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SPACE-TEMPORAL DYNAMICS AND FACTORS ASSOCIATED WITH NEWBORN MORTALITY

Dinâmica Espaço-temporal e fatores associados à mortalidade neonatal

Dinámica Espacio-temporal y factores asociados a la mortalidad del recién nacido

Jessica Cristina Moraes de Araújo[1]
Daniele de Brito Sousa[2]
Leonardo Miranda Ribeiro[3]
George Jó Bezerra Sousa[4]
Thatiana Araújo Maranhão[5]
Maria Lúcia Duarte Pereira[6]

ABSTRACT

Objective: to analyze the spatial and temporal distribution of neonatal mortality and associated factors in Piauí from 2007 to 2017. **Method:** the Joinpoint method, Bayesian statistics and the Scan technique were used. The multivariate analysis of the indicators was performed using the Ordinary Least Squares Estimation model, considering p<0.05. **Results:** neonatal mortality decreased linearly and significantly over the period studied. The highest Bayesian rates ranged from 16.34 to 18.38 deaths per 1,000 live births, especially in Southeast Piauí. There was a negative association between neonatal mortality and the variables: Illiteracy rate (β = -0.60; p= 0.027), Family Health Strategy Coverage (β = -2.80; p= 0.023) and Human Development Index Municipal (β = -0.60; p= 0.003). **Conclusion:** neonatal mortality continues to decrease and its distribution in the territory proved to be irregular. Socioeconomic and health indicators influence neonatal mortality in Piauí.

DESCRIPTORS: Infant Mortality; Epidemiology; Time Series Studies; Ecological Studies; Spatial Analysis;

[1,2,3,6] State University of Ceará, Ceará, Fortaleza, Brazil.
[4] Department of Health of the State of Ceará, Ceará, Fortaleza, Brazil.
[5] State University of Piauí, Piauí, Parnaíba, Brazil.

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Corresponding Author: Greice Carvalho de Matos greicematos1709@hotmail.com

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RESUMO

Objetivo: analisar a distribuição espacial e temporal da mortalidade neonatal e fatores associados no Piauí de 2007 a 2017. **Método:** foi utilizado o método Joinpoint, estatística bayesiana e a técnica de varredura Scan. A análise multivariada dos indicadores foi realizada através do modelo Ordinary Least Squares Estimation, considerando-se p<0,05. **Resultados:** a mortalidade neonatal reduziu de forma linear e significativa ao longo do período estudado. As maiores taxas bayesianas variaram de 16,34 a 18,38 óbitos por 1.000 nascidos vivos, especialmente no Sudeste piauiense. Houve associação negativa entre a mortalidade neonatal e as variáveis: Taxa de analfabetismo (β = -0,60; p= 0,027), Cobertura da Estratégia Saúde da Família (β = -2,80; p= 0,023) e Índice de Desenvolvimento Humano Municipal (β = -0,60; p= 0,003). **Conclusão:** a mortalidade neonatal segue decrescente e sua distribuição no território mostrou-se irregular. Indicadores socioeconômicos e de saúde influenciam a mortalidade neonatal no Piauí.

DESCRITORES: Mortalidade Infantil; Epidemiologia; Estudos de Séries Temporais; Estudos Ecológicos; Análise Espacial;

RESUMEN

Objetivos: analizar la distribución espacial y temporal de la mortalidad neonatal y factores asociados en Piauí de 2007 a 2017. **Método:** se utilizó el método Joinpoint, la estadística bayesiana y la técnica Scan. El análisis multivariado de los indicadores se realizó mediante el modelo de Estimación por Mínimos Cuadrados Ordinarios, considerando p<0,05. **Resultados:** la mortalidad neonatal disminuyó lineal y significativamente durante el período estudiado. Las tasas bayesianas más altas oscilaron entre 16,34 y 18,38 muertes por 1.000 nacidos vivos, especialmente en el Sudeste de Piauí. Hubo asociación negativa entre la mortalidad neonatal y las variables: Tasa de Analfabetismo (β = -0,60; p= 0,027), Cobertura de la Estrategia de Salud de la Familia (β = -2,80; p= 0,023) e Índice de Desarrollo Humano Municipal (β = -0,60; p= 0,003). **Conclusión:** la mortalidad neonatal continúa en descenso y su distribución en el territorio resultó ser irregular. Indicadores socioeconómicos y de salud influyen en la mortalidad neonatal en Piauí.

