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Research Article
Evaluating Infectious Waste Management Performance: Proposal for a Composite Index

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Abstract

Background and Objective: Over the last two decades, governments have made great efforts to improve policy, regulatory and institutional support for infectious waste management (IWM). However, quality assessment methods of IWM systems still need to be improved to direct efforts and resources to critical regions. This article reports an innovative and integrative approach to assess urban IWM performance by using a composite index. **Materials and Methods:** The IWM composite index was constructed following a framework described by the Organization for Economic Co-operation and Development. For weighting purposes, the budget allocation process was used. This approach was successfully tested in Parintins city, Brazil. **Results:** According to the proposed index, the IWM quality for Parintins was unsatisfactory (0.378 on a scale from 0-1). Management practices, such as infectious waste storage, transportation, treatment and final disposal, were not appropriately adopted. These results can partly be explained by poverty and technical difficulties, such as the city's location on an island. **Conclusion:** The method described in the study allowed public policies related to IWM to be assessed and compared across regions, so that governments can target problems in priority areas.

Key words: Infectious waste management practices, composite index, assessment method, amazon rainforest, healthcare waste management

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Appropriate infectious waste management (IWM) for waste generated from healthcare services is crucial in urban waste management because of potential public health risks and negative environmental, social and financial impacts if not managed and disposed properly[1,2]. Even with relatively low quantities of infectious waste (IW), the risk of negative effects is significant. Hence, many strategies regarding IWM attempt to reduce its negative impacts and health risks[3]. These strategies include IWM implementation guidelines[4-6], which present a framework with best management practices for IW[7,8]. In general, these guidelines point out the following aspects[7-14]: (a) Segregation and packaging, (b) Collection, (c) Storage, (d) On-site transportation, (e) Off-site transportation, (f) Treatment, (g) Disposal, (h) Training and planned behavior and (i) Waste reduction.

Nevertheless, because of high implementation costs, the lack of regulation and the need for specific technologies, a large number of healthcare facilities do not properly implement these practices, especially those in developing countries[14]. This has been shown by studies conducted in Algeria[15], Brazil[9,16], Mongolia[17], Cambodia, China, Indonesia, Lao, Mongolia, Myanmar and Thailand[11], Hong Kong[18], Egypt[19], Cameroon[20], Tanzania[21], Kingdom of Bahrain[22] and the Gaza strip[14].

In this regard, several studies have been undertaken to improve the IWM systems at the healthcare facility level, e.g., case studies to assess the quality of waste management systems[23-26]. Other related studies include those conducted by system evaluations using checklists[9], applying multi criteria evaluation to select the best treatment options[27] and developing management strategies for these systems[1,26,28-30]. In addition, studies have been conducted to survey IW sources, such as hospitals[31], evaluate IW generation and composition[32,33] and test models for dynamic systems in order to simulate public health impacts[23,34].

Nevertheless, quality assessment methods of IWM for a region have not yet been deployed. The innovative aspect of this study is to contribute to the aforementioned research field by developing a method to assess developing region's IWM in an integrated approach using an innovative composite index, aggregating several indicators into a single quantity[35,36].

MATERIALS AND METHODS

Selecting and weighting the IWM practices: A composite index was constructed within a coherent framework with suitable parameters that may influence IWM policy goals. The IWM composite index was constructed following the framework described by Nardo *et al.*[37]. To construct the index, it was necessary to first select relevant IWM practices that had to be weighted and aggregated.

The relevant practices covering different aspects of IWM evaluation at healthcare facilities were established based on Resolution No. 306 of the Brazilian Health Surveillance Agency[38] (ANVISA) and Resolution No. 358 of the National Environmental Council[39] (CONAMA). Together, these two resolutions form the basis of Brazilian environmental legislation on this subject. The ANVISA resolution is applicable to all stages of healthcare waste management and the CONAMA resolution covers the treatment and final disposal of healthcare waste.

Selected practices were weighted to represent their potential for negative environmental impacts. These weights were discussed and stipulated based on expert opinions using the budget allocation process weighting method[37,40]. Five experts on healthcare haste management estimated an importance factor for each practice by following a five-point Likert scale, from unimportant to highly important. The weights were then calculated as normalized median importance factors. Table 1 exhibits these practices, their weights and the adequacy levels.

