ÁREA TEMÁTICA: Gestão Ambiental

Análise Multicritério e Multidecisor para Gestão de Resíduos Sólidos na Comunidade Rural Lagoa da Cruz, Princesa Isabel - PB

Daiana de Paiva Gomes[1] (daianagomes741@gmail.com), Sílvia Raphaele Morais Chaves[2] (raphaele.morais@gmail.com), Wilson Fadlo Curi[3] (wfcuri@gmail.com), Artur Moises Gonçalves Lourenço[4] (artur.lourenco@ifpb.edu.br)
1 Universidade Federal da Paraíba
2 Universidade Federal de Campina Grande
3 Instituto Federal da Paraíba

RESUMO
A seleção de formas adequadas de disposição de resíduos sólidos é um problema aonde se deve considerar de diversos critérios qualitativos e quantitativos. Este trabalho teve como objetivo avaliar alternativas para gestão de resíduos sólidos na comunidade Lagoa da Cruz, Princesa Isabel - PB, utilizando análise multicritério e multidecisor. O software RIOSS (*Riverbasin Information and Operation Support System*) foi utilizado para solução do problema multicritério e multidecisor, utilizando o método PROMETHEE II e Copeland, respectivamente. Foram analisados quatro cenários de gestão a curto e médio prazo para a comunidade, quatro dimensões e sete critérios. A alternativa CI (Compostagem Individual) foi escolhida como melhor opção na análise multicriterial considerando os pesos dos decisores, em sete vezes de um total de oito decisores. Na análise multidecisor foi confirmada a escolha da alternativa CI, tendo um número de três vitórias após a ordenação utilizando o método Copeland. Neste estudo inicial, foi possível verificar que métodos de análise multicritério podem ser utilizados para apoiar a decisão em políticas públicas, especificamente na área de resíduos sólidos, entretanto é necessária uma gama de índices e indicadores que possam caracterizar bem as alternativas e a comunidade, além de sempre levar em conta a preferência da comunidade e profissionais da área permitindo uma gestão participativa e com melhores chances de efetivação.
Palavras-chave: Apoio à Decisão, Disposição de Resíduos Sólidos, Saneamento Rural.

Multicriteria and Multidecisor Analysis for Solid Waste Management in a Rural Community in Princesa Isabel Municipality - Brazil

ABSTRACT
The selection of suitable forms for solid waste disposal is a problem where is requiring the analysis of several qualitative and quantitative criteria. This work evaluates alternatives for solid waste management in the Lagoa da Cruz rural community located in the Princesa Isabel municipality, state of Paraíba - Brazil, using Multicriteria and Multidecisor Analysis. The River basin Information and Operation Support System (RIOSS) software was used to solve the multicriteria and multi-decision problem using the PROMETHEE II and Copeland methods respectively. We assessed four short- and medium-term management scenarios for the community, four dimensions, and seven criteria. The alternative IC (Individual Composting) was the best option in the multi-criteria analysis considering the weights of the decision makers, seven times out of eight decision makers. In the multidecisor analysis, the choice of the alternative IC was confirmed, having a number of three victories after the ordering using the Copeland method. In this initial study, it was possible to verify that multicriteria analysis methods can be used to support the decision in public policies, specifically in the area of solid waste, however a range of indexes and indicators are needed to better characterize the alternative and the community, besides always take into account the preference of the community and experts allowing a participatory management with better chances of effectiveness.

Keywords: Decision Support; Rural Sanitation; Solid Waste Disposal.

1. INTRODUCTION

The problem of solid waste is one of the significant obstacles to achieving sustainable development given its increasing amount and the lack of adequate disposal sites or systems (JACOBI and BESEN, 2006). The insufficiency in the Solid Waste Management (SWM) entails environmental (pollution of water, air, and soil), social (public health, inadequate subsistence of waste pickers), and economic problems (devaluation of land, costs of recovering environmental damage) reaching all domains in the natural and anthropic environments.

