Environmental indicators of intra-urban hetererogeneity

Indicadores ambientais para detectar heterogeneidade intraurbana

Indicadores ambientales para detectar la heterogeneidad intra-urbana

Rita Franco Rego [1]
Veronica Cadena Lima [1]
Ana Cerqueira Lima [1]
Mauricio L. Barreto [2]
Matildes S. Prado [2]
Agostino Strina [2]

[1] *Faculdade de Medicina da Bahia, Universidade Federal da Bahia, Salvador, Brasil.*
[2] *Instituto de Saúde Coletiva, Universidade Federal da Bahia, Salvador, Brasil.*

Correspondence
R. F. Rego
Programa de Pós-graduação em Saúde Ambiente e Trabalho, Faculdade de Medicina da Bahia, Universidade Federal da Bahia.
Pça. XV de Novembro s/n, Salvador, BA 40025-010, Brasil
ritarego@ufba.br

Abstract

A large number of human diseases are related to poor access to water and sewer systems, inadequate solid waste management and deficient storm water drainage. The goal of this study was to formulate environmental sanitation indicators and classify sanitation conditions in specific sewer basins and their respective neighborhoods. The database used contains information on the following sanitation components in these areas: water supply, sewer systems, urban drainage, road pavement, building typology and public cleaning. Data was analyzed using cluster analysis. The key variable of each component was identified, and eight sewer basins and twenty-three neighborhoods were classified into the following categories: good, regular, and poor. The use of environmental sanitation indicators allows decision makers to identify critical areas and define priorities for improving environmental sanitation conditions.

Environmental Indicators; Sanitation; Environmental Health

Resumo

Várias patologias que acometem os seres humanos estão ligadas à deficiência de acesso a água e serviços de esgotamento sanitário, inadequado manejo de resíduos sólidos e deficiência do sistema de drenagem das águas pluviais. Este estudo buscou desenvolver indicadores sanitário ambientais e classificar áreas intraurbanas. Utilizou-se uma base de dados contendo informações sobre: abastecimento de água, sistema de esgoto, drenagem e limpeza urbana, pavimentação e tipologia construtiva referentes a bacias de esgotamento sanitário e áreas sentinela. Foi aplicada a técnica de analise de cluster*. Identificou-se a variável que melhor representava cada componente, e oito bacias de esgotamento e vinte e três áreas sentinelas foram classificadas em três categorias: boa, regular e insatisfatória. O uso de indicador sanitário ambiental permitiu a identificação de áreas críticas e o estabelecimento de prioridades de investimentos para as melhorias sanitário ambientais.*

Indicadores Ambientais; Saneamento; Saúde Ambiental

Introduction

The evaluation of urban environmental quality is a challenging task for those involved in the environmental health field. The formulation of environmental indicators is fundamental to the assessment of environmental quality; thus environmental indicators are crucial to the formulation and implementation of public policies. Studies show that the provision of adequate basic sanitation services (a safe water supply and solid waste, sewage and stormwater management) plays a crucial role in public health [1, 2] and is paramount to improving people's health and quality of life. The consideration of heterogeneity between urban areas through the identification of "intra-urban differentials" is also essential to the assessment process.

A United Nations report [3] highlights increasing urbanization and associated environmental problems in several countries throughout the world. A report recently published in Brazil evaluates compliance with the Millennium Development Goals (MDGs), including target 7 (Ensuring Environmental Sustainability) and goals 10 to 14 which address issues related to basic sanitation. The report highlights: "*Another important challenge is to improve the quantity and quality of evaluations of policies and programs and the existing information on housing conditions and sanitation in Brazil, since the sources available from the National Household Sample Survey and Census provide limited information about these issues*" [4]. Poor basic sanitation and housing conditions are an environmental risk to human health and overcoming this problem is a major challenge, especially in developing countries that seek to meet the development goals contemplated in the Millennium Declaration [5].

The formulation of environmental sanitation indicators and the identification of intra-urban differentials are essential to achieving the Millennium Goals. Furthermore, these indicators are extremely useful environmental and epidemiological surveillance tools and an important input to guide resource allocation plans and programs.

Several environmental risk factors may contribute to the occurrence of diseases and disorders in human populations [2,6]. Pruss-Ustun and Corvalán [2] estimated that around 24% of worldwide illnesses can be traced back to environmental risk factors. The authors observed that 85 out of the 102 major diseases and injuries classified by the World Health Organization (WHO) in a report published in 2004 can be attributed to environmental risk factors. In particular, an estimated 94% of the incidence of diarrhea is attributable to environmental factors.

Epidemiological studies indicate that incidence rates of waterborne diseases such as diarrhea [7], cholera [8], hepatitis [9], intestinal parasites [10] and typhoid fever are highest in urban locations characterized by low or insufficient coverage of basic sanitation services [11, 12].

