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Indicadores de saúde em cidades amazônicas: estudo de caso no Estado do Pará, Brasil

Health indicators in Amazonian cities: case study in the State of Pará, Brazil

Indicadores de salud en ciudades amazónicas: estudio de caso en el Estado de Pará, Brasil

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Resumo

A provisão adequada de serviços de saneamento básico é uma condição essencial para a saúde pública e para qualidade de vida da população. A inexistência ou insuficiência da cobertura dos serviços de saneamento pode ocasionar várias externalidades que podem prejudicar a saúde pública e o bem-estar da sociedade. Este estudo teve como objetivo elaborar um indicador de saúde (IS) por meio da relação entre a taxa de mortalidade infantil, população urbana e a cobertura dos serviços de saneamento (compreendido estes como água encanada, coleta de resíduos sólidos, abastecimento de água e esgoto sanitário). Foi um estudo documental e exploratório que utilizou técnicas de analises multivariadas e critérios de eficiência (r^2, Nash e Sutcliffe e raiz do erro quadrático). A área de abrangência do estudo foram os municípios do estado do Pará, divididos nas seis mesorregiões geográficas. Os dados relacionados aos indicadores de saneamento, taxa de mortalidade infantil até 5 anos de idade e população urbana, foram obtidos por meio do site do Programa das Nações Unidas para o Desenvolvimento (PNUD). Os resultados indicam que variável população urbana em domicílios sem coleta de resíduos sólidos urbanos (PUDSCRSU) apresentou menor significância no indicador de saúde. Verificou-se que associação entre IS e os serviços de saneamento básico (variáveis explicativas), em geral, é bem explicada estatisticamente por r^2 e NASH, indicando que os modelos estatísticos são apropriados e eficientes. Conclui-se, que a redução de mortalidade infantil está diretamente proporcional a cobertura do saneamento.

Palavras-chave: Saúde pública; Saneamento básico; Associação; Universalização; Análise multivariada.

Abstract

The adequate provision of basic sanitation services is an essential condition for public health and quality of life of the population. The lack or insufficiency of sanitation services coverage may cause several externalities that could harm public health and social well-being. The purpose of this study was to elaborate a health indicator through the relationship between infant mortality rate, urban population and sanitation services coverage (such as piped water, solid waste collection, water supply and sewage). This was a documentary and exploratory study that utilized multivariate analysis techniques and efficiency criteria (r^2, Nash-Sutcliffe and root mean square error). The area covered by the study were the municipalities of the State of Pará, divided into six geographical mesoregions. The data related to the sanitation indicators, infant mortality rate until the age of 5 and urban population were obtained through the United Nations Development Programme (UNDP) website. The results indicate that the urban population variable in households without municipal solid waste collection showed lower significance in the health indicator. It was found that association between IS and basic sanitation services (explanatory variables), overall, is statistically well explained by r^2 and

NASH, signaling that the statistical models are appropriate and efficient. It is concluded that the reduction of infant mortality is directly proportional to sanitation coverage.

Keywords: Public health; Basic sanitation; Association; Universalization; Multivariate analysis.

Resumen

La prestación adecuada de servicios sanitarios básicos es una condición esencial para la salud pública y la calidad de vida de la población. La falta o la insuficiencia de cobertura de los servicios de saneamiento puede causar varias externalidades que podrían perjudicar la salud pública y el bienestar social. El propósito de este estudio fue elaborar un indicador de salud a través de la relación entre la tasa de mortalidad infantil, la población urbana y la cobertura de los servicios de saneamiento (como el agua corriente, la recogida de desechos sólidos, el abastecimiento de agua y el alcantarillado). Se trataba de un estudio documental y exploratorio que utilizaba técnicas de análisis multivariado y criterios de eficiencia (r^2, Nash-Sutcliffe y error de media cuadra). El área abarcada por el estudio fueron los municipios del Estado de Pará, divididos en seis mesoregiones geográficas. Los datos relativos a los indicadores de saneamiento, la tasa de mortalidad infantil hasta los 5 años de edad y la población urbana se obtuvieron a través del sitio web del Programa de las Naciones Unidas para el Desarrollo (PNUD). Los resultados indican que la variable población urbana en los hogares sin recolección de desechos sólidos municipales mostró una menor significación en el indicador de salud. Se comprobó que la asociación entre la SI y los servicios de saneamiento básico (variables explicativas), en general, está estadísticamente bien explicada por la r^2 y la ENA, lo que indica que los modelos estadísticos son apropiados y eficientes. Se concluye que la reducción de la mortalidad infantil es directamente proporcional a la cobertura de saneamiento.

Palabras clave: Salud pública; Saneamiento básico; Asociación; Universalización; Análisis multivariado.

1. Introduction

The appropriate supply of basic sanitation services is a fundamental condition for public health, since they are important to its promotion (Rossoni, 2016) as well as to the quality of life of the population (Teixeira et al., 2012). The precarious situation of sanitary infrastructure causes several externalities that may harm public health (Ferreira et al., 2016;

Scriptore & Toneto Jr, 2012; Urh et al., 2016), the environment and the well-being of society (Scriptore & Toneto Jr, 2012).

Therefore, investing in sanitation becomes a strategic base for long-term economic and social growth of the country, preventing hazards that are resulting from the existence of pathogens, toxic substances, residues, among others (Toffoli & Toffoli, 2016).

The lack or insufficiency of sanitation services provision may cause several problems due to inappropriate disposal of human waste and animal manure, such as the contamination of headwaters, hydric sources and soils, cooperating with the formation of favorable environments for the proliferation of waterborne disease transmission vectors (Saiani et al., 2013).

These are responsible for infant morbidity and mortality through the transmission of infectious and contagious diseases caused by bacteria, viruses and parasites present in excrements and in human and animal urine (Teixeira et al., 2006), representing an inconvenience to public health in many developing countries (Uhr, 2016).

Hu et al. (2016) emphasize that around half of the people inhabiting this planet, mainly in developing and in the poorest countries, currently live without safe basic sanitation systems, and many do not even have bathrooms with sanitary facilities.

According to Ferreira et al. (2016), in the poorest and in emerging countries, the sanitation thematic is still despised and low public investments are focused on this sector. The Joint Program for Monitoring of the World Health Organization (WHO)/UNICEF (2015) estimates that around 32% of the people on the planet do not utilize proper sanitary installations and 9% do not have access to safe hydric sources.

Brazil is one of the developing countries that presents deficiencies in this sanitation sector, which evidently manifest in municipal scale, directly harming its inhabitants (LISBOA et al., 2013). The insufficiency of sanitation services provision in the country is heavily centered in rural residences and small-sized municipalities with low per capita income.

The service deficiency is historic in Brazilian reality, mainly in the North and Northeast regions, in which the indicators related to water and sewage services and to proper treatment and destination of solid waste present coverage index below the values considered satisfactory (Scriptore & Toneto Jr, 2012).

The Brazilian government actions with regard to planning and managing water supply and sanitation services have oscillated, according to historical trends experimented by the sector, between state and municipal spheres. This uncertainty causes negative consequences, contributing to the country's failure in providing a universal coverage.

It leaves a substantial proportion of the population, mainly the poorest, who live in peripheries and rural areas, with access to services or care below the required (Heller et al., 2014), as well as it directly impacts the indicators that consist in guidelines associated with infant mortality (Toffoli & Toffoli, 2015).

Infant mortality is a relevant health indicator for a country, sate, municipality or community, as it is related to elements such as maternal health, food and nutrition, basic sanitation (Careti et al., 2014), socioeconomic conditions and public health practices (Freitas et al., 2012).

Several researches have been conducted relating health indicators with sanitation services provision in the country, for instance, Buhler et al. (2014), Fonseca & Vasconcelos (2011) and Teixeira et al. (2012).

In this regard, this study aimed at elaborating a health indicator (Indicador de Saúde [IS]) through the relation between infant mortality rate, urban population and sanitation services coverage (understood as piped water, solid waste collection, water supply and sewage) in the mesoregions of the State of Pará.

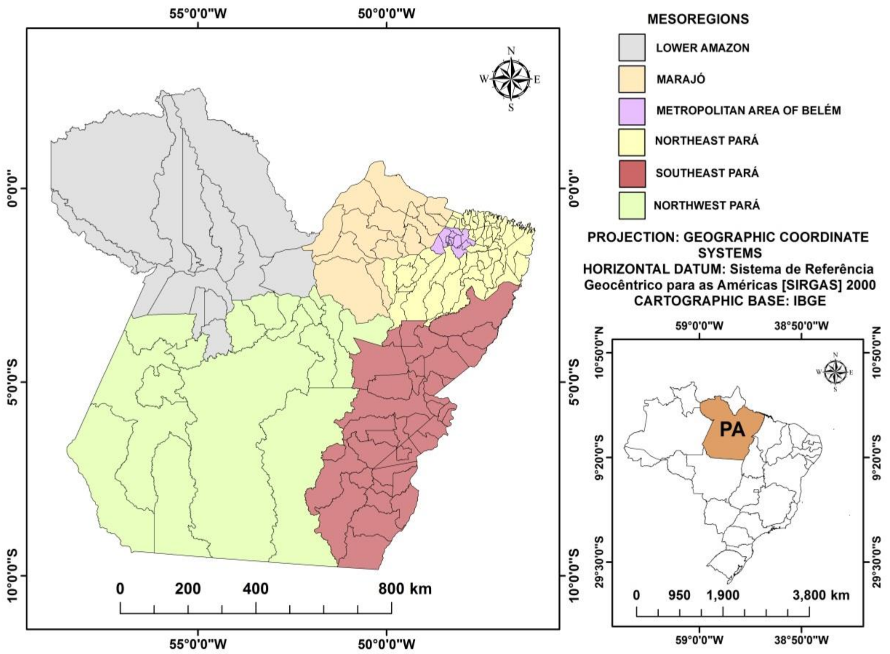
2. Materials and Methods

2.1 Study área

The state of Pará has an area of 1,247,955.381 km², the second largest in the country in terms of territorial extension, according to the Instituto Brasileiro de Geografia e Estatística [IBGE] (2010).

It is situated in the Northern region of the country, constituted by a total of 144 municipalities, divided in six geographical mesoregions: Lower Amazon, Marajó, Metropolitan area of Belém, Northeast Pará, Southwest Pará and Southeast Pará (Figure 1). The estimated population of the state in the year of 2016 was of 8,272,724 inhabitants (IBGE, 2016), with a demographic density in the year of 2010 of 6.07 inhabitants per square kilometer.

Figure 1. Mesoregions of the state of Pará map.



Source: Authors (2020).

The Geographical Mesoregions, according to the IBGE definition, are a set of contiguous municipalities belonging to the same federation unit (Unidade da Federação [UF]). They present forms of organizing the geographical area defined as determinant by the social process, as conditioning by the natural framework, and their communication and location networks as an element of special articulation. The association of these forms of organization enables the space, delimited as mesoregion, to have a regional identity.

For IBGE, the division of the UF in mesoregions seeks to translate, although in a synthetic way, the differences in the national territory organization concerning social and political questions, and enables this delimited space to have a specific regional identity.

2.2 Data used in the research

The methodology utilized was based on a documental and explanatory reseach. The data used to construct the model was taken from the United Nations Development Programme (UNDP) website, considering the information related to the years of 1991, 2000 and 2010.

For the elaboration of the health indicator, some variables were applied on each municipality of the mesoregions of the state of Pará. These were: infant mortality rate (IMR) until the age of 5; urban population (População Urbana [PU]); urban population in households

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without piped water (in Portuguese acronym, PUDSAE); urban population in households without solid waste collection (PUDSCRSU); and urban population in households without water supply and sanitary sewage collection (PUDSAAES).

2.3 Health indicator model

The health indicator model was built by multiple linear regression and least squares method. The multiple linear regression is a mathematical model that correlates the behavior of a dependent variable Y according to two or more explanatory variables X1, X2, ..., Xn.

This relation, according to Haan (1977), can be developed by means of a linear model given by (Equation 1):

$$Y = \beta_0 + \beta_1.X_1 + \beta_2.X_2 + \ldots + \beta_n.X_n + \varepsilon \qquad \text{(Eq. 1)}$$

In which Ɛ signals regression errors and β0, β1, β2 and βn are regression parameters to be estimated by means of least squares method.

To determine the Infant Mortality Rate x Urban Population (dependent variable), the PUDSAE, the PUDSCRSU and the PUDSAAES were applied as explanatory variables (Table 1):

Table 1. Variables used in the model.

Health indicator variable (IS)	Basic sanitation variables
IS = Infant Mortality Rate x Urban Population	PUDSAE
	PUDSCRSU
	PUDSAAES

Source: Authors.

These variables were chosen from researches developed by Borja & Moraes, (2003), Vinagre (2006), Marinho & Nascimento, (2014) and Sousa (2014).

2.4 Model performance evaluation

To evaluate the model performance, a comparison was held between the observed and simulated data related to infant mortality and the information studied in the periods of 1991, 2000 and 2010, using the determination coefficient (r²), the Nash-Sutcliffe coefficient (NASH) and the root mean square error (RMSE), based on Table 2.

Table 2. Coefficients, measure differences, and variations for evaluating the model.

Coefficient or measure	Equation	Variable reach
Determination coefficient	$r^2=\left[\frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}\right]^2$	0 to 1
Efficiency coefficient (Nash-Sutcliffe, 1970)	$NASH=1-\frac{\sum_{i=1}^{n}(x_i-y_i)^2}{\sum_{i=1}^{n}(x_i-\bar{x}_i)^2}$	- ∞ to 1
Root Mean Square Error	$RMSE=\sqrt{\sum_{i=1}^{n}\frac{(y_i-y_i)^2}{n}}$	0 to ∞

Notes: n = number of observations; $\bar{x}$ = average observed values; $\bar{y}$ = average simulated values; x_i, y_i= observed and expected values at the time i.

The values classified as great to these parameters were 1 to r² and NASH, and 0 to RMSE. The simulation results are usually considered good on values higher than or equal to 0.75, acceptable to NASH values between 0.75 and 0.36 and unsatisfactory to values lower than 0.36 (Van Liew & Garbrecht, 2003). The root mean square error (RMSE) represents the difference between the observed and the simulated values from the model in the variable unit investigated (Hallak & Pedreira Filho, 2011).

3. Results and Discussion

Table 3 presents the health models that were designed for the mesoregions of the state or Pará, by means of the utilization of multivariate analyses, based on the data concerning the years used in this research. The product of the infant mortality rate (%) by urban population was applied as dependent variable, enabling a better estimative of the reality of the study area scenario.

Table 3. Equations obtained by multiple linear regression and statistical criteria utilized to

analyze the accuracy of the mesoregions models referring to the studied years.

$IS = \beta_0 + \beta_1 \times PUDSAE + \beta_2 \times PUDSCRSU + \beta_3 \times PUDSAAESA$

Mesoregion	Year	Model	r²	NASH	RMSE
Lower Amazon	1991	$Y = 20.0317 + 0.0216 . X_1 + 0.0288 . X_2 + 0.0234 . X_3$	1	1	87
	2000	$Y = 57.1152 + 0.0259 . X_1 + 0.0118 . X_2 + 0.0184 . X_3$	1	1	41
	2010	$Y = 44.8956 + 0.0171 . X_1 + 0.0243 . X_2 + 0.0177 . X_3$	0.99	0.99	69
Marajó	1991	$Y = -18.6049 + 0.0403 . X_1 + 0.0240 . X_2 + 0.0056 . X_3$	0.98	0.99	39
	2000	$Y = 2.5943 + 0.0382 . X_1 + 0.0071 . X_2 + 0.0041. X_3$	0.99	0.99	31
	2010	$Y = -9.6394 + 0.0073 . X_1 + 0.0474 . X_2 + 0.0260 . X_3$	0.82	0.82	100
Metropolitan area of Belém	1991	$Y = -44.0526 + 0.046 . X_1 - 0.006 . X_2 + 0.0291 . X_3$	1	1	147
	2000	$Y = 432.48 + 0.0037 . X_1 - 0.0198 . X_2 + 0.0281 . X_3$	1	1	649
	2010	$Y = 45.356 + 0.048 . X_1 + 0.0295 . X_2 + 0.014 . X_3$	1	1	68
Northeast Pará	1991	$Y = -33.8941 + 0.0649 . X_1 – 0.014 . X_2 + 0.0279 . X_3$	0.95	0.95	148
	2000	$Y = 11.62 + 0.0319 . X_1 + 0.0065 . X_2 + 0.0236 . X_3$	0.91	0.91	155
	2010	$Y = 34.1009 + 0.0111 . X_1 + 0.0243 . X_2 + 0.0277 . X_3$	0.94	0.94	101
Southeast Pará	1991	$Y = -44.6822 - 0.0192 . X_1 + 0.0497. X_2 + 0.0417 . X_3$	0.95	0.95	270
	2000	$Y = -182.2656 + 0.0633 . X_1 – 0.005 . X_2 + 0.0076 . X_3$	0.98	0.98	148
	2010	$Y = 9.3412 + 0.0588 . X_1 + 0.0272 . X_2 + 0.0169 . X_3$	0.97	0.97	165
Southwest Pará	1991	$Y = -19.1974 + 0.0866 . X_1 - 0.0276 . X_2 + 0.0119 . X_3$	1	1	24
	2000	$Y = -118.0603 + 0.0681 . X_1 - 0.0058 . X_2 – 0.0035 . X_3$	0.99	0.99	70
	2010	$Y = -33.2655 + 0.0765 . X_1 + 0.0191 . X_2 + 0.0078 . X_3$	0.99	0.99	40

Notes: IS = Y; PUDSAE = X1; PUDSCRSU = X2; PUDSAAESA = X3.
Source**:** Research data (2020).

On Table 3, it is possible to observe that the PUDSCRSU variable presented negative coefficient β2 in almost all of the mesoregions, except Lower Amazon and Marajó. This confirmed an expected relation, inversely proportional to mortality under 5 years of age, while positive inclination coefficients (β1 e β3) from other explanatory variables demonstrate the directly proportional relation with the dependent variable, that is, the increase of the value in these variables implies the increase of the IS value.

Based on the multivariate analysis, it was verified that the association between the IS and the three basic sanitation services (explanatory variables), overall, is statistically well explained by r² and NASH, which indicates that the statistical models are appropriate and efficient. This provides a better understanding on the influence of the absence of basic sanitation services on infant mortality, once the values found are superior to 0.75, signaling effectiveness of the models and highlighting a linear cause-effect relationship between the variables of the models.

The developed model for the year of 2000 was the one that presented better results concerning the efficiency to the Lower Amazon, Marajó and Southeast Pará mesoregions. On the other hand, the model elaborated for the year of 2010 obtained a better performance on the Metropolitan area of Belém and Northeast mesoregions, and the model designed for the year of 1991 presented a better development in the Southeast mesoregion.

To analyze which of the independent variables has the greatest correlation with the health indicator, simple linear regression and efficiency criteria were employed, with the purpose of verifying which explanatory variable of sanitation is more significant on the decrease in infant mortality (Table 4).

By means of the application of simple linear regression, the determination coefficients were obtained (r^2), as observed on Table 4, in which it can be stated that the PUDSCRSU variable presented lower significance in the health indicator, designed for mesoregions based on the years researched. This result may be related to the percentage of public attendance with this service, as the urban solid waste collection covers a larger part when comparing to other sanitation variables used in this research. However, the PUDSAAES and PUDSAE variables showed, respectively, substantial significance in the model, offering a better, statistical explanation of the estimated values for the IS, highlighting that the lower the sanitation coverage service, the greater will be the correlation with the health indicator.

Uhr et al. (2016) conducted a study associating basic sanitation (understood as running water supply, sanitary sewage and solid waste management variables) and Brazilian population health, under the aspect of hospitalizations caused by waterborne diseases, and observed that the population health is related to sanitation conditions, particularly on what concerns sewage collection services and solid wastes. According to the authors, the results are in conformity with current public policies of expansion of the sewage collection system, still inefficient in the country, in detriment of the expansion of the water supply system (which reaches a considerable share of households).

Table 4. Correlation of the explanatory variables with the health indicator (by simple regression).

Mesoregion	Efficiency coefficients	PUDSAE			PUDSCRSU			PUDSAAES		
		1991	2000	2010	1991	2000	2010	1991	2000	2010
Lower Amazon	r^2	0.99	0.99	0.96	1	0.95	0.67	1	0.98	0.99
	NASH	1	1	1	1	0.95	0.7	1	1	1
	RMSE	167	97	157	140	276	475	156	159	99
Marajó	r^2	0.98	0.99	0.69	0.93	0.8	0.11	0.79	0.96	0.75
	NASH	0.98	0.99	0.69	0.93	0.8	0.04	0.79	0.96	0.75
	RMSE	55	34	129	97	145	227	168	68	117
Metropolitan area of Belém	r^2	0.99	0.94	0.92	0.92	0.54	0.94	1	0.99	1
	NASH	1	1	1	0.92	0.54	0.94	1	1	1
	RMSE	3	2222	1839	2604	6406	1574	299	682	272
Northeast Pará	r^2	0.93	0.89	0.68	0.88	0.66	0.35	0.91	0.86	0.92
	NASH	1	1	1	0.88	0.66	0.06	1	1	1
	RMSE	176	171	241	226	307	415	195	197	133
Southeast Pará	r^2	0.93	0.98	0.89	0.93	0.7	0.62	0.94	0.94	0.93
	NASH	1	1	1	0.93	0.7	0.62	1	1	1
	RMSE	334	156	295	334	574	557	307	262	239
Southwest Pará	r^2	0.99	0.99	0.98	0.91	0.83	0.68	1	0.82	0.98
	NASH	1	1	1	0.91	0.83	0.68	1	1	1
	RMSE	90	71	63	337	332	267	23	222	47

Source**:** Research data (2020).

Cheng et al. (2012) conducted a survey quantifying the relationships between water, sanitation, infant and maternal mortality, what the results indicated statistically significant relationships between access to water, sanitation, infant and maternal mortality. For the municipalities of the state of Pará to be able to effectively meet the Sustainable Development Goal 6, subsequently reducing infant and maternal mortality, it will be necessary to universalize access to safe water and sanitation for all, since they are key strategies.

As reported by Teixeira et al. (2012), in a research held in Latin America countries, which associated sanitary services coverage and epidemiologic indicators, it was identified that the larger the public attendance coverage by sanitary sewage services and water supply systems, the lower the infant mortality (until 5 years of age). According to these authors, sanitary measures and accessible, efficient services provision may have a beneficial impact on decreasing infant mortality. However, expanding these services must be associated, among other things, with the increase of the average schooling of the population, the increase of municipal per capita, the growth of health education campaigns and the development of public policies aiming at basic health care.

As stated in the sanitation atlas (IBGE, 2011), the sanitation services provision progressed from 2000 to 2008 in all regions of the country. Thus, many municipalities had a raise on their services coverage. In the meantime, the existence of a trend to universalization was verified in relation to solid waste collection and water distribution services, by means of supply networks. In these authors' view, the greater the coverage and the more effective these services are, the lower will be the hospitalization register in hospital units due to waterborne diseases or lack of sanitation. Although the water supply service has increased its coverage in the municipalities of the country, the scope of residences assisted by the sewage collection system, so far, is small, around 40% in the year of 2011 (UHR et al., 2016).

The model developed does not have the objective of making predictions, but to guide decision-making, basing on projections of modifications in the situations observed, with the purpose of assisting the conduction and the fomentation of public policies by means of the establishment of priorities on delivering a determined sanitation service. Thereby, the model can be employed as criterion and support instrument to the chiefs of executive power in the decisions to be made for determining the utilization of financial resources in relation to the explanatory variables, aiming at infant mortality reduction in the mesoregions researched.

In possession of population information for each variable (PUDSAE, PUDSCRSU and PUDSAAES), the use of the equation (for a specific year) results in an IS value. If, for instance, the municipal public manager, in 2010, had invested in expanding basic sanitation services, only by weight analysis (r^2) it becomes clear that investing in the reduction of the most significant variable implies a greater reduction of IS and, therefore, of the number of dead children in the first year of life.

The differential in this behavioral model is the possibility of providing responses based on the weight analysis and level distinction. For instance, hypothetically, in a municipality in the year of 2010, a financial amount would allow investing 6% on piped water assistance, or 15% on solid waste collection, or 2% on water supply and sanitary sewage collection coverage. Which would be the best investment? The model outlined is able to clarify that, although a variable has the greatest weight on the model, in terms of numerical quantity, the variable improvement implies greater IS reduction efficiency and, consequently, greater infant mortality reduction.

Barbieri et al. (2016) conducted a study that analyzed the relation between investing in basic sanitation and infant mortality rates, and stated the existence of a linear correlation between the application of financial resources on basic sanitation and infant mortality rate on the municipalities researched. However, they highlighted that the infant mortality indicators consist in the relation of a set of significant variables, for instance, socioeconomic condition, education and health services coverage.

4. Conclusion

The health indicator (IS) designed in this study shows analytical and implementation facility, employing secondary data and multivariate analysis. Thereby, the methodology used can be developed on other areas of study, serving as a tool to guide decision-making and to increment public policies by means of criteria settling and provision priorities in a specific sanitation service.

The sanitation variables used in this research presented good correlation with infant mortality, responding to the proposition that basic sanitation is linked with infant mortality. This study suggests that the infant mortality rate (until 5 years of age) may reduce with the increase in the percentage of assisted population with piped water, water supply and sewage collection services.

It is general consent that basic sanitation investments optimize public health services. Therefore, behavioral (or oversight) models, even though they do not estimate future projections, may help with the comprehension on how the dependent variable behaves according to changes in explanatory variables, becoming an effective tool for public management by enabling to orient investments in a less subjective way, with subsidy of statistical and mathematical criteria, when these present strong correlation.

A suggestion for future research with the objective of making the health indicator more robust is the inclusion of social, economic, environmental and institutional indicators, in order to identify which ones may have the highest correlation with infant mortality. In addition, to observe which explanatory variables need priority in the implementation of public policies by the State aiming to reduce infant mortality, based on statistical and mathematical criteria.

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