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Regression Model to Evaluate the Impact of Basic Sanitation Services in Households and Schools on Child Mortality in the Municipalities of the State of Alagoas, Brazil

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Abstract: The aim of this article is to measure the impact of basic sanitation services on the mortality rate of children under five years of age (U5MR) in the municipalities of the State of Alagoas, Brazil. A multivariate multiple linear regression model was applied for all 102 cities of Alagoas for data years 1991, 2000 and 2010. The research findings are evidence that access to basic sanitation services in the municipalities of the State of Alagoas, especially household sanitary sewage, is associated with a statistically significant reduction of U5MR, $p < 0.01$. The estimates show that the 10% increase in access to household sanitary sewage is associated to a reduction of 5.7 deaths per 1000 born alive (BA). Based on a simulation of universal basic access sanitation services in the municipalities of the State of Alagoas, it is observed that only this public policy would be able to reduce child mortality by more than 94%. The end results of this study are important subsidies to guide basic sanitation policies not only in the State of Alagoas, Brazil, but also in developing regions all over the world, considering the evidences of social and environmental impact.

Keywords: basic sanitation; child mortality; state of Alagoas; Brazil; municipal public policies; social-environmental determinants

1. Introduction

An individual's welfare is related to a multitude of factors among which health, education and income are determining components for promoting the well-being of human beings [1–15]. As part of the global endeavor to eradicate poverty and effectively incorporate the economic, social and environmental dimensions of the sustainable development, the United Nations (UN) established the Sustainable Development Goals (SDGs) as part of a new agenda targeting 2030. From a total of seventeen universal transforming objectives focused on human beings, the SDGs aim at guaranteeing, by 2030, sustainable availability and management of water and universal sanitation, addressing issues such as poverty eradication (Goal 1), clean water and sanitation (Goal 6), inequality reduction (Goal 10) and sustainable cities and communities (Goal 11), among others.

Gross domestic product (GDP) was historically employed as the only variable used to measure quality of life of a population until mid-1990, when Anand and Sen [16] introduced the Human Development Index (HDI) as a tool to evaluate international economic growth. The HDI is based on three pillars that measure key dimensions of human development: health, education and income. The health dimension is represented by a longevity factor. Researchers and public policy makers have examined other factors that exert influence on the health dimension, including inadequate or absence of basic sanitation [17–24].

In Brazil, most research on population welfare has revealed that absence of basic sanitation is a primary determinant behind the health factor [8,25–30]. Guerrant et al. [31] highlighted that the precarious essential services offered, and their relation to poverty, have made the low-income population even more vulnerable to diseases resulting from inadequate hygiene and exposition to pollution. In recent years, diseases delivered by water, led by environmental risk factors associated with such diseases (in addition to other health hazards arising from a lack of basic sanitation), have become a central issue for public policy as well as a public health problem. In 2010, such diseases were responsible for 282,000 hospital admissions in Brazil, affecting children under five years of age at a rate of one per each group of 10 admitted to hospital. In the Northeast, an investigation has revealed an alarming ongoing health situation accounting for 42.46% of total of hospital admissions and more than one-third of child deaths in the age range up to five years old. These mortality rates for children under five years of age are the result of an absence of basic infrastructure services and health care [32]. Based on this profile, the Brazilian government launched a Strategic Plan in 2013 that takes into account what is established in Article 52 of the National Directive Law for Basic Sanitation (Law No. 11445/2007) as "national and regional goals, from short, medium and long terms, for the universalization of basic sanitation services and the nationwide growing levels of such services" from 2013 to 2033 [33].

In spite of the fact that a focus on human health most of the time favors older ages [34], it is in early infancy that basic health care is most needed [35]. According to Gerolomo and Penna [36], besides its direct influence on quality of life, basic sanitation reduces public spending on health, which in turn impacts the collective and individual economic dimensions. In order to figure out its effects, R$ 179.6 million was spent by the Brazilian Unified Health System (BUHS) to account for the hospitalization of children under five years of age for infectious and parasitic diseases. Likewise, there does exist a growing concern towards investigating the way basic sanitation relates to health [37–42]. Such investigation also takes into account the way the public sector approaches universalization issues as far as drinking water supplies and the fundamental sanitation facilities supporting human life are concerned.

Scientific studies emphasize the need to understand the interconnection between socioeconomic context, an individual's health and a child's development. The scientific concepts surrounding under-five deaths in developing countries encompass a complex and multidimensional problem that involves socioeconomic factors interrelated with environmental factors as empirical evidence. Previous research has identified that improvement in urban and rural sanitation reduces infant morbidity and mortality [3]. Despite the existence of studies approaching this issue, no study has provided an adequate definition nor deepened information in relation to cities with a low HDI. Such conditions may be a promising and potentially fruitful arena for debate, as research has tended to ignore the relevance of satisfactory investigations between municipal HDIs and levels of child mortality resulting from recurrent inequalities due to lack of sanitation [17,20,43]. Accordingly, this article investigates the impact of basic sanitation on mortality under five years of age, a fundamental component related to the longevity of a population and its influence on HDI level.

Exposure to adequate sanitation facilities at home and at school is considered to be representative of basic sanitation. An evaluation of home–school integration is based on Scriptore [29] and Neri [44], who highlighted the substantial direct effects of lack of sanitation on health and students' performances. The relationship between health and school performance has also been the subject of investigations by other researchers [45–49]. Such issues still demand deeper examinations regarding improved quality of life and preschooler health conditions when population density and income, among other aspects, are taken into account.

Few studies have incorporated home and school infrastructure when the well-being of the popular was being evaluated in regards to the role of water supply and sanitation. Esty et al. [50] established an environmental sustainability ranking of countries, taking into account access to water and sanitation.

To do so, they drew on demographic data from 70 low-and-medium income countries, from 1986 to 2007, aiming at categorizing the varying determinants relevant for the health of individuals among the countries investigated. In her study, Scriptore [29] observed the impact of sanitation on health and education. She pinpointed the home location asymmetry identified in each geographical region in Brazil, as well as the resulting vulnerability.

In order to complement the pertinent literature (mainly from Brazil), structural equation modeling (SEM) has been employed to determine the relationship between house infrastructure and kindergarten schools as far as child mortality and HDI are concerned. Regression modeling of structural equations is widely used in social and human sciences, and is a theoretical approach that allows multidimensional understanding [51]. Consequently, it is suitable for measuring the impact of basic sanitation in Brazil and its connection with health conditions and environmental sustainability. This is especially useful for the planning and management of public and social policies.

Despite death reduction and sanitation network improvements in Brazil, the sanitation deficit is still a challenge to guaranteeing access to universal sanitation and, consequently, inequality reduction in Brazilian regions. The 2010 Demographic Census suggests that 80.88% of the population had access to toilet and piped water, but that, on the other hand, more than one-third of the population in the Northeast still did not have access to piped water and basic sanitation facilities, which are an essential right for all citizens. These figures reveal the challenges and the health risks for school children, and it is a relevant milieu for examining the data implications.