The present study is part of a series of studies developed under the Epidemiological Impact Assessment of the Todos os Santos Bay Environmental Sanitation Program (the Bahia Azul Program), a government program that focused on extending the sewer network funded by the Inter-American Development Bank and implemented by the Bahia State Water and Sanitation Company (EMBASA). The present study comprises a subproject implemented during the Bahia Azul Program monitoring process to evaluate its environmental impact using environmental sanitation variables. One of the goals of the study was to assess intra-urban differentials through the classification of sanitation conditions in specific sewer basins and their respective neighborhoods located in the capital of the State of Bahia, Salvador. The study also carried out a quantitative analysis of the environmental sanitation components using a reduced number of variables and a low cost and simple methodology.

The Bahia Azul Program's limited resources were invested, as a priority, in areas with the poorest sanitation conditions and the environmental and health impacts were monitored by the Program. Results show that the prevalence of diarrhea fell by 21% (95%CI: 18%-25%), from 9.2 days per child-year before the intervention (95%CI: 9.0-9.5), to 7.3 (95%CI: 7.0-7.5) days per child-year after program completion. After adjustment for baseline sewer coverage and potential confounding variables, the overall reduction in prevalence was 22% (95%CI: 19%-26%) [7].

Although a number of studies have focused on the formulation of indicators of intra-urban differentials [13], a need for further research to assess intra-urban environmental quality associated with sanitation conditions has been highlighted [13,14].

No similar approaches to defining environmental indicators were found in the literature. The environmental indicators described by this study allow intra-urban differentials to be detected with the use of primary data, thus facilitating the assessment of the impacts of sanitation programs in medium-sized cities. This study has the following specific objectives: (a) formulate environmental sanitation indicators; (b) identify the distinguishing variable for each environmental sanitation component; (c) classify sanitation conditions in intra-urban areas; (d) identify priority areas for intervention and resource allocation.

Materials and methods

Located in the Northeastern region of Brazil, Salvador is the capital of the State of Bahia. Its 2.6 million inhabitants are exposed to health problems that are typical of large metropolitan areas. It is likely that the improvement in water supply made in the 1980s and 1990s (by 1997 over 90% of the city's households had access to piped water) had an effect on early childhood diarrhea (children up three years of age); however baseline data for the period before these improvements were made does not exist. A longitudinal study carried out in 1997 showed that the prevalence of childhood diarrhea was 9.2 days per child-year [7]. Before 1997 approximately 26% of households were connected to a safe sewer system, while the remaining population used sanitary alternatives (such as septic tanks) or unsanitary methods (such as discharging their sewage into the street). As a result, a large scale sanitation program called Bahia Azul ("Blue Bay") was initiated in 1997 with the goal of increasing the proportion of the population connected to an adequate sewer system from 26% to 80%.

The original goal of the sanitation project was to control marine pollution largely caused by the discharge of domestic wastewater into the ocean. Around half of the total budget of US$440 million, funded mainly by the Inter-American Development Bank, was earmarked for extending the sewer network in Salvador and ten smaller towns in the State of Bahia. Investments were also made in improvements to water supply and solid waste management and in institutional capacity building. Construction work was executed by 140 different construction companies and the largest contract amounted to 20% of the total budget. In Salvador, the construction works were carried out over a period of eight years (between 1996 and 2004) and consisted of more than 2,000km of sewer pipes and 86 pumping stations, and the connection of more than 300,000 households to the sewer network. Heavy engineering work, such as laying sewer pipes and building pumping stations, was undertaken during the initial phase of the project. Since household connections were made during a later phase, very few connections to the sewer system were made before the end of the first cohort study.

An evaluation study consisting of two longitudinal studies [7] was conducted to assess the epidemiological impact of the program. Study and design and sampling have been described in detail by other authors [7,15,16].

Ethical approval was granted by the Research Ethics Committee of the Institute of Collective Health of the Federal University of Bahia (ISC/UFBA). Written informed consent was obtained from study participants.

A separate study comprising of two cross-sectional investigations was conducted to evaluate the environmental impact of the intervention. Environmental research was conducted in three stages. The first stage consisted of a survey of 1,225 street sections between September 1997 and February 1998 before the beginning of the Bahia Azul Program. The second stage included 973 street sections and was carried out between August 2000 and January 2001 during the implementation of the program. The third phase included 1,070 street sections and was performed between October 2003 and March 2004 after completion of the program.

Description of the environmental sanitation components and study variables

The environmental assessment of basic sanitation components in the study areas was carried out between August 2000 and January 2001. The unit of analysis was the "street section" where the children enrolled in the epidemiological study lived, which consisted of a 100m long street section in front of the children's homes. A total of 973 street sections were visited. Information on infrastructure, the sanitation system, land use and building typology was collected for each street section [15]. Data collection methods and the procedures followed to ensure quality of fieldwork are described in detail by Rego et al. [15].

This study uses data from the Epidemiological Impact Assessment of the Bahia Azul Program (PAIE-BA) collected in 2000 by ISC/UFBA. The database contains information on environmental sanitation components by street section in eight sewerage basins and 23 neighborhoods.