Data collection: A questionnaire containing these practices was developed to be applied with stakeholders responsible for all healthcare facilities of a city. Data were collected by applying the questionnaire to all eight hospitals and healthcare centers managers in Parintins between 2014 and 2015. Managers had to score each practice in terms of its performance on a scale of 1 (very low performance) to 5 (very high performance). A benchmark of very high performance was designed and presented for each indicator (Table 1). These adequacy levels were defined by using the mentioned resolutions combined with the following: (a) the healthcare services waste management standards stated by the Brazilian Association of Technical Standards and (b) guidelines from previous scientific research. The following Brazilian Standards (NBR) were applied in this study: NBR 12808, NBR 12809, NBR 12810, NBR 7500 and NBR 9190. The guidelines were taken from Caniato *et al.*[2], Moreira and Gunther[9], Liu *et al.*[27], Chartier *et al.*[7], Dursun *et al.*[12], Windfeld and Brooks[41], Pruss *et al.*[8], Ananth *et al.*[11], Bendjoudi *et al.*[15], Diaz *et al.*[17], Chaerul *et al.*[42] and Mbongwe *et al.*[43].

Composite index to assess IWM performance of Brazilian cities: Each practice could be assigned a value between 0 and

Table 1: Practices used to evaluate IW management along with their weights (proportion) and the adequacy level for each practice

Practice	Weight	Adequacy level
Training of professionals responsible for waste collection	0.06	Periodical, at least once every six months
Use of PPE (uniform, gloves, apron, mask, boots, safety glasses) during waste handling	0.03	All PPE are used
Waste segregation	0.06	The waste is separated at the time of generation
IW packaging	0.06	Milky white bag with infectious substance symbol
Practice of emptying IW containers	0.06	Once a day, when they reach 2/3 of their capacity, closed with a knot, string or wire
Treatment of infectious liquid waste (e.g., blood)	0.06	Sterilized and then sent to a special treatment company
Storage of sharp waste	0.06	Specific sturdy boxes with a sharp waste symbol
Conservation of putrefactive waste (amputated limbs, fetuses, human tissues, placentas)	0.04	Stored under refrigeration and collected within a maximum 24 h period after generation
Temporary storage of IW	0.06	Room that is properly identified and that has packaging containers, smooth and washable floors and walls and an electrical outlet
Internal transportation	0.06	Certain routes and times are established and followed to avoid waste contact with patients
Frequency of internal waste transportation	0.04	At least four times a day from the generation site to the temporary storage site and at least once a day from the temporary storage site to the external storage site
Medium used for internal transportation	0.04	Carts made of smooth and impermeable, rigid material, resistant to washing and disinfection and fitted with covers and wheels made of material that reduces noise, identified with a symbol
Sterilization of carts and final IW storage area	0.06	Washed and sterilized every day
Final IW storage	0.06	There is an external storage with exclusive access for trained personnel, with identification and an emergency and safety system, easy-to-clean brick storage area, with ventilation and electrical outlets
External IW transportation	0.06	Specialized company with license
Means of external IW transportation	0.06	Exclusive vehicles that meet minimum safety standards and are properly identified are used
External collection frequency	0.04	Three times a week or more
IW treatment	0.06	IW sterilized by a licensed company
Final disposal of IW	0.06	In specific licensed landfill

PPE: Personal protective equipment, IW: Infectious Waste

1, which was calculated as the sum of individual practices and represents the measure of the global adequacy level of a city. A higher value means a city with more facilities with an adequate level. The IWM practice indices, I_P, were calculated by the Eq. 1 and presented using a radar chart to enhance graphical data interpretation and analysis:

$$I_{P_i} = \frac{1}{n}\sum_{j=1}^{n} P_j \quad (1)$$

where, j represents healthcare facilities and P_j represents practice indicators with respect to healthcare facility j (j = 1, ..., n).

I_p values were then combined into a composite index through the linear aggregation method[37,40]. The IWM performance index (I_{IWMP}) was calculated by the Eq. 2:

$$I_{IWMP} = \frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{m} P_{ji} w_i \quad (2)$$

$$\sum_{i=1}^{m} w_i = 1$$

$$w_i \geq 0$$

where, w_i is i-th practice indicator weight and P_j is i-th practice indicator with respect to healthcare facility j (j = 1, ..., n, I = 1, ..., m).

