Infant mortality trends in the State of Rio Grande do Sul, Brazil, 1994-2004: a multilevel analysis of individual and community risk factors

Tendência da mortalidade infantil no Rio Grande do Sul, Brasil, 1994-2004: uma análise multinível de fatores de risco individuais e contextuais

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Abstract

The aim of this study was to analyze the trend in infant mortality rates in the State of Rio Grande do Sul, Brazil, from 1994 to 2004, in a longitudinal ecological study, by means of panel data analysis and multilevel linear regression (two levels: microregion and time) to estimate factors associated with infant mortality. The infant mortality rate decreased from 19.2‰ (1994) to 13.7‰ (2004) live births, and the principal causes of death in the last five years were perinatal conditions (54.1%). Approximately 47% of the variation in mortality occurred in the microregions, and a 10% increase in coverage by the Family Health Program was associated with a 1‰ reduction in infant mortality. A 10% increase in the poverty rate was associated with a 2.1‰ increase in infant deaths. Infant mortality was positively associated with the proportion of low birthweight newborns and the number of hospital beds per thousand inhabitants and negatively associated with the cesarean rate and number of hospitals per 100 thousand inhabitants. The findings suggest that individual and community variables display significant effects on the reduction of infant mortality rates.

Information Systems; Infant Mortality; Cause of Death

Introduction

The infant mortality rate (IMR), which expresses the probability of a live born infant dying before completing one year, is considered one of the most efficient indicators of a population's social, economic, and ethical development, and its follow-up allows inferences on the population's quality of life and its determinants [1,2,3].

Each year, some 11 million children die before reaching five years of age, the majority from avoidable causes and in poor countries. Of these, 7 million fail to complete their first year of life, with 70% of the deaths associated with nutritional causes or such diseases as respiratory infections, diarrhea, or malaria [4].

In Brazil, the infant mortality rate decreased by approximately 20% in five years, to 21.2 deaths per thousand live births in 2005 [5], leaving the country in 84th place in the United Nations (UN) ranking, led by Singapore (2.3), as opposed to Angola (187.5) [6].

The State of Rio Grande do Sul has consistently shown the lowest infant mortality rates in Brazil, decreasing from 19.2 (1994) to 13.7 (2004) deaths per thousand live births [5]. However, this rate is still higher than the acceptable value set by the World Health Organization (WHO), namely 10 deaths/thousand live births, a target already reached by such countries as Costa Rica, Chile, and Hungary [6].

Infant mortality is associated with numerous factors, summarized in a conceptual model proposed by Mosley & Chen [7] for developing countries, based on the assumption that social and economic determinants of infant mortality operate through proximate biological determinants. Thus, the decline in infant mortality is attributed, among other factors, to improvement in basic environmental sanitation, expanded access by the population to basic health services, control of diarrheic diseases, immunization, promotion of breastfeeding, greater coverage of prenatal care, and certain social programs [7].

Despite the decreases in infant mortality rates, there are persistent differences in the patterns of decline in mortality between geographic regions and population subgroups, i.e., differential decreases occur between States, as well as between microregions within a single State [3,8,9].

Infant mortality is divided into two components: neonatal (less than 28 days of life) and post-neonatal (28-364 days), since the two periods involve quite specific causes of death and thus require distinct preventive measures. Neonatal deaths can be considered avoidable through adequate prenatal and childbirth care [3,10,11]. Likewise, a portion of post-neonatal deaths, which are simpler to control, can be avoided since they are directly associated with quality of life, like basic environmental sanitation and access to health services [12].

Various studies have investigated maternal and infant characteristics as factors associated with infant mortality [12,13,14,15]. However, most of these studies overlook the inherent hierarchical structure in the data (multilevel structure), i.e., they fail to take into account the correlation between individuals in the same group, which can lead to incorrect inferences. Among the studies that consider the hierarchical structure, the majority only investigate grouping at the family level [16,17,18], overlooking the effects of the communities or regions in which the children and their mothers live.

In this sense, multilevel longitudinal studies are essential to expand knowledge on the changes that occur in a population [19]. In addition, they allow separately estimating the variability at each level, making possible the analysis of the individual or regional characteristics that can explain these differences, thereby contributing to preventive strategies [20,21,22].

Thus, this study's objectives were to analyze the trend in infant mortality rates and their components in the State of Rio Grande do Sul, Brazil, and to identify the relevant individual and community factors by means of panel data and multilevel analytical models.

Method

This was a longitudinal ecological study of data on live births and infant deaths (0-364 days).

