frontiers | Frontiers in Sustainability

TYPE Original Research
PUBLISHED 03 October 2024
DOI 10.3389/frsus.2024.1409418

OPEN ACCESS

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RECEIVED 30 March 2024
ACCEPTED 15 August 2024
PUBLISHED 03 October 2024

CITATION
Sasahara C, Rodrigues LS, Cetrulo TB, Gimenez BG, Alencar MV, Elliff CI, Cetrulo NM, Gonçalves Dias SLF, Conti LA, Scrich VM and Turra A (2024) Municipal solid waste governance: development and application of an index embodying the Global South context.
Front. Sustain. 5:1409418.
doi: 10.3389/frsus.2024.1409418

Municipal solid waste governance: development and application of an index embodying the Global South context

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Introduction: The quality of municipal solid waste governance is a key public issue associated with environmental, social, and health concerns that still demands appropriate indicators to encompass different policy, management, and data availability settings worldwide. This study aimed to develop and apply a Municipal Solid Waste Governance Index (MSWGI) to support the monitoring and assessment of the ultimate factors that influence the performance of municipal solid waste (MSW) management in municipalities, incorporating particularities of Global South countries.

Methods: The development of the MSWGI comprised two approaches: (1) the establishment of a general theoretical framework with the identification of dimensions for monitoring MSW governance and (2) the development and application of the index using Brazil as a study case. The latter was accomplished through five incremental steps: (i) data selection and data quality analysis, (ii) data normalization and definition of data scores, (iii) data weighting and aggregation through statistical and participatory methods, (iv) data classification and, finally, (v) visualization of the index and its dimensions. Based on a broad literature review, three dimensions were proposed as the framework of the MSWGI: (i) regulatory quality (e.g., laws), (ii) voice and accountability (e.g., access to information; existence and functioning of the municipal council for the environment), and (iii) government effectiveness (e.g., financial and human resources; execution of government programs). A case study was then carried out with the 5,570 Brazilian municipalities to showcase the application and relevance of the MSWGI in a Global South context.

Results: Despite the high regulatory quality condition in Brazil, this was not reflected in the MSWGI. In general, most municipalities have high (31.4%) and very high (23.7%) regulatory quality, contrasting low voice and accountability (32.4%), and medium government effectiveness (27.8%), the latter associated with the low quality of public services performed in municipalities. The index was also negatively influenced by the precarious mechanisms and structure of social participation; high levels of informality in the recycling sector, and low completeness and consistency

of databases. The MSWGI was associated with socioeconomic development, and its concept and dimensions captured the complexities associated with MSW management.

Discussion: The index, and the approach behind it, can be used as an objective tool to improve databases and the enabling conditions to foster MSW governance and management, while also creating indicators to assess its progress, facing the policy implementation gaps that are common to Global South countries. Also, rather than presenting an index to be directly transposed and applied to other locations, the steps of a strategy for generating an MSWGI from existing data were outlined. In this sense, this study creates mechanisms to refine these indicators within data-deficient context, presenting strategies that can be broadly applied.

KEYWORDS

governance index, municipal solid waste, local governance, monitoring, Global South, marine litter

1 Introduction

Among the triple planetary crisis-climate change, pollution and biodiversity loss [United Nations Framework Convention on Climate Change (UNFCCC), 2022], pollution stands out as a growing concern given its multifaceted and complex nature. Different environmental stressors caused by human activities have been degrading nature, including the marine environment (Halpern et al., 2019), such as solid waste. This is because factors such as population and economic growth, rapid urbanization, and changing consumption patterns have accelerated the generation of municipal solid waste (MSW) (Minghua et al., 2009). Consequently, there is an increase in the disposal and accumulation of waste in the environment, bringing impacts of different magnitudes and complex challenges for the governance of this problem (Sujauddin et al., 2008), which has been a growing topic of debate in the world discussion arenas.