The street sections were identified and grouped according to their sanitation components (water supply, sewer system, urban drainage, road pavement, public cleaning services and building typology). The environmental sanitation components and the respective variables and categories are described in Table 1. The categories include a reference category (RC) defined by the researchers as the most desirable condition for each variable.

Statistical technique

Cluster analysis was used to analyze data. This technique is commonly used to group similar elements or entities according to a set of variables using a matrix of n cases or elements (matrix rows) and p variables (matrix columns) that represent the characteristics of the elements chosen

Table 1

Environmental sanitation components and variables assessed in the street sections. Salvador, Bahia State, Brazil, 2000.

Components	Variables	Categories
Water supply	Type of supply	Partially public network (presence of water well and/or *gato* * and/or public tap)
		Exclusively public network (RC)
	Condition of network	Network with problems
		Network with no problems, in apparently good condition (RC)
	Frequency of service	3 to 4 times a week
		Everyday
		24 hours a day (RC)
Drainage system	Stormwater runoff	Risk occurrence (more than one risk: stormwater floods the street, some or all homes; floods part of the street and some homes; floods only the street; presence of puddles and holes in the street, risk of landslides)
		No risk occurrence (RC)
	Type of drainage system	Non-existent
		Concrete cascade drain or other
		Storm sewer
		Channel and gutter (RC)
	Condition of Drainage system	Non-existent
		Network with problems (more than one risk: stormwater floods the street, some or all homes; floods part of the street and some homes; floods only the street; presence of puddles and holes in the street, risk of landslides)
		Network with no problems and in apparently good condition (RC)
	Existence/operation	Non-existent
		Network *out-of-service*
		Network operating (Bahia Azul and others) (RC)
Sewer system	Status of sewer	Non-existent
		Another network other than the Bahia Azul
		Another network other than the Bahia Azul + Bahia Azul network
		Only Bahia Azul network (RC)
	Condition of sewer	Non-existent
		Network with problems
		Network in apparently good condition (RC)
	Operational condition of sewer	Non-existent
		Bahia Azul network *out-of-service*
		Network operating (Bahia Azul and others) (RC)
	Condition of Manholes	Manholes non-existent and/or manholes with problems
		Manholes in apparently good condition (RC)
Urban cleaning service	Collection type	Non-existent
		Stationary collecting points and/or dumpers
		Door-to-door/garbage truck/compactor/alternative (RC)
	Collection frequency	Non-existent
		Existent, but irregular
		Daily collection (RC)
	Existence of garbage point	Existent
		Non-existent (RC)
	Existence of debris point	Existent
		Non-existent (RC)

(continues)

Table 1 (continued)

Components	Variables	Categories
Building typology	Housing type	Horizontal 1 floor
		Horizontal 1 and/or 2 or more floors
		Vertical low and high template and combinations (RC)
	Type of construction	Precarious (mud, wood, clay, straw, stilt homes and homes with or without brick/block structure)
		Intermediate (plastered brick/block structure, with partial coating, pre-fabricated)
		Good (brick/block plastered with coating) (RC)
	Type of occupation	At the bottom of a hill
		On a slope
		On a plateau/ridge (RC)
Paving	Road pavement typology	Inadequate (gravel, earth, soil, sand or a combination)
		Adequate (cement or concrete surface, cobbles, mortar, cement)
		More appropriate (asphalt and paving stones) (RC)
	Type of sidewalk	Inadequate (non-existent, unpaved)
		Partially adequate (dusty track, sand or a combination)
		Adequate (cement or concrete surface, cobbles, gravel, Portuguese stone, asphalt, granite) (RC)

RC: reference category.

* *Gato* is a popular term meaning an illegal unpaid connection to the water supply service.

to measure level of similarity. Level of similarity is based on the distance between the elements; if the distance between two elements is zero they are considered identical and belong to the same category. A commonly used measure of similarity is the Euclidean distance [17]. This measure was used by this study to determine the distance between pairs of street sections for six environmental sanitation components, each with a specific number of variables. For example, for a component made up of three binary variables X_1, X_2 and X_3, the average Euclidian distance between the street sections A and B is calculated using the following equation:

$$d(A,B) = \left[\frac{1}{p} \sum_{i=1}^{p} (X_i(A) - X_i(B))^2\right] \quad (1),$$

where p is the number of variables (p = 3 in this case) and d (A,B) is a real number. The distance between pairs of elements is usually expressed as an n x n symmetric matrix.

When a variable has more than two categories the usual procedure is to transform these variables into binary variables by creating fictitious variables [17]. Thus, three binary variables are needed to represent a variable with three categories.

The average linkage method was used to group the distances between street sections. The results of the cluster analysis are generally represented in a tree-like diagram called a dendrogram. Genuine cluster groups are identified by "cutting" the dendrogram at a certain level subjectively chosen by visual examination [17].