The dependent variable was IMR, expressed as the number of deaths in infants (< 1 year) per thousand live births, among children residing in the State's 35 microregions (groupings of neighboring municipalities or counties, with the aim of integrating the organization, planning, and execution of common public services) in the State of Rio Grande do Sul, from 1994 to 2004.

Data were obtained from the records in the Information System on Live Births (SINASC) and the Mortality Information System (SIM), available at the Information Technology Department of the Unified National Health System (DATASUS; http://www.datasus.gov.br).

Underlying cause of death was defined according to the chapters of the 10th revision of the International Classification of Diseases (ICD-10) [23] for the period from 1996 to 2004.

The study considered predictive variables on a continuous scale (centered on the mean) at two levels. The criteria used to include variables in the models were the theoretical framework and the statistical significance of the parameters' estimates.

The determinants that were considered at the individual level, available for the 11 years of the study, were: time, low birthweight rate, cesarean rate, women with seven or more prenatal visits, premature births, and measles and BCG vaccination.

The demographic characteristics of the microregions were: urbanization rate (proportion of the population residing in urban areas), life expectancy at birth (mean number of years that people live, starting from birth), and fertility (mean number of children per woman during her childbearing period). Socioeconomic indicators were: illiteracy (percentage of persons 15 years or older who could not read or write a simple note), mean schooling (years), poverty (percentage of the population with a per capita household income less than half the minimum wage, or approximately U$100/month), hospitalization due to assaults (percentage of hospitalizations due to assaults), population homicide rate, and labor force participation (economically active population as a percentage of the working-age population), in addition to gross domestic product (per capita GDP), socioeconomic development index, and household crowding (percentage of persons living in households with density greater than 2, as expressed by the number of residents per room, not counting bathrooms or one kitchen). Some coverage indicators were also considered, like: Family Health Program (FHP; percentage of persons enrolled), water (proportion of permanent private dwelling connected to the running water supply), sanitation (percentage of households connected to the general sewerage system), and supplementary health (percentage of beneficiaries of private health healthcare plans covering medical consultations, tests, and hospitalization).

Other health indicators were: number of practicing physicians (including medical residents) and hospital beds per thousand inhabitants, hospitals per 100 thousand inhabitants, and healthcare expenditure per inhabitant.

The variables were obtained from the databases of the Brazilian Institute of Geography and Statistics, or National Census Bureau (IBGE); DATASUS (National Immunization Program, under the Primary Health Care Data System – SIAB); National Supplementary Health Care System (ANS); Institute of Applied Economic Research (IPEA); Foundation for Economics and Statistics (FEE); National System of Urban Indicators (SNIU), and the Rio Grande do Sul State Socioeconomic Atlas (Rio Grande do Sul State Secretariat of Planning and Management), from different periods (2000 census, 1994-2004, 2003, or 2004), based on the availability of data.

Data from a same microregion were observed over the course of 11 years. To analyze trends in each time series, percentage rates in annual variation were used, adjusted by exponential regression of the mortality rates.

For analysis of the panel data via mixed models, the use of the MIXED procedure in SAS 9.1 (SAS Inst., Cary, USA) allowed considering different covariance structures, selecting the most adequate for within-individual variation in measures, adjusting a model whose coefficients were significant ($p < 0.05$). The best covariance structure was that which presented the lowest values for AIC (Akaike's Information Criterion) [24] and BIC (Schwarz's Bayesian Criterion) [25].

For selection of the community variables, in addition to the theoretical framework, an analysis of correlation was performed to evaluate multicollinearity.

In the multilevel linear regression, a hierarchical structure was considered, according to the microregions in Rio Grande do Sul (level 2) and the period from 1994 to 2004 (level 1), for which an unconditional (empty) model was adjusted, in addition to models with fixed and random coefficients. Models with complex variance were also considered, that is, models that allowed modeling the IMR variance as a function of the explanatory variables.

Estimation by the unconditional model produced information on the outcome's variability at each level, and the intra-microregion correlation coefficient was calculated by: $\rho = \sigma^2_{uo}/(\sigma^2_{uo}+\sigma^2_{eo})$ [26]. The regression coefficients were estimated by IGLS (iterative generalized least squares).

The statistical significance of the estimates was verified by the Wald test, and the best model was chosen by the goodness-of-fit (deviance) test, comparing the main results. As measures of the model's diagnosis, residues were analyzed for the two levels, as well as measures of leverage and influence.

The multilevel and panel data analyses were developed with the aid of MLwiN 2.02 computational applications (Centre for Multilevel Modelling, Bristol, UK) and SAS 9.1, respectively.