Furthermore, empirical data are necessary to examine the reasons why Brazilian regions experiencing social and environmental problems maintain high levels of child mortality over decades. The State of Alagoas is one example, and is where the lowest HDI in the country can be found. The lowest HDI was recurrent over the last three decades, resulting in the highest number of deaths among children under five years of age. Therefore, this study take into account all 102 municipalities in the State of Alagoas, aiming at measuring the role of basic household and school sanitation services on mortality of children under five years of age by drawing on a regression model of structural equations. This model takes into account the access to basic sanitation service infrastructure in areas with low-income populations and low HDIs, focusing on the highest levels of child mortality. Its approach and results may be used for public policy planning for other Brazilian states, as well as for other countries facing similar social problems.

This article is divided into four sections, including this introduction. The second section presents the data and the empirical model based on the structural equations, detailing the estimated parameters for measuring the efficiency of available basic household and basic sanitation services and their impact on improving quality of life, child health promotion and environmental protection. In sections three and four, the main results and the final comments are presented, respectively.

2. Methods and Data

In order to carry out the study, decennial data issued by the Brazilian Institute of Geography and Statistics (BIGS), from 1991, 2000 and 2010 was used. This municipal data contains detailed information about the characteristics of Brazilian households. Drawing on public data regarding the effects of Brazilian school infrastructure on municipal Human Development Indexes and health conditions, data from the Basic Education Census issued by the National Institute of Studies and Educational Research Anísio Teixeira (NISERAT) was used, along with information systems from the BUHS Information Technology Department (BUHSITD) and the Brazilian Atlas from the United Nations Development Programme (UNDP). The data were classified by year, to allow the regression analysis process and the analytical consistency of the results and conclusion, encompassing a theoretical model employing the SEM to the State of Alagoas databases.

The analysis drew on multivariate multiple linear regression modeling employing SEM, taking into account the correlational structure and conceptual approaches in the literature regarding human well-being and sustainable development [5,6,12–24]. This is relevant for understanding the relation between basic sanitation and child mortality, as well as the HDI and its long-term relation to basic sanitation.

The combined application with SEM makes the proposed model more consistent than the classic model, as it allows the simultaneous estimation of coefficients and standard errors as far as the linear relation between endogenous variables is concerned. SEM makes use of a matrix of dependent variables, which makes it more efficient if compared to the isolated analyses of regression models that take into account single dependent variables [51].

Besides this relevant feature, the employment of SEM in this investigation allowed the independent analysis of cause and effect variables simultaneously. Moreover, the model makes it possible to estimate the variance of endogenous variables not explained by the exogenous variables designated by the model residues [52,53]. As such, it is entitled to concurrently examine the associated problems in this study, as well as the need to reduce education and income inequality (i.e., detected by the HDI), the infrastructure investment demands and universalized access to water and basic sanitation in cities with low human development and unequal child mortality. The use of SEM in this study enables the regression equation system graphically expressed in Figure 1.

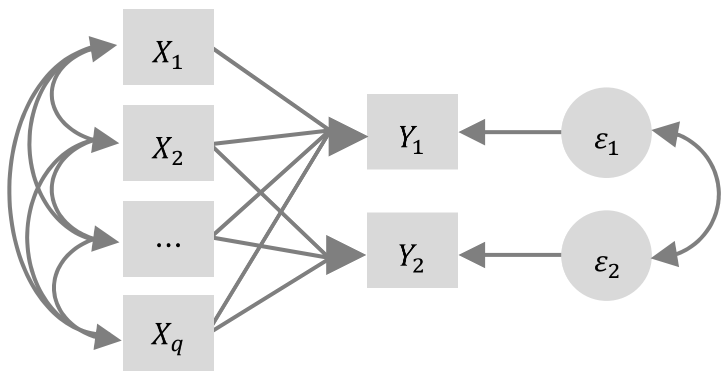


Figure 1. Graphic representation of a Multivariate Multiple Linear Regression (MMLR) model based on SEM. Source: Adapted from Marôco [51].

SEM is a statistics modelling technique that allows the regression analysis of chosen variables based on an established theoretical approach [52]. It can be described as an extension of linear models that unifies the classical techniques of multivariate statistics (e.g., MANOVA, MANCOVA and linear regression [51–54]). The model coefficient estimates are based on the correlation of the investigated variables. Taking into account that the development of a given region may influence health and child indexes, and that child mortality has impact on longevity and, consequently, HDI, mortality rate (Y_1) and Human Development Index (Y_2) are adopted as dependent variables. The Y_2 was used to guide the adjustment model of the observed variables and to test its adequacy for detecting improvements in the well-being of the population according to the proposed objective as discussed in Section 1. The MMLR modeling combined with SEM is classified as trajectory recursive analysis [53] and depicted in Figure 1, where X_i, $i = 1, \dots, q$ are independent variables in the model and ε_i, $i = 1, 2$ are the model prediction errors.

Taking into account the current state of the issue under investigation, this research aims to advance knowledge of the interconnected variables present in home and school sanitation conditions. Such a procedure allows the possibility of obtaining an estimate of all the factors related to the phenomenon under investigation, including the effects of basic sanitation structure in relation to child mortality as an approach to sustainability associated with a worthy and full human life. The model of structural equations used in this research takes for granted the existence of a linear relationship between the two endogenous variables (dependents/criteria), Y_1 and Y_2, and the six exogenous variables (independents/predictors) shown in Table 1.

Table 1. Model variable descriptions for measuring the impact of basic sanitation services on child mortality in the municipalities of the State of Alagoas.

Variables	Description	Acronym	Scale	Source
Y_1	Mortality rate under five years of age per 1000 born alive (BA)	U5MR	BA	BUHSITD [55]
Y_2	Municipal Human Development Index according to the longevity, education and income normalized to percentage	MHDI	%	UNDP [56]
X_1	Rate of houses having primary individual treatment systems of domestic sewage or public sewage services	DSPS	%	BIGS [57–59]
X_2	Rate of home populations having toilet and piped water	HPTPW	%	BIGS [57–59]
X_3	Rate of coverage of urban cleaning services including regular collection of household waste	CUCS	%	BIGS [57–59]
X_4	Quality index of sanitation services in child schools	SSCS	%	NISERAT [60]
X_5	Urbanization rate	URB	%	BIGS [57–59]
X_6	Size of population per 100,000 residents	POP	0–100,000	BIGS [57–59]

To calculate the variable X_4, the following items are considered to exist in a given school j: access to water $\left(I_{1j}\right)$, a sewage system $\left(I_{2j}\right)$, appropriate and adequate toilet and washing facilities $\left(I_{3j}\right)$ and student access to filtered drinking water $\left(I_{4j}\right)$. Contrary to the data concerning home infrastructure, school infrastructure data are not available; moreover, such information is presented as binary data (i.e., if each school "has" or "does not have" each one of the items mentioned). Therefore, X_4 is calculated according to the expression:

$$X_4 = \left(\frac{1}{4n}\sum_{j=1}^{n}\sum_{i=1}^{4} I_{ij}\right) \times 100 \quad (1)$$

where $I_{ij} = 1$ if there exists the i sanitation condition in the school infrastructure j, or $I_{ij} = 0$ if that does not exist; e is the number of schools considered. The index represents the percentage of a group of items in a school that concern the school's infrastructure. Only active children's education schools were considered, which were identified in the School Census database as schools classified as Level/Modality under "Children's Education" (Kindergarten and Preschool).