Data analysis

Initially, a descriptive and exploratory analysis of the dataset was performed for each variable shown in Table 1. Cluster analysis was used to group and classify the sewer basins and neighborhoods. Indicators were formulated by completing the following steps during analysis: (1) transformation of variables; (2) clustering of street sections; (3) identification of the distinguishing variable for each component; (4) classification of sanitation conditions in the sewer basins and neighborhoods by component; and (5) general classification of sanitation conditions in the sewer basins and neighborhoods.

In step one, the variables that had more than two categories were transformed into binary variables. For example, the variable frequency of service has three categories (three to four times a week, everyday, and 24 hours a day). Each category was converted into a binary variable in which the value one (1) means that the characteristic is present and the value zero (0) means that the characteristic is absent [17]. For example, let X_3, X_4 and X_5 represent three to four times a week, everyday and 24 hours a day, respectively. In the case that the frequency of water supply in street A is 24 hours a day, $X_3 = 0$, $X_4 = 0$, $X_5 = 1$.

In step two, cluster analysis was used to group the 973 street sections according to each environmental sanitation component by neighborhood and basin. For instance, the variables type of supply (X_1), general condition of the network (X_2), and frequency of service, the latter mentioned above and reclassified into three binary variables (X_3, X_4 and X_5), were used to group the 973 street sections according to the water supply component. Equation 1 was used to calculate the distances between pairs of street sections considering the five variables X_1, X_2, X_3, X_4 and X_5 (p = 5) and the average linkage method was used to group these distances into three categories (1, 2 and 3). The SPSS version 13.0 software was used for statistical analysis (SPSS Inc., Chicago, USA).

In step three, each resulting cluster (1, 2 and 3) was identified according to its main characteristic based on a descriptive analysis of each environmental sanitation component. Comparing the characteristics of the clusters (1, 2 and 3) it was possible to note that the main difference was attributed to a single variable in each component. This variable was therefore considered the distinguishing variable for each component.

In step four a classification of neighborhoods and basins by component was produced based on the distinguished variable defined in step three. To this end, the reference cathegories shown in Table 1 were used. The sewer basins and neighborhoods were classified based on the percentage of street sections with the given characteristic as follows: 0 to 33.3% = poor; 33.4 to 66.6% = regular; 66.7 to 100% = good.

These classification criteria were employed since they were considered to be the most objective, coherent and accessible.

In step 5, an overall classification of sanitation conditions in the sewer basins and neighborhoods was carried out based on the average percentage of all sanitation components as follows: 0 to 33.3% = poor; 33.4 to 66.6% = regular; 66.7 to 100% = good.

Results

Table 2 shows the results of the cluster analysis carried out in step 2 for the water supply component. It can be observed that in the Armação and Paripe Basins 73 (78.5%) and 5 (4%) of the street sections, respectively, were classified as cluster 2, showing heterogeneity between sewer basins.

Table 3 shows the main characteristics of the environmental sanitation components for each cluster. With respect to water supply, 92.1% of street sections (n= 429) in cluster 1 benefited from an exclusively public network, in 72.7% of sections the network had no problems and were in apparently good condition, and in 100% of sections the frequency of the service was every day. In cluster 2, 95.5% of street sections (n = 330) benefited from an exclusively public network, in 81.2% of sections the network had no problems and was in apparently in good condition, and in 100% of sections the frequency of service was 24 hours a day. Finally, in cluster 3, 79.9% of street sections (n = 214) benefited from an exclusively public network, in 64% of sections the network had no problems and was in apparently good condition, and in 100% of sections the frequency of service was three to four times a week. A comparison of the characteristics of the clusters shows that the main difference was due to the variable frequency of service. It can therefore be concluded that frequency of service is the key variable that explains the difference between clusters for the water supply component. In other words, the variable frequency of service is the key variable that discriminates between clusters.

The sewer basins and neighborhoods were classified as poor, regular and good based on the percentage of street sections receiving water 24 hours a day (reference category); thus, the street sections in each cluster were labeled as follows: cluster 1 = "water every day"; cluster 2 = "water 24 hours a day"; and cluster 3 = "water three to four times a week".

Table 3 summarizes the results of the cluster analysis for all components, from which it is possible to identify the distinguishing variable for each component and main characteristic. With regard to water supply, frequency of service stood out in the statistical analysis as the key variable and the reference category was a 24-hour a day water supply.

Table 4 presents the results of the classification of the sewer basins and neighborhoods in Salvador using the steps described above. It can be observed that the best ranked sewer basin was the Armação Basin, where 71% of street sections were classified as having good services. Service provision was classified as regular in the Médio Camurujipe, Lobato and Calafate sewer basins, where 34.7 to 43.2% of street sections were classified as having good services. In the Mangabeira, Cobre, Periperi and Paripe sewer basins service provision was classified as poor with around only 27% of street sections being classified as having good services.

With respect to individual neighborhoods, Table 4 shows that service provision was classified as good in areas 571 and 575 since 71% of street sections had good services. In areas 322, 327, 330, 208, 204, 263, 323 and 961 service provision was considered regular, whereas areas 118, 205, 672, 677, 678, 191, 962, 1011, 1025, 1026, 1054, 1057 and 1072 were classified as poor.

