicina Integral Professor Fernando Figueira – Recife (PE), Brazil.

[III]Secretaria de Saúde – Recife (PE), Brazil.

[IV]Fundação Joaquim Nabuco, Recife, Pernambuco, Brazil.

Corresponding author: Indianara Maria de Barros Canuto. Rua 24 de Junho, 35, ap. 803, Encruzilhada, CEP: 53030-100, Recife, PE, Brasil. E-mail: indianaracanuto@hotmail.com

Conflict of interests: nothing to declare – **Financial support:** Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil (CAPES), funding code 001.

RESUMO: ***Objetivo:*** Elaborar um índice de carência social para a estratificação dos municípios e a identificação de áreas prioritárias para a redução da mortalidade fetal. ***Métodos:*** Estudo ecológico, realizado no estado de Pernambuco, entre 2010 e 2017. Utilizou-se a técnica de análise fatorial por componentes principais para a elaboração do índice de carência social. Na análise espacial, aplicou-se o estimador bayesiano empírico local, e verificou-se a autocorrelação espacial de Moran. ***Resultados:*** O índice de carência social selecionou dois fatores que, juntos, explicaram 77,63% da variância total. A taxa de mortalidade fetal evitável apresentou aumento entre estratos de carência social, com taxas de 8 por mil nascimentos (baixa carência), 8,1 por mil (média carência), 8,8 por mil (alta carência) e 10,7 por mil (muito alta carência social). Alguns municípios das mesorregiões São Francisco e Sertão tiveram, simultaneamente, elevada mortalidade fetal e fetal evitável, além de índice de carência social muito alto. ***Conclusão:*** A análise espacial identificou áreas com maior risco para a mortalidade fetal. O índice de carência social relacionou alguns determinantes das mortes fetais em áreas com piores condições de vida. Detectaram-se áreas prioritárias para a intervenção das políticas públicas de redução da mortalidade fetal e seus determinantes.

Palavras-chave: Mortalidade fetal. Estatísticas vitais. Análise espacial. Iniquidade social.

INTRODUCTION

Geographic areas with great social needs are responsible for a significant number of preventable fetal deaths in the world, particularly in Africa and Latin America[1]. It is estimated that 2.6 million fetal deaths occur annually, mostly due to preventable causes[2]. The Brazilian fetal mortality rate was 10.8 deaths per thousand births in 2015[3]. The Northeast had the highest rate among the regions of the country, with 13.2, while the state of Pernambuco had a rate of 12.08 per thousand births[3].

Fetal death is defined as the product of pregnancy that shows no sign of life after the expulsion or complete extraction from the maternal organism[4]. Avoidable deaths are sentinel events, unnecessary and preventable events due to the proper functioning of health services with access to effective medical technologies[5].

The elimination of preventable fetal mortality is part of the commitments made in the action plan for all newborns[4]. This plan consists of a global movement to eliminate preventable fetal mortality and reduce regional disparities by 2035[6]. To this end, it is necessary to face social needs and monitor them[4,6]. High rates of preventable fetal mortality explain the inefficiency of intersectoral policies that promote housing, sanitation, education, work, and income conditions to guarantee quality of life and the right to reproductive planning, healthy pregnancy, and humanized childbirth for socially vulnerable women[7,8].

In epidemiological studies, the development of Social Deficiency Indices (*Índices de Carência Social* – ICS) show that indicators referring to poverty, inadequate water supply, lack of a sewage network, absence of own housing, and low education are linked to the risk of fetal death[8,9]. To assess the relationship between socioeconomic conditions and public health problems, statistical models such as the Generalized Linear Models (GLM) have been used to model the mean of the response variable[7], however many phenomena require that the modeling of other distribution parameters be considered[7]. Thus, the use of the framework for the Generalized Additive Models for Location, Scale and Shape (GAMLSS) stands out for allowing to model the response variable and to specify all its parameters as linear functions of a set of explanatory variables[10,11].

Studies on social deprivation and fetal mortality can use spatial analysis techniques for visualization, exploratory analysis, and modeling of georeferenced data[9-12]. Such analysis makes it possible to identify the factors in the territory that hinder access to basic goods and services and favor the occurrence of preventable deaths[8,13].