Waste generation rates and practices depend on the culture, socioeconomic situation, population density, and level of commercial and industrial activities in a city or region (Abubakar et al., 2022). In municipalities of the Global South, defined by Santos (2007) as countries of the modern world system that occupy peripheral and semi-peripheral regions that, according to Brandt (1980), encompass the developing countries (or transition economies) located south of the industrially developed countries (other than Australia and New Zealand), there are additional problems, often associated with either a weak or inadequate waste management system at all stages of waste collection, handling, treatment, and disposal, which leads to severe direct and indirect environmental and public health problems (Abubakar et al., 2022). Inadequate and ineffective MSW management results in indiscriminate dumping of waste in streets, open public spaces, and water bodies observed, for example, in Brazil, Pakistan, India, Nepal, Peru, Guatemala, Kenya, Rwanda, South Africa, Nigeria, Zimbabwe, among others (Abubakar et al., 2022), which can be a source of the watershed and marine litter (Alencar et al., 2023).

Thus, while high-income countries mainly face the need to reduce large amounts of waste generated in their territories, Global South nations still need to deal with institutional, technological, and socioeconomic challenges that reflect the lack of adequate collection and final disposal; and even operational inefficiency in all processes involving MSW management (Guerrero et al., 2013). All these aspects are ultimately associated with the quality of MSW governance in different economic, social, and political national and subnational settings (Szirmai, 2012).

Rose-Ackerman (2017) points to different interpretations of the concept of governance, depending on the context in which it is used, resulting in a challenge for its application. Marques (2013) understands governance as a "set of State and non-State actors interconnected by formal and informal ties operating within the policy-making process and embedded in specific institutional settings" (Marques, 2013, p. 16–17). Here we used definition of governance of Kaufmann and Kraay (2021), which considers the process of exercising institutions and traditions through the authority of a country or municipality, including the selection and monitoring of governments, their capacity to formulate and implement public policies, and the relationship between citizens and state and economic institutions.

Governance thus forms a complex institutional arrangement that can be expressed by subtle norms of interactions and, more indirectly, by influence on agendas, from which actors access resources and adopt and contest decisions (Lebel et al., 2006). Thus, the notion of governance emphasizes the need to involve multiple formal and informal actors in dynamic processes of interaction between public and private organizations, including more complex understandings of the non-linearity of sociotechnical systems (Shove and Walker, 2010), such as technologies, policies, users, infrastructures, and cultural discourses that were historically created. These system elements are reproduced, maintained, and improved incrementally by actors such as companies, resource users, policymakers, regulators, and specific interest groups.

To assess and monitor the diversified elements of governance, the development and application of indices have been recurring demands, which has resulted in an enormous growth of indicator sources used to measure government performance, institutional quality, and

Abbreviations: MSW, Municipal Solid Waste; MSWGI, Municipal Solid Waste Governance Index; WGI, Worldwide Governance Indicators.

people's perception (Yong and Wenhao, 2012). The use of methods capable of gathering information on governance performance, such as indices, has been increasingly required by municipalities, especially for continuous improvement in implementing public policies (Vergara and Tchobanoglous, 2012; Pereira and Fernandino, 2019).

These indices, also called synthetic indicators, point to the relative governance weaknesses of cities, allowing them to rectify their problems by implementing sensible reforms (Yong and Wenhao, 2012). Notably, creating and implementing governance assessment and monitoring indices is not neutral; it is permeated by power relations and directly influenced by social and political factors (Buta and Teixeira, 2020). This highlights the importance of proposing methods capable of translating these different dimensions of reality to assess the governance of such urgent issues, including MSW management.

Achieving a satisfactory condition of MSW governance that captures the particularities of Global South countries demands the integration of factors such as the redefinition of waste as a resource, the inclusion and participation of social interest groups (e.g., waste pickers of recyclable materials, users, and community groups) in the process of decision-making, the production and availability of systematic and robust information, and the consideration of institutional arrangements for MSW management, while also adopting strategies preferably based on waste prevention (non-generation) (Gutberlet et al., 2020). Such a holistic, systemic, precautionary, and inclusive approach is also underlying the ongoing discussions for the creation of a legally binding global instrument on plastic pollution, including in the marine environment (i.e., Plastic Treaty), whose first negotiation session took place at the end of 2022 (UNEP, 2022).

Informal sector activities are predominant in MSW management in the Global South. Waste pickers are part of the informal sector and are often referred to as the "informal recycling sector", "scavengers" in the United States, and "catadores" or "cartoneros" in South America. This informality can be seen as an expression of the broader social organization system (Velis, 2017). Such an organization, constituted by relationships between the multiple social actors involved in the urban cleaning public service, is a central point for understanding local governance, whose relevant characteristic is the cooperation between public and private actors for the elaboration of policies and execution of the services (Mayntz, 2001; Buta and Teixeira, 2020). However, these aspects are not often included in quantitative analyses and considered in indices for assessing and monitoring management, including because data on the informal sector of the waste management system are inconsistent and nonexistent, especially in smaller municipalities of Global South countries (Velis, 2024; Alencar et al., 2022).