Similar to the IWM practice indices, I_{IWMP} values varied between 0 and 1, representing the worst and best possible result, respectively. Using the data, IWM practice adequacy level indices I_p and the IWM performance index, I_{IWMP}, were calculated with a case study in Brazil.

Case study: Parintins city is part of Tupinambarana Island, located on the Amazon River in Amazonas state, Brazil, with an area of 5,952 km^2 (Fig. 1). The local climate is equatorial and the vegetation includes Hileianas and Paludosas Ribeirinhas perennial forests. It has a shallow water table because it is an island and part of the city is flooded between March and July. Parintins has a population of 111,575. It is a poor municipality in which 60.07% of the population lives below the poverty line with an annual gross domestic product (GDP) of 206 million dollars and a Gini coefficient of 0.46. It has a Human Development Index of 0.658, which is lower than that of most Brazilian municipalities[44].

The water supply of the city is managed directly by the public administration. Sixty-seven percent of the population has access to treated water. However, there is no sewage

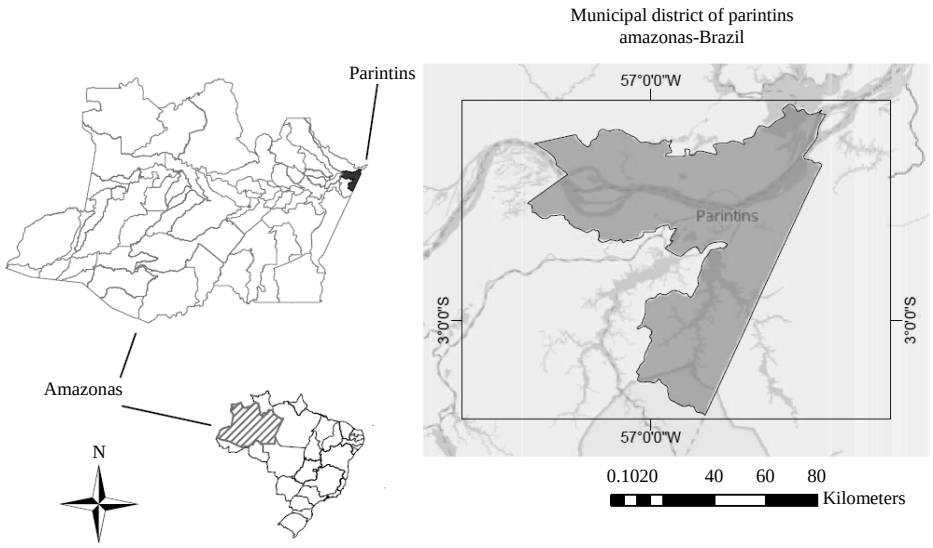

Fig. 1: Location of the city of parintins city, amazonas state, Brazil

system and most of the city's wastewater is disposed of in precarious septic tanks or released directly into water bodies[45].

There are eight hospitals and healthcare centers, which contain 111 hospital beds. The Brazilian Information System on Water, Sanitation and Solid Waste[45] data for these establishments indicate that (a) The collection is outsourced to a company over which the city does not apply a control system, (b) 396 t of IW were collected in the year 2015 and (c) The waste is not sent to other municipalities.

RESULTS AND DISCUSSION

Figure 2 shows the level of compliance of the hospitals and healthcare centers in Parintins city with IWM practices. All facilities showed a high performance for practices of IW segregation and sharp waste storage (I_{P3} and I_{P7}). However, IW segregated at the source was mixed with non-IW along the waste management stream. For the practices of putrefactive waste conservation, waste treatment and waste disposal (I_{P8}, I_{P18} and I_{P19}, respectively), all establishments showed low performance. The establishments' compliance with other practices was closer to zero. This indicates that most healthcare facilities did not adequately meet the practice requirements.

The I_{IWMP} represents the overall description of these practices weighted by their respective degrees of importance in causing environmental impacts. The I_{IWMP} of Parintins was 0.3776 on a scale from 0-1.

Parintins, like most Brazilian cities, does not comply with the Brazilian legislation for IWM. All Brazilian healthcare facilities must follow ANVISA Resolution No. 306/2004 and CONAMA Resolution No. 358/2005 when managing their IW. However, as indicated by the results of this study, even after 10 years of issuing these regulations, IWM is not performed as is required.