DESCRIPTORES: Mortalidad Infantil; Epidemiología; Estudios de Series Temporales; Estudios Ecológicos; Análisis Espacial.

INTRODUCTION

Neonatal mortality (NM) is the death of children up to 28 days old and is considered one of the most sensitive indicators for assessing access to health services and the quality of care provided to pregnancy, childbirth and the newborn (NB).[1]

Over the last few decades, infant mortality in Brazil has fallen significantly, mainly due to the reduction in post-neonatal mortality (28 days to one year of age), which is attributed to the improvement in the socio-economic and health conditions of the population.[2] On the other hand, neonatal mortality has shown an insignificant reduction and is the main component of mortality in the first year of life, since it is responsible for around 70% of deaths in this age group.[3]

Neonatal mortality shows significant disparities between Brazilian regions, with the North and Northeast having the highest rates compared to the South and Southeast. In 2020, the Northeast, one of the poorest regions in the country, had a neonatal mortality rate of 9.4 deaths per 1,000 live births, higher than the national rate (8.3 deaths per 1,000 live births). In addition, it should be noted that most northeastern states have high neonatal mortality rates, including Piauí, which had 9.2 deaths per 1,000 live births in 2020.[4,5]

In this context, there is a need to analyze the distribution of neonatal mortality over time and space and the factors associated with its occurrence, considering that the findings can give visibility to the problem and provide information to managers for decision-making aimed at implementing actions and strategic planning to improve the quality of and access to health services, especially maternal and child services. From this perspective, ecological studies are of great interest, as they allow for the identification of areas at greater risk and in need of monitoring, making it possible to identify atypical patterns in the evolution of mortality levels and in the structure of its causes.[6] In view of the above, this study aims to analyze the spatial and temporal distribution of neonatal mortality, as well as the factors associated with its occurrence in the state of Piauí between 2007 and 2017.

METHOD

This is an ecological study using secondary data recorded in the Sistema de Informação sobre Mortalidade (SIM) e no Sistema de Informação sobre Nascidos Vivos (SINASC). The data was obtained from the website of the Departamento de Informática do Sistema Único de Saúde (DATASUS).

The geographical area of interest of this study is the state of Piauí, located in the Northeast region of Brazil. Piauí has 224 municipalities divided into four development mesoregions: Norte piauiense, Centro-norte piauiense, Sudeste piauiense and Sudoeste piauiense.[7]

The data for this study was collected in September 2019. They refer to the deaths of children under 28 days of age recorded in the SIM, according to the municipality of residence, and who died between 2007 and 2017. In addition, information on births recorded in SINASC was also taken into account, which helped calculate neonatal mortality rates.

The socioeconomic and demographic variables of the state's municipalities were obtained from the websites of the Instituto Brasileiro de Geografia e Estatística (IBGE) and DATASUS. Sixteen indicators related to income, work and housing conditions were collected. These indicators enabled the construction of the Ordinary

Least Squares (OLS) multivariate linear regression model, which aimed to identify the predictors of neonatal mortality.

The Annual Percentage Change (APC) was calculated using the free software Joinpoint Regression Program version 4.6.0.0 with a 95% confidence interval (95%CI) and 5% significance level. Negative APC values indicate a downward trend and positive values indicate an upward trend, while non-significant values indicate a stationary trend.