Table 4 allows the comparison of sewer basins and neighborhoods by component. In the

Table 2

Classification of basins and neighborhoods according to the results of the cluster analysis for the water supply component.

Neighborhoods/Basins	Water supply cluster						Total of street sections
	1		2		3		
	n	%	n	%	n	%	
Armação							
571	10	12.8	66	84.6	2	2.6	78
575	1	6.7	7	46.7	7	46.7	15
Total	11	11.8	73	78.5	9	9.7	93
Médio Camurujipe							
322	30	48.4	31	50.0	1	1.6	62
327	19	32.2	39	66.1	1	1.7	59
330	30	57.7	18	34.6	4	7.7	52
Total	79	45.7	88	50.9	6	3.5	173
Lobato							
118	9	52.9	4	23.5	4	23.5	17
205	19	57.6	8	24.2	6	18.2	33
208	10	20.8	35	72.9	3	6.3	48
Total	38	38.8	47	48.0	13	13.3	98
Calafate							
204	20	43.5	25	54.3	1	2.2	46
263	21	58.3	15	41.7	0	0.0	36
323	22	50.0	16	36.4	6	13.6	44
Total	63	50.0	56	44.4	7	5.6	126
Mangabeira							
672	31	55.4	20	35.7	5	8.9	56
677	25	62.5	10	25.0	5	12.5	40
678	28	60.9	13	28.3	5	10.9	46
Total	84	59.2	43	30.3	15	10.6	142
Cobre							
191	18	78.3	0	0.0	5	21.7	23
961	11	47.8	0	0.0	12	52.2	23
962	20	40.4	10	22.2	15	33.3	45
Total	49	53.8	10	11.0	35	35.2	91
Periperi							
1011	34	58.6	3	5.2	21	36.2	58
1025	9	25.0	5	13.9	22	61.1	36
1026	10	33.3	0	0.0	21	66.7	30
Total	53	42.7	8	6.5	63	50.8	124
Paripe							
1054	18	39.1	0	0.0	28	60.9	46
1057	30	62.5	5	10.4	13	27.1	48
1072	4	12.5	0	0.0	28	87.5	32
Total	52	41.3	5	4.0	69	54.8	126
Total number of street sections	429		330		214		973

Table 3

Main characteristics of environmental sanitation components by cluster.

	Cluster	n	%	Variables	n	%	Main characteristics
Water supply	1	429	44.1	Type of supply	395	92.1	Exclusively public network
				Condition of network	312	72.7	Network with no problems and in apparently good condition
				Frequency of service	429	100.0	Everyday
	2	330	33.9	Type of supply	315	95.5	Exclusively public network
				Condition of network	268	81.2	Network with no problems and in apparently good condition
				Frequency of service	330	100.0	24 hours a day
	3	214	22.0	Type of supply	171	79.9	Exclusive public network
				Condition of network	137	64.0	Network with no problems and in apparently good condition
				Frequency of service	214	100.0	3 to 4 times a week
Drainage system	1	356	33.6	Stormwater runoff	236	66.3	No risk
				Type of drainage system	215	60.4	Storm sewer
				Condition of drainage system	182	51.1	Network with no problems and in apparently good condition
				Existence/Operation	356	100.0	Network in operation
	2	600	61.7	Stormwater runoff	311	51.8	No risk
				Type of drainage system	600	100.0	Non-existent
				Condition of drainage system	600	100.0	Non-existent
				Existence/Operation	600	100.0	Non-existent
	3	17	1.7	Stormwater runoff	10	58.8	No risk
				Type of drainage system	11	64.7	Storm sewer
				Condition of drainage system	13	76.5	Network with no problems
				Existence/Operation	17	100.0	Network out-of-service
Sewerage system	1	403	41.4	Status of sewer	185	45.9	Another network other than the Bahia Azul
				Condition of sewer	324	80.4	Network in apparently good condition
				Operational condition of sewer	403	100.0	Network in operation (Bahia Azul and others)
				Condition of Manholes	309	76.7	Manholes non-existent and Manholes with problems
	2	269	27.6	Status of sewer	269	100.0	Non-existent
				Condition of sewer	269	100.0	Non-existent
				Operational condition of sewerage	269	100.0	Non-existent
				Condition of Manholes	269	100.0	Non-existent
	3	301	30.9	Status of sewer	289	96.0	Another network other than Bahia Azul + Bahia Azul network
				Condition of sewer	254	84.4	Network in apparently good condition
				Operational condition of sewer	301	100.0	Bahia Azul network out-of-service
				Condition of manholes	207	68.8	Manholes non-existent and Manholes with problems

(continues)

Armação Basin, for example, the classification of neighborhoods by water supply is variable; service provision in neighborhood 571 is classified as good (water supply is 24-hour a day in 84.6% of street sections), while in neighborhood 575 it is considered regular (water supply is 24-hour a day in only 46.7% of street sections).