Generally, the following formal notation is adopted for this MMLR model:

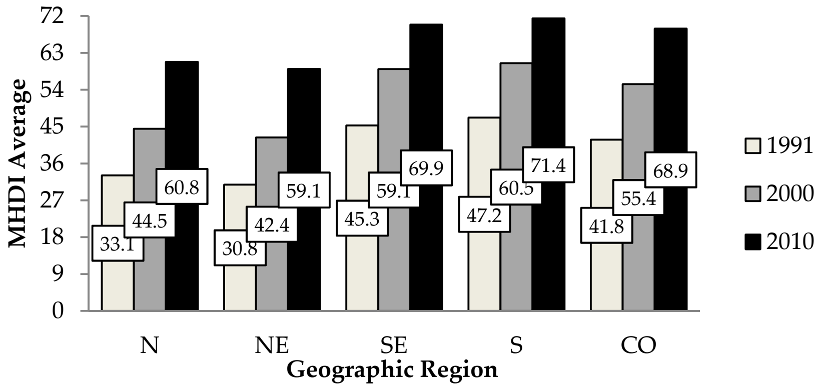
$$Y_i = \beta_{i0} + \beta_{i1}X_1 + \ldots + \beta_{iq}X_q + \varepsilon_i \quad (2)$$

where the dependent variables $Y_i,\ i = 1,2$, representing the *U5MR* and the *MHDI*, respectively; $X_j,\ j = 1,2,\ldots,q$ are independent variables listed in Table 1; β_{ij} are the linear regression coefficients and ε_i represents the stochastic error term.

For statistical interpretation, 5% was the level of significance considered. The software AMOS (IBM, v.22) was used to estimate the regression coefficients, employing the maximum likelihood estimation method for significance analysis.

Sample Selection

In Brazil, *MHDI* is low and unequal in the geographic regions, as Figure 2 illustrates. According to the UNDP [56] classification, an *MHDI* lower than 60.0% is classified as low human development; between 60.0% and 69.9% as medium human development; and from 70.0% upwards the level of human development is considered to be high. In 2010, only 34.74% of Brazilian municipalities had a high level of *MHDI*. The percentage is lower in the poorest areas in the country (i.e., in the Northeast and in the North), where just 1.90% and 5.58% of municipalities, respectively, had a high level of *MHDI* in 2010. This is a recurring inter-regional inequality. During the past 30 years, the *MHDI* from those areas was the lowest in Brazil. But it is in the Northeast where the situation is most critical, as it holds the lowest *MHDI* levels despite the improvement detected over these years.

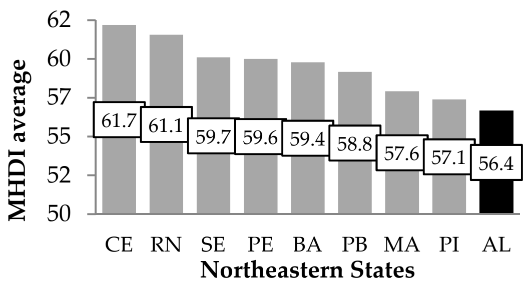


N = North; NE = Northeast; SE = Southeast; S = South; and CO = Central West

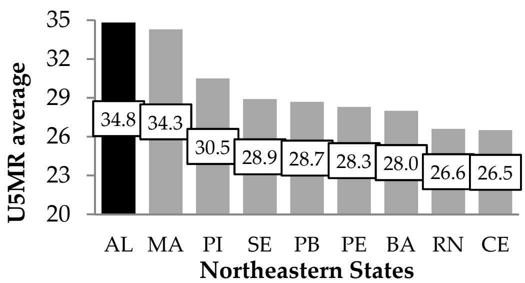
Figure 2. Historical perspective of the municipal Human Development Index in Brazil.

A similar context is observed in relation to the rate of mortality for children under five years of age (*U5MR*). In Brazil, the average *U5MR* decreased from 59.54% in 1991 to 21.53% in 2010; in other words, there was a reduction of around 64% (Appendix A). During the same period, the Northeast registered the biggest regional *U5MR* reduction, reaching almost 70%, from 96.43% in 1991 to 29.33% in 2010. In spite of this significant reduction, the Northeast is still considered to be an area of social inequality and exclusion, a position held for the last three decades. This is due to the fact that the mortality rate for children under five years of age in the Northeast is the highest in Brazil, as shown in Figure 2. Despite its position nationwide, improvement of the *U5MR* average is an indication that it is possible to face the challenge and improve living conditions of the most vulnerable population in the abovementioned region.

As the lowest averages are reported in the Northeast, information about each Northeastern state is indicated in Figure 3, where the 2010 *MHDI* and *U5MR* of the nine Northeastern states can be found. It can be observed that the State of Alagoas had the lowest *MHDI* (56.4%) in relation to the region and the country. This number corresponds to the UNDP classification, which defines it as a low level of development (from 50.0% to 59.9%). The State of Alagoas is also depicted as having the highest *U5MR* (34.8%) in relation to the region and the country, indicating an unfavorable situation as far as child vulnerability is concerned. In view of the numbers mentioned above, the State of Alagoas was chosen to be the MMLR object of investigation.



(**a**)



(**b**)

Figure 3. *MHDI* (**a**) and *U5MR* (**b**) compared, considering the nine Northeastern states in 2010.

The State of Alagoas has 102 municipalities. After comparing the databases, the municipalities that did not conform to the information required in Table 1 were excluded. This way, the data collected was restricted to 94 occurrences in 1991, 99 in 2000 and 102 in 2010. This amounts to 295 occurrences on an unbalanced panel during the years in which the model was applied.

3. Results and Discussion

In order to contextualize a complex and multidimensional problem that evolved as a result of interrelated socioeconomic and environmental factors, this section introduces an exploratory analysis of the data. Afterwards, the results are presented based on the application of the MMLR modeling of the group of 102 municipalities from the State of Alagoas from 1991 to 2010.

3.1. Exploratory Data Analysis

In Figure 4, the variable boxplot used in this research is presented using the data listed in Table 1. The information from the collected data from 1991, 2000 and 2010 are grouped in the diagram. These statistics, highlighting the average graphic value, provide a panoramic look at the State of Alagoas, at the Northeast and at Brazil, aiming towards a better contextualization. Table A1 in the Appendix A shows the values of the minimum, maximum, average and standard deviation of each variable.