Multilevel models for continuous outcomes

Multilevel modeling considers a set of hierarchical data, with the response variable measured at the individual level and with explanatory variables that can be measured at the individual or community level. Thus, conceptually, the model can be viewed as a hierarchical system of regression equations, allowing estimation of the individual (intra-group) and community (inter-group) effects [19].

Level 1 models are developed separately in each unit of level *j*, considering the possibility of variation of intercepts and slopes [19,26].

For algebraic simplicity, the two-level model is considered here:

$$Y_{ij} = \beta_0 + \beta_1 X_{ij} + u_{0j} + e_{0ij} \qquad (1)$$

with $i = 1, 2, ..., n_j$ and $j = 1, 2, ..., J$; Y_{ij}: outcome of the i^{th} unit of level 1, grouped in the j^{th} of level 2; X_{ij}: predictive variable measured in the i^{th} unit of level 1, grouped in the j^{th} of level 2; β_0: model's general intercept; β_1: slope coefficient associated with predictive variable X; u_{0j}: random effect of level 2; e_{0ij}: random effect of level 1.

Residues u_{0j} and e_{0ij} are assumed to be independent and normally distributed, with mean zero and variances σ^2_{u0} and σ^2_{e0} respectively.

The residual variance, i.e., the variance conditioned on X, is given by:

$$Var\ (Y_{ij}/X_{ij}) = var\ (u_{0j}) + var\ (e_{0ij}) = \sigma^2_{u0} + \sigma^2_{e0} \qquad (2)$$

The covariance between two individuals (i_1, i_2) in the same group j is:

$$Cov\ (Y_{i1j}, Y_{i2j}/X_{i1j}, X_{i2j}) = var\ (u_{0j}) = \sigma^2_{u0} \qquad (3)$$

The intra-group correlation coefficient, which expresses the fraction of total variability that can be attributed to level 2, is given by:

$$\rho_I\ (Y_{ij}/X_{ij}) = \frac{\sigma^2_{u0}}{\sigma^2_{u0} + \sigma^2_{e0}} \qquad (4)$$

This measure is an indicator of the degree of the population's grouping corresponding to the correlation between the values for two individuals in a group, controlling for variable X [19,26,27].

The model for equation (1) can be extended such that:

$$Y_{ij} = \beta_{0j} + \beta_{1j} X_{1ij} + e_{0ij} \qquad (5)$$

$$\beta_{0j} = \beta_0 + u_{0j} \text{ e } \beta_{1j} = \beta_1 + u_{1j}$$

β_{0j}: intercept for the *j^th^* unit of level 2; β_{1j}: slope coefficient associated with variable X of the *i*th unit of level 1, grouped in the *j*th of level 2; β_0: expected value of the intercepts in level 2; β_1: expected value of the slopes in level 2; u_{0j}: random effect of the *j*th unit of level 2 on intercept β_{0j}; u_{1j}: random effect of the *j*th unit of level 2 on slope β_{1j}.

This model is known as a "random coefficients model", which assumes that each group has a different intercept (β_{0j}) and slope (β_{1j}), presenting a complex variance-covariance structure [19,26], given by:

$$\text{Var}\begin{bmatrix} u_{0j} \\ u_{1j} \end{bmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma^2_{u0} & \sigma_{u0u1} \\ \sigma_{u1u0} & \sigma^2_{u1} \end{pmatrix}\right] \text{ and Var } (e_{0ij}) \sim N\ (0, \sigma^2_{e0})$$

The intercepts and slopes are estimated for units grouped within level 2, producing reduced residues ordered around an overall mean. In this case, the residues can be estimated, multiplying the crude residues ($\tilde{y}_j$) by a reduction factor:

$$\hat{u}_j = \frac{n_j \sigma^2_{u0}}{n_j \sigma^2_{u0} + \sigma^2_{e0}} \tilde{y}_j \qquad (6)$$

Ethical issues

The study was approved by the Institutional Review Board of the School of Medicine at the Federal University in Rio Grande do Sul and complies with the requirements in *Ruling nº. 196/96* of the Brazilian National Health Council.

Results

In Rio Grande do Sul, from 1994 to 2004, there were 1,897,002 live births and 31,576 deaths in children under one year of age. Figure 1 shows the spatial distribution of mean infant mortality rates by microregion. The lowest means were in the microregions of Guaporé (11.2‰) and Montenegro (11.9‰), and the highest were in the microregions of Campanha Meridional (24‰) and Campanha Central (22.3‰).