It is interesting to note that the worst results in terms of percentages were obtained for the paving and housing typology components, while

Table 3 (continued)

	Cluster	n	%	Variables	n	%	Main characteristics
Urban cleaning service	1	425	43.7	Collection type	425	100.0	Door-to-door/garbage truck/compactor/ alternative
				Collection frequency	240	56.5	Daily collection
				Existence of garbage point	344	80.9	Non-existent
				Existence of debris point	335	78.8	Non-existent
	2	108	11.1	Collection type	108	100.0	Stationary collection points and/or Dumpers
				Collection frequency	70	64.8	Daily collection
				Existence of garbage point	72	66.7	Existent
				Existence of debris point	73	67.6	Non-existent
	3	440	45.2	Collection type	440	100.0	Non-existent
				Collection frequency	440	100.0	Non-existent
				Existence of garbage point	349	79.3	Non-existent
				Existence of debris point	320	72.7	Non-existent
Housing typology	1	361	37.1	Type of housing	264	73.1	Horizontal 1 and/or 2 or more floors
				Type of construction	244	67.6	Intermediate
				Type of occupation	361	100.0	At the bottom of a hill
	2	269	27.6	Type of housing	188	69.9	Horizontal 1 and/or 2 or more floors
				Type of construction	169	62.8	Intermediate
				Type of occupation	269	100.0	On a plateau/ridge
	3	343	35.3	Type of housing	248	72.3	Horizontal 1 and/or 2 or more floors
				Type of construction	288	84.0	Intermediate
				Type of occupation	343	100.0	On a slope
Paving	1	246	25.3	Road pavement typology	195	79.3	More appropriate
				Type of sidewalk	246	100.0	Adequate
	2	67	6.9	Road pavement typology	58	86.6	More appropriate
				Type of sidewalk	67	100.0	Partially adequate
	3	660	67.8	Road pavement typology	401	60.8	Inadequate
				Type of sidewalk	660	100.0	Inadequate

the best results were obtained for urban cleaning. This example shows the utility of the methodology used by this study for prioritizing government investment in sanitation.

Discussion and conclusion

Through the use of cluster analysis it was possible to formulate environmental sanitation indicators, classify sanitation conditions in specific sewer basins and their respective neighborhoods, and detect intra-urban differentials in sanitation conditions. This method is particularly useful for assessing the impact of sanitation programs in medium-sized cities such as the Bahia Azul Program [7,10]. Furthermore, this method allows the comparison of sanitation conditions in sewer basins and neighborhoods in different moments in time. By using environmental sanitation indicators it was possible to identify priority areas for interventions and allocation of resources. It is important to emphasize that this is a low cost and simple methodology and is therefore a key decision-making support for politicians and environmental health managers.

Furthermore, based on the results of this study, it is possible to infer that if more resources had been invested in all environmental sanitation components in those sewer basins with the worst indicators (Mangabeira, Cobre, Periperi and Paripe) it is likely that the diarrhea prevalence rate observed by Barreto et al. [7] would have been lower. The results show that all components in these basins were classified as poor, except urban cleaning which was considered regular.

Cluster analysis also allowed us to identify the variable that best distinguished between the environmental sanitation components, thus helping to reduce the number of variables in the study and indicate the key variable for each component.

Table 4

Classification of neighborhoods and basins by component and general classification.