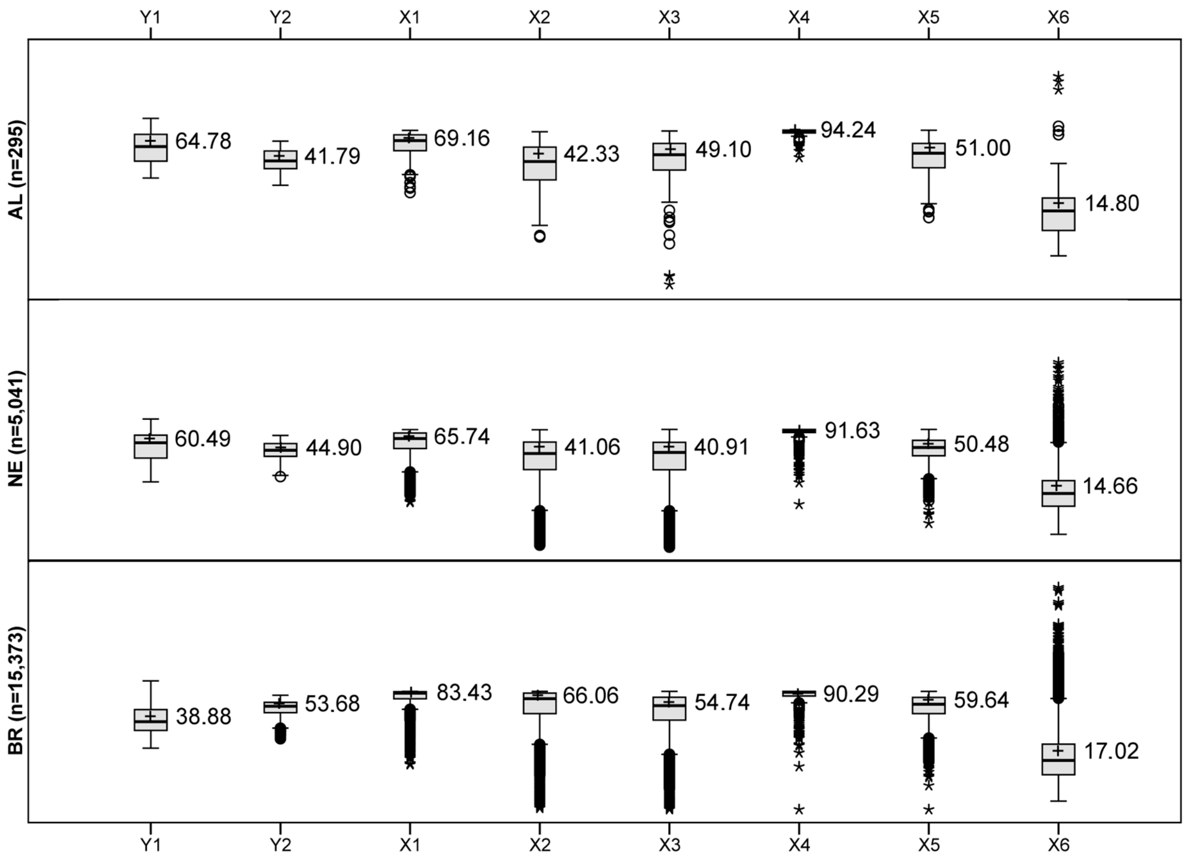


Figure 4. Model boxplot variables for the municipalities of the State of Alagoas, for the Northeast and for Brazil from 1991 to 2010.

Following the variable analysis of the databases, three procedures were employed for the preliminary analysis of the cloud data. First, a visual inspection was used to identify atypical observations. Then, outlier spots were defined using the boxplot limits (upper bound (UB): °°°Q3 + 1.5 IQR; lower bound (LB): Q1 − 1.5 IQR | ∗ UB: Q3 + 3 IQR; LB: Q1 − 3 IQR). Finally, the critical analysis of data errors versus units holding actual different values was determined. After carrying out a careful examination, the observations concerning the evaluation function of the registered individual reliabilities were maintained.

For instance, the X_6 values indicated that the municipalities in Brazil had distinct population densities. During this inspection stage, extreme outliers (*) could be observed in the State of Alagoas diagram (AL, n = 295) for the most populous cities (i.e., the capital city, Maceió) and the second most populous city (Arapiraca, in the countryside). The other extreme, the observed "inliers" from the X_3 variable, were consistent with local questions and with the level of investment in the urban collection of household residues, mainly (and more intensely) in the countryside municipalities of the State of Alagoas. This reports families living in municipalities with no urban cleaning, periodic collection of residues or household residue management. Additionally, before employing the regression model described in Section 3.2, a diagnostic test of outliers related to regression residues and their impacts on the model coefficients was carried out. This is detailed in the current section.

At the exploratory data stage, it is possible to observe that the access to home sewage (*DSPS*, X_1) was unsatisfactory in areas in the country, since 83.43% of the Brazilian population did not have access to a public sewage service. In the State of Alagoas, this figure reached 69.16%, representing 5.20% more in relation to the results in the Northeast. The smallest *DSPS*, X_1, was detected in the Northeast, in São Raimundo do Doca Bezerra (MA), at 4.77% (i.e., 95.23% of households did not have proper facilities for the disposal of sewage.) In the State of Alagoas, the lowest *DSPS* was detected in Belo Monte (AL), 15.05%, meaning that 84.95% of households did not have a sewage disposal method. In both cases, a "high" level of child mortality ($U5MR \geq 50$) and a "very low" level of municipal Human Development Index ($MHDI < 50$) were observed.

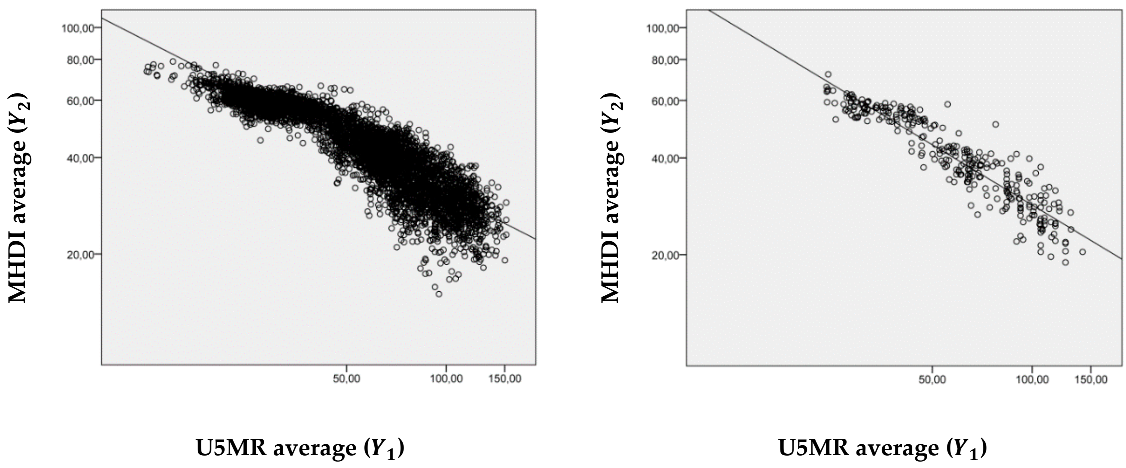
The population lack of access to piped water and toilet facilities in their homes ($100 - \hat{X}_2$) was recurrent in the municipalities in the State of Alagoas, with 50% of the population vulnerable as far as water and basic sanitation services are concerned. The standard deviation variable X_2, *HPTPW* (population rate having piped water and toilet facilities), indicated a high heterogeneity of households with toilet and piped water in Brazil and in the State of Alagoas. To illustrate this statement, only 3.35% of the population of Inhapi (AL) has access to toilet and piped water, while in São Miguel dos Campos (AL) 95.41% of the population has access to this basic infrastructure.

Considering the variable X_3, the average *CUCS* (rate of coverage of urban cleaning services, including regular collection of household waste) for the State of Alagoas from 1991 to 2010 was better, by about 20.00%, when compared with the Northeastern average performance during the same period. On the other hand, it was 10.30% lower than the national average. However, the recorded standard deviation for municipalities in the State of Alagoas revealed a high variation, considering the extremes figures −0.07% as lowest value and 97.65% as highest value for Belo Monte (AL) and Satuba (AL), respectively. This indicates the dispersion and disclosure, a priori, of state distortions in relation to the coverage of periodic urban residues cleaning services.

