
Regionalisation studies for municipal solid waste management in Brazil

Aline Pimentel Gomes*, Pedro D.M. Prietto,
Rosa Maria Locatelli Kalil and
Adalberto Pandolfo

Department of Civil Engineering and Architecture,
University of Passo Fundo, Brazil,
Email: alinepimentel@upf.br
Email: pdmp@upf.br
Email: kalil@upf.br
Email: pandolfo@upf.br
*Corresponding author

Sergio Reyes

Department of Geography,
University of Malaga, Spain
Email: sergioreyes@uma.es

Abstract: Municipal solid waste (MSW) management at the regional level has become increasingly important over the last years. The regionalisation studies evaluate ideal arrangements of municipalities to constitute consortia for sharing infrastructure and management. A document analysis of regionalisation studies for MSW management from 18 Brazilian states was made in order to identify and evaluate the shape of the regions, the criteria and the methods used. The results evidenced a big difference regarding the number of regions proposed, the number of municipalities, the area and population of each region, the environmental, economic, social and political criteria, the hierarchy and the tools used. There is a lack of padronisation in the elaboration of these studies and the development of a consistent method, with the definition of hierarchical criteria, the use of appropriate geospatial tools, as well as the social participation in the decision-making process can contribute to the elaboration of regionalisation studies.

Keywords: municipal solid waste; MSW; waste management; regionalisation for waste management; public consortia; Brazil.

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Biographical notes: Aline Pimentel Gomes is a civil engineer. He is hold a Master and PhD in Civil and Environmental Engineering. He is a Professor of the Department of Engineering and Architecture at the University of Passo Fundo. He is a research areas municipal solid waste management, regional planning, and intermunicipal consortia.

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Pedro D.M. Prietto is a civil engineer. He holds a Master and PhD in Geotechnical Engineering. He is a Professor of the Graduate Program in Civil and Environmental Engineering at the University of Passo Fundo. Research areas: environmental geotechnics, solid waste management, waste technology, and soil mechanics.

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Rosa Maria Locatelli Kalil is an architect and urban planner and economic scientist. He holds a Master in Engineering and PhD in Architecture and Urbanism. He is a retired professor of the Graduate Program in Civil and Environmental Engineering at the University of Passo Fundo. His research areas regional planning and development, urban sociology, post-occupation evaluation, and sustainable development.

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Adalberto Pandolfo is a civil engineer. He holds a Master and PhD in Production Engineering. He is retired professor of the Graduate Program in Civil and Environmental Engineering at the University of Passo Fundo. Research areas: project evaluation, process management, and municipal solid waste management.

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Sergio Reyes is a geographer. He is a Master in Spatial Planning and Geographic Information Technologies, Doctor with international mention in Geography, Geographer specializing in landscape and geographic information systems. He is a Professor of the Department of Geography at the University of Malaga. His research areas are landscape analysis, land planning, urban planning, GIS, and cultural presentations of landscape.

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1 Introduction and background

Municipal solid waste (MSW) management is a cross-cutting issue that affects many aspects of society, economy and environment, having strong links with a number of other global challenges, such as health, education, climate change, poverty reduction, sustainable production, and consumption.

For this reason, the MSW management was included in the Sustainable Development Goals (SDG), with emphasis on SDG 11 and 12. SDG 11 talks about “making cities and human settlements inclusive, safe, resilient and sustainable”, having as goal (11.6) “to reduce the negative environmental impact per capita of cities, including paying special attention to air quality and municipal waste management.” SDG 12 is about “ensuring sustainable production and consumption patterns” and “to substantially reduce the generation of waste through prevention, reduction, recycling and reuse” (goal 12.5) (United Nations, 2020).

Communities worldwide are facing difficulties in managing MSW, due to the increase in urbanisation and in waste generation, the complexity of the waste generated (Kaza et al., 2018), the general trend towards industrialisation (Rabbani et al., 2018) and the scarcity of treatment and final disposal areas (Kuranchie et al., 2020). In addition, there are the stringent technical requirements, the high management costs, the increase in the population’s environmental awareness (Abou Najm et al., 2002), and the insufficient technical and financial capacity for the proper waste management in many municipalities, especially the small ones.

A large volume of waste is generated every day around the world, which is associated with significant environmental and public health risks (Dolar et al., 2016), mainly due to air, soil, and water pollution (Brunner, 2013) caused by the inadequate final disposal still adopted in many developing countries.

In Brazil, small municipalities predominate, with precarious economic conditions, significant solid waste generation and inadequate final disposal, in addition to little technical and management capacity.

In this context, the regionalisation (intermunicipal arrangements) appears as a good strategy for an adequate MSW management, presenting as benefits the gain of scale, the reduction of the number and the increase of the efficiency of the facilities for the waste treatment and final disposal, the reduction of the demand by qualified professionals and of pollution prevention and environmental protection costs (Chang and Lin, 1997; Wang et al., 2008; Ferreira and Jucá, 2017; Silva et al., 2020). Also the cost of implementing measures required by legislation can be reduced. Through intermunicipal cooperation, new opportunities for learning and hence, for innovation, may emerge (Niutanen and Korhonen, 2003). In addition, it is necessary to take regional characteristics into account in local and national decision-making. This is especially relevant for cities and regions that develop local environmental policies (Towa et al., 2021).