In national studies, although the production is increasing on fetal mortality, there are still few studies developed in the Northeast Region[8,13]. Hence the importance of analyses on the spatial distribution of preventable fetal mortality and its relationship with social deprivation in states like Pernambuco, which have a rate above the national average and inequalities expressed by epidemiological indicators and living conditions[2,7]. Such analyses may contribute to the development of public policies aimed at reducing health inequalities[13,14].

Considering that composite indices are useful instruments to investigate health care inequalities and socioeconomic conditions[8], this study aimed to develop an ICS for the stratification of municipalities and the identification of priority areas for the reduction of fetal mortality.

METHODS

An ecological study whose unit of analysis was the municipalities of Pernambuco, located in the Northeast Region of Brazil, was carried out. The state had 9,557,071 inhabitants in 2019[15], distributed in five mesoregions: São Francisco (15 municipalities); *Sertão* (41); *Agreste* (71); Mata (43); and Metropolitan Region of Recife (15)[15].

The study included all fetal deaths (occurring after the 22nd complete week of gestation, or 154 days, or fetuses weighing 500 g or more or height from 25 cm) from mothers residing in the state of Pernambuco, from 2010 to 2017.

Deaths were considered preventable by the criteria of the Brazilian list of causes of preventable deaths (*lista brasileira de causas de mortes evitáveis* – LBE) due to interventions by the Unified Health System (*Sistema Único de Saúde* – SUS)[16]. This list uses the categories: preventable, ill-defined causes, and other causes that are not clearly avoidable.

Data from the Mortality Information System (*Sistema de Informação sobre Mortalidade* – SIM) and the Live Birth Information System (*Sistema de Informações sobre Nascidos Vivos* – Sinasc) were used to calculate fetal mortality and preventable fetal mortality rates.

For the construction of the ICS, Pearson's correlation of 64 social indicators related to demography (13), education (10), sanitation (9), health (12), work (8), and vulnerability (12) with the preventable fetal mortality rate (Supplementary Material Chart 1). Indicators with $p < 0.05$ remained in the process.

The indicators used in the elaboration of the ICS were: proportion of women heads of household, without complete elementary school, and with children under 15 years of age; dependency ratio; distortion rate of secondary education due to total administrative dependency (state, municipal, federal or private); proportion of the population with bathroom and running water; proportion of unemployed persons aged 18 years old or older; and proportion of the extremely poor and mean household income of those vulnerable to poverty (Table 2 of Supplementary Material).

The Bartlett[17] sphericity test and the Kaiser-Meyer-Olkin test (KMO)[18] were applied to identify whether the correlation matrix with the chosen indicators was statistically different from the identity matrix. The technique used in the construction of the ICS was the factor analysis by main components, which allows simplifying the data, reducing the number of indicators. These are called principal components or factors and are obtained using the linear combinations of the original indicators[19]. The relationships between each original indicator and the new factors are measured according to the factor loads on the components.

The indicators used for the creation of the ICS were normalized by Equation 1:

$$X' = \frac{X - média\ (\mathrm{X})}{\text{desvio padrão (X)}} \tag{1}$$

The factors to be extracted were defined by means of the graphic of variance *versus* the number of components (scree plot), in which the points at the highest slope indicate the appropriate amount of components to be retained. The reliability of the factors was evaluated, and the index ≥ 0.50 was considered acceptable[17].

After finding the acceptable factors, the index was normalized to the interval [0.1] by Equation 2:

$$ICS = \frac{CP_1 - mín\ (\mathrm{CP_1})}{\text{máx (CP}_1\text{)- mín (CP}_1\text{)}} \tag{2}$$

To explain the relationship between the ICS and the preventable fetal mortality rate, the regression model was used for the Box-Cox T probability distribution[20], which obtained the lowest Akaike information criterion (AIC)[21] among the models tested by the regression analysis framework GAMLSS[22] (in which distributions were tested for strictly positive data). The Box-Cox T distribution[20] has the following parameters: μ (the median); σ (a term for variability); ν (asymmetry); and τ (kurtosis). The coefficient of variation was calculated, which can be approximated (for small σ, moderate ν, and moderate or large τ) by Equation 3:

$$\hat{cv} = \hat{\sigma}\left(\frac{\hat{\tau}}{\hat{\tau} - 2}\right)^{\frac{1}{2}} \tag{3}$$

We chose to use the original parameterization of the distribution[20], since the link function for the location parameter (which, in this case, is the median) is the identity function, which is easy to interpret.