Table 1 shows the trend in infant mortality rates and the component rates, in addition to the percentage rate of annual variation. There was a decrease of 2.5% in this rate for live births ($p < 0.001$), 2.2% for infant mortality ($p = 0.002$), 1.2% for neonatal mortality ($p = 0.011$), and 4% for post-neonatal mortality ($p = 0.003$). Early neonatal mortality (0-6 days) decreased by 1.9% ($p < 0.001$), while for late neonatal mortality (7-27 days) there was a non-significant increase of 1% ($p = 0.186$).

Table 2 shows the distribution of the principal causes of infant deaths. The leading causes were perinatal conditions (8.52‰), followed by the group of congenital malformations, deformations, and chromosomal abnormalities (3.33‰).

In the mixed models analysis (model 1), the most adequate covariance structure was autoregressive moving average (ARMA; 1, 1), with residual variance, covariance, and correlation of 12.26, 0.25, and 0.88, respectively, in addition to AIC = 2,045.2, BIC = 2,049.9, and deviance = 31.51 ($p < 0.001$). Other results are presented in Table 3.

In the multilevel analysis, considering a random intercepts model (model 2), the residual variance of the microregions was estimated at 10.49 (95%CI: 5.06-15.92; $p < 0.001$), while the residual variance for the years was 12.01 (95%CI: 10.23-13.79; $p < 0.001$). The estimated intra-microregion correlation coefficient was 0.4662, suggesting that 46.62% of the variation in the infant mortality rate was due to microregional variability in Rio Grande do Sul.

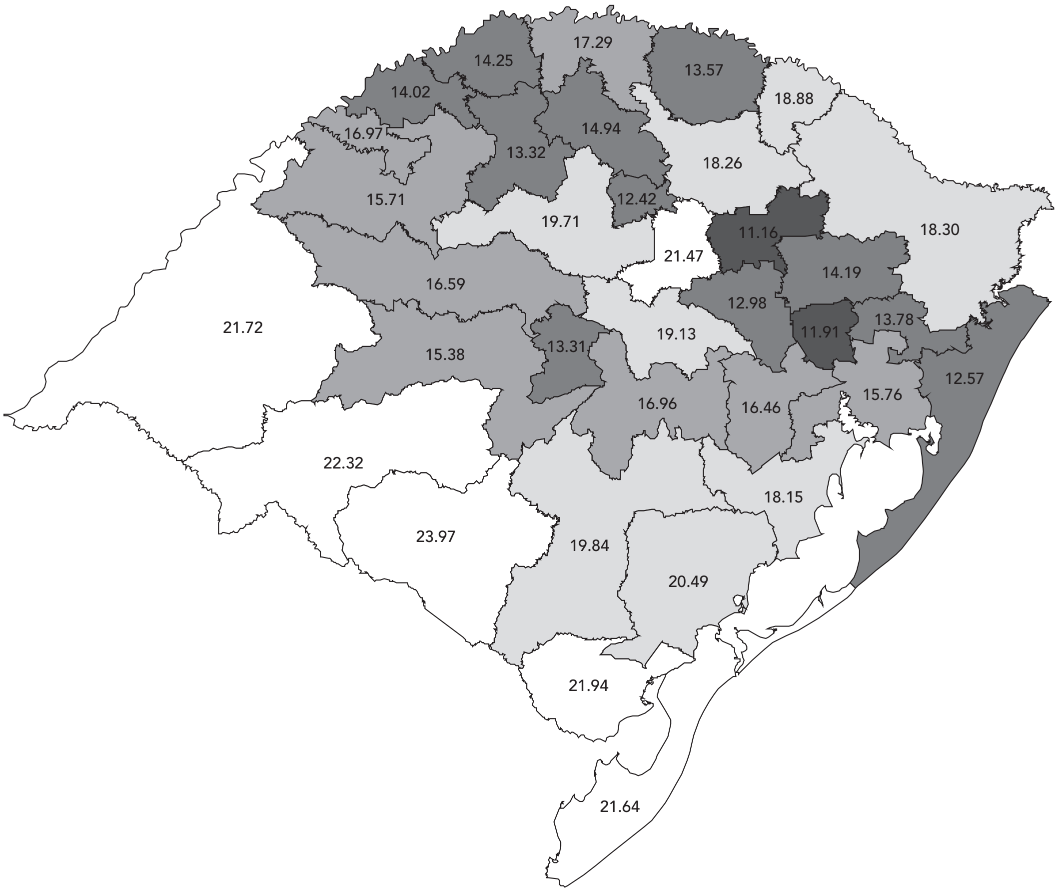
To investigate the possible determinants of this variability, specific characteristics of the microregions were included in the model. Table 3 shows some results from the multilevel models.