According to Hulst et al. (2009), cooperation among neighbouring municipalities is commonly implemented officially and unofficially in various forms and is adapted to the historical, geographical, legal, or political background of each country. It can be classified into three perspectives:

- 1 composition (only municipalities or include other public authorities or private sector organisations)
- 2 scope (single-purpose or multi-purpose)
- 3 degree of organisational integration (public services are delivered by separately established organisations or through agreements of partnering cities).

Numerous studies have been carried out on the planning of MSW management on a regional scale, mainly in order to assess different routes for waste collection, select alternatives and allocate infrastructure for the collection, waste treatment and final disposal, that can assist decision-makers in choosing the ideal MSW management system for the regions under study, considering factors like complexity, uncertainty, subjectivity and multiplicity of criteria and objectives (Caruso et al., 1993; Everett and Modak, 1996; Chang and Lin, 1997; Abou Najm et al., 2002; Lin et al., 2006; Shmelev and Powell, 2006; Chang and Davila, 2007; Wang et al., 2008; Adamides et al., 2009; Londoño et al., 2010; Marchezetti et al., 2011; Effat and Hegazy, 2012; Chatzouridis and Komilis, 2012; Rada et al., 2013; Chen et al., 2014; Majale and Mireri, 2014; Colón et al., 2015; Vélez and Mora, 2016; Santibañez-Aguilar et al., 2017; Blanco et al., 2018; Khan et al., 2018; Somplák et al., 2019).

These studies refer to defined regions, such as metropolitan areas, sub-regions or regions of provinces or countries. There are few studies dealing with the definition of ideal territorial arrangements for integrated MSW management. In this case, we can highlight the article by Suzuki and Gomes (2008), in which groups of municipalities are identified to form intermunicipal consortia in the State of Paraná (Brazil), aiming at the appropriate final destination of waste, taking into account data population, road system, geographic location of the urban headquarters and the hydrographic basin. Likewise, the

article by Guabiroba et al. (2014) presents a procedure for the definition of an interregional arrangement for the implementation of selective door-to-door collection in the State of Rio de Janeiro (Brazil), using performance indicators, such as the optimised use of collecting vehicles and the respective emission of pollutants, the study used the grouping method of k-means to partition the study region into sub-regions. More recently, Richter et al. (2019) used the Thiessen regular polygon method to define regions with different sizes and shapes in the provinces of Saskatchewan and Nova Scotia (Canada) in order to minimise the distances and costs of transporting waste.

Thus, the importance of regionalisation studies for the management of MSW is clearly perceived and this work intends to bring a relevant contribution by addressing them. Most of these studies consist of the identification of territorial arrangements among municipalities, contiguous or not, with the objective of sharing services and activities of common interest, thus allowing to maximise the human, infrastructure and financial resources, resulting in economies of scale (SINIR, 2018).

In Brazil, the National Solid Waste Policy – NSWP (Brazil, 2010a) encourages the regionalisation of waste management through the formation of public consortia that bring together municipalities to plan, regulate, inspect and provide services according to appropriate technologies. The regionalisation studies are a necessary part of the MSW state plans, which in turn are a mandatory condition for the states to have access to federal financing resources related to public waste management.

Seeking to support public policy makers, the Brazilian Ministry of the Environment has prepared a guide for the elaboration of MSW management plans, according to which, the process of constructing intermunicipal arrangements begins with the establishment of criteria for the aggregating municipalities options, among which the following stand out: coverage area intended for the consortia (maximum distance among municipalities); territorial contiguity; hydrographic basin; access conditions (transport infrastructure among municipalities); similarity in terms of environmental and socio-cultural characteristics; existence of economic flows among municipalities; pre-existing regional arrangements; common experiences in waste management; difficulties in locating suitable areas for waste treatment and disposal in some municipalities; existence of municipalities with regional leadership; existence of small municipalities that cannot be segregated from the regional arrangement; number of municipalities involved; total population to be served; total volume of waste generated in the municipalities. The guide is useful for the elaboration of MSW state plans, but its approach to the regionalisation studies is very succinct, only presenting a few general criteria, without explaining which ones are priority and how they should be considered (SRHU/MMA, 2011).

The federal government has supported Brazilian states and municipalities in the elaboration of regionalisation studies and formation of intermunicipal consortia, with financial resources for studies and projects (Britto et al., 2016). To this date, just over half of the states have concluded the regionalisation studies for the MSW management.

Various regionalisation scenarios are possible within a theoretical and methodological scope of segmentation and territorial management. In general, scenarios should be defined based on information from a prospective diagnosis in order to guide planning, involving extensive statistical and cartographical data (MMA, 2012). Similarities and contrasts, affinities and divergences, advantages and disadvantages of the alternative groupings of municipalities should be identified to define the best scenario for regionalisation, which will support the development of guidelines, strategies, goals, programs, projects, and actions (FUNASA, 2014).

In this context, expecting to contribute to the deepening of the discussion on the MSW public management, this paper aimed to analyse the regionalisation studies for MSW management in Brazil, identifying and evaluating the regions shapes, the criteria and the methods used in their elaboration.

The paper is organised as follows: Section 2 presents the method and materials, Section 3 presents and analyses the results, Section 4 provides the discussion, and Section 5 establishes the concluding remarks.

2 Method and materials

Brazil is composed of 26 federal states, which occupy an area of 8,510,820.623 km² with population of 210,147,125 inhabitants, resulting in a demographic density of 22.43 inhabitants/km² (IBGE, 2020). The generation of MSW in 2019 was around 79 million tons, 92% of which were collected, 59.5% of the collected waste was sent to landfills, while the remaining 40.5% (approximately 30 million tons) were disposed off in dumps or controlled landfills (ABRELPE, 2020).