While there are other synthetic indicator initiatives for evaluating and monitoring MSW management, specific MSW governance indexes and data for its application are lacking. Turcott Cervantes et al. (2022) applied a set of indicators to assess waste governance in two Mexican municipalities and faced a lack of data to assess the corruption control criterion. When considering the evaluation and monitoring of MSW management, the main metrics applied include measuring the accessibility and availability of services offered to users (Vergara and Tchobanoglous, 2012; Pereira and Fernandino, 2019), but there was a lack of metrics and indicators for governance itself, such as voice and accountability and regulatory quality (Kaufmann et al., 2010). While governance is considered the decision-making process, management is the implementation of those decisions. Management metrics reveal the proximate factors that do not indicate the underlying causes of the evaluated phenomenon, which would be the ultimate factors (Szirmai, 2012), i.e., the quality of the governance.

Therefore, the present study aimed to address the lack of specific governance indexes and data for MSW by developing and applying a Municipal Solid Waste Governance Index (MSWGI) to contribute to the evaluation and monitoring of the enabling conditions of MSW management, including the specificities of municipalities of Global South countries. It is expected that the results of this study can contribute to practical improvements in municipal waste management worldwide, but especially in Latin America, and in countries of the Global South, which share similar socioeconomic, environmental, technological, and political settings. The development of the Municipal Solid Waste Governance Index (MSWGI) was based on the composition of synthetic governance indicators adopted worldwide by the OECD (2008), and adjusted to the context of MSW, due to low reliability, absence, and/or inconsistencies of the available data (Conke and Nascimento, 2018).

2 Methods

This study was conducted based on two approaches (Figure 1). The first included an overview of the applications of synthetic indicators for governance analysis and the definition of a general theoretical framework for the MSWGI. The second presented the development and the application of the index in a case study in Brazilian municipalities based on the data available to populate the criteria defined by the theoretical approach. The steps for developing and applying the MSWGI included: (i) data selection and data quality analysis, (ii) data normalization and definition of data scores, (iii) data weighting and aggregation through statistical and participatory methods, (iv) data classification, and (v) visualization of the results, which are described below.

2.1 Theoretical framework (approach 1)

2.1.1 Overview of synthetic indicators for governance analysis

Several Governance Indicators have been proposed and analyzed in recent decades, such as the Worldwide Governance Indicators (WGI) (Kaufmann et al., 2010) and the Ibrahim Index of African Governance (Mo Ibrahim Foundation, 2017). Different authors (Apaza, 2009; Buduru and Pal, 2010; Löwenheim, 2008; McFerson, 2009; Yong and Wenhao, 2012) are dedicated to criticizing or proposing adjustments to the WGI. Others offer criticisms or adjustments to the Ibrahim Index of African Governance (Farrington, 2009, 2010, 2011; McFerson, 2009; Mitra, 2013). Some present alternative dimensions and indicators for measuring governance without relying on these more widespread indices (Fukuyama, 2013; Gani and Duncan, 2007; Mello and Slomski, 2010; Merry, 2011; Morrison, 2014; Oliveira and Pisa, 2015; Pereira and Fernandino, 2019).

It is important to highlight that WGI is the most widespread (and criticized) index used by the World Bank to monitor the level of governance in countries. It is based on a very comprehensive