Data from The National System of Environmental Information and The National Survey of Water, Wastewater and Waste, which were collected in 2012, showed that IWM in various cities was in a similar situation to that of Parintins. These data showed that each day, 8,909 t of medical waste is collected in Brazil. This amount of waste is handled in different manners across the 5,570 Brazilian cities. the data indicated that 2,311 cities did not perform any treatment on the waste and that 931 cities burned the medical waste in inadequate or open kilns. Regarding final waste disposal, 3,403 cities disposed of medical waste together with other types of waste in landfills or dumpsites[46].

According to Patil and Shekdar[47] and Al-Khatib and Sato[48], inadequate IWM is greatly affected by the economic conditions of the location and adoption of legislation does not necessarily improve the situation. As a result, IWM in the northern and northeastern regions of Brazil, which are the poorest in the country, is worse than in other regions. The case of Parintins highlights this assumption, as over 60% of its population lives below the poverty line.

In addition to the economic conditions, other aspects exacerbate the IWM situation at healthcare facilities in Parintins. The city does not have wastewater collection and treatment and infectious liquid waste is released directly into cesspits or water bodies. Consequently, practice 6 (infectious liquid wastewater treatment) cannot be met. Moreover, practices 18 (IW treatment) and 19 (final IW disposal) cannot

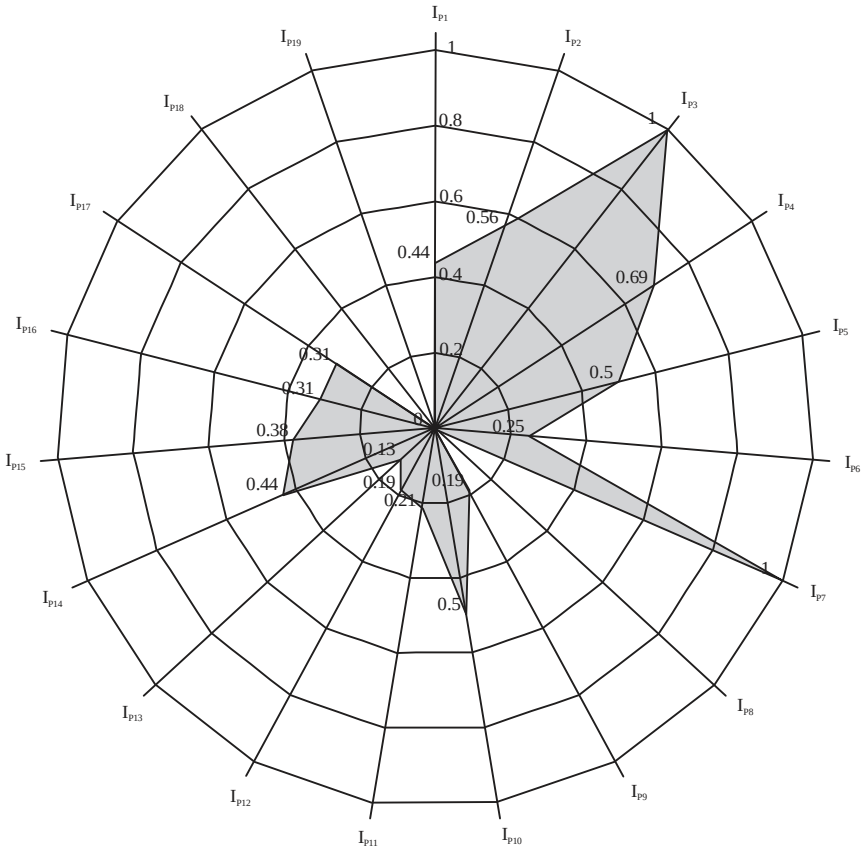

Fig. 2: Infectious waste (IW) management practice indices (I_P) of the hospitals and healthcare centers in Parintins. I_{P1}: Training of professionals responsible for waste collection. I_{P2}: Use of personal protective equipment during waste handling, I_{P3}: Waste segregation, I_{P4}: IW packaging, I_{P5}: Practice of emptying IW containers, I_{P6}: Infectious liquid waste treatment, I_{P7}: Storage of sharp waste, I_{P8}: Conservation of putrefactive waste, I_{P9}: Temporary IW storage, I_{P10}: Internal transportation I_{P11}: Frequency of internal waste transportation I_{P12}: Internal means of transportation, I_{P13}: Sterilization of IW carts and final storage area, I_{P14}: Final IW storage, I_{P15}: External IW transportation, I_{P6}: External means of IW transportation, I_{P17}: External collection frequency, I_{P18}: IW treatment and I_{P19}: Final IW disposal