In this paper, all regionalisation studies for MSW management carried out in Brazil until 2019 were analysed, which correspond to 18 states, as shown in Figure 1: Acre (PEGIRS-AC, 2012), Alagoas (PERGRS-AL, 2010), Bahia (PRGIRS-BA, 2012), Ceará (PRGIRS-CE, 2012), Espírito Santo (SEDURB, 2008), Minas Gerais (PRE-RSU, 2009; PR-GIRS-BSF, 2010), Pará (PRGRS-PA, 2013), Paraíba (PRGIRS-PB, 2013), Paraná (PGIRSU-PR, 2013), Pernambuco (PEGCIRS-PE, 2013), Piauí (PRGRS-PI, 2011), Rio de Janeiro (PERS-RJ, 2013), Rio Grande do Norte (PEGIRS-RN, 2012), Rio Grande do Sul (PERS-RS, 2014), Santa Catarina (PGIRS-SC, 2012), São Paulo (PERS-SP, 2014), Sergipe (PERS-SE, 2014) and Tocantins (PERS-TO, 2017). The population covered by the analysed states corresponds to 83% of the country's total population.

The regionalisation studies were accessed by searching the Ministry of the Environment website from March 2018 to March 2019. The methodology used for data collection was a document analysis, which is a systematic procedure for reviewing or evaluating documents, both printed and electronic material, used in qualitative researches (Bowen, 2009). The analytic procedure entails finding, selecting, appraising, and synthesising data contained in documents, producing data that are organised into major themes, categories, and case examples (Labuschagne, 2003; de Oliveira, 2016).

Thus, the regionalisation studies were put into categories, in order to group similar information according to common characteristics. The territorial arrangements proposed in each study were analysed according to the number of regions, coverage area, number of municipalities and population of each region. The criteria and the methodology used to define the territorial arrangements proposed in the regionalisation studies were also identified (Figure 2). These categories were compared among the 18 states and the existence of patterns was verified.

Figure 1 Brazilian estates that made regionalisation studies of MSW management (see online version for colours)

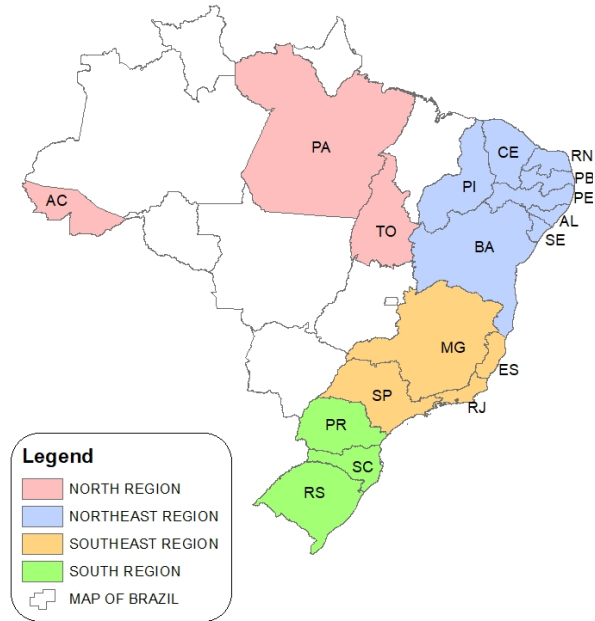
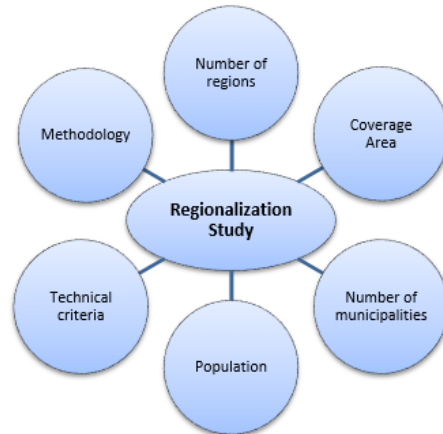


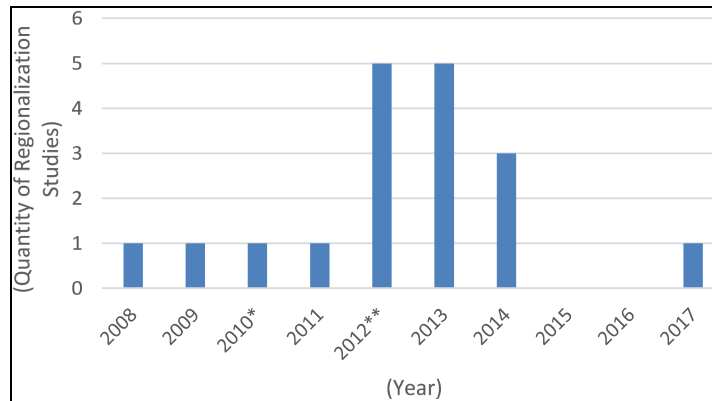
Figure 2 Document analysis categories for the regionalisation studies (see online version for colours)



3 Results

The regionalisation studies for MSW management analysed were prepared between the years 2008 and 2017 (Figure 3), the majority from 2010 onwards, the year in which the Brazilian NSWP was sanctioned (Brazil, 2010a), and half of them after 2012, the year in which the MSW state plans, including the regionalisation studies, should have been concluded (Brazil, 2010b).

Figure 3 Year of regionalisation study elaboration (see online version for colours)



Notes: *2010: Brazilian National Solid Waste Policy.