In the last decades, the Brazilian scenario in the SWM has made some progress, but still very incipient, mainly in the less developed regions. In the year 2016, the solid waste situation in Brazil showed a setback compared to the previous year, 59.8% of the Brazilian municipalities incorrectly allocated their waste, and in the Northeast, this figure reached 74% of the municipalities (ABRELPE, 2016). Rural areas, generally devoid of environmental control technologies and far from urban areas, also present alarming numbers. According to data from FUNASA (2012), 80.2% of the solid waste generated in the rural area is not collected and end up having other destinations. These destinations are varied, but the most common practices are burning, thrown in the open or in water bodies, which are legally prohibited and emphasized in article 47 of Law No. 12305 of August 2, 2010, in art. 17 of the National Policy on Solid Waste (BRASIL, 2010).

The community of Lagoa da Cruz is located in the rural area of the municipality of Princesa Isabel, located in the semiarid of state of Paraiba, Brazil. As the national and regional scenery, the community has faced problems with inefficient, or even absent, solid waste management. The poor collection of waste by improvised trucks, comprising intervals of up to one month, generates disappointment in the community, leading to the burning of waste or the disposal in unsuitable places. Also, the community shows no other action to solve the waste problem. The municipality of Princesa Isabel disposes the collected residues in a garbage dump, which merely moves the problem to another place. The failure in public policies and efficient management models to implement the National Solid Waste Policy (PNRS) together with the absence of community participation in the management, community is lacking in information both related to the management of these residues and their implications in public health, end up generating the environmental and socio-economic problems mentioned above.

Residues produced in rural areas ranging from household waste to animal feed supplements also depend on the nature of the property, seasons, climatic conditions, and household habits and living standards (DAROLT, 2008).

Thus, participatory management models adapted to the local characteristics should be analyzed considering several criteria before their implementations. The prolonged period of drought in the region combined with the poor management of water resources has caused the municipality of Princesa Isabel a shortage of water. This has caused the search for new sources of supply, such as unmonitored dams, and an increase in well installations without inspection and control in the urban and rural areas. Many of these alternative sources are at the mercy of contamination due to inadequate disposal of solid waste.

2. OBJECTIVE

In view of the above, the objective of this study is to evaluate alternatives for solid waste management in the Lagoa da Cruz rural community in the Princesa Isabel municipality, state of Paraiba - Brazil, using Multicriteria and Multidecisor Analysis.

3. THEORICAL FRAMEWORK

3.1 Multicriteria and Multidecisor Analysis

Viable management alternatives should be based on criteria covering environmental, local socio-economic and technical-operational dimensions, thus allowing decision-making based on a technical-scientific analysis. Still, society participation in management models is essential for success. Community preferences coupled with the balancing of technical staff expertise is a successfully employed strategy (LIRA and CANDIDO, 2013).

The selection of suitable forms of solid waste disposal is a complex problem, consisting of the analysis of several qualitative and quantitative criteria in an integrated way (ARIKAN et al., 2015). According to Balaban and Baki (2010), the main reason is that solid waste management is not only a social problem but also a multicriteria decision problem that consists of political, socio-cultural, technical-operational, economic and environmental aspects.

Multicriteria methods have the characteristic of easy use and implementation, since they do not involve dense mathematical calculations or robust computational systems, for example in multiobjective optimization approaches. Huang, Keisler and Linkov (2011) carry out a vast review of research involving multicriteria applied in the environmental sciences. According to the authors, 300 studies were published between 2000 and 2009, and there was an expressive increase in the successful use of these techniques in the period evaluated. However, the applications of multicriteria decision support methodology in public policies are still scarce (SILVA and JANNUZZI, 2009).

3.2 Applications in Solid Waste Management

According to Ornelas (2011) it is necessary to develop methodologies to assist decision-making in the processes inherent to urban solid waste management (USWM), involving the processing and analysis of spatially distributed data and information. Therefore, its work intends to contribute to the operationalization of USWM through the application of concepts, techniques and procedures inherent in geoprocessing and spatial analysis, proposing and testing methodologies for sanitary landfills site selection, definition of voluntary delivery points (VDP) of recyclable waste and definition of urban solid waste collection and disposal routes (USW).