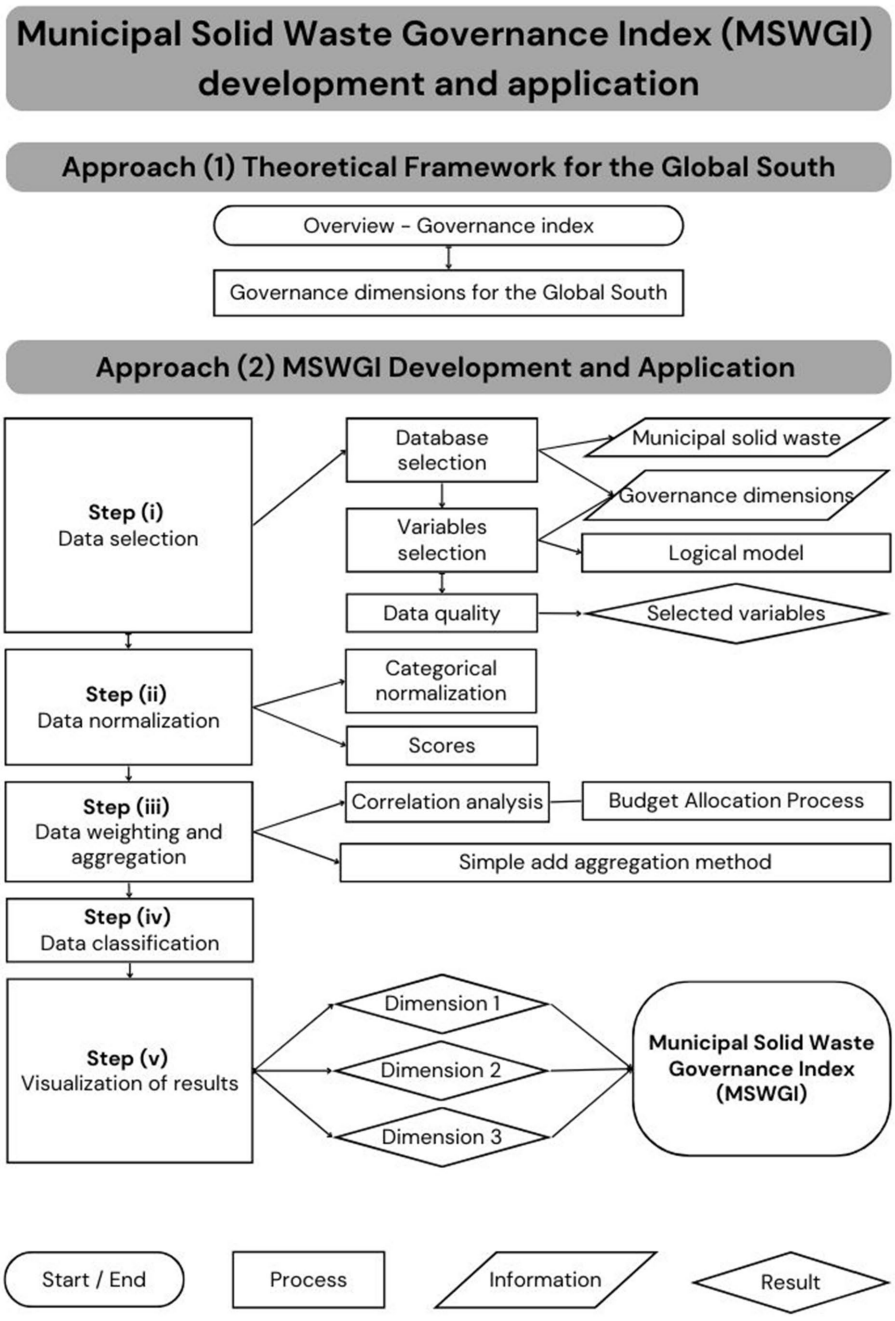

FIGURE 1
Approaches and steps for developing and applying the Municipal Solid Waste Governance Index (MSWGI).

comparison scale, whose data have been collected since 1996 covering more than 200 countries. The WGI involves six dimensions: Voice and Accountability; Political Stability and Absence of Violence or Terrorism; Government Effectiveness; Regulatory Quality; Rule of Law; and Control and Corruption (Kaufmann et al., 2010).

Löwenheim (2008) points out that the WGI composes an evaluation system and offers a critical perspective on the governance indicators in international politics, through a governance approach focused on political meanings and outcomes of the increasing tendency to rate and rank the governance capacities and performances of states. Thomas (2010) questions the accuracy of the WGI, highlighting the need to validate indicators' evidence. In turn, McFerson (2009) argues that WGI represents the most comprehensive and reliable set of indicators of governance. Finally, Yong and Wenhao (2012) also defend WGI's validity and use it as a basis for creating a governance scale for the local context, as the adaptation to the municipal scale in Global South countries here proposed.