As regards X_4, average *SSCS* (quality index of sanitation services in children's schools) in the State of Alagoas was slightly superior in relation to the average in the Northeast (+2.85%), as well as to the average in Brazil (+4.37%) from 1991 to 2010. The standard deviation of the variable X_5, *URB* (urbanization rate) expressed the high variation within the State of Alagoas. At any given moment, a specific municipality in the State of Alagoas recorded an urbanization rate of 6.70% (i.e., most of the population (93.30%) was located in rural area). The average *URB* from the period was slightly above the Northeastern average (+1.03%), but inferior to the national average (–14.49%) from 1991 to 2010.

The variable X_6, average *POP* (size of population per 100,000 residents) in the State of Alagoas, was slightly superior to the Northeastern average, but a bit smaller when compared to the Brazilian average. It is worth noting that the population of the municipalities in the State of Alagoas was smaller than the national average, sustaining the demographic density profile from the region. The standard deviation of the State of Alagoas data discloses a high dispersion in relation to the population average from its municipalities, expressing a high demographic density in some municipalities but a low density in others. For instance, Maceió (AL) had 932,748 inhabitants, while Pindoba (AL) had only 2866.

A Pearson correlation analysis was carried out between the dependent variables *MHDI* (Y_1) and *U5MR* (Y_2) employing SPSS Statistics (IBM, v.22). The analysis revealed a strong negative linear correlation ($r = -0.916; p < 0.01$) between the endogenous variables, corroborating the theoretical and empirical studies that state that the mortality rate of children under five years of age significantly and negatively influences HDI. Figure 5 shows the *MHDI* dispersion diagram in relation to the *U5MR* concerning the Northeast and the State of Alagoas, pinpointing a strong negative relationship between *MHDI* and *U5MR*. In this way, an analysis of the basic sanitation factors from households and children's education schools (decisive for child mortality rates under five years of age) may provide directives for public policies aiming to improve the *MHDI*.



(**a**) (**b**)

Figure 5. *MHDI* and *U5MR* data dispersion diagram in the Northeast (**a**) and in the State of Alagoas (**b**).

All things considered, it can be understood that the decreasing tendency of under-five mortality in Northeastern cities, especially in the State of Alagoas, is encapsulated in the *MHDI* (Figure 2). Along these lines, conjunctural factors such as income variation, health and long-term education, seem to explain the reduction in child mortality to a large extent. It is widely known that endogenous factors, specifically the personal socioeconomic one, directly affect life expectancy [17]. In this context, it is worth noting the impact of income on housing condition, which consequently provides better access to health and public services. Lower income implies that an individual is inclined to live in inadequate housing condition, with more chances to be infected by diseases. Such facts exert a powerful influence on quality of life. In short, the lower the purchasing power, the higher the chances of the housing facility being located in an area with low basic infrastructure. The rate of sanitation coverage positively impacts an individual's health. Such social determinants may be substantiated by the principle that the higher the educational level of residents, the more prone they are to a standard of living (income) that influences productive capacity (health) and learning (education). Therefore, while emphasizing basic sanitation policies and urban cleaning services, the public administrator to some extent creates a virtuous cycle in which the level of sanitation will significantly influence an individual's health.

Aiming for a consistency analysis regarding the parameters' significance in the regression model (to be discusses in the next section), the research proceeded by validating the normality assumptions and diagnostic outliers of all variables used in the study using SPSS (IBM, v.22) based on Mahalanobis distance square (D^2). The test identified 25 potential observations as outliers in the State of Alagoas, all of them reflecting intrinsic characteristics of the population directly related to income inequality, demographic density and efficiency of the basic municipal sanitation systems reverberating through the higher country *U5MR* (Y_1) and the lower *MHDI* (Y_2) registered in this state. Therefore, following the database analyses, there were no observations removed as a result of detected measurement errors, nor distortions capable of affecting the model adjustment quality. Moreover, the variance inflation factor test (VIF) did not identify multicollinearity violations that could interfere with the application of the data to the regression model in regards to the general objective of the study.

3.2. Analysis of the Results of the Regression Model

In order to empirically reflect on the interconnected complexities of the conceptual formulations of children's health, as well as on demographic and environmental influences, an MMLR model was adopted drawing on SEM between *U5MR* and *MHDI* (endogenous variables) and the variables *DSPS* (X_1), *HPTPW* (X_2), *CUCS* (X_3), *SSCS* (X_4), *URB* (X_5) and *POP* (X_6). Table 2 shows the regression coefficients considering all six independent variables (Case 1) and assuming $p < 0.01$. All predictors were statistically significant, except the variable X_6 in reference to the two endogenous variables. In other words, the X_6 coefficients for Y_1 ($p = 0.098$) and X_6 to Y_2 ($p = 0.389$) did not propose that demographic density in a given municipality in the State of Alagoas presented a statistically significant effect that exerts influence on child mortality or HDI.

Table 2. Analysis of the regression coefficients of the model in two steps.

	Y_1=*U5MR*				Y_2=*MHDI*			
	Case 1		Case2		Case1		Case2	
	β_{1j}	S.E.	β_{1j}	S.E.	β_{2j}	S.E.	β_{2j}	S.E.
β_{i0}	150.704	11.105	150.865	11.137	6.033	3.777	6.062 *	3.775
X_1	−0.570	0.087	−0.566	0.087	0.246	0.030	0.247	0.030
X_2	−0.384	0.087	−0.375	0.087	0.218	0.030	0.220	0.030
X_3	−0.378	0.099	−0.381	0.099	0.115	0.034	0.115	0.034
X_4	−0.382	0.118	−0.392	0.119	0.110	0.040	0.108	0.040
X_5	0.466	0.074	0.481	0.073	−0.130	0.025	−0.127	0.025
X_6	0.040 *	0.024			0.007 *	0.008		
R^2	0.667				0.790			
F	115.834 ($\nu_1 = 5$, $\nu_2 = 289$)				216.935 ($\nu_1 = 5$, $\nu_2 = 289$)			

* $p > 0.05$; S.E. = standard error.

The direct effect with the largest impact on child mortality (Y_1) was the variable that encapsulated the characteristics of household sanitation systems (X_1), showing a regression coefficient $\beta_{11} = -0.566$. The coefficient estimates indicate that, for example, when there is a rise of 1 unit in the household sanitation conditions in the State of Alagoas X_1, the rate of child mortality Y_1 reduces 0.566 units. It is worth mentioning that this is the variable that had the largest impact on HDI (Y_2). The existence of households with sanitation systems revealed a direct positive effect on *MHDI* in the State of Alagoas, with coefficient $\beta_{21} = 0.247$. Thus, the rise of 1 unit in the household sanitation conditions in the State of Alagoas caused a rise of 0.247 units in the *MHDI*.

Given the correlations between the variables, a multicollinearity diagnostic approach was used to calculate variance inflation factors (as described in the previous section) by holding an established tolerance value of 0.15 and reflecting a $VIF < 10$ in order to understand the relations among variables [51,61]. In turn, the measurement reliability and theoretical relevance specifying the importance of the variable effects under study (sewage, piped water, urban cleaning services, urbanization process) associated the regression analysis rationale with structural equations, the whole process of which originated in theoretical reference [53,54]. For example, while analyzing the correlation between X_2 and X_3 ($\rho = 0.85$), as depicted in Figure 6, two questions should be taken into account when the study is applied to Brazilian data. Basic Brazilian sanitation results from a set of services, but the provisions are segregationally made with diffuse responsibilities: the state government acting in one segment and the municipality acting in another, with the private sector holding a part of the services. Whenever the public or private sector is not available, failure in the attendance is not charged.