Lima et. al., (2014) analyzed the technologies to support the management and treatment of urban waste (MSW) in front of different processes involving political, economic, environmental and social aspects. The technologies analyzed were: recycling, composting, mechanical-biological treatment, anaerobic digestion, incineration with combined cycle electric power, landfill with and without power generation. The technologies were ranked in the models based on four criteria: environmental, social, economic and political.

Thus, we identify, through the literature review, three most used types of approaches of multi-criteria methods in solid waste management: evaluation of the efficiency of the management models implanted (HANAN, BURNLEY and COOKE, 2013; PIRES, MARTINHO and CHANG, 2011; HAMADA, 2011), the choice of viable management alternatives to be implemented (ARIKAN et al., 2015, VUČIJAK, MIDŽIĆ KURTAGIĆ and SILAJDŽIĆ, 2016) and the selection of optimum landfill sites health care (CABRAL, 2012; ESKANDARI, HOMAEE and MAHMODI, 2012; BELTRAN et al., 2010). Among the literature consulted, most of the studies do not consider the participation of all the decision-makers involved in solid waste management processes, thus not including multi-decision analysis techniques. Also, no research was found that addressed the use of multicriteria and multidecisor techniques in rural communities.

However, for He (2012), there is a need for suitable management models for municipal solid waste in community and villages in rural areas, especially in developing countries, as Brazil. The author emphasizes that agricultural waste management is a significant component of the integrated management of solid waste in developing countries, and proper treatment of such waste requires efficient management. Thus, we still need researches aimed at the use of techniques that provide reliable alternatives, making management efficient, in rural communities taking into account all their characteristics and participation of all involved actors.

4. RESEARCH METHOD

The following methodological steps were performed with their respective descriptions:

4.1 Study Area

The rural community Lagoa da Cruz is located in the municipality of Princesa Isabel, state of Paraiba - Brazil. According to IBGE (2010), the municipality has approximately 21,283 inhabitants, of which 31% are located in rural communities. The estimated population growth was 8.45% in 2016, totaling 23,247 inhabitants (IBGE, 2016). The Municipal Human Development Index (HDI) is 0.606, and its economy is based on services, agriculture and some poultry industries, which are virtually responsible for all the region's gross income (GNI). The city has an area of 368,067 km², and the area has a predominance of rural territory. Rural community of Lagoa da Cruz was delimited as a census sector (nº 251230905000013) in the 2010 Brazil Census, presenting nowadays a total of 680 inhabitants according to the city Department of Health. Leaving towards the municipality of Tavares in highway BR-426, at 7.5 km we take a dirt road for another 1.5 km until reach the community.
We verify that the community already undergoes a process of urbanization, with some squares and paved streets, a factor that generates the production of new types of solid waste besides those generally produced in rural areas.

4.2 Characterization of the Study Area

Lagoa da Cruz community already has crisis in solid waste management. Public health problems are felt and reported by the community. According to the survey, health workers report an increase in the incidence of people with respiratory problems due to the waste burning. They also reported a rise in the appearance of cases of arboviral diseases, noting that the northeast region is experiencing an outbreak of this type of disease, and the inadequate waste disposal is a factor that has contributed to the disease spread.

Burning waste leads to public health problems as well as causes air pollution and other negative environmental impacts over long and medium term. The negative effects to the environment are diverse. Launches of open-pit waste pollute and contaminate the soil, making areas unproductive for family farming, affecting subsistence in a specific part of the community. Even when collecting waste from the community, which occurs once a month, a long interval, according to the residents, the city of Princesa Isabel disposes the solid waste in a dump, thus generating problems such as inadequate access by waste pickers, who are subject to any disease, requiring models that also aim at the economic emancipation of these people.