Model 3 (random intercepts), with individual-level variables only, showed deviance = 80.14 ($p < 0.001$), suggesting that the inclusion of these variables significantly improved the model's fit, helping explain the reduction in variance between years (16.78%) as well as between microregions (43.94%). In model 4 (random intercepts), the inclusion of community variables resulted in deviance = 34.22 ($p < 0.001$), also indicating a better fit, i.e., these variables also helped explain the reduction in variance between microregions (74.83%).

For model 5 (random intercepts and random slopes as a function of time), the goodness-of-fit test (deviance =13.44) indicated that the inclusion of the complex variance component at the level of microregions was significant ($p < 0.001$), suggesting that the variability in infant mortality rates between microregions is time-dependent, presenting a decrease until 2001 and increasing from that year onward. According to this model, the estimated infant mortality in the microregions was 18.95‰ ($p < 0.001$), with variance 5.68, and the estimated time-related slope coefficient (years) was -0.90, with variance 0.11. Estimated

Figure 1

Mean infant mortality rate (IMR) by microregion in the State of Rio Grande do Sul, Brazil, 1994-2004.



covariance was -0.67, producing a correlation of -0.85, indicating that the microregions with the lowest IMR in 1994 showed the largest decreases in infant mortality rates over the years. In relation to level 1, the variation between IMR values was constant over the 11 years.

Considering the effect of community variables, the 10% increase in FHP coverage was associated with a 1‰ drop in infant mortality, controlling for the other variables, and the 10% increase in the poverty rate was associated with a 2.1‰ increase in infant deaths. The number of hospital beds per thousand inhabitants was positively associated with the outcome, i.e., a 1% increase in this rate was associated with a 1.91‰ increase in infant deaths, while a 10% increase in hospitals per 100 thousand inhabitants was associated with a 3.6‰ drop in infant mortality.

The other variables were tested as random effects. However, these effects were not significant, and only remained in the model as fixed effects. Possible interactions between the variables were also considered, but none was statistically significant.

The analysis of the residues and predicted values indicated that the assumptions of normal distribution and linearity were met, and no outliers or influential values were identified. Some microregions also differed significantly from the overall mean, with Três Passos and Não-me-Toque showing an estimated intercept below the mean value for the microregions, while Campanha Meridional showed an estimated intercept above the mean intercept. Meanwhile, Campanha Meridional and Cachoeira do Sul showed estimated slopes below the mean, while Três Passos and

Table 1

Infant mortality rates and principal components in the State of Rio Grande do Sul, Brazil, 1994-2004.

Rates	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Live births *	188,666	188,351	182,140	180,760	177,538	184,797	176,719	160,590	155,261	149,165	153,015
Mortality											
Infant **	3,631	3,543	3,330	2,874	3,071	2,790	2,676	2,530	2,429	2,382	2,320
Percentage	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Rate (thousand)	19.25	18.81	18.28	15.90	17.30	15.10	15.14	15.75	15.64	15.97	15.16
Neonatal ***	2,138	2,037	1,899	1,793	1,784	1,787	1,686	1,598	1,497	1,461	1,541
Percentage	58.86	57.47	57.05	62.39	58.09	64.04	63.01	63.17	61.64	61.30	66.42
Rate (thousand)	11.33	10.81	10.43	9.92	10.05	9.67	9.54	9.95	9.64	9.79	10.07
Early neonatal #	1,629	1,525	1,430	1,338	1,386	1,350	1,227	1,167	1,083	1,009	1,102
Percentage	44.83	43.06	42.99	46.54	44.57	48.41	45.84	46.16	44.63	42.33	47.49
Rate (thousand)	8.63	8.10	7.86	7.40	7.71	7.31	6.94	7.27	6.98	6.76	7.20
Late neonatal ##	509	512	469	455	416	437	459	431	414	452	439
Percentage	14.03	14.41	14.06	15.85	13.53	15.63	17.17	17.02	17.01	18.97	18.93
Rate (thousand)	2.70	2.71	2.57	2.52	2.34	2.36	2.60	2.68	2.66	3.03	2.87
Post-neonatal ###	1,493	1,497	1,431	1,081	1,287	1,003	990	932	932	921	779
Percentage	41.14	42.53	42.99	37.61	41.91	35.96	36.99	36.83	38.36	38.70	33.58
Rate (thousand)	7.92	8.00	7.86	5.98	7.25	5.43	5.60	5.80	6.00	6.18	5.09

Source: Mortality Information System, SIM, and Information System on Live Births, SINASC (Information Technology Department of the Unified National Health System, http://www.datasus.gov.br).

Note: Percentage rate of annual variation adjusted by exponential regression.