New governance indicators have been created and are quite varied. The Ibrahim Index of African Governance, for example, is used to measure and monitor governance performance in African countries, but it can be also used in other countries (Farrington, 2009, 2010, 2011). Oliveira and Pisa (2015) developed an index to measure

governance in Brazilian states with indicators of effectiveness, transparency and accountability, participation, equity, and legality. Gani and Duncan (2007) proposed a scale containing three main dimensions: Rule of Law, Governmental Effectiveness, and Regulatory Quality, each consisting of a set of indicators. The lack of governance indicators based on quantitative information prompted the development of governance indicators for the Fiji context using mainly published data that are made available regularly. Furthermore, governance indicators based on annual data can provide governments with regular updates on the quality of their governance. Mello and Slomski (2010) developed an electronic governance index, composed of two dimensions: electronic government and electronic democracy. Finally, Fukuyama (2013) presented four dimensions for assessing the quality of governance: (i) procedural measures, which involve conditions related to the structure of public agencies, such as hierarchy, meritocracy, career, control, and asset separation; (ii) capacity measures, which include the capacity of government action to collect and manage resources; (iii) outcome measures, related to government capacity to provide public services; and (iv) measures of autonomy, related to the degree of bureaucratic autonomy of different components of the State.

2.1.2 Definition of a general theoretical framework for the MSWGI

The overview of synthetic indicators for governance analysis presented above covered the definition of the concept of governance itself and presented the analytical framework for evaluating and monitoring governance, which was the base for the development of the MSWGI. As the context of evaluating public governance was considered, thus, the governance concept established by Kaufmann and Kraay (2021) was embraced.

In addition to the concept of governance, the dimensions and components that aggregate the MSWGI were defined based on WGI (Kaufmann and Kraay, 2021) dimensions of governance described above (Voice and Accountability, Political Stability and Lack of Violence, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption). Turcott Cervantes et al. (2022) proposed five categories of indicators of MSW governance: Institutional Framework; Government Effectiveness; Transparency and Accountability; Network Creation; Participation; and Corruption Control. In their framework, Turcott Cervantes et al. (2022) employed governance categories and terminologies that differ from those defined by Kaufmann and Kraay (2021). They distinguished between Voice and Accountability by subdividing it to include "Transparency" and redefining the first component as "Participation." They also adopted the term "Institutional Framework" in place of "Regulatory Quality" and incorporated additional components related to this term. Furthermore, they introduced the "Network Creation" dimension, which refers to the informal system—an area with inconsistent and nonexistent data in the Global South (Velis, 2024).

This study employed the Turcott Cervantes et al. (2022) index as a framework for analyzing MSW governance, excluding Political Stability and Lack of Violence, and Rule of Law dimensions (Kaufmann and Kraay, 2021). However, the framework was modified to align with the WGI dimensions (Kaufmann and Kraay, 2021), thereby enabling comparative analysis at the country level, considering the municipal scale at which solid waste governance occurs. The Corruption Control dimension (Kaufmann and Kraay, 2021) had no data for the two municipalities analyzed by Turcott Cervantes et al. (2022) and was excluded from the present study, which assesses the municipalities within a country context.

TABLE 1 Dimensions of the proposed Municipal Solid Waste Governance Index (MSWGI).

Dimension	Definition	Component
Regulatory quality	Government capacity to formulate and implement more effective policies and regulations.	Policies, Plans, Programs, Projects, and Legislation.
Voice and accountability	Social participation in public management and accountability.	Social participation structures (e.g., Environmental Councils) and transparency (e.g., open data portals).
Government effectiveness	Quality of public services and government commitment to policies and services.	Supervision, Financial Resources, Services and Human Resources.

Source: Elaborated by the authors based on Kaufmann and Kraay (2021).

As a result, three governance dimensions from WGI (Kaufmann and Kraay, 2021)—Regulatory Quality, Voice and Accountability, and Government Effectiveness—were incorporated and constitute the MSWGI (see Table 1), engaging directly with the WGI. These three dimensions are populated with variables that represent the aspects of solid waste governance, for which municipal-level data are available.

The Regulatory Quality dimension includes variables associated with the planning, formulation, and implementation of MSW management actions. This dimension synthesizes technical and political aspects, which allow the understanding of phenomena and perceptions in different fields of knowledge and create opportunities for interference and changes in the reality (Merry, 2011). The regulatory dimension encompassed information on legislation, waste plans, and programs.