We verified that all waste is disposed in an irregular manner, with 92% sent to the garbage dump, either the municipal dump or a small dump surrounding community and another 8% of waste is burned (IBGE, 2011). These data reinforce the need for new approaches to solid waste management in the community, as well as the insertion of the community in decision-making processes - through multi decisional analysis - bringing significant changes in attitude and knowledge appropriation.

4.3 Definition of Scenarios and Dimensions

Scenarios/alternatives of solid waste management were defined for the community. The situations were pre-filtered according to the characteristics of the community, for example, the construction of a sizeable composting plant, not feasible due to the small volume of organic waste generated by the community.
After the filtration, four management scenarios/alternatives for the solid waste generated in the community were defined, considering the short- and medium-term actions where the community itself would mobilize through the association of residents. The scenarios were: Selective Collection (SC), Situation Current (SA), Individual Composting (IC) and Composting Courtyard (CC). In the SC

scenario, a system of selective collection in the community would be implemented, making it possible to reuse, recycle and compost. The SA scenario would remain the way solid wastes are disposed. In the IC scenario, each family would compost their organic household waste, facilitating the work of the collectors and generating fertilizer for agriculture. Finally, in the CC scenario, a collective composting yard for the community would be implemented where all community organic waste would be composted, including those generated in agricultural production.
In this step, the study dimensions taken into account in the multicriteria analysis were also defined. A report can encompass the study of environmental, social, economic, technical-operational, among others. It is also possible to use sub-dimensions for each dimension chosen, e.g. the ecological aspect can have the sub-dimensions fauna and flora, these may have other sub-dimensions such as terrestrial fauna and aquatic flora, respectively.
The multi-criteria analysis used in this work have four dimensions: Environmental, Economic, Social and Operational. The Environmental Dimension involves criteria related to the environment preservation. The Economic Dimension is related to rules that describe feasibility on the capital's point of view. The Social Dimension seek to incorporate social welfare into the chosen management model. The Operational Dimension address the technical-operational aspects of the management model.

4.4 Choice of Criteria

Criteria are qualitative or quantitative values derived from indexes, indicators or simply values assigned to some judgment. When the criterion has qualitative value (e.g.: good, bad and very bad) it is transformed into quantitative by the use of a utility function, which usually normalizes this criterion on a scale between 0 and 1.
The criteria were chosen based on the scenarios, dimensions and sub-dimensions, checking the data availability.
The Management of Solid Residual Domiciliary (GSRD) should be integrated and participatory, so the criteria taken into consideration should cover environmental, socioeconomic and technical-operational aspects. The criteria used in the multicriteria problem can be described as follows:

- Environmental Return: It involves positive impacts of the management model on the environment;
- Cost: Involves the amount needed to implement the management model;
- Economic Return: Involves the generation of income for the community through the management model used;
- Community Involvement: Involves community participation as responsible for the management process;
- Vulnerability: It involves risks to the residents.

4.5 Preparation and Application of Questionnaires

The questionnaires were based on the choice of dimensions and criteria. The objective of the surveys was to obtain a vision, albeit not a general one, of the community's perception about the solid waste problem and the degree of importance of each dimension and criterion to be used in the multidecisor analysis, thus including the community in the decision-making processes. We interviewed two members of the community. We also applied questionnaires to other 5 segments, namely: academics, teachers from the environmental area and other areas of concentration of this study, thus incorporating technical and scientific knowledge in the analysis; Students, also belonging to and not belonging to the study concentration area, Organized Civil Society, with representative of an NGO of the municipality; the Private Sector, which comprises an environmental engineering and consulting firm; and the Public Power, which was represented by a local governor.

The questionnaire had a brief explanation of the work and was divided into sections. In the first section, the respondent faced questions for collecting general information, such as: Name (not mandatory); Its segment, and the level of satisfaction with how the municipality manages solid waste. The second section contained questions about the level of preference for each of the dimensions considered in this study. In the third, they were questioned regarding the level of choice for each of the criteria. It is important to emphasize that in the questionnaire both the dimensions and the requirements were characterized, described and exemplified, thus facilitating the interpretation of the respondents.