The use of GAMLSS makes it possible to model all parameters of a probability distribution, since many phenomena do not present the assumptions of usual linear regression models, for example[22]. GAMLSS has a wide range of available probability distributions, being flexible for the analyses, which allows for rich interpretations and better performance in terms of adjustments[22].

To create the social need ranges, four clusters were generated using the k-means clustering technique to distinguish municipalities with similar indices. The number of clusters was obtained by the elbow graph, which resulted in the strata of social need: low (0–0.29), medium (0.29–0.49), high (0.49–0.77), and very high (0.77–1). The R programming language, version 3.6, and the GAMLSS[22] packages, version 5.1-5, were used for modeling, and FactoMineR[23], version 2.0, for the composition of the ICS.

In the spatial analysis of the TerraView[24] program, version 4.2.2, the municipalities were stratified by the ICS (low, medium, high, and very high) and by the rates of fetal mortality and preventable fetal mortality. For the spatial smoothing of these rates, the local empirical Bayesian method was applied, which, to calculate the estimate locally, uses the geographical neighbors of the area in which the rate is to be calculated, converging toward a local mean[25].

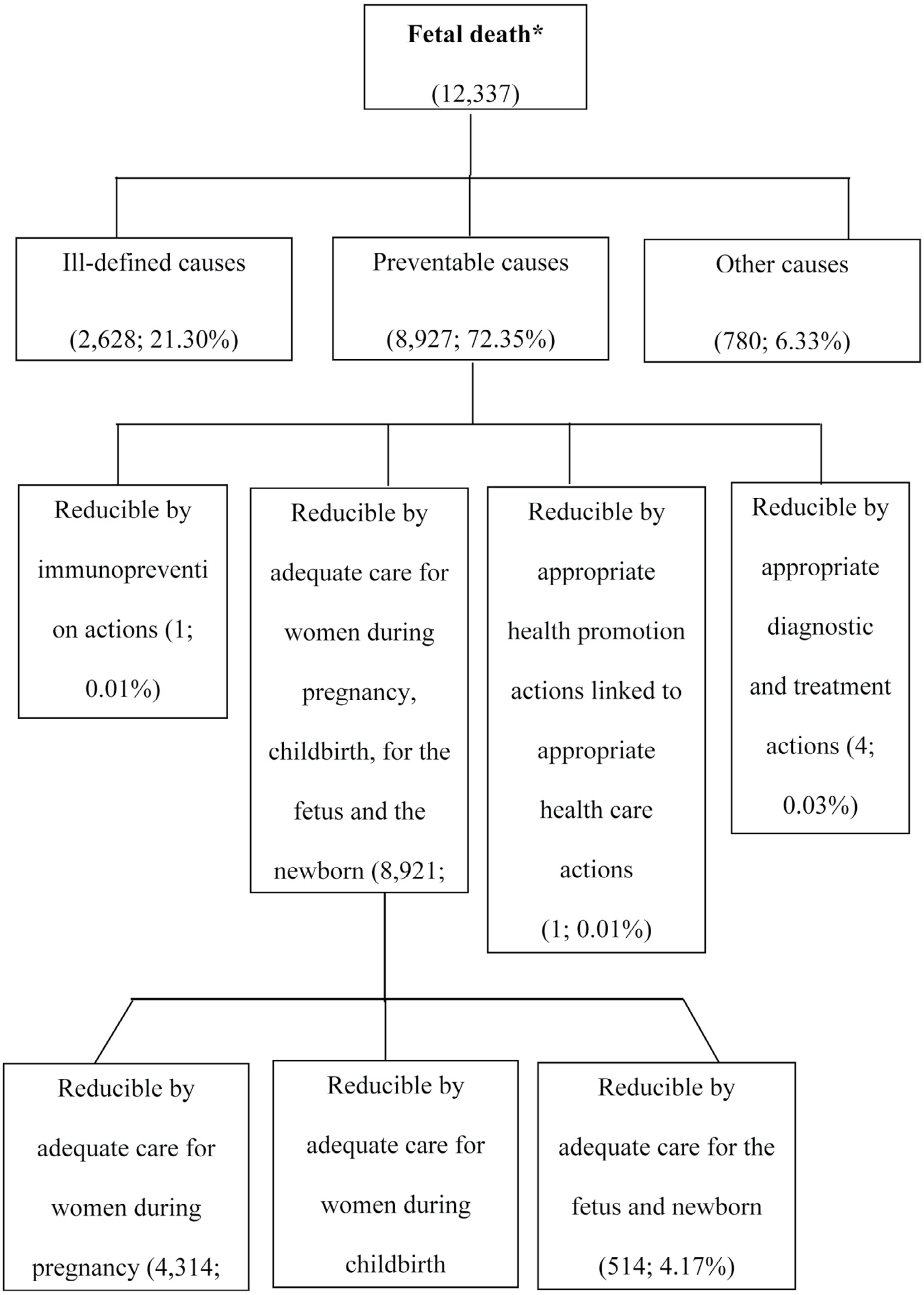
The spatial autocorrelation of preventable fetal mortality rates and ICS was estimated by the Local Moran Index, a decomposition of the Global Moran Index[26]. To compare the values of the attribute in an area with the mean of its neighbors, a two-dimensional graph was formed and divided into four quadrants identified in the Box Map: Q1 (high-high); Q2 (low-low); Q3 (high-low); and Q4 (low-high)[27]. The Moran Index ranges from -1 (inverse correlation) to +1 (direct correlation). Results close to zero demonstrate the absence of significant spatial autocorrelation in neighboring areas[26]. In the Moran Map, the statistically significant areas ($p > 0.05$) were highlighted in each of the four quadrants of the Moran scattering diagram. The LISA Map made it possible to detect clusters with the significance of 95, 99 and 99.99%.