**2012: final deadline for regionalisation studies elaboration.

Many of these studies were carried out through agreements with the Ministry of the Environment. In some states, they were prepared by state departments, while in others, they were prepared by private consulting companies.

In most states, regionalisation studies were carried out concurrently with the MSW state plans based on waste management diagnosis and presenting prognosis for a 20-year planning horizon, as recommended by the NSWP (Brazil, 2010a).

While in some states a single regionalisation proposal or scenario was presented, which was later adjusted, in others, 2 to 4 regionalisation alternative proposals were prepared. In both cases, the final proposal was chosen during public workshops, seminars and conferences.

Most of the regionalisation studies were prepared considering a public intermunicipal consortia for each region of the study. Waste management facilities, such as voluntary delivery points, transfer stations, treatment and final disposal facilities were pre-dimensioned and allocated within each territorial arrangement. In some studies, the costs of these facilities have been estimated.

3.1 Territorial arrangements in regionalisation studies

Table 1 presents a summary of the regionalisation studies for MSW management in 18 Brazilian states. The number of territorial arrangements in which each state was divided varies between 2 (in the State of Acre) and 51 (in the State of Minas Gerais).

Table 1 Summary of regionalisation studies for MSW management in 18 Brazilian states

State	Area of the state (km ²)*	Population of the state*	No. municipalities of the state	No. regions of the study	Area of each region (km ²)	No. municipalities of each region	Population of each region
Espirito Santo	46,074.44	3,972,388	78	3 + 1**	NI	15 and 28	NI
Minas Gerais	586,521.12	21,040,622	853	51	NI	NI	NI
Alagoas	27,843.295	3,322,820	102	7	1,857.53 and 5,539.09	8 and 22	174,486 and 1,152,821
Piauí	251,616.82	3,264,531	224	10	NI	11 and 37	59,238 and 963,063
Ceará	148,894.76	9,075,649	184	14	2,711.00 and 22,849.00	5 and 26	130,799 and 2,940,177
Acre	164,123.74	869,265	22	2	NI	8 and 14	190,910 and 464,475
Rio Grande do Norte	52,809.60	3,479,010	167	7	NI	24 and 44	223,625 and 1,278,486
Santa Catarina	95,730.92	7,075,494	295	26	NI	4 and 20	50,306 and 919,445
Bahia	564,722.61	14,812,617	417	26	NI	8 and 27	59,009 and 3,506,152
Paraíba	56,467.24	3,996,496	223	14	1,890.00 and 10,414.00	7 and 39	76,377 and 1,189,121
Pará	1,247,955.24	8,366,628	144	NI	NI	NI	NI
Pernambuco	98,068.02	9,496,294	184	12	NI	7 and 26	135,502 and 3,768,902
Paraná	199,307.94	11,320,892	399	20	NI	7 and 33	185,964 and 3,223,836
Rio de Janeiro	43,750.42	17,159,960	92	22	NI	2 and 15	NI
Rio Grande do Sul	281,707.15	11,329,605	497	12	NI	8 and 81	301,434 and 2,268,009
São Paulo	248,219.48	45,538,936	645	25 + 5**	NI	5 and 43	129,384 and 1,488,762
Sergipe	21,926.91	2,278,308	75	4	2,267.49 and 8,842.36	11 and 28	286,322 and 946,543
Tocantins	277,466.76	1,572,866	138	A = 19 and B = 10***	NI	A = 4 to 15 and B = 5 to 27***	NI

Notes: *area and estimated population in 2019 (IBGE, 2020).

**metropolitan areas that were not included in the regionalisation study.

***this regionalisation study presents two proposals, A and B.

In the State of Minas Gerais, which is the second largest in size and population and has the largest number of municipalities, 51 optimal territorial arrangements and 285 clusters among municipalities were proposed, not specifying how the consortia would be formed. In the State of Bahia, the 26 Sustainable Development Regions were subdivided into 105 territorial arrangements and 98 individualised solutions (only one municipality). In the State of Paraíba, the 14 Geoadministrative Regions were subdivided into 33 regional arrangements and nine individualised solutions. Besides to Bahia and Paraíba states, individualised solutions were adopted in the states of Rio Grande do Norte and Rio de Janeiro, as the grouping was not considered viable for some municipalities.

In the State of Rio Grande do Norte, six regions and one individualised solution were defined and in the State of Rio de Janeiro, in addition to the eight existing intermunicipal consortia, 33 territorial arrangements and one individualised solution were defined. The metropolitan areas were excluded from the regionalisation studies in the states of Espírito Santo and São Paulo. In the State of Tocantins, two proposals were presented, being the implementation of the regionalisation within the scope of intermunicipal consortia dependent on debates and adjustments, according to the objectives of the future members of the consortia.

The number of municipalities in each territorial arrangement varies widely, from 2 (in the State of Rio de Janeiro) to 81 (in the State of Rio Grande do Sul). The territorial area varies from 1,890 km² (in the State of Paraíba) to 22,849 km² (in the State of Ceará), considering only the states that presented this information, and the population ranges from 50,306 inhabitants (in the State of Santa Catarina) to 3,768,902 (in the State of Pernambuco).

In summary, a great difference is perceived in relation to the number of arrangements proposed in each state, the number of municipalities, the area, and population of each arrangement. To understand the reason for the discrepancies, the criteria and methodologies used in each state were analysed.