4.6 Multi-Criteria Decision Analysis

The multicriterial method applied in this study was one of the ways of the PROMETHEE II family (Preference Ranking Organization Method for Enrichment Evaluations II) of the French school of Multicriteria Analysis to the Decision (AMD). The method involves concepts and parameters that are easily understood and assimilated by decision makers (ARAÚJO and ALMEIDA, 2009). The process does not require computational robustness to be applied and is considered easy to implement. Another advantage of the method is that it aims at the complete ordering of alternatives, avoiding any incomparability (MORAIS and ALMEIDA, 2006).
The multidecisor method of Copeland was used by Copeland and was proposed by the American researcher A. H. Copeland (1898-1970), the Copeland method is derived from the Condorcet method, thus uses the same matrix obtained in the method. From it, one calculates the sum of the victories less the defeats, that is, the lines are subtracted by the columns, in a simple majority voting, then the alternatives are ordered by the result of that sum (LEVINO and MORAES, 2010).
The Copeland method has the advantage of always providing a total ordering (as opposed to the Condorcet method) and significantly reduces the influence of irrelevant alternatives, however, it is computationally demanding (FERREIRA, GOMES and MELLO, 2011; GOMES e MELLO, 2005, GOMES JUNIOR et al., 2005).
After the problem structuring, the analysis and application of the multicriteria and multidecisor methods were performed using the River basin Information and Operation Support System (RIOSS) software and decision support software. RIOSS (Lourenço and Curi, 2015) is a decision support software for natural resource management (although it allows applications in several areas) that has been developed by the research group GOTA (Total Water Optimization Group), today in a partnership between researchers from UFCG (Federal University of Campina Grande) and IFPB-PI. The software has integrated subsystems that are responsible for making the variables involved in decision processes - Metrology Subsystem - storage of variable series - Measurement Subsystem - , and for the analysis allowing the creation of indices and indicators and multicriteria analysis (by PROMETHEE II method) and multidecisors (several methods) - Analysis Subsystem.

5. RESULTS

The Table 1 shows the synthesis of the criteria used in the multicriteria problem according to the analyzed dimensions and the defined scenarios.

Table 1. Synthesis of the criteria

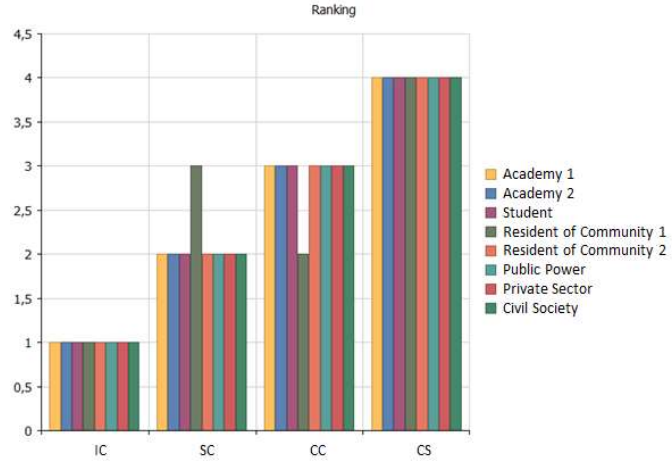
Dimension	Criteria	Scenerios*			
		SC	SA	IC	CC
Enviromental	Enviromental return	Medium (2)	None (0)	High (3)	High (3)
Economic	Cost (R$/ton)	389	26	0,0016	60
	Economic return	High (3)	None (0)	Low (1)	Medium (2)
Social	Community participation	Yes (1)	Yes (1)	Yes (1)	Yes (1)

	Vulnerability Situation	No (0)	Yes (1)	No (0)	No (0)
Operational	Deployment Time (days)	30	0	1	180
	Answer time (days)	120	30	90	300

* CS- Selective Collection; SA- Current Situation; IC- Individual Composting; CC-Composting Station.