Microsoft Office Excel software was used to calculate the average crude neonatal mortality rates for each municipality in Piauí. To do this, the indirect method was used, where the numerator was the total number of neonatal deaths divided by the number of years studied (eleven) and the denominator was the population of live births in the central year (2012), multiplied by 1,000 live births. However, in order to minimize the instability of the crude rates, they were smoothed using the Local Empirical Bayesian method, adopting the contiguity criterion for the spatial proximity matrix.[8]

The formation of purely spatial clusters of neonatal deaths was assessed using the Scan spatial statistical technique. In order to identify clusters with high neonatal mortality rates, a circular base window corresponding to 50% of the population at risk was used, using the Poisson probabilistic model and a 5% significance level. The Scan method also made it possible to construct spatial maps of the Relative Risk (RR) for the formation of clusters.[8]

The dependent variable (neonatal mortality rate) and independent variables (socioeconomic variables) were adjusted using the multivariate Ordinary Least Squares Estimation (OLS) model. However, the regression model was not adjusted for the entire state of Piauí, but only for the municipalities that proved to be statistically significant clusters of neonatal deaths in the Scan spatial statistical technique. Thus, of the 224 municipalities in Piauí, 17 were part of the most likely primary cluster and 16 of the cluster considered secondary, totaling 33 municipalities included in the analysis.

TerraView v.4.2.2® and SatScan v.9.6® software were used to calculate Bayesian statistics and the Scan spatial statistical technique, respectively. The maps derived from these statistics were created using QuantumGis v.2.14.17® software. The OLS regression model was run using STATA v.12® software.

All the ethical and legal aspects of health research were respected, as recommended by Resolutions 466/12 and 510/2016 of the National Health Council. The project of which this study is a part was submitted to and approved by the Research Ethics Committee of the State University of Piauí (CEP/UESPI) under opinion no. 3.286.819 and CAAE no. 07558218.7.0000.5209.

RESULTS

In Piauí, between 2007 and 2017, 6,539 neonatal deaths were reported, with the majority being male (n=3,729; 57.0%), brown (n=4,517; 83.4%) and underweight (n=4,241; 68.4%). In addition, the highest proportion of neonatal deaths was among children whose mothers had seven years of schooling or less (n=2,742; 51.0%) and were aged between 20 and 29 (n=2,943; 48.8%) (Table 1).

Almost three out of every five children were born vaginally (n=3,724; 59.7%) and a significant proportion were premature, as 67.2% (n=3,885) were born from pregnancies lasting 36 weeks or less. The majority of deaths were due to conditions originating in the perinatal period (n=5,419; 81.7%) (Table 1).

Neonatal mortality fell from 14.4 deaths per 1,000 live births in 2007 to 10.4 deaths per 1,000 live births in 2017. The Joinpoint analysis shows that this reduction occurred linearly and significantly ($p<0.05$), with a 3.0% drop per year for the entire period analyzed.

Table 1 - General profile of neonatal deaths and maternal characteristics in Piauí, Northeast Brazil, 2007-2017. Parnaíba, PI, Brazil, 2020 (N= 6,539).

VARIABLES	n	%
Gender †		
Male	3.729	57,0
Female	2.810	43,0
Race/color ‡		
White	766	14,1
Black	123	2,3
Yellow	4	0,1
Brown	4.517	83,4
Indigenous	4	0,1
Mother's schooling §		
None	336	6,3
1 to 3 years	755	14,0
4 to 7 years	1.651	30,7
8 to 11 years	2.126	39,5
≥ 12 years	514	9,5
Mother's age ††		
10 to 19	1.601	26,6
20 to 29	2.943	48,8
30 to 39	1.302	21,6
40 or >	185	3,0
Type of delivery ‡‡		
Vaginal	3.724	59,7
Cesarean section	2.521	40,3
Gestational age §§		
Less than 22 weeks	354	6,2

22 to 27 weeks	1.182	20,4
28 to 31 semanas	1.160	20,1
32 to 36 semanas	1.189	20,5
37 to 41 semanas	1.833	31,7
42 weeks and over	64	1,1
Birth weight †††		
Low weight	4.241	68,4
Insufficient weight	743	11,9
Appropriate weight	1.084	17,4
Excess weight	142	2,3
ICD-10 Chapter ‡‡‡		
I. Some infectious and parasitic diseases	25	0,38
XVI. Some conditions originating in the perinatal period	5.419	81,7
XVII. Congenital malformations, deformities and chromosomal anomalies	1.098	16,6
XVIII. Symptoms, signs and abnormal clinical and laboratory findings	55	0,9
XX. External causes of morbidity and mortality	13	0,2
Other	16	0,22

† 112 cases with the sex field set to "unknown" were excluded.
‡ 1,237 cases with the race/color field set to "unknown" were excluded.
§ 1,269 cases with the mother's education field set to "unknown" were excluded.
†† 620 cases with the mother's age field set to "unknown" were excluded.
‡‡ 406 cases with the type of delivery field set to "unknown" were excluded.
§§ 22 cases with the gestational age field set to "unknown" were excluded.
††† 441 cases with the birth weight field set to "unknown" were excluded.
‡‡‡ 25 cases with the ICD-10 chapter field set to "unknown" were excluded.