* Annual variation (95%CI) = -2.5% (-1.72;-3.28); p < 0.001;

** Annual variation (95%CI) = -2.2% (-1.22;-3.18); p = 0.002;

*** Annual variation (95%CI) = -1.2% (-0.42;-1.98); p = 0.011;

\# Annual variation (95%CI) = -1.90 (-1.12;-2.68); p < 0.001;

\## Annual variation (95%CI) = 1.00 (-037; 2.37); p = 0.186;

\### Annual variation (95%CI) = -4.0% (-2.04; 5.96); p = 0.003.

Não-Me-Toque showed slopes above the mean. For all the other microregions, the estimates did not differ significantly from the mean.

Discussion

Infant mortality rates in Brazil decreased by approximately 70% in the last 60 years, principally in the post-neonatal component and in urban and more developed areas [1,2,9,14,28], despite persistent socioeconomic inequalities over time [9]. Considered a multifactor process [15], the reduction in infant mortality in Brazil is associated with a series of improvements in living conditions and maternal and infant health care, related to food and nutritional security, basic environmental sanitation, and immunization [18,29].

In the State of Rio Grande do Sul, although the proportion of low birthweight newborns increased during this same period [5], infant mortality decreased, consistent with studies performed in Belo Horizonte (Minas Gerais) [3], Rio de Janeiro [14], and Londrina (Paraná) [30]. As in other States of Brazil [3,14,30,31], post-neonatal mortality rates showed the largest decrease, and with the drop in this component a concentration of deaths occurred in the neonatal period, mostly in the first six days of life, thus highlighting the relationship between the deaths and quality of care for pregnant women.

A study [32] on the trend in infant mortality that analyzed the results of 80 surveys from 1980 to 2000 in 31 countries, including Brazil, concluded that the decline has been more pronounced in late neonatal and post-neonatal mortality. In addition, these decreases were not distributed equally between regions, with more rapid increases occurring in countries of Latin America and the Caribbean, North Africa and the Middle East, South and Southeast Asia, and the Pacific, while the decline was slower in Sub-Saharan Africa, especially in the early neonatal period [32].

In recent decades in Brazil, along with the decrease in the share of infectious and parasitic diseases, respiratory diseases, and malnutrition,

Table 2

Infant mortality rate by principal causes of deaths in Rio Grande do Sul State, Brazil, 1996-2004.

Principal causes of deaths	**Infant mortality rate (‰)**								
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Certain conditions originating in the perinatal period	9.10	8.68	8.25	8.19	7.94	8.45	8.59	8.55	8.52
Congenital malformations, deformations, and chromosomal abnormalities	2.72	2.42	2.91	2.79	2.90	3.09	3.29	3.16	3.33
External causes	0.68	0.69	0.72	0.62	0.76	0.68	0.72	0.66	0.67
Diarrhea and gastroenteritis of presumed infectious origin	0.70	0.37	0.48	0.30	0.39	0.21	0.19	0.26	0.24
Pneumonia and other acute respiratory infections	1.97	1.42	1.62	1.01	0.92	0.82	0.71	0.90	0.89
Ill-defined causes	0.67	0.63	0.94	0.56	0.59	0.57	0.69	0.83	0.39
Other causes	3.07	2.15	3.18	2.05	2.16	1.89	1.24	2.78	2.25

Source: Mortality Information System – SIM (Information Technology Department of the Unified National Health System, http://www.datasus.gov.br).

Table 3

Changes in the infant mortality rate (IMR) associated with changes in predictive variables in the State of Rio Grande do Sul, Brazil, 1994-2004.

Variables	**Estimate (standard error) ***				
	Panel data analysis via mixed models	**Multilevel regression analysis**			
	Model 1	**Model 2 ****	**Model 3 *****	**Model 4 #**	**Model 5 ##**
Fixed effects					
Level 1					
Mean IMR (intercept)	18.92 (0.51)	16.84 (0.57)	18.81 (0.59)	18.92 (0.47)	18.95 (0.57)
Year (centered on 1994)	-0.90 (0.20)	-	-0.93 (0.19)	-0.91 (0.19)	-0.90 (0.19)
Quadratic term for years	0.07 (0.02)	-	0.07 (0.02)	0.07 (0.02)	0.07 (0.02)
Low birthweight (% population)	1.24 (0.20)	-	1.36 (0.21)	1.22 (0.20)	1.21 (0.19)
Cesarean section (% population)	-0.13 (0.04)	-	-0.23 (0.05)	-0.14 (0.04)	-0.12 (0.04)
Level 2					
FHP (% enrolled individuals in the population)	-0.10 (0.03)	-	-	-0.10 (0.03)	-0.10 (0.03)
Poverty (% population with per capita income < ½ minimum wage)	0.21 (0.04)	-	-	0.20 (0.04)	0.21 (0.04)
Hospital beds (per thousand inhabitants)	1.92 (0.49)	-	-	1.90 (0.44)	1.91 (0.43)
Hospitals (per 100 thousand inhabitants)	-0.39 (0.17)	-	-	-0.39 (0.15)	-0.36 (0.15) p = 0.017
Random effects					
Level 1 variance	12.26 (0.93)	12.10 (0.91)	10.07 (0.76)	10.14 (0.77)	9.02 (0.72)
Variance of intercepts	-	10.49 (2.77)	5.88 (1.63)	1.48 (0.58) p = 0.011	5.68 (2.05) p = 0.006
Covariance between intercepts and slopes	-	-	-	-	-0.67 (0.28) p = 0.017
Variance of slopes	-	-	-	-	0.11 (0.05) p = 0.020
2loglikelihood (IGLS)	2,039.20	2,132.19	2,052.05	2,017.83	2,003.60