The study was approved by the Research Ethics Committee of the Health Sciences Center of *Universidade Federal de Pernambuco* on June 12th, 2018 (Certificate of Presentation of Ethical Appreciation — CAEE: 13981419.6.0000.5208).

RESULTS

There were 12,337 fetal deaths and, of these, 8,927 (72.35%) due to preventable causes, of which 4,314 (34.96%) were due to adequate care for women during pregnancy (Figure 1).

The mean distortion rate of high school due to administrative dependence (27.30) was similar to the proportion of women heads of household, without complete elementary



*Ignored (2; 0.02%).

Figure 1. Classification of fetal deaths according to the Brazilian List of Avoidable Causes of Death. Pernambuco. 2010–2017.

school and with children under 15 years of age (27.79). The average proportion of employed persons without income aged 18 or over (19.16) was similar to the proportion of extremely poor (19.63), but their different coefficients of variation, with 65.6 and 42.8%, respectively (Table 1 of Supplementary Material).

The Bartlett sphericity test ($\chi^2 = 144.463$; $p < 0.01$) and the KMO coefficient (0.8) showed that the correlations between the items were adequate for the factor analysis, as well as the correlations between the indicators.

There was a high correlation between the dependency ratio and the proportion of extremely poor (0.79), as well as between the average household income of the vulnerable and poverty (-0.80). There was a high correlation between the proportion of extremely poor people and the variables proportion of the population in households with bathrooms and running water (-0.71) and the proportion of employed persons without income (0.81). The mean household income of those vulnerable to poverty has a high correlation with the proportion of the employed without income (-0.78) and the proportion of extremely poor (-0.97) (Table 1).

To evaluate the number of factors to be extracted, eigenvalues (> 1.5) and scree plots were used. Two factors together explained 77.63% of the total variance. The ICS was considered for the first principal component (PC1) and explained 63.58% of the total variance. Five variables showed a strong correlation (> $|0.70|$) with social deprivation, as indicated in PC1, with a factor load greater than 70%. PC2 represented the education dimension and explained 14.05% of the total variance (Table 2).

Table 1. Correlation matrix between the variables that make up the Social Deficiency Index. Recife (PE), Brazil, 2010–2017.

Variable	1	2	3	4	5	6	7
Proportion of female heads of household without complete elementary school and with children under 15 years of age	1.00						
Dependency ratio	0.60	1.00					
Distortion rate in high school due to administrative dependency	0.16	0.37	1.00				
Proportion of population in households with bathroom and running water	-0.40	-0.64	-0.12	1.00			
Proportion of employed persons with no income aged 18 years old or older	0.41	0.67	0.15	-0.75	1.00		
Proportion of extremely poor people	0.48	0.79	0.26	-0.71	0.81	1.00	
Mean household income of those vulnerable to poverty	-0.45	-0.80	-0.26	0.67	-0.78	-0.97	1.00

Table 2. Eigenvalues of the estimated principal components. Recife (PE), Brazil, 2010–2017.