3.2 Criteria for preparing regionalisation studies

Some regionalisation studies are quite detailed, clearly showing the adopted criteria and methodology, while others are more succinct, presenting only the result of the study. Table 2 shows the main criteria according to the frequency they were used.

The criteria presented in Table 2 are the same as suggested by the Ministry of the Environment for the elaboration of MSW management plans, however, it was observed that in some studies only a restricted set of criteria were used to determine territorial arrangements, while in others a much larger number of criteria were used.

3.3 Methods for preparing regionalisation studies

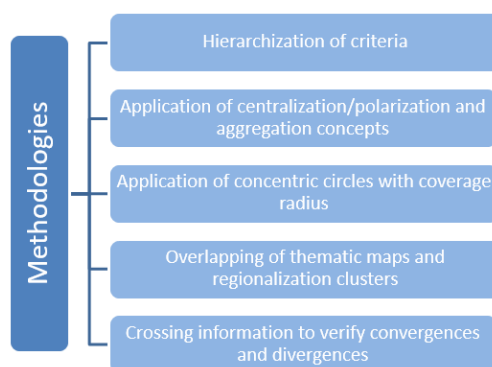
In most regionalisation studies, for the states of Piauí, Sergipe, Ceará, Acre, Rio Grande do Norte, Paraíba, Pernambuco, Rio de Janeiro, São Paulo and Acre, the main methodology used was the adjustment or adoption of pre-existing regionalisations, for which technical data and defined public policies already existed. Hence, these studies started from predetermined territorial arrangements and, for those, information was collected about population, amount of waste generated, number of municipalities, coverage area, road accessibility, distances, existence of waste final disposal areas,

conservation units, etc. depending on the study, that is, these criteria were not always considered in determining territorial arrangements.

Table 2 Criteria used in regionalisation studies of MSW management in Brazilian states

<i>Criteria used in regionalisation studies</i>	<i>Nature of criteria</i>	<i>No. occurrences/frequency</i>
Road accessibility among municipalities	Economic	15/83.3%
Distance among municipalities	Economic	13/72.2%
Population	Economic	10/55.6%
Amount of waste generated in each region	Economic	10/55.6%
Previous existence of arrangements among municipalities	Political	10/55.6%
Existence of a main city in each region	Political	9/50.0%
Location of the landfill	Environmental/economic	9/50.0%
Locational restrictions to location of the landfill	Environmental	7/38.9%
Available areas for solid waste final disposal	Environmental/economic	5/27.8%
Hydrographic basins	Environmental	5/27.8%
Environmental characteristics (relief)	Environmental	5/27.8%
Economic characteristics	Economic	3/16.7%
Socio-cultural characteristics	Social	3/16.7%
Location of urban agglomerations	Political	2/11.1%
Number of municipalities in each region	Political	2/11.1%
Energy potential of biogas generated by waste	Economic	2/11.1%
Territorial contiguity	Political	1/5.6%
Grouping municipalities with weak economy and strong economy	Economic	1/5.6%

Figure 4 Methodologies used for regionalisation studies elaboration (see online version for colours)



For the regionalisation studies from the states of Alagoas, Santa Catarina, Bahia, Pará, Paraná and Rio Grande do Sul, the most used methodologies for the definition of

territorial arrangements are represented in Figure 4. The regionalisation studies from the states of Espírito Santo and Minas Gerais do not present any methodology for defining territorial arrangements.

As a necessary methodological step, the hierarchy of criteria, defining the relative weight of each one, is of paramount importance, raising some relevant questions. Is it more important to limit the distance among the municipalities in the territorial arrangement or to reach a minimum population for economy of scale? Maintaining pre-existing arrangements or grouping municipalities with a fragile economy to municipalities with a strong economy to generate development? Do the criteria have the same relevance in all regions?

Another methodology step used was the application of centralisation/polarisation and aggregation concepts, which consisted in identifying the municipalities with the greatest vocation to play a regional leadership role (main municipalities) and defining the municipalities that best integrated with them to constitute a territorial arrangement. In some regionalisation studies, after the definition of the main municipalities, concentric circles were drawn with coverage radius of up to 200 km in order to identify the region of influence of these municipalities.

Overlapping thematic maps (road network, population, waste generation, main municipalities, urban agglomerations/metropolitan areas, and availability of areas for solid waste final disposal) and clusters of regionalisation (intermunicipal consortia, state administrative regions, associations of municipalities, and hydrographic basins) and crossing statistical information were strategies employed in some regionalisation studies to verify convergences and divergences and to adjust the limits of territorial arrangements.

The most used tool in the researched regionalisation studies was the geographic information system (GIS) for the development of thematic maps, for the location of final disposal areas, degraded areas due to inadequate disposal, potentially favourable areas for final disposal, waste treatment units, conservation units, main cities, population, existing consortia, etc. Google Earth was used in a regionalisation study to determine waste routes.

While the elaboration of most studies went through the process of popular participation through public meetings, workshops, seminars, and conferences to define the criteria, its hierarchy and validate the final regionalisation proposal, others did not present information about it, and may have been prepared exclusively by a technical team.

4 Discussion

4.1 Criteria and methods used in the regionalisation studies in Brazil

Road accessibility among municipalities was the most used criterion in regionalisation studies. The modalities of transport available should be assessed, including possible road, rail and river connections, pointing out the existing realities for solid waste transportation (SRHU/MMA, 2011).