Sewer basins/ Neighborhood	Total of street sections	Environmental sanitation components/Distinguishing variable												Overall classification	
		Water supply/ Frequency of service (%)		Drainage system/ Existence/ Operation		Sewer system/ Operational condition		Urban cleaning service/ Collection type		Housing typology/ Type of occupation		Paving/ Road pavement typology			
Armação															
571	78	84.6	G	59.0	R	89.7	G	94.9	G	48.7	R	50.0	R	71.2	G
575	15	46.7	R	86.7	G	100.0	G	20.0	P	80.0	G	93.3	G	71.1	G
Total	93	78.5	G	63.4	R	91.4	G	82.8	G	53.8	R	57.0	R	71.2	G
Médio Camurujipe															
322	62	50.0	R	46.8	R	61.3	R	37.1	R	16.1	P	35.5	R	41.1	R
327	59	66.1	R	62.7	R	74.6	G	27.1	P	20.0	P	42.4	R	48.8	R
330	52	34.6	R	44.2	R	53.8	R	9.6	P	37.0	R	23.1	P	33.7	R
Total	173	50.9	R	51.4	R	63.6	R	25.4	P	23.9	P	34.1	R	41.6	R
Lobato															
118	17	23.5	P	29.4	P	47.1	R	58.8	R	0.0	P	17.6	P	29.4	P
205	33	24.2	P	36.4	R	42.3	R	18.2	P	0.0	P	27.3	P	24.8	P
208	48	72.9	G	43.8	R	56.3	R	43.8	R	12.5	P	31.3	P	43.4	R
Total	98	48.0	R	38.8	R	50.0	R	37.8	R	6.1	P	27.6	P	34.7	R
Calafate															
204	46	54.3	R	39.1	R	56.5	R	19.6	P	34.8	R	30.4	P	39.1	R
263	36	41.7	R	72.2	R	55.6	R	44.4	R	52.8	R	50.0	R	52.8	R
323	44	36.4	R	36.4	R	63.6	R	50.0	R	13.6	P	38.6	R	39.8	R
Total	126	44.4	R	47.6	R	58.7	R	37.3	R	32.5	P	38.9	R	43.2	R
Mangabeira															
672	56	35.7	R	19.6	P	5.4	P	71.4	G	16.1	P	12.5	P	26.8	P
677	40	25.0	P	15.0	P	20.0	P	35.0	R	20.0	P	15.0	P	21.7	P
678	46	28.3	P	10.9	P	45.7	R	56.5	R	37.0	R	15.2	P	32.3	P
Total	142	30.3	P	15.5	P	22.5	P	56.3	R	23.9	P	14.1	P	27.1	P
Cobre															
191	23	0.0	P	26.1	P	8.7	P	21.7	P	21.7	P	17.4	P	15.9	P
961	23	0.0	P	17.4	P	30.4	P	78.3	G	73.9	G	17.4	P	36.2	R
962	45	22.2	P	35.6	R	4.4	P	28.9	P	26.7	P	11.1	P	21.5	P
Total	91	11.0	P	28.6	P	12.1	P	39.6	R	37.4	R	14.3	P	23.8	P
Periperi															
1011	58	5.2	P	8.6	P	3.4	P	56.9	R	44.8	R	1.7	P	20.1	P
1025	36	13.9	P	30.6	P	27.8	P	41.7	R	8.3	P	27.8	P	25.0	P
1026	30	0.0	P	3.3	P	3.3	P	16.7	P	6.7	P	3.3	P	5.6	P
Total	124	6.5	P	13.7	P	10.5	P	42.7	R	25.0	P	9.7	P	18.0	P
Paripe															
1054	46	0.0	P	23.9	P	8.7	P	13.0	P	15.2	P	10.9	P	12.0	P
1057	48	10.4	P	37.5	R	16.7	P	72.9	G	2.1	P	4.2	P	24.0	P
1072	36	0.0	P	50.0	R	53.1	R	31.3	P	31.3	P	18.8	P	30.8	P
Total	126	4.0	P	35.7	R	23.0	P	40.5	R	14.3	P	10.3	P	21.3	P

G: good; P: poor; R: regular.

This methodology also allowed us to create an indicator for each environmental sanitation component and rank sewer basins and neighborhoods according to sanitation conditions.

As mentioned in the material and methods section above, a separate environmental impact assessment was conducted as part of the Epidemiological Impact Assessment of the Todos os Santos Bay Environmental Sanitation Program. This assessment was divided in three stages. The results of the first stage between September 1997 and February 1998 were published by Milroy et al. [18]. Using the same data collection methods in the same neighborhoods covered by the present study, the authors used principal component analysis followed by cluster analysis to identify the following sanitation condition categories: high, intermediate, poor and very poor.

A comparison of the results of Milroy's study (first stage) [18] with those of the present study (second stage) shows that little change occurred in the classification of the sanitation conditions of these neighborhoods. The only change observed was in neighborhood 961, which was classified as poor in the first stage and as regular in the second stage. The improvements observed in this neighborhood were due to a high rating for the components "urban cleaning service" and "building typology" (Table 4). No change in the sanitation conditions of these neighborhoods was observed even after using other statistical methods. This is probably due to the fact that the Sanitation Program was in the initial phase of implementation at that time.

The environmental sanitation indicators formulated by this study can help managers to detect situations of environmental risk, monitor changes in the environment, identify potential health hazards and assess the impact of public policy interventions on environmental sanitation conditions.

The factors that influence environmental sanitation conditions are dynamic and therefore subject to constant change. The data collected by cross-sectional studies represents only one moment in time and therefore provides limited knowledge of a given reality. This method is therefore appropriate for assessing the impact of public policies and interventions on environmental sanitation conditions provided that further cross-sectional studies using the same methodology are conducted in the same areas in different windows of time.

The study data was analyzed using cluster analysis and Euclidian distance to measure the level of similarity. It is important to note that other types of distance may be used to measure the level of similarity, such as the simple correlation coefficient and Sokal distance, and it is recommended that future studies consider such approaches. Nevertheless, this study is an important step towards providing an effective classification of sanitation conditions in urban areas to guide resource allocation planning in developing countries.