Variable	CP1	CP2
Proportion of female heads of household without complete elementary school and with children under 15 years of age	0.62	0.08
Dependency ratio	0.89	0.16
Distortion rate in high school due to administrative dependency	0.33	0.91
Proportion of population in households with bathroom and running water	-0.81	0.26
Proportion of employed persons with no income aged 18 years old or older	0.87	-0.23
Proportion of extremely poor	0.95	-0.06
Average household income of those vulnerable to poverty	-0.93	0.04
Variance	4.41	0.93
Explained variance ratio	63.58	14.05
Accumulated explained variance ratio	63.58	77.63

PC: principal component.

As for the model's estimates, the following results are true:

$$\widehat{\mu_i} = 7{,}1 + 2{,}44$$
$$\widehat{\sigma_{ij}} = e^{-2+0{,}66F_{\text{Carência média}}+0{,}62F_{\text{Carência alta}}-0{,}31F_{\text{Carência muito alta}}}$$
$$\widehat{v_i} = 7{,}1 + 2{,}44$$
$$\widehat{\tau_{ij}} = e^{16{,}25-12{,}82F_{\text{Carência média}}-15{,}22F_{\text{Carência alta}}-16{,}49F_{\text{Carência muito alta}}}$$

Where:
i = municipalities in the state of Pernambuco;
j = ICS social deprivation bands (low deprivation is the reference range).

The preventable fetal mortality rate increased among the social strata, with rates of 8 (low deprivation), 8.1 (medium deprivation), 8.8 (high deprivation) and 10.7 per thousand (very high social deprivation) . There were 44 municipalities with low ICS, 66 with medium, 61 with high, and 13 municipalities with very high (Figure 2). The estimated regression model explains that, for each 0.1 point of ICS, the preventable fetal mortality rate has a median increase of 0.24.

In the spatial analysis, the fetal mortality rate was 12.1 per thousand births, and the preventable fetal mortality was 8.5 per thousand births. With the Bayesian analysis, the municipality of Moreilândia, located in the Sertão mesoregion, presented a higher rate of fetal mortality (55.10) (Figure 2B) and preventable fetal mortality (37.34) (Figure 2G).