FHP: Family Health Program; IGLS: Iterative Generalized Least Squares.

* For estimates without specified significance values, $p < 0.001$;

** Unconditional (empty) random intercepts model;

*** Random intercepts, with level 1 variables;

Random intercepts, with level 1 and 2 variables;

Random intercepts and slopes (as a function of years), with level 1 and 2 variables (complex variance).

perinatal conditions have become the main group of causes of infant death, i.e., problems that arise before completing one week of life, like prematurity, intrapartum asphyxia, and neonatal infections, followed by congenital malformations [33]. In Rio Grande do Sul, perinatal conditions were the principal causes of infant mortality, followed by congenital malformations, jointly counting for some 75% of all deaths from 2000 to 2004. In the neonatal period, these two causes accounted for 96% of the deaths. Although more difficult to avoid, they can be reduced by measures that guarantee adequate prenatal care and improvements in childbirth care [33], as well as early diagnosis and treatment of maternal and fetal factors that can increase the risk of death.

Although Rio Grande do Sul had one of the lowest infant mortality rates in Brazil in 2004, 20.3% of infant deaths in the State could have been avoided by adequate prenatal and childbirth care in 2004, representing 470 lives that could have been saved. In addition, there are significant regional differences in infant mortality rates, which vary according to the level where they occur and complex social, economic, and demographic factors [34].

Several studies have reported that individuals immersed in health processes undergo influences at different levels. However, this hierarchy is not always taken into consideration, which can produce biased estimates when traditional regression techniques are used [19]. Thus, this study used panel data and multilevel models to evaluate the effect of the levels and the determinants of infant mortality in Rio Grande do Sul, testing numerous variables. The results of the two analyses do not display relevant differences, but it was important to consider the different covariance structures in the panel analysis, since it improved the estimates of the respective parameters [19].

Multilevel analysis allows computing the magnitude of each level's contribution to explaining the outcome [19,20]. In this study, practically half of the variability in infant mortality rates was due to the community level, i.e., the microregions' effect was considerable. In addition, inclusion of the complex variance term indicated inequality in the rates' variation between microregions over the years, increasing from 2001 onward. Thus, the variability in infant mortality rates between microregions changed as a function of time, but for each microregion the variations remained constant over time. A multilevel study on mortality in children under five years of age in the State of Rio Grande do Norte, based on data from the 2000 population census (http://www.ibge.gov.br), found a 62% effect for microregions and 38% for municipalities, and the main socioeconomic factors were: adequate basic environmental sanitation (access to bathrooms and running water), education (literacy rate), and dependency ratio greater than 75% [35]. The larger effect of the microregions observed in the above-mentioned study can be explained by the greater heterogeneity between microregions in the Northeast of Brazil as compared to the South.

The inclusion of individual and community variables according to a multilevel approach allowed elucidating some aspects of infant mortality, and the significant determinants were: time, proportion of low birthweight, cesarean rate, FHP coverage, poverty rate, and number of hospital beds and hospitals per thousand inhabitants.

Infant mortality is closely related to birthweight. This study showed that in Rio Grande do Sul, a 1% decrease in the proportion of low birthweight newborns would decrease the infant mortality rate by 1.2 points. Thus, in order for Rio Grande do Sul to decrease its infant mortality rates, strategies are needed to prevent low birthweight, such as expanding access to qualified prenatal care, better maternal nutrition, and programs to reduce maternal smoking, among others [15,32].