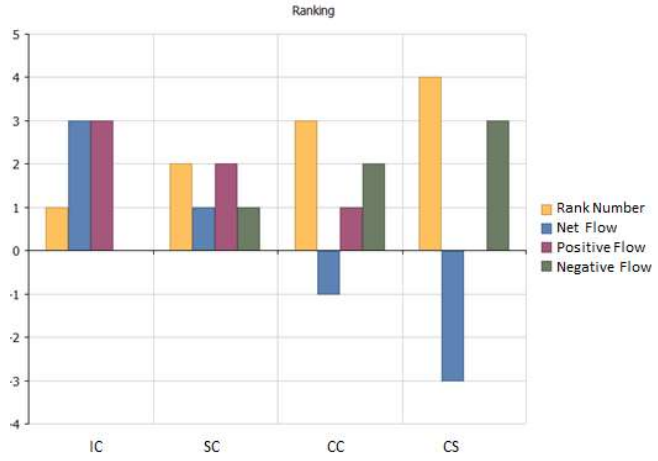
The values of the quantitative criteria were verified together with literature and research in companies that work with solid waste management. The qualitative criteria were numerically staggered considering the level in each scenario and had their conceptualization based on considerations made in the literature and the authors' view.
Figure 6 shows the results of the multicriteria analysis performed using the RIOSS software, considering the weights of each decision maker, thus presenting the preference of each of them for each management alternative.

Figure 4. Multicriteria analysis for each decision maker and scenario



Academy 1 represents the teacher in the area of environmental sciences; Academy 2 represents the diverse concentration area teachers; Student, is a student of the IFPB-PI who resides in the community; the Resident of Community 1 and 2, are the two representatives of Lagoa da Cruz community; the Public Power is a representative of the municipal Legislative Branch; the Private Sector is a representative of an engineering firm; civil society are representatives of an NGO also located in the municipality.
The Resident of Community 2 expresses itself in a differentiated way concerning the others, occurring the change of ranking of the alternative PC from the third place to the second place occupying the alternative CS. However, all decision-makers considered the IC alternative as the best option for solid waste management.
The choice of Individual Composting (IC) to treat community waste would impact a considerable change in the community in the short term. Low operational cost and ease of use can facilitate the implementation of composting, as well as the advantages of composting, avoiding pollution and environmental contamination, among others. It would immediately facilitate the process of sorting the own collectors of recyclable materials that reside in the community itself.
The form would have to be defined individually according to the conditions of each inhabitant. According to Wangen and Freitas (2010), the form to be used depends on the available space. A composter or pile usually uses less space than a string. If the amount of material to be composted is small, grounding may be more practical. Figure 7 presents the results of the multidecisor analysis using Copeland method.

Figure 5. Result of multidecisor analysis



As already mentioned, the Copeland method has a single ranking that we calculated according to the preferences of all decision makers. The Net Flow represents the total number of wins of a scenario obtained through the difference between Positive Flow and Negative Flow, that is, wins minus losses, respectively.
The final ordering chose the IC scenario as the best alternative. This scenario obtained the number of three victories, that is, it was preferred in all Scenarios studied.

6. FINAL CONSIDERATIONS

In this work, we perform analysis of solid waste management alternatives for the rural community of Lagoa da Cruz. We analyzed four alternatives, four dimensions, and seven criteria. We chose the IC alternative as the best option in the multi-criteria analysis considering the weights of the decision-makers, seven times out of a total of eight decision makers. The proposed alternatives considered the current panorama of the community, the municipality and the possibility of owning the community to manage its waste, avoiding being left to the mercy of external agents that can bring solutions that are not viable and/or out of time. In the multidecisor analysis, the choice of the IC alternative was confirmed, having many victories after the ordering using the Copeland method.
We verified that it is possible to use multicriteria analysis techniques to support decision making in public policies. Further study is needed, especially regarding the characteristics of waste produced in the community (gravimetry) and use of more (mainly quantitative) criteria, avoiding personal judgments. We hoped that studies like this might also contribute to the implementation of the municipal solid waste plans provided in the National Solid Waste Policy (PNRS).

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