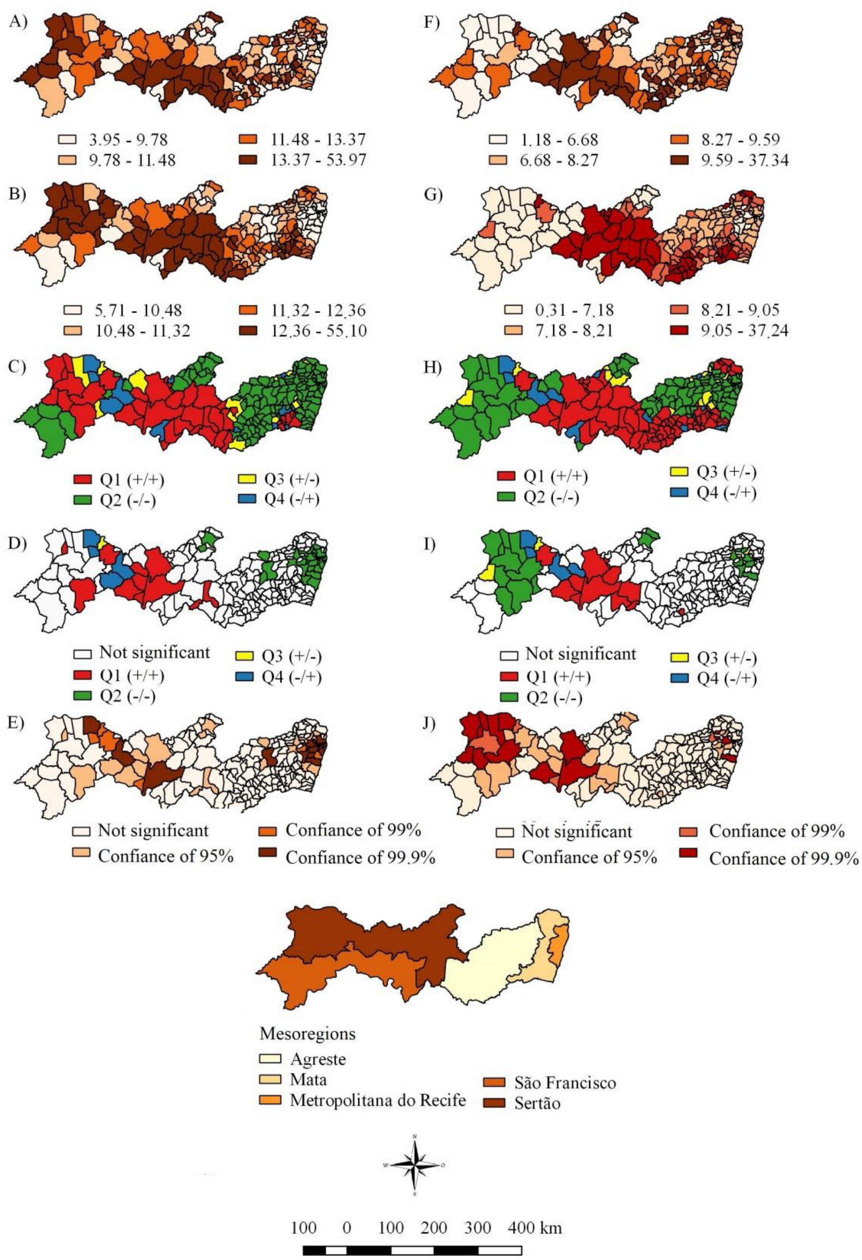


Figure 2. (A) Thematic map of the fetal mortality rate; (B) thematic map of the Bayesian fetal mortality rate; (C) Box Map of the Bayesian fetal mortality rate; (D) Moran Map of the Bayesian fetal mortality rate; (E) LISA Map of the Bayesian fetal mortality rate; (F) thematic map of the preventable fetal mortality rate; (G) thematic map of the Bayesian preventable fetal mortality rate; (H) Box Map of the Bayesian preventable fetal mortality rate; (I) Moran Map of the Bayesian preventable fetal mortality rate; (J) LISA Map of the Bayesian preventable fetal mortality rate. Pernambuco, 2010–2017.

As for the ICS, a higher rate was found in the municipality of Carnaubeira da Penha (São Francisco mesoregion) (Figure 3A). The Global Moran Index found significant spatial autocorrelation for the Bayesian fetal mortality rate (I = 0.10; p = 0.05), for the Bayesian preventable fetal mortality rate (I = 0.13; p = 0.03), and for the ICS (I = 0.53; p = 0.01).

In the Box Map, priority clusters (Q1) were detected for Bayesian fetal mortality in the Mata, São Francisco and Sertão mesoregions (Figure 2C). For Bayesian preventable fetal mortality, Q1 clusters were seen in all mesoregions, except in Metropolitan Recife (Figure 2H). Q1 clusters were identified for the ICS, especially in the Agreste, São Francisco and Sertão mesoregions (Figure 3B).

In the Moran Map, priority areas (Q1) for Bayesian fetal mortality and preventable Bayesian fetal mortality were seen in the São Francisco and Sertão mesoregions (Figures 2D