The Voice and Accountability dimension aggregates variables related to spaces for social participation and accountability in municipalities. The concept of accountability refers to a process that involves the public power's responsiveness to its acts, including the provision of information and justifications to society, as well as accountability for acts in disagreement with the public interest (Bovens, 2007). Yong and Wenhao (2012) associate Voice and Accountability with the participation of citizens, civil society, and the private sector in public affairs. This dimension was fed based on data on access to information, participation mechanisms, and formal municipal structures associated with waste governance (e.g., municipal environmental council).

Finally, the Government Effectiveness dimension is composed of variables associated with the quality of services of local governments, regarding MSW management. Components of this dimension included data on human and financial resources and the execution of government plans and programs.

Each of these three dimensions was supplied by selected available data, related to MSW governance dimensions in municipalities. The next section will describe the process to identify and analyze the data used in the Brazilian case of study to feed these three dimensions.

2.2 Development and application of the MSWGI to the Brazilian context (approach 2)

2.2.1 Data selection (step i)

Data selection comprised the surveying of relevant MSWGI variables available in public and online databases for all the Brazilian municipalities (see Supplementary Table S1). To select the variables, public databases from the federal government containing municipal solid waste data were initially identified. Governance dimensions, outlined in the theoretical framework, and a logical model guided the data selection from these databases. The selected data underwent a data quality analysis, resulting in the variables selected for composition of the proposed MSWGI.

In Brazil, the primary public governmental databases concerning solid waste are: (i) National Information System on Solid Waste Management (Government of Brazil, 2019b), under the responsibility of the Federal Government, through the Ministry of the Environment and it is currently populated with data from sources including (ii) National Information System of Sanitation (Government of Brazil, 2019c) and (iii) the Survey of Basic Municipal Information (Government of Brazil, 2019a, 2020). To cover the regulatory quality dimension, the database from study of Gonçalves-Dias et al. (2023), with a map of regulations, standards, and federal, state, and municipal laws on single-use plastic from the Center for Research in Organizations, Society, and Sustainability of the University of São Paulo [Núcleo de Pesquisa em Organizações, Sociedade e Sustentabilidade/University of São Paulo (NOSS/USP), 2021], was also utilized to fulfill and evidence the municipal regulatory quality dimension.

In the selection of variables from the chosen databases, the assessed governance dimensions were considered. The regulatory dimension encompassed variables of legislation, solid waste plans, and programs; while the voice and accountability dimension covered variables of participation and accountability with data on access to information, participation mechanisms, and formal municipal structures associated with waste governance. Variables of the government effectiveness dimension included human and financial resources, as well as the execution of government plans and programs.

Most of the MSW data pertained to the government effectiveness dimension, closely related to MSW management and the proximate factors. A logical model was employed to select the variables, with a primary focus on this dimension. The logical model is a systematic and visual procedure to present the relationships among the available resources to operate management, activities developed, and the changes or results intended to achieve and/or enhance MSW management (WK Kellogg Foundation, 2004). It considers resources dedicated to the proposed objective (inputs) as well as processes, tools, events, technologies, and actions in the execution of the objective (activities) and the workload arising from actions performed (products/services) (Figure 2). The application of this model supported the selection and subsequent inclusion of data in the MSWGI, by providing guidance on available variable selection for assessing MSW management. Data included inputs (such as financial and human resources), activities (e.g., Integrated Solid Waste Management or basic sanitation plans; inspection and regulation of basic sanitation services; mechanism for participation and social control) and products/services (e.g., achievement of the objectives outlined in the municipal plan for sanitation or solid waste management; coverage rate of population served by regular and recycling collection services; incorrect destination in relation to the population served; expenses per inhabitant) associated with MSW government effectiveness at the municipality level (see Supplementary Table S1).

After surveying relevant variables for the three dimensions of the MSWGI, based on the theoretical framework and the logical model (Supplementary Table S1), a quality assessment process was carried out, based on the following criteria used by Alencar et al. (2022): data collection range (census or sample), data collection method (measured or self-report), metadata transparency (yes, no, or partially), time (2020; 2019–2018; 2017–2011; 2010–2006; 2005–2001), and response rate (percentage of municipalities presenting the information; 100–80%; 80–60%; 60–40%; 40–20%; 20–0%) (Figure 3).