be met, because there is no treatment or special landfill licensed for IW throughout Amazonas. However, even if there were a special landfill in another city, river transportation, which is the only available means of external transportation, would be complex and would involve risks, especially since there are no specialized and licensed companies in the state to manage IW transportation. It is therefore also difficult to meet practices 15 and 16 (both concerning external IW transportation).

The final disposal of IW is a critical practice for IWM in Parintins. Waste that is not burned at the healthcare facilities themselves or disposed of in local cesspits is collected and disposed of in the city landfill, which has no containment or leachate generation control. These uncontrolled disposals, along with the shallow water table, result in water pollution at this location. The problem is exacerbated between March and July, due to flooding of the landfill sites caused by floods from the Amazon River and its tributaries.

Applications recommendations and implications: Due to the environmental and public health risks, IW-related issues in Brazilian municipalities must be prioritized on political agendas. Robust national legislation and its effective implementation should be enabled to ensure sound environmental protection[7,49]. Since Brazil already has well-established legislation in this regard, the main leverage point for better IWM lies in its implementation[7]. As the management is handled by the waste producer, the government's role encompasses both the support and the incentive of good practices by efficiently and effectively

allocating resources (either financial or human), in addition to raising public awareness about the problem. Moreover, the IWM index is a tool for ranking cities in a region and allowing the government to prioritize cities that demand more resources and inspection, so as to improve their IWM-related systems. Indeed, poorly performing cities pose a greater risk to the environment and public health.

Government must also provide incentives for the development and implementation of best practices regarding handling, storage, treatment and disposal by healthcare institutions[7,50]. Once the healthcare waste management plan is prepared, a regular inspection and review program can be undertaken within the healthcare institution[49]. It is recommended that practices should be monitored by the city through both ANVISA and environmental agencies[48]. A national program should prioritize surveillance in regions that present environmental and public health risks because of the difficult control over all healthcare facilities in across all Brazilian cities.

The IWM index is useful for supporting this prioritization process. However, the implementation of IWM should not be initiated by the total application of best practices in poorly performing cities, such as Parintins. Instead, it should be incremental to promote a gradual increase of environmental protection levels to meet the benchmarks[7,51]. The targets for the achievement of IWM plans must further be strictly controlled. If the objectives are not achieved, then adjustments should be approved through official arrangements. However, sanctions should be applied if the agreements are not satisfied, as foreseen by the Brazilian legislation regarding environmental crimes.

The proposed method considers Brazilian cities, with the potential to be generalized to other regions, provided that practice selection respects local legislation. Furthermore, local experts must be consulted for the weighting process, because they are aware of the potential impacts of IW on local environments. This study did not aim to solve the problems of IWM assessment, but sought only to demonstrate a tool to assess a city's IWM practices. Thus, this tool has several limitations that should be seen as starting points for future research.

CONCLUSIONS

This study employed an innovative method to evaluate urban IWM. The method described in this study allows public policies related to IWM to be assessed and allows regions to be compared, so that governments can target efforts to solve problems in priority areas. The prioritization can be defined based on total or partial IWM performance quality, e.g., final IW disposal. The method employed enabled this, because, in addition to the I_{IWMP}, the results showed the measure of the level of adequacy in each IWM practice of healthcare facilities in a city. This type of assessment is essential to monitor cities IWM performance, so that state and federal governments can formulate incentive and disincentive policies for municipalities and healthcare facilities and that human and financial resources can be directed to municipalities lacking adequate IWM systems.

SIGNIFICANCE STATEMENT

This study makes a significant contribution to the literature because it offers an innovative method to assess IWM for a region, unlike the traditional approaches applied in most cases. The IWM index can be used to rank cities and support government policies of incentive and disincentive, as well as allowing the prioritization of cities that require more resources and inspection. Further, this study offers an accurate and efficient evaluation method that can be generalized to systems in other parts of the world.

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