Resumen

Varias enfermedades que afectan a los seres humanos están vinculadas a la deficiencia en el acceso a servicios de agua y alcantarillado, la gestión inadecuada de los residuos sólidos y el deficiente sistema de drenaje de aguas pluviales. Este estudio trata de desarrollar indicadores de salud ambiental y clasificar las áreas dentro de las ciudades. Se utilizó una base de datos que contiene información sobre: limpieza urbana, abastecimiento de agua, alcantarillado, drenaje y calles, pavimentación de las calles y tipología de construcción en diferentes barrios. Se aplicó la técnica de clúster para el análisis de datos. Se identificó la variable que mejor representa cada componente y veintitrés áreas de la ciudad se clasificaron en tres categorías: buena, regular y mala. El uso de indicadores de salud ambiental permitió la identificación de áreas críticas y el establecimiento de prioridades en la inversión para la salud y mejora del medio ambiente.

Indicadores Ambientales; Saneamiento; Salud Ambiental

Contributors

R. F. Rego, M. L. Barreto, M. S. Prado and A. Strina contributed to study design and data collection. R. F. Rego, V. C. Lima and A. C. Lima carried out data analysis. All researchers contributed to data interpretation and drafting of the manuscript. All researchers had access to all study data and jointly agreed to submit this article for publication.

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Conflict of interest

The sponsors of this study had no role in the study design, data collection, data analysis, data interpretation, decision to publish or preparation of the manuscript. The authors had full access to all study data and jointly agreed to submit this article for publication.

References

1. Andreazzi MA, Barcellos C, Hacon S. Old indicators for new problems: the relationship between sanitation and health. Rev Panam Salud Pública 2007; 22:211-7.
2. Pruss-Ustun A, Corvalan C. How much disease burden can be prevented by environmental interventions? Epidemiology 2007; 18:167-78.
3. United Nations. The Millennium Development Goals Report. http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2010/MDG_Report_2010_En_low%20res.pdf (accessed on 05/Jan/2012).
4. Instituto de Pesquisa Econômica Aplicada. Objetivos de desenvolvimento do milênio: 3º Relatório Nacional de Acompanhamento. http://www.pnud.org.br/Docs/3_RelatorioNacionalAcompanhamentoODM.pdf (accessed on 07/Jan/2012).
5. Ezzati M, Utzinger J, Cairncross S, Cohen AJ, Singer BH. Environmental risks in the developing world: exposure indicators for evaluating interventions, programmes, and policies. J Epidemiol Community Health 2005; 59:15-22.
6. Pruss-Ustun A, Bonjour S, Corvalan C. The impact of the environment on health by country: a meta-synthesis. Environ Health 2008; 7:7.
7. Barreto ML, Genser B, Strina A, Teixeira MG, Assis AM, Rego RF, et al. Effect of city-wide sanitation programme on reduction in rate of childhood diarrhoea in northeast Brazil: assessment by two cohort studies. Lancet 2007; 370:1622-8.
8. Bhunia R, Ramakrishnan R, Hutin Y, Gupte MD. Cholera outbreak secondary to contaminated pipe water in an urban area, West Bengal, India, 2006. Indian J Gastroenterol 2009; 28:62-4.

9. Swain SK, Baral P, Hutin YJ, Rao TV, Murhekar M, Gupte MD. A hepatitis E outbreak caused by a temporary interruption in a municipal water treatment system, Baripada, Orissa, India, 2004. Trans R Soc Trop Med Hyg 2010; 104:66-9.
10. Barreto ML, Genser B, Strina A, Teixeira MG, Assis AM, Rego RF, et al. Impact of a citywide sanitation program in Northeast Brazil on intestinal parasites infection in young children. Environ Health Perspect 2010; 118:1637-42.
11. Farooqui A, Khan A, Kazmi SU. Investigation of a community outbreak of typhoid fever associated with drinking water. BMC Public Health 2009; 9:476.
12. Fewtrell L, Kaufmann RB, Kay D, Enanoria W, Haller L, Colford Jr. JM. Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. Lancet Infect Dis 2005; 5:42-52.
13. Akerman M, Campanario P, Maia PB. Environment and health: an analysis of intra-urban differentials in the city of Sao Paulo, Brazil. Rev Saúde Pública 1996; 30:372-82.
14. Stephens C, Akerman M, Avle S, Maia PB, Campanario P, Doe B, et al. Urban equity and urban health: using existing data to understand inequalities in health and environment in Accra, Ghana and Sao Paulo, Brazil. Environ Urban 1997; 9:181-202.
15. Rego RF, Barreto ML, Santos R, Oliveira NF, Oliveira S. Rubbish index and diarrhoea in Salvador, Brazil. Trans R Soc Trop Med Hyg 2007; 101:722-9.
16. Teixeira MG, Barreto ML, Costa MCN, Strina A, Martins Jr. D, Prado M. Sentinel areas: a monitoring strategy in public health. Cad Saúde Pública 2002; 18:1189-95.
17. Johnson RA, Wichern DW. Applied multivariate statistical analysis. 5th Ed. Upper Saddle River: Prentice Hall; 2002.
18. Milroy CA, Borja PC, Barros FR, Barreto ML. Evaluating sanitary quality and classifying urban sectors according to environmental conditions. Environment Urban 2001; 13:235-55.

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