Applying the data quality criteria, variables were categorized from 1 to 5, as follows:

1. (very good) = Measured data from census with published metadata, surveyed in the last 4 years and available for all 5,570 municipalities (which represents 100%);

2. (good) = Data measured or self-reported from a census or sample with published metadata, surveyed in the last 4 years with response rate for all 5,570 municipalities (which represents 100%);

3. (medium) = Self-reported data from a census or sample with complete or partially published metadata, surveyed in the last 10 years with high and medium response rates (between 40 and 80% of municipalities);

4. (bad) = Self-reported data from census or sample with complete or partially published metadata, collected from 5 to 15 years ago with response rate for only some (between 20 and 40%) municipalities; and

5. (very bad) = Self-reported data from a census or sample without metadata or with partial publication, collected from 5 to more than 20 years ago and available for only a few (between 0 and 20%) municipalities.

With the application of this data quality analysis, variables with a result greater than or equal to 2 (very good and good) were selected. Government of Brazil data from the SNIS (2019) of the Ministry of Cities did not contain information for all municipalities and were self-reported. Data could have been used for each dimension but were incomplete in the system for all municipalities. Therefore, the governance index data that were available and consistent from the Government of Brazil were selected—MUNIC (Government of Brazil, 2019a, 2020) of IBGE (Brazilian Institute of Geography and Statistics; the country's national official provider of data and information) for municipal intervention.

After the data quality analysis, all selected databases contained data on all variables for all municipalities (see Supplementary Table S2). In this sense, there was no need to address missing data.

2.2.2 Data normalization and definition of data scores (step ii)

The normalization step was carried out to make different variables comparable. A qualitative categorical scale score method (OECD, 2008) was used since it best applies to the type of data from the database used. Thus, scores were defined for each possible observation of a certain selected variable. For example, the variable on tax for waste collection ("MREG062," see Supplementary Table S3) contains the following possible observations: "Yes," "No," or "Refusal." The score

FIGURE 2
Logical model for developing the Municipal Solid Waste Governance Index (MSWGI). Source: Adapted from WK Kellogg Foundation (2004).

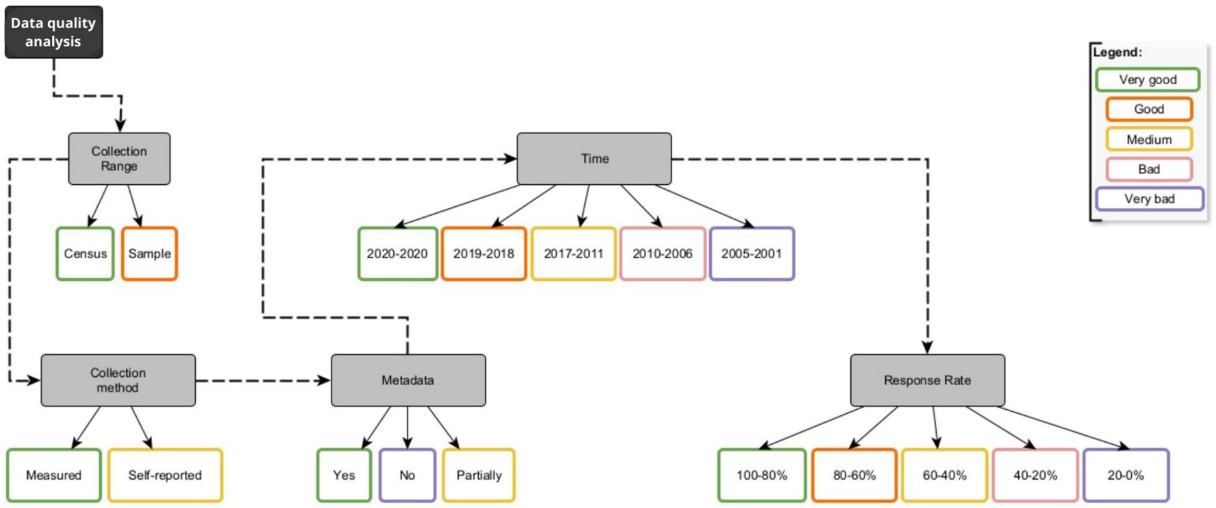

FIGURE 3
Data quality analysis of the variables identified to develop and apply the Municipal Solid Waste Governance Index (MSWGI). Source: Elaborated by the authors based on Alencar et al. (2022).

was established as follows: 1 for "Yes," 0 for "No," and 0 for "Refusal." We considered 1 as satisfactory and 0 as unsatisfactory for this variable. This process was reproduced for all selected variables (see Supplementary Table S3).