This affects direct accessibility to services by the population, and reveals distortions in the capacity of simultaneous provisions, particularly in poor areas of the country. When there is a correlation between piped water (X_2) and residue collection (X_3), one variable captures the household infrastructure for having piped water and for having private internal installations and pipelines, while the other variable is independent of this individual structure since it is a residue collection service physically operated along public streets. This reflects generalization loss in the redundancy collinearity diagnostics for one or more independent variables in the employed model. A meticulous judgement is required from the researcher, rigorously following the theoretical principles previously established while applying the SEM, which transcends the strict statistical significance [51]. In this part of the study all the independent variables were maintained.

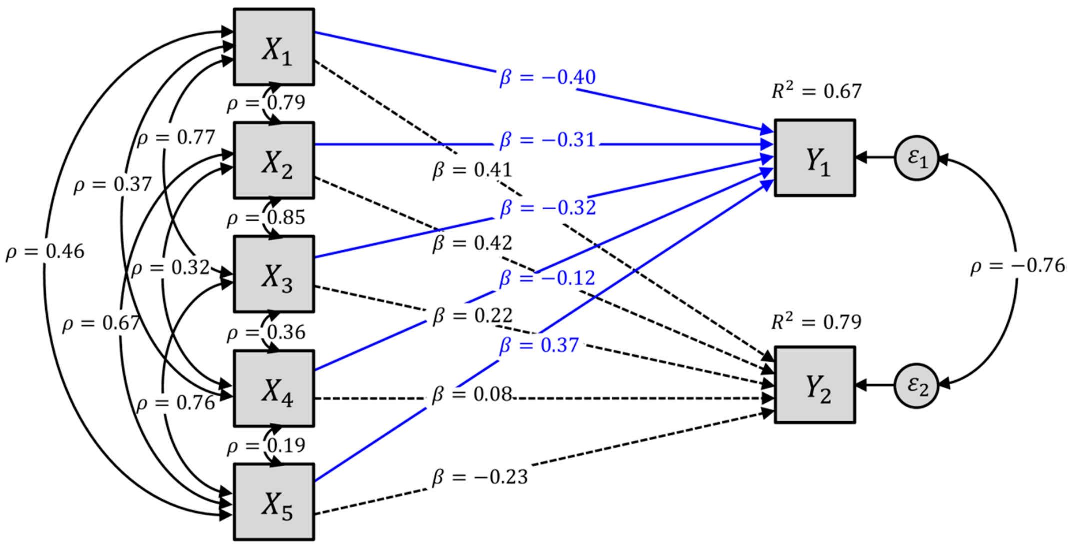


Figure 6. The regression model diagram applied to the final model with the State of Alagoas data but without variable X_6.

Figure 6 details the final model, providing an illustration of the standardized estimates β (trajectory weights), R^2 values for each dependent variable (variability percentage of the adjusted model) and the correlation coefficients between the predictors ρ, including the correlation coefficient between the dependent variable errors. Considering the general objective of the study, the variable that had the highest impact on child mortality (Y_1) was the treatment of household sewage or general system collection (X_1), as can be observed in Table 2.

The impact of urbanization in the municipalities of the State of Alagoas should be noted. This is revealed by the variable X_5 (urbanization rate), given that it exhibited the second largest direct effect to justify the Y_1 rise during the period. The increase in population density in the State of Alagoas showed a reverse relation with *U5MR*, suggesting that the population concentration without urban planning directly influences the precarious infrastructure of basic sanitation services and the commitment to well-being among the municipalities under investigation.

It was also found that the school infrastructure (X_4) was the variable that exerted the slightest influence over the dependent variables during the studied period. It is worth mentioning that these findings are consistent, and they reverberated across a specific population segment whose exposure to household–school social milieu was examined, taking into account the education of children under five years of age. This pairs with the poor education services in the municipalities of the State of Alagoas, where only 37% of children under five years of age attend school [57]. The other variables reverberated altogether throughout the entire population.

Assuming that X_6 was not relevant in any of the endogenous variables, the X_6 variable was discarded and the coefficient estimates were recalculated. These are shown in Table 2 (Case 2). It was observed that the β_{20} was not statistically relevant, so the model for the Y_1 variable, which represents the object of investigation of this research, was considered. The $U5MR$ final adjusted model explained 67% of the variability of Y_1, highlighting that the variability percentage was high for both ($R^2 > 0.5$), according to Marôco [51]. In order to verify the statistical significance of the proposed model in Table 2 (Case 2), analysis of variance (ANOVA) was carried out and the statistic F value was calculated. As a result, the calculated F was much higher than the tabulated critical one, $F_{(5,289);5\%} = 2.21$, proving the statistical significance of the model with 95% confidence. Therefore, child mortality can be expressed by the equation:

$$\hat{Y}_1 = 150.865 - 0.566X_{11} - 0.375X_{12} - 0.381X_{13} - 0.392X_{14} + 0.481X_{15} \tag{3}$$

Once the model was statistically validated, simulations were carried out in order to provide useful information that could help shape sanitation and health policies regarding child mortality. On average, it is estimated that an increase of just 10% in the rate of domestic sewage collection would lead to a reduction of 5.7 deaths per 1000 born alive (BA), influencing children's development and whether an individual have the "right to live". However, the isolated analysis unveils some disadvantages, and these should be recognized. The efforts to expand basic sanitation coverage should be acknowledged as an integrated approach. They should provide full school and home assistance, which in turn reduces the levels of vulnerability of the under-five group, leading to general improvements in health quality.

When the model is applied to the current scenario where the X_i values are recurrent from 1991 to 2010 in Figure 4 (boxplot), it is estimated that $U5MR = 64.8$, the same value observed in the database. A universalized context in which sanitation services are offered and available (i.e., all households have sanitation facilities ($X_1 = 100\%$), piped water ($X_2 = 100\%$), regular collection of household residues ($X_3 = 100\%$)), and all children's schools have a sewage service, access to water, fully adapted school-children's bathroom and accessible filtered water for the students ($X_4 = 100\%$) it is estimated $U5MR = 4.0$ so long as the urbanization rate (X_5) is maintained (considering the average value during the period (51)). This simulated rate turns the State of Alagoas into the state with the lowest level of children mortality in Brazil, while occupying the 16th spot in the global ranking, as shown in Figure 7. It would also avoid 61 deaths among children under five years of age per 1000 born alive. The estimated result in the universalization simulation in this study is not uncommon in developed countries. Available household and school sanitation services guarantee a healthier life for individuals comprising social benefits. In 2010, 15 of the 195 countries monitored by the UN managed to reduce to less than four deaths per 1000 born alive in the under-five age group (Figure 7), a figure close to the simulation for the State of Alagoas considering the universalization of basic sanitation services.