This criterion is directly linked to the cost of waste transportation, which may turn unfeasible the participation of a municipality in a territorial arrangement. This criterion is more relevant in developing countries, due to the lack of appropriate transport

infrastructure for waste collection and transportation (Parrot et al., 2009). Each region or country requires quality and efficient transportation infrastructures network to serve intra-regional and interregional mobility and to boost economic and regional development (Polyzos and Tsiotas, 2020).

The road network as well as the waste generation sites, and existing sanitary landfills were the criteria used in the study by Richter et al. (2019) for the definition of regions for MSW management in the provinces of Saskatchewan and Nova Scotia (Canada).

The distance between waste generation and the waste treatment/final disposal facilities was the second most used criterion in regionalisation studies, which is also directly related to the costs of collection and transportation. A large part of the cost of MSW management is made up of these steps. In Athens (Greece) collection and transportation costs may represent more than 70% of total waste management costs (Chalkias and Lasaridi, 2011). In Canada, about 46% of local waste management budgets are spent on the collection and transportation of waste (Richter et al., 2019). In Bilaspur (India) collection and transportation represent from 50 to 70% of total waste management costs (Rathore and Sarmah, 2019).

It is interesting to point out that in the analysed studies three different distances were considered: between municipalities and the landfill (up to 30 or 45 km, depending on the study), among municipalities of the arrangement (up to 30, 35, 45 or 60 km, depending on the study) and between each municipality and the main city (up to 200 km). There is no consensus on which is the viable distance from municipalities to the landfill in the analysed studies and even in the literature. It can vary from 25 to 50 km.

For MMA (2012), transportation through collecting vehicles should be limited to distances of 30 km from the landfill. When distances are greater, it should be considered to include transfer stations at strategic points, for vehicles with greater load capacity and lower cost per km. According to PRGRS-PA (2013), the viable distances for transportation are up to 35 km for collecting vehicle and up to 100 km for long distance transportation by road. For the Solid Waste Association of North America, Northern Lights Chapter (2008), a general rule of thumb is that transfer station may be more economical where haul distances are greater than 25 or 35 km. Suzuki and Gomes (2008) used the maximum distance of 50 km between the urban headquarters of the municipalities to the regional landfill, in order to limit the time spent by the collection truck to transport the waste in one hour to the landfill, considering an average speed of 50 km/h. In India, the municipalities should be located within a distance of 50 km (or more) from the regional landfill (Kojima, 2020).

The served population is also a frequent criterion. In some regionalisation studies, a minimum population of 100,000 inhabitants was considered while in others, 200,000. In some studies, the minimum quantity was not defined and only the urban population was used.

As stated previously, the regionalised management generates economies of scale, but what is the scale? What is the minimum served population for regionalised management to be viable? It depends on the adopted solutions for the treatment and final disposal of waste (Ferreira and Jucá, 2017). The larger the capacity of the waste treatment and disposal facility, the lower the unit costs associated with the construction of the facility. These include composting plants, waste-to-energy plants, and sanitary landfill sites (Kojima, 2020).

According to the results of a survey conducted by Brandão and Silva (2011) in 126 Brazilian municipalities, the larger the population served by a landfill, the lower is the

monthly per capita cost of waste treatment and final disposal. Generally, the bigger the landfill, the lesser the cost of final disposal, due to economies of scale (Spigolon et al., 2018).

It is observed that some intermunicipal consortia for MSW management in Brazil, serve population up to 200,000 inhabitants, as the Consórcio Intermunicipal de Resíduos Sólidos Urbanos da Região Sul (CIRSURES, 2021) and the Consórcio Intermunicipal de Gestão e Resíduos Sólidos (CIGRES, 2021). On the other hand, in Europe, the population served by some intermunicipal MSW consortia are higher than the minimum considered in the Brazilian studies. For instance, the Empresa Intermunicipal de Tratamento e Gestão de Resíduos Sólidos (Ambisousa), in Portugal, that serves a population of about 330,000 inhabitants (Ambisousa, 2020), the Consorcio Provincial de Resíduos Sólidos of Málaga, in Spain, serves a population of about 540,000 inhabitants (Consorcio RSU Málaga, 2020) and the Serviço Intermunicipalizado de Gestão de Resíduos do Grande Porto (LIPOR), in Portugal, serves a population of about 985,000 inhabitants (LIPOR, 2020).

In a study by Guabiroba et al. (2014) for the definition of a territorial arrangement for a public consortium in the State of Rio de Janeiro (Brazil), the analysed region had a population of about 450,000 inhabitants.

The amount of waste generated is related to the served population in each region and the per capita waste generation rate. The world generates on average about 0.74 kg/inhabitant/day, yet national waste generation rates fluctuate widely from 0.11 to 4.54 kg/inhabitant/day. In high-income countries, municipalities are more urbanised and generate more waste both per capita and in total (Kaza et al., 2018). However, since Brazil is an extensive country with great demographic contrasts, there is a big difference in the per capita waste generation in the regions, varying from 0.759 to 1.232 kg/inhabitant/day (ABRELPE, 2020).

In the analysed regionalisation studies, the minimum amount of waste generated in each territorial arrangement was considered 200 to 350 tons/day and, in some studies, the minimum amount was not defined. According to Majale and Mireri (2014), a landfill should handle at least 300 tons/day. The minimum amount of waste also depends on the waste treatment and final disposal that will be adopted.