Figure 1 - Time trend by JoinPoint of neonatal deaths in Piauí from 2007-2017. Parnaíba, PI, Brazil, 2020.

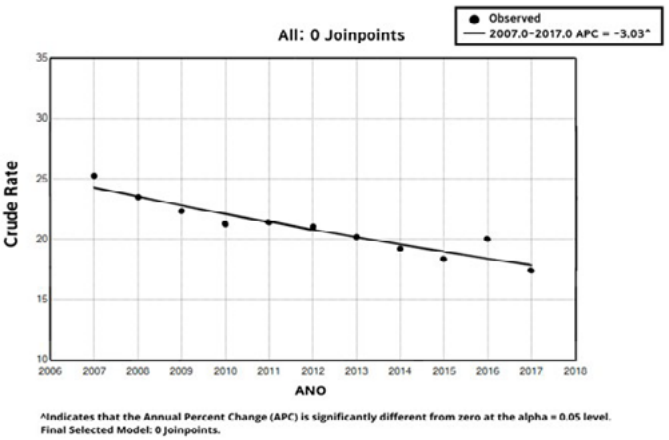

Figura 2 - Spatial distribution of the crude incidence rate (A) and the Bayesian mortality rate (B). Relative risk (C) and neonatal mortality clusters (D). Parnaíba, PI. Brazil, 2020

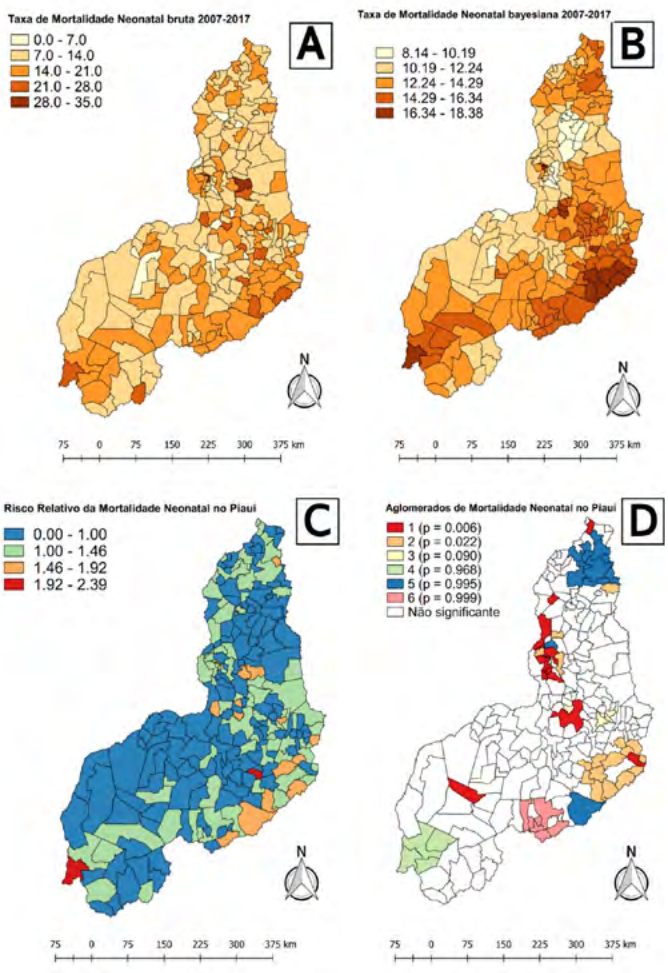

Table 2 - Spatial clusters of neonatal deaths in Piauí defined by purely spatial scan statistics. Parnaíba, PI, Brazil, 2020.