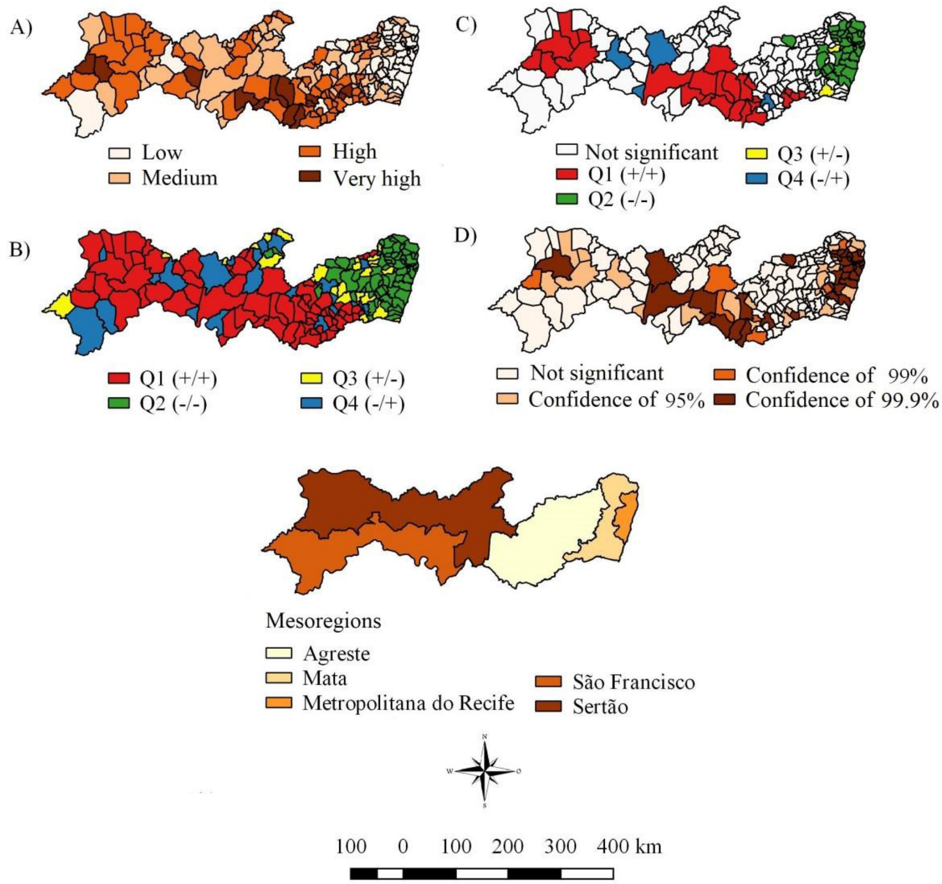


Figure 3. (A) Thematic map of the Social Deficiency Index; (B) Box Map of the Social Deficiency Index; (C) Moran Map of the Social Deficiency Index; (D) LISA Map of the Social Deficiency Index. Pernambuco, 2010–2017.

and 2I). The Q1 areas for the ICS were observed mainly in the Agreste, São Francisco and Sertão mesoregions (Figure 3C).

In the LISA Map, among the Q1 cluster, there was 99.9% confidence in the São Francisco mesoregion for Bayesian fetal mortality (Figure 2E), as well as in the São Francisco and Sertão mesoregions for Bayesian preventable fetal mortality (Figure 2J) and ICS (Figure 3D).

DISCUSSION

Fetal deaths occurred mainly due to preventable causes and weaknesses in care for women during pregnancy and childbirth. In the elaboration of the ICS, the variables referring to demography, education, sanitation, work, and vulnerability were associated with mortality. The preventable fetal mortality rate was higher among the strata with the greatest social need. High fetal and preventable fetal mortalities, in addition to very high ICS, occurred mainly in the São Francisco and Sertão mesoregions.

The fetal mortality rate in this study (12.1) was higher than the national mean in 2015, which was stable since 2010[28], a result similar to that found in the state of Ceará, with 12.6 deaths per thousand in 2012[27]. Brazilian fetal mortality is heterogeneous in the regions of the country, with the highest rates located in states in the Northeast, due to its precarious socioeconomic conditions[28].

In this study, preventable deaths predominated among fetal deaths. This finding shows weaknesses in the effectiveness of health systems. Analyses of preventable fetal deaths allow assessing the performance of prenatal and obstetric care services and contributing to understand the factors involved in their occurrence[29]. Monitoring this indicator makes it possible to compare the situation of maternal and child health actions in different periods and geographic spaces[7] and is essential for the development of public policies aimed at reducing deaths[14,30].

Fetal deaths were shown to be reducible mainly by adequate care for women during pregnancy, although in a lower proportion than that found by another study[31]. There is a consensus on the importance of adhering to prenatal care, minimum frequency of six consultations, clinical follow-up along with laboratory and imaging tests during pregnancy as strategies to prevent maternal, fetal, and infant deaths[32]. Quality prenatal care acts in health promotion, prevention and early detection, and treatment of diseases[33,34], however, according to a Brazilian study carried out in 2019, attendance lower than recommended persists, and less than 1/3 of pregnant women assisted in public health units did not perform laboratory tests in the first and third trimesters, or imaging tests during pregnancy[33]. An expressive part of fetal antepartum deaths result from inappropriate prenatal care, with difficulty in accessing laboratory and imaging tests, making it impossible for maternal pathological conditions to be prevented, identified, monitored, and treated[35].