Considering the intermunicipal consortia for waste management, it is noted that in the Consórcio Intermunicipal de Resíduos Sólidos Urbanos da Região Sul, 36 tons of waste are treated per day (CIRSURES, 2021) and in the Consórcio Intermunicipal de Gestão e Resíduo Sólidos, 56 tons/day are treated (CIGRES, 2021). For the sake of comparison, in the facilities for waste treatment and final disposal from Unione Parco Altavaldere, in Italy, 360 tons of waste are treated per day (Belvedere, 2020) and in the Mancomunidad de Municipios de la Costa del Sol Occidental, in Spain, 900 tons per day are treated (Complejo Medioambiental Costa del Sol, 2020).

The fourth most frequent criterion in the regionalisation studies is the previous existence of arrangements. A pre-existent relationship among the municipalities and their administrators make the regionalisation easier. Previous arrangements should be maintained whenever possible, and the use of current federal subdivisions can be beneficial from a financial point of view. According to Feiock (2007) apud Gerber and Loh (2011), regional efforts can be done or undone based on the strength of the individuals involved in creating them. Trust and good personal relationships among those involved are important for the establishment of successful regional agreements.

The existence of main municipalities is also an important and frequent criterion in regionalisation studies. Cities considered to be regional development hubs in each

territorial arrangement will have a relevant importance for waste management, as they have a strong economic influence and can centralise the flow of recyclables in the region providing the necessary scale for the commercialisation of these materials (PRGRS-PI, 2011). The starting point for establishing the place for waste treatment and final disposal (landfill) considers the largest municipal headquarters in a territorial arrangement, in which the largest amount of waste is generated and with a tendency to be the strongest economic centre (PEGCIRS-PE, 2013).

In fact, in some regionalisation studies, the starting point for the definition of territorial arrangements was the definition of main municipalities, considering that in each arrangement there must be at least one main municipality to play a regional leadership.

Another frequent criterion is the location of the landfill. Depending on the study, the regional landfill should be an existing landfill or to be located in the most populous municipality, with the highest waste generation, at the centre of the territorial arrangement or distant up to 30–45 km from the municipalities.

Whenever it is possible, an existing waste final disposal facility should be used, to minimise or spatially restrict environmental impacts and, also, due to the difficulties in finding new sites for the construction of landfills.

In most studies, it is not specified whether regional landfills should be located in existing public or private landfills. In the State of Rio Grande do Sul, for example, there are 13 existing landfills duly licensed by the state environmental agency. From these, 10 are private and serve the majority of the state population, distant, in some cases, more than 400 km from the landfill (FEPAM, 2020), increasing public spending with excessive transportation costs.

The final disposal of waste in a private landfill was a short-term solution found by some public managers to comply with the NSWP regulations, meaning that the costs of an adequate MSW management in accordance with the NSWP are incompatible with the financial reality of most small Brazilian municipalities. Therefore, intermunicipal consortia are a good option and, again, it shows the importance of the regionalisation studies.

Generally, the most populous municipality is the one with the highest generation of waste and, if the landfill is located in this municipality, the lower the transport costs will be, but this is not always possible. Likewise, it is not always possible to locate the landfill in the centre of the region. According to PRGIRS-CE (2012), the landfill does not necessarily need to be located in the main city, because the most developed municipalities are generally more urbanised and with less areas available for the installation of this type of facility.

In several studies, locational restrictions for the construction of landfills were considered as a criterion, which include airport areas, environmental preservation areas, indigenous and quilombola lands (area belonging to descendants of enslaved Africans) and rural settlements. Areas close to waterbodies, wetlands, industrial zones, rural areas, parks, gas pipelines, transmission lines and power plants should also be avoided (Khan et al., 2018).

The availability of areas for solid waste final disposal also has been considered as a criterion in some studies. For the identification of these areas, the Municipal Master Plan must be observed considering the zoning of the territory (SRHU/MMA, 2011). The low availability of areas in the municipalities is considered, endowed with adequate technical and environmental characteristics for the installation of landfills, as well as the difficulty

of road access to these areas, contributing even more to the need of promoting regional sanitary landfills (PERS-RJ, 2013).

In some studies, the areas of the hydrographic basins were considered as regionalisation units, with the main objective of avoiding the transfer of waste among basins, facilitating the control of environmental risks (PEGCIRS-PE, 2013).

The landform was observed in some regionalisation studies, considering the massifs, plateaus, river valleys, and coastal regions. The mapping of slopes is an important factor that helps in understanding the territory, making it possible to perceive areas that present relevant geographic accidents, influencing the issue of accessibility (Nascimento Neto and Moreira, 2009).

Economic and socio-cultural characteristics were used as criteria for the formation of homogeneous regions, favouring unity and greater interaction in the region.

The location of urban agglomerations and metropolitan areas was considered a criterion for regionalisation in some studies. These agglomerations and areas are instituted by complementary laws and for them there is already a legally defined forum to deal with issues of regional interest (PERS-SP, 2014).

The number of municipalities in each region is another criterion for regionalisation. According to PRGRS-PI (2011), political conditions are likely to change with each election, influencing political articulations and interfering in obtaining federal resources to improve the infrastructure. Thus, a smaller number of municipalities would facilitate the management of the consortia.

The potential of biogas generation in landfills is a criterion, but not a condition for defining the territorial arrangements, since it is a technology that is justified only when a certain quantity and quality of solid waste is available (PERS-RJ, 2013).

The territorial contiguity criterion is also not a condition for the definition of the territorial arrangement among municipalities, however, the formation of a contiguous region, with well-defined territorial limits, generates greater interaction among municipalities, strengthening ties of identity and of belonging to the territory, in addition to decreasing the distances and costs of transportation.