This analysis suggests that an increase in FHP coverage, controlling for the other variables, reduced the infant mortality rate. This result was expected, since by increasing the health services' proximity to the local reality, the program seeks to plan and implement actions based on the problems within a given area, and such measures have contributed decisively to reducing infant mortality. A longitudinal, non-multilevel study (1990-2002) led by the Ministry of Health for all States of Brazil showed that the FHP had a significant impact on the drop in infant mortality: for each 10% increase in FHP coverage, infant mortality decreased by 4.5% [36]. This reduction was probably smaller in Rio Grande do Sul since the rates were already lower, and there was less variability between microregions in the State, which is also more developed and provides greater access to basic health services.

The decrease in the poverty rate was associated with a reduction in infant deaths. A study of panel data on infant mortality in Brazil as a whole and in the Southeast region also found a significant effect by this indicator of monetary poverty, but average years of schooling showed a much stronger effect [34].

The number of hospital beds was positively associated with the outcome. Importantly, all hospital beds were considered, not only pediatric beds. We believe that if only intensive or intermediate-care neonatal beds were included, this association might be inverted, i.e., the more such neonatal beds, the lower the infant mortality. Meanwhile, the increase in the hospital rate was negatively associated with infant mortality. We found no multilevel regression study in the literature that considered these community variables, thus making it difficult to compare our findings with others.

Caution is necessary when interpreting the negative association between cesarean rate and infant mortality. The protective effect of cesareans against infant deaths detected in this study is probably due not to the procedure itself, but to the type of population in which cesareans are more common. Cesarean rates are known to be higher in private and outsourced hospitals, which treat a patient population with higher socioeconomic status, better nutrition, and access to qualified prenatal care, in addition to lower infant mortality.

The study's limitations include the possible presence of a measurement bias due to the use of secondary data, the size effect of microregions, which show great internal variability, and the absence of other determinants of infant mortality in the model, like alcohol consumption, smoking, and breastfeeding rates. However, due to the large number of variables that were tested and the correlation between some of them, the explanatory power of some variables that were not included would probably be small. Despite the limitations, multilevel modeling was able to capture significant effects, characterized at the respective levels.

Although Rio Grande do Sul has achieved the lowest infant mortality rate in Brazil, there are still microregions that require greater attention by government, like Cachoeira do Sul and Campanha Meridional, which showed a below-average reduction in infant mortality during the period analyzed.

Some comprehensive, simple, and relatively low-cost interventions should be prioritized, since they are capable of acting in the health promotion of socially vulnerable population groups and in the primary and secondary prevention of more prevalent diseases. These include sex education programs for adolescents, qualified prenatal care, programs for access to (and humanization of) childbirth care, programs to promote exclusive breastfeeding in the first six months and complemented by two years or more, programs for the identification of infant risk and early treatment of illnesses (Program for Integrated Management of Childhood Illness, Ministry of Health), National Immunization Program, and expanded coverage of the FHP [8,18,29,33].

The multilevel analysis of the trend in infant mortality rates provided a pioneering approach in the State of Rio Grande do Sul. In addition to demonstrating the importance of this methodology for identifying each level's contribution to the data's hierarchy, this study showed important results related to the factors associated with infant mortality, suggesting the need for efficient public measures targeting vulnerable groups.

Resumo

O objetivo deste trabalho foi analisar a tendência das taxas de mortalidade infantil no Rio Grande do Sul, Brasil, de 1994 a 2004, em estudo ecológico longitudinal, por meio de análise de dados de painel e regressão linear multinível (dois níveis: microrregião e tempo) para estimar fatores associados à mortalidade infantil. A taxa de mortalidade infantil reduziu de 19,2‰ (1994) para 13,7‰ (2004) nascidos vivos, e a principal causa de óbito, nos últimos cinco anos, foi afecções perinatais (54,1%). Aproximadamente 47% da variação nas taxas de mortalidade ocorreram nas microrregiões, e 10% de acréscimo na cobertura do Programa Saúde da Família esteve associado à redução de 1‰ na mortalidade infantil. O aumento de 10% na taxa de pobreza esteve associado com um aumento de 2,1‰ nos óbitos infantis. A mortalidade infantil associou-se positivamente com a proporção de recém-nascidos com baixo peso e número de leitos hospitalares por mil habitantes e negativamente com a proporção de cesarianas e número de hospitais por 100 mil habitantes. Os resultados sugerem que variáveis individuais e contextuais apresentam efeitos significativos na redução das taxas de mortalidade infantil.

Sistemas de Informação; Mortalidade Infantil; Causa de Morte

Contributors

R. R. Zanini and A. B. Moraes contributed with the design, data collection, statistical analysis, and interpretation, and writing of the article J. Riboldi and E. R. J. Giugliani collaborated in the supervision, writing, and revision of the article.

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