Cluster	No. of municipalities	Distance (Km)	No. of Cases	Expected number of cases	RR †	LLR ‡	p-value
1	17	66,44	2.381	2.210,14	1,12	9,79	0,006
2	16	99,85	254	194,37	1,31	8,60	0,022
3	4	15,85	220	169,71	1,30	7,00	0,090
4	4	78,46	79	59,02	1,34	3,08	0,969
5	13	72,95	345	304,597	1,39	2,69	0,995
6	7	49,75	176	148,09	1,19	2,53	0,999

† RR: Relative risk for the cluster compared to the rest of the state.
‡ LLR: Log-likelihood ratio test.

The map of the crude neonatal mortality rate (Map A) shows irregular dispersion, with no apparent spatial pattern. Given this instability, Bayesian smoothing generated more stable corrected indicators that showed a clearer regional pattern of neonatal mortality, with the elimination of municipalities with a rate equal to zero. Map B shows that most municipalities had rates ranging from 12.24 to 14.29 deaths per 1,000 live births. Some municipalities, concentrated especially in the southeast of the state, had the highest rates (16.34 to 18.38 deaths per 1,000 live births) (Figure 2).

In map C, the municipalities represented in blue have a lower relative risk of neonatal death than the relative risk observed for the whole of Piauí. Conversely, the municipalities highlighted in the other colors have a higher relative risk. Two municipalities are highlighted in red: Barreiras do Piauí and Bela Vista do Piauí, which have a 1.92 to 2.39 times higher risk of neonatal death compared to the other municipalities in Piauí (Figure 2).

Map D shows two clusters with statistical significance ($p<0.05$). The primary cluster ($p=0.006$), i.e. the one with the lowest probability of having occurred at random, included 17 municipalities (in red). These include Teresina, São Pedro do Piauí, Monsenhor Gil, Parnaíba and Oeiras. The second cluster, although secondary, was also statistically significant ($p=0.022$) and included 16 municipalities (in orange).

Table 2 shows the details of the clusters of deaths defined by the purely spatial Scan statistics. The primary cluster has a radius of 66.44 km and its municipalities have an average 1.12 times greater risk of neonatal death.

The fit of the multivariate regression model shows that the set of variables selected was able to partially explain the variability (R2) of neonatal mortality by 33.73%. The independent variables investigated that showed a negative association with neonatal mortality in the final model were: illiteracy rate ($\beta = -0.60$; $p= 0.027$), FHS coverage ($\beta = -2.80$; $p= 0.023$) and MHDI ($\beta = -0.60$; $p= 0.003$) (Table 3).

Table 3 - Final Multiple Linear Regression Model (Ordinary Least Squares) of the factors associated with neonatal mortality in the municipalities in Piauí that proved to be clusters of the problem. Piauí, Brazil, 2007-2017.

Independent Variables†	Neonatal Mortality		
	Coefficient (β)	IC 95%	Value of p
Constant	122,33	(118,87 – 619,27)	0,005
Illiteracy rate	-0,60	(-1,13 – -0,07)	0,027
FHS coverage	-2,80	(-5,18 – -0,42)	0,023
IDHM	-97,50	(-157,77 – -37,22)	0,003

† Coefficient of determination (R2) = 0,3373.

DISCUSSION

In this study, the majority of neonatal deaths were recorded among male newborns, with low birth weight, premature babies and whose mothers had low levels of schooling and were between 20 and 29 years old, which is in line with studies carried out in other Brazilian contexts.[9,10] In addition, the fact that the majority of deaths were of brown race partly exposes the influence that ethnic differences have on the birth

conditions and survival of newborns, since this population tends to have associated unfavorable maternal characteristics, such as low income and greater difficulties in accessing health services.[11,12]

The downward trend in neonatal mortality over the years studied in Piauí may be associated with the health policies implemented, especially with regard to maternal and child health actions which began in the state in 2011 when the first stages of the Stork Network were implemented.[13,14] A study which evaluated the impact of the Stork Network on infant mortality in Pernambuco after its implementation showed a significant decrease in neonatal mortality rates, with the reduction being more pronounced in the early neonatal component.[14]