Grouping municipalities with a weak economy and others with a strong economy, although it was an aspect considered in only one regionalisation study, is potentially important, since small municipalities, when associated with larger ones, can overcome their management weaknesses, rationalise and expand the scale of waste treatment and disposal activities, benefit from a better prepared technical team, and may even operate waste processing unities (SRHU/MMA, 2011).

Analysing all the regionalisation studies from Brazilian states, it's noted that different technical, environmental, social, and economic criteria were used to define the territorial arrangements.

The technical team responsible for the regionalisation study together with the organised society must define which criteria should be considered in the study, according to the reality of each state, and classify them according to the degree of relevance.

The popular participation is one of the priority axes of the NSWP, using public discussion and conferences to enhance the role of organised society and strengthen spaces for social participation (SRHU/MMA, 2011). Thus, the holding of seminars is important for city halls, state and federal agencies, social movements, and other interested parties to manifest themselves and provide transparency to the process of construction and validation of the regionalisation proposal (FUNASA, 2014).

As stated earlier, all the methodologies adopted are different and were defined by the technical team responsible for their preparation. The lack of guidelines, methods and publications on this type of study has hampered its elaboration. This may have contributed to the delay in the elaboration of the regionalisation studies by the Brazilian states.

4.2 Regionalisation studies and the formation of intermunicipal consortia in Brazil

The main objective of regionalisation studies for MSW management is to enable the establishment of public consortia, which can effectively contribute to the integrated management advocated by then Brazilian NSWP and defined as the set of actions aimed at finding solutions for solid waste issue, considering the political, economic, environmental and social dimensions, with the participation of society and under the premise of sustainable development (Brazil, 2010a).

In Brazil there are public consortia in various modalities, such as: health, education, social assistance, tourism, culture, housing, transport, environment, basic sanitation and solid waste. Many municipalities participate in public consortia in the area of solid waste management (IBGE, 2016). These consortia are mainly formed by small municipalities, with less than 50,000 inhabitants, which find in the constitution of public consortia an alternative to implement public policies for the proper management of MSW (Henrichs, 2018).

These consortia are more concentrated in the Southeast region, where 35.6% of the municipalities participating in MSW management consortia. The South region, with 26% of the municipalities, and the Northeast region, with 23% of the municipalities, comes next (SNIS, 2018).

The Southeast region is where the consortia policy for MSW has made the most progress in recent years, mainly in the states of Espírito Santo and Rio de Janeiro. In these cases, the state government has been technically supporting the formation of intermunicipal consortia. In the South region, the number of consortia for solid waste management is also quite expressive, many of which are prior to Public Consortia Law from 2005, which defines the general rules for the union, states, federal district and municipalities to contract public consortia for the achievement of objectives of common interest (Brazil, 2005). These two regions with the highest number of intermunicipal consortia, are the ones that present the best MSW management indicators in the country (ABRELPE, 2020; SNIS, 2018).

The Northeast region has a large number of solid waste consortia, mainly due to the state government actions to promote their institutionalisation (Britto et al., 2016).

As for the remaining regions, only 3 out of 18 regionalisation studies are from states in the North region (Acre, Pará and Tocantins) and, to date, no study has been carried out in the states of the Midwest region.

It should be noted that most of the MSW management consortia in Brazil were constituted, mainly, by municipal initiative, without the support of the states and the federal government and before the elaboration of the regionalisation studies reported here, which were elaborated from 2008 onwards.

The elaboration of regionalisation studies by the states, covering all the municipalities in their territory, intends to encourage the formation of new public consortia and to reduce the institutional fragility of these arrangements since they provide a technical database capable of facilitating the understanding and the negotiations among the different municipal players, increasing the chances of building a solid articulation among municipalities, and speeding up the process of constituting public consortia.

As a final remark, regionalisation studies can be carried out for any region, state or country, contributing to the MSW integrated management, minimising environmental problems caused by inadequate waste management, preserving natural resources, generating economic and social benefits through reducing management costs, improving the population's quality of life, and providing sustainable development.

5 Conclusions

The elaboration of regionalisation studies is a complex task, which requires a deep knowledge of the territory, the environment, population's economic, social and political characteristics, and the management stages of the MSW.

It is not only about the spatial distribution of landfills. It is necessary to know the political divisions of the municipalities, with their respective areas, inhabitants, economic activities and environmental characteristics, the administrative divisions and the pre-existing territorial arrangements, the location of the urban agglomerations and the main cities, the distances among the municipalities and the distribution of the road network in the territory, the quantities and characteristics of the waste generated, the location and characteristics of the existing and available treatment and final disposal facilities. However, analysing this information by itself is not enough. It must be superimposed so that the convergences and divergences are identified. It is a job that must count on the participation of technicians, managers and public agencies related to waste management and should be widely debated so that, in this way, the ideal territorial arrangements for MSW management can be proposed and implemented.

Brazil is a continental country, with a large number of states, of varied sizes and populations and great differences regarding regional characteristics. Although most states have already prepared regionalisation studies for MSW management, mainly due to legal imposition, when analysing them, the lack of padronisation is clearly noticed, which makes the elaboration of these studies even more difficult. The elaboration of regionalisation studies at the state level can facilitate the establishment of intermunicipal consortia, contributing to the MSW integrated management, to the improvement in the provision of public services and to the reduction of regional inequalities.

The development of a method with clear definition of hierarchical criteria, the use of appropriate geospatial tools, and the social participation in the decision-making process may significantly contribute to the elaboration and implementation of regionalisation studies.

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