Another portion of fetal deaths, which occurred during childbirth, could be prevented by timely access to obstetric services and quality humanized care based on good practices and the best technical and scientific evidence[35,36]. Good practices during labor begin with access to health facilities with sufficient human and structural resources for adequate assistance, which avoids the parturient's pilgrimage in the hospital network[36,37]. They contemplate the reception of pregnant women, their entry into the health service and the performance of the multidisciplinary team, to guarantee women's right to obstetric care without unnecessary and sometimes iatrogenic medical interventions[36,37].

In this study, the preventable fetal mortality rate, which is related to poor care for women during pregnancy and childbirth, increased as social deprivation increased. The technique of factor analysis by principal components was used in another study to develop the indices that pointed to social variables linked to fetal mortality[9]. A survey carried out in Spain indicated that women with low schooling and coming from areas with a low human development index (HDI) had approximately four times the risk of fetal death[30]. As identified in this study, research carried out in Argentina showed a socioeconomic index associated with fetal mortality and composed of variables related to housing, sanitation, education, and work[9].

In the spatial analysis, the application of the Bayesian technique for the preventable fetal and fetal mortality rates allowed the stabilization of the rates between the nearby areas. An international survey that verified inequities in fetal health and survival found the importance of using Bayesian analysis in local smoothing and in identifying areas with the highest rates[14].

In the analysis of spatial autocorrelation, high priority clusters were verified for fetal mortality and social deprivation in the state of Pernambuco. These clusters were located in municipalities in the São Francisco and Sertão mesoregions, which showed priority for fetal mortality, preventable fetal mortality, and social deprivation. The municipalities in these regions also had low or medium municipal HDI[38]. This aspect reinforces the importance of intervention in intersectoral public policies that act on the basic needs of the population to guarantee the best living conditions and expand the possibilities of fetal survival[39].

The spatial distribution of preventable fetal mortality and its relationship with the social deficiency found in this study made it possible to identify municipalities and health regions with greater social and health care needs. As observed in other studies, spatial analysis is able to guide the health sector in choosing priority areas for maternal and child care and health surveillance actions[40,41]. The use of geoprocessing techniques allows to detect risk factors for death and causes of death in different population groups and to monitor the distribution of mortality rates in geographic spaces[7,9].

The limitations of this study were related to the use of secondary data, with a possible underreporting of deaths and incompleteness of information systems, which can underestimate the rates presented, particularly in the most distant municipalities of the Metropolitan Region of Recife. Despite this, there are studies that show the level of adequacy of information in the state[42]. Another limitation was due to the use of LBE, which is not exclusive for fetal deaths, but includes neonatal deaths that present circumstances and etiologies similar to those of fetal deaths. As the units of analysis were municipalities, there may have been inequalities due to heterogeneous characteristics in population groups.

The results of the study showed that fetal deaths could have been prevented mainly by adequate care for women during pregnancy and childbirth. The ICS revealed that variables related to demography, education, sanitation, work, and vulnerability were associated with fetal mortality, and the preventable fetal mortality rate increased as social deprivation increased. Clusters of municipalities were identified with, simultaneously, the highest rates of fetal mortality and preventable fetal mortality, in addition to higher ICS. Such clusters were considered priority areas for the reduction of spatial inequalities in fetal mortality.

n the areas highlighted in this study, it is recommended to expand the coverage of the Family Health Strategy, the reorganization of the decentralized childbirth care network by regions of the state, a greater emphasis on obstetric care based on evidence and good practices, and the intensification of health surveillance for fetal death. The identification of the causes of death, the circumstances of the occurrence and the rectification of the basic causes allow the correct specification in the SIM and the appropriate framework in the avoidability classification. The strengthening of death surveillance and the improvement of vital statistics may favor the planning of actions for the organization of the maternal and child care network, particularly when deepening the theme through spatial analyses that identify the areas of greatest social vulnerability and priority for interventions.

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Received on: 08/24/2020
Revised on: 11/12/2020
Accepted on: 12/03/2020

Authors' contribution: Canuto IMB, Bonfim CV and Macêdo VC contributed to the design of the study, analysis and interpretation of data, writing of the manuscript, critical review, and its intellectual content. Portugal JL and Costa HVV contributed to the elaboration of the data. Oliveira CM and Frias PG contributed to the analysis and interpretation of the data and writing of the manuscript. All authors approved the final version of the manuscript.