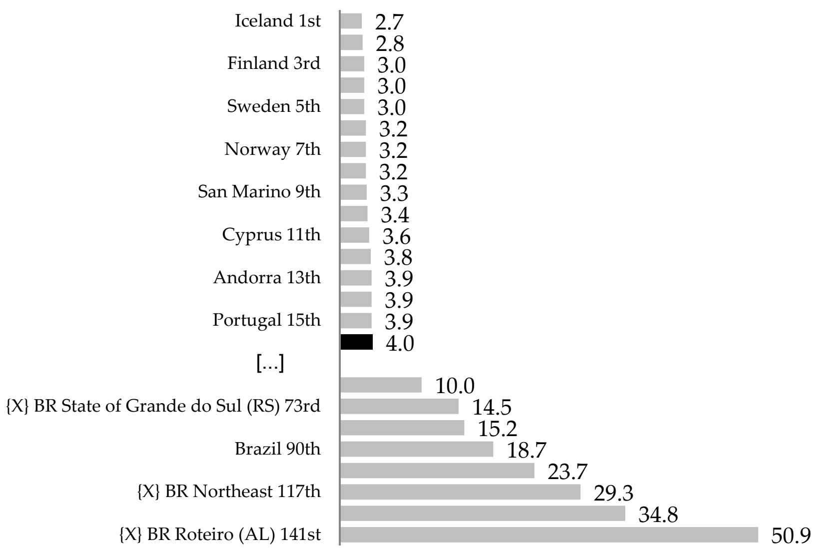


Figure 7. Global ranking of the average rate of mortality for children under five years of age. Source: Adapted from the UN [62].

In this way, sanitation infrastructure investments significantly affect child mortality reduction, particularly in developing regions. The findings justify investments to improve and expand water main supplies and sanitation services, and it is necessary to recognize the challenge faced by the State of Alagoas. Both the municipalities' and the state's governances play an extremely relevant role in planning and applying public policies that can contribute to the well-being of the population. This is due to the fact that 75% of the water supply is under the responsibility of administration of the State of Alagoas, and 25% is under the municipal management. The administration of the State of Alagoas provides sanitation services to only 3% of all municipalities, while 97% are still in urgent need of this basic service. This is where the municipalities' administrative teams have to immediately respond to the population needs. All urban household residue management and disposal is managed by the municipal administration [63]. Growing evidence suggests that sanitation influences child mortality reduction, given the fact that living in a place with access to basic sanitation services contributes to a healthier population and to a decrease in poverty and the inequalities of the most vulnerable regions [40]. The results found in this research are consistent with other international studies that have investigated the same issue. Esrey et al. [2], for example, identified that access to water and sanitation has an average impact of 55% in the reduction of child mortality, sourcing 144 studies from all over the world. Likewise, Derslice et al. [3] discovered that the nonexistence of water and sanitation facilities has negative consequences for newborn babies, and increases the risk of diarrhea by 88% in their first six months of life in low-income urban areas. Equally, Poppel and Heijden [19] reached similar conclusions as far as water and sanitation are compared in developing countries, drawing a comparison between studies that reported declines in child mortality. Watson [22] estimated that in areas where sanitation programs were not implemented, mortality rates for children under five years of age were higher than current rates when considering an absence of investments in sanitation infrastructure projects. Similarly, Hutton et al. [10] estimated the effects of universal access to water and basic sanitation on promoting health in developing countries, indicating a potential reduction of 47% in cases of diarrhea around the world. Fink et al. [12] carried out a study involving 70 countries and verified direct positive effects of sanitation on children's health and on reducing mortality among children under five years of age. Children had an average of 23% less likelihood of mortality when living in households with quality sanitation services. Scriptore's [29] findings, in relation to Brazil, suggest that access to basic sanitation also has a negative effect on school attendance, and that people without bathrooms and who are exposed to open air raw sewage have three times more likelihood of hospital admission as a consequence of diarrheal diseases. This context is confirmed through a retrospective analysis for which four demographic censuses were combined by Alves and Belluzzo [8], who reported that improvement in water and sanitation services contributes to the decline of mortality among children under five years of age.

Figure 7 shows the 2010 global rankings of 195 countries in terms of mortality rates among children under five years of age. The results marked with an {X} are used to indicate the Brazilian situation within a worldwide context.

A panoramic view is depicted for the State of Alagoas, its environmental area, the Brazilian reality in general and the global performance regarding the mortality rate among children under five years of age. It can be observed that Cachoeira do Sul (RS) is the Brazilian municipality with the best $U5MR$, holding the 53rd position, in spite of the fact that Brazil is in the 90th position and the State of Alagoas is in the 125th position. Satuba, a municipality in the State of Alagoas, holds the 107th position, while Roteiro holds the 141st. It is in the State of Rio Grande do Sul where the best $U5MR$ is detected. The $U5MR$ places this state in the 73rd position in Brazil.

This result, identified by (∗), takes into account the universalization simulation of the basic sanitation coverage in the State of Alagoas ($U5MR = 4.0$). The projected result for the State of Alagoas, considering the impact of the universalization of basic sanitation, would place the state 16th in the rankings, despite the 90th position it holds in Brazil ($BR: \; U5MR = 18.7$), or, according to the current performance, in the 125th position for 2010 ($AL: \; U5MR = 34.8$).

This study is the first attempt to systematically analyze the effects of basic sanitation availability on mortality among children under five years of age in the State of Alagoas when drawing on a full database from municipalities for the period of 1991 to 2010. Basic sanitation is an important measurement instrument for evaluating the improvement of health conditions and human development within a given period of time, and is statistically depicted in this article in consideration of a poor state in Brazil. Such a study provides a valuable contribution to the public policy literature on human and socioenvironmental development. First, it is an attempt to propose an adjustment quality index (AQI) for a statistic model with recognizable variables as far as Brazilian basic sanitation services are concerned. The proposed AQI is a particularly useful tool for monitoring municipalities from a region that historically has been burdened by remarkably low levels of social development, and that is an arena of perennial health challenges among school-age children due to the high mortality rate. Second, the investigation carried out embeds, within a statistic model, a synchronized evaluation process between endogenous factors. As such, it provides the opportunity to study the existing connection between a set of factors. Moreover, this study also statistically inquiries into the question of whether a change in basic sanitation implementation may explain the improvement of children's health and *MHDI* during the abovementioned period using a trajectory diagram to better understand the interpretation of the results. Finally, the application of the modelling of structural equations employed in the study, based on a combination of theory and empirical results from previous research, allows it to specifically measure and predict the impact of investments in basic sanitation services on social indicators such as child mortality rate, which can be replicated in other municipalities, states and countries.

4. Conclusions

The main objective of this study was to measure the impact of basic sanitation regarding mortality rates among children under five years of age in areas with low HDIs. One-hundred and two municipalities from the State of Alagoas were investigated, drawing on official data from 1991, 2000 and 2010. Within this context, it was possible to observe that the *U5MR* reduction was a key element in the attempt to guarantee an improvement in the well-being of the population as detected by the *MHDI*.

A measurement model was proposed to test the hypothesis that child mortality is higher when household and school sanitation conditions are inadequate. The estimate parameters representing basic sanitation factors were statistically relevant for the period scrutinized. The implications for governance and public policies resulting from the findings are valuable for the expansion of basic sanitation. Such measures establish new parameters for children below five years of age to have access to better hygiene conditions at home and at school, improving health conditions and socio-economical vulnerability during a child's development. The proposed model is useful to provide governance with precise information as regards the highly relevant social benefits resulting from universalized basic sanitation.