Research has shown that as a result of the implementation of the Stork Network, prenatal care has improved, with an increase in the number of pregnant women who have had seven consultations.[13,14] As a result, the downward trend in neonatal deaths was also repeated in Rio Branco, the capital of Acre, where the neonatal mortality rate fell by 4.73% per year from 1998 to 201622,[15], as well as in the municipality of Lagarto, in Sergipe, where there was a significant reduction of 5.79% in early neonatal mortality and 10.3% in late neonatal mortality.[16]

The results of this study show the uneven distribution of neonatal mortality in the state of Piauí. The map shows that the municipalities with the highest rates are located in the southeast of the state. In general, the municipalities that make up the southeast of Piauí are small, have a low MHDI, low population density and few health facilities.[17]

The formation of neonatal mortality clusters was observed in Teresina and Parnaíba, characterized by being the two most populous municipalities in Piauí and macro-regional references for medium and high-complexity healthcare for the north-central and northern parts of the state.[17] This situation can be explained by the higher local demographic density, the availability of specialized maternal and child care and neonatology centers and the higher concentration of births in these cities. These facts favor the possible incorrect filling in of the mother's residence field, with the address where the birth took place possibly being recorded as the residence.[18]

It is also important to consider that Piauí has a large territory and low population density, which makes it difficult to achieve homogeneous coverage of health services. This fragility in local service structures means that the capital, Teresina, is a reference point for the entire population of the state, which ends up overloading the system and can lead to a reduction in the quality of perinatal care offered.[18]

In this study, the Municipal Human Development Index (MHDI) was shown to be a protective factor for the occurrence of neonatal death in Piauí. This same result is also presented in other studies which reinforce the close association between socioeconomic conditions and neonatal mortality.[6,18] In sub-Saharan Africa, for example, a child is 10 times more likely to die in the first month of life than a child born in a country with higher development indices.[19] This data therefore exposes the inequality in income distribution in the state, revealing the need to implement and evaluate public policies aimed at guaranteeing socioeconomic equity in this region.

During the period studied, a negative association was found between illiteracy and neonatal mortality. This result should be interpreted with caution, given that maternal education is an indirect indicator of the family's socioeconomic status and a risk predictor for infant mortality.[12,20,21] Regions with higher levels of education are located in more developed regions and possibly have better death notification systems. Meanwhile, poorer areas with higher levels of illiteracy may have high unrecorded mortality rates due to underreporting of deaths.[22]

The negative association between neonatal mortality and FHS coverage found in this study highlights the importance of investing in the quality of health services at primary care level. This relationship can be explained by the importance of prenatal care offered by primary care, which is essential for maintaining the health and vitality of the newborn.[2] A study carried out in Paraná showed that women who had fewer than seven prenatal visits had a higher chance of neonatal death when compared to those who had seven or more visits.[14,23]

The actions carried out by the Family Health Strategy (FHS), such as prenatal care, childcare, vaccinations and guidance on breastfeeding, contribute to reducing neonatal mortality and increasing the life expectancy of newborns. In addition, the implementation of the FHS improves accessibility for women and children to health services and the development of a bond with professionals, contributing to the prevention of complications during pregnancy and the monitoring of risk situations for neonatal death.[24]

The main limitation of this study is the use of secondary data, which depends on the reliability and completeness of death certificates and live birth certificates. An example of this is the high number of variables with ignored answers, which hinders a more reliable analysis of the problem studied.

CONCLUSION

Neonatal mortality in the state of Piauí showed a downward trend between 2007 and 2017. The majority of deaths occurred among male children, born via vaginal delivery, brown, with low birth weight, premature, born to mothers aged between 20 and 29 and with up to seven years of schooling. The main cause of death was diseases related to the perinatal period. The distribution of deaths was uneven among the municipalities in Piauí, with high rates in the southeast of the state and clusters of mortality in the capital and other large cities that are benchmarks for maternal and child care.

Neonatal mortality in Piauí is associated with a low MHDI and low FHS coverage. This relationship reinforces the strong influence that socio-economic conditions and health care have on the life expectancy of newborns and once again

highlights the need to prioritize actions aimed at the social and economic development of the most vulnerable areas. This highlights the importance of developing strategies to strengthen Primary Health Care by improving prenatal care and monitoring child growth and development.

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