2.2.3 Data weighting, aggregation, and the proposed MSWGI (step iii)

The weighting was used to adjust the influence of the variables selected according to a correlation analysis and expert participation method.

The correlation analysis of data that do not follow a normal distribution (Spearman, 1904), performed via PaSt—Palaeontological Statistics—developed by Hammer et al. (2001), allowed to adjust the weights of variables with a high degree of correlation (see Supplementary Graph S1, where $p > 0.05$ crossed = non-significant correlation), avoiding double counting in the index. When the variables represented highly correlated information, the weight of the variable (=1) was divided by the number of variables containing the information [see Supplementary Table S4—Weight (Statistical correlation)].

The participation of governance experts occurred to judgments of the relative importance of these variables for the composition of the index. It was developed through the application of the budget allocation process method. This method recommends experts be invited to allocate a "budget" of 100 points to a set of variables, based on their experiences. The main advantages of the budget allocation process are its transparent nature and its relative simplicity and short duration (D'hombres, 2019).

An electronic form was developed and distributed via email to approximately 70 PhD experts in governance, public policies, and MSW with scientific analytical capacity, theoretical grounding, and a comprehensive understanding of the subject matter, selected from the list available on the Plataforma Lattes—National Council for Scientific and Technological Development [Brazilian National Council for Scientific and Technological Development (CNPq), 2022]

repository of the curriculum databases, research groups, and institutions into a unified information system. In total, three experts, which were university professors, responded to the form. Participants were required to weigh variables via the budget allocation process, allocating 100 points among the number (n) of variables selected in the end of the process described above, of the Regulatory Quality dimension, 100 points among the n of variables, of the Voice and Accountability dimension and, finally, 100 points among the n of variables, of the Government Effectiveness dimension. Furthermore, an allocation of 100 points was requested among the three dimensions that are part of the index (Regulatory Quality, Voice and Accountability, and Government Effectiveness).

A final definition of variable weights was carried out by considering the results of the correlation analysis and the budget allocation process method (see Supplementary Table S4). After weighting, the results of the dimensions and MSWGI were synthesized using the simple additive aggregation method (OECD, 2008).

The score for the Regulatory Quality dimension (Dim1) was calculated based on the following formula:

$$Dim1 = \frac{\sum_{i=1}^{n} V_i P_i}{\sum_{i=1}^{n} P_i}$$

Where:

V_i = variables selected at the end of the data selection process for the Regulatory Quality dimension (see Supplementary Table S2), where i = each variable; n = maximum number of variables selected for the Regulatory Quality dimension; P_i = weight of each variable.

The score for the Voice and Accountability dimension (Dim2) was calculated based on the following formula:

$$Dim2 = \frac{\sum_{i=1}^{n} V_i P_i}{\sum_{i=1}^{n} P_i}$$

Where:

V_i = variables selected at the end of the data selection process for the Voice and Accountability dimension (see Supplementary Table S2), where i = each variable; n = maximum number of variables selected for the Voice and Accountability dimension; P_i = weight of each variable.

The score for the Government Effectiveness dimension (Dim3) was calculated based on the following formula:

$$Dim3 = \frac{\sum_{i=1}^{n} V_i P_i}{\sum_{i=1}^{n} P_i}$$

Where:

V_i = variables selected at the end of the data selection process for the Government Effectiveness dimension (see Supplementary Table S2), where i = each variable; n = maximum number of variables selected for the Government Effectiveness dimension; P_i = weight of each variable.

The description of the variables selected for the MSWGI and respective weights are available in the Supplementary Table S4.

The final score of the MSWGI resulted from the sum of scores of the three dimensions divided by the sum of their respective weights:

$$MSWGI = \frac{\sum_{i=1}^{3} \mathrm{Dim}_i \mathrm{P}_i}{\sum_{i=1}^{3} \mathrm{P}_i}$$

Where:

Dim_i = score of the dimensions of waste governance, namely Regulatory Quality (Dim1), Voice and Accountability (Dim2), and Government Effectiveness (Dim3); P_i = weight of each waste governance dimension.

2.2.4 