As well as reducing educational and financial inequalities, investments in infrastructure and programs of universalization of access to water and environmental sanitation in developing regions, detected by *MHDI*, are necessary to lower the child mortality rate, as in the case of the State of Alagoas, and to be taken as parameter for the Northeast and the country. In order to detect the estimated impacts of such investments, an increase of 10% in household sewage collection services was associated with an estimated reduction of 5.7 child deaths per 1000 born alive in the State of Alagoas.

While validating empirical evidence based on a mathematical model, the relevance of directing efforts to surpass challenges in order to respond to the basic needs of populations are highlighted. This demonstrates the importance of public management and implementation of the National Plan for Basic Sanitation and Collection and Disposal of Solid Residues, which results in benefits for public governance and society as a whole. Considering the quantification of the benefits resulting from universalized basic sanitation, and bearing in mind social development and the improvement of children's health, prioritizing investments and public resources for increasing basic sanitation services is essential, particularly in the poorest regions.

In short, case studies addressing other Brazilian states, which have distinct social, economic, and political realities, are recommended. This is useful in order to measure possible impact heterogeneities resulting from universalized basic sanitation on a health indicator. To do so, the objectives of the National Plan for Basic Sanitation and Collection and Disposal of Solid Residues, as well as the SDG directives for 2030, should be observed.

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Appendix A

Table A1. Descriptive summary of the variables of the State of Alagoas, Northeast and Brazil from 1991 to 2010.

State of Alagoas (N = 295)								
Variable	**Min.**	**Max.**	**Average**	**SD**	**Min.**	**Max.**	**Average**	**SD**
	1991 to 2010				1991			
Y_1 (U5MR)	23.72	141.67	64.78	29.15	63.66	141.67	99.81	16.12
Y_2 (MHDI)	18.90	72.10	41.79	12.43	18.90	50.70	28.66	5.50
X_1 (DSPS)	15.05	99.31	69.16	20.71	15.05	90.47	50.53	17.58
X_2 (HPTPW)	3.35	95.41	42.33	23.92	3.46	78.01	25.73	14.95
X_3 (CUCS)	0.07	97.65	49.10	24.12	0.07	77.79	28.87	17.31
X_4 (SSCS)	44.12	100.00	94.24	8.98	44.12	100.00	88.83	12.25
X_5 (URB)	6.70	99.93	51.00	22.19	8.14	92.74	44.28	20.38
X_6 (POP)	1.50	488.97	14.80	42.49	1.80	329.76	13.60	34.56
	2000				2010			
Y_1 (U5MR)	38.85	96.63	62.45	11.43	23.72	50.94	34.77	7.16
Y_2 (MHDI)	28.10	58.40	39.26	5.11	48.40	72.10	56.35	3.96
X_1 (DSPS)	37.12	96.55	67.14	14.59	65.94	99.31	88.30	7.80
X_2 (HPTPW)	3.35	86.13	37.38	19.20	18.20	95.41	62.44	20.31
X_3 (CUCS)	15.32	93.76	51.50	19.76	24.18	97.65	65.40	19.58
X_4 (SSCS)	66.67	100.00	95.25	6.75	85.71	100.00	98.23	2.81
X_5 (URB)	6.70	99.75	51.44	21.71	8.32	99.93	56.78	22.74
X_6 (POP)	1.53	418.21	14.68	42.51	1.50	488.97	16.04	48.99
Northeast (N = 5041)								
Variable	**Min.**	**Max.**	**Average**	**SD**	**Min.**	**Max.**	**Average**	**SD**
	1991 to 2010				1991			
Y_1 (U5MR)	11.92	151.60	60.49	29.94	40.00	151.60	96.43	19.27
Y_2 (MHDI)	14.90	78.80	44.90	12.76	14.90	57.60	30.84	6.07
X_1 (DSPS)	4.77	99.90	65.74	24.28	4.97	96.69	46.21	20.18
X_2 (HPTPW)	0.08	98.73	41.06	24.57	0.08	90.52	24.18	16.82
X_3 (CUCS)	0.00	100.00	40.91	25.49	0.00	99.01	22.95	19.36
X_4 (SSCS)	4.35	100.00	91.63	12.02	4.35	100.00	84.78	15.41
X_5 (URB)	1.54	100.00	50.48	20.54	2.52	100.00	44.89	20.20
X_6 (POP)	0.66	1402.66	14.66	52.57	0.66	1088.88	14.26	47.23

Table A1. *Cont.*

Northeast (N = 5041)								
Variable	**Min.**	**Max.**	**Average**	**SD**	**Min.**	**Max.**	**Average**	**SD**
	2000				2010			
Y_1 (U5MR)	29.50	106.29	61.81	11.21	11.92	50.94	29.33	6.45
Y_2 (MHDI)	24.10	66.40	42.37	6.12	44.30	78.80	59.07	4.33
X_1 (DSPS)	4.77	98.88	61.83	21.01	32.85	99.90	85.79	12.32
X_2 (HPTPW)	0.13	94.55	34.00	19.35	3.26	98.73	61.99	19.27
X_3 (CUCS)	0.00	97.91	39.07	23.13	0.00	100.00	57.64	20.96
X_4 (SSCS)	33.33	100.00	92.08	10.53	52.08	100.00	96.87	5.78
X_5 (URB)	1.54	100.00	50.38	20.46	8.32	100.00	55.22	19.71
X_6 (POP)	0.69	1280.95	14.13	51.56	0.66	1402.66	15.51	57.54
Brazil (N = 15,373)								
Variable	**Min.**	**Max.**	**Average**	**SD**	**Min.**	**Max.**	**Average**	**SD**
	1991 to 2010				1991			
Y_1 (U5MR)	9.98	151.60	38.88	25.37	17.12	151.60	59.54	31.16
Y_2 (MHDI)	14.90	86.20	53.68	13.97	14.90	69.70	39.63	9.79
X_1 (DSPS)	4.77	100.00	83.43	21.38	4.97	100.00	72.09	25.56
X_2 (HPTPW)	0.05	100.00	66.06	30.09	0.05	100.00	51.06	29.76
X_3 (CUCS)	0.00	100.00	54.74	28.53	0.00	99.94	36.24	26.55
X_4 (SSCS)	0.00	100.00	90.29	13.00	0.00	100.00	84.85	15.35
X_5 (URB)	0.00	100.00	59.64	23.05	2.52	100.00	54.85	23.08
X_6 (POP)	0.39	5899.43	17.02	101.62	0.39	5060.08	16.69	99.08
	2000				2010			
Y_1 (U5MR)	12.99	106.29	40.00	18.19	9.98	50.94	21.53	7.32
Y_2 (MHDI)	24.10	82.00	52.48	10.39	41.80	86.20	65.92	7.20
X_1 (DSPS)	4.77	100.00	81.89	21.19	32.85	100.00	93.85	9.93
X_2 (HPTPW)	0.13	100.00	62.98	30.84	3.26	100.00	80.88	21.71
X_3 (CUCS)	0.00	100.00	53.74	26.90	0.00	100.00	70.26	21.85
X_4 (SSCS)	15.69	100.00	90.10	12.29	23.23	100.00	94.75	9.55
X_5 (URB)	0.00	100.00	59.21	23.24	4.18	100.00	63.83	22.04
X_6 (POP)	0.42	5471.50	16.30	98.50	0.42	5899.43	17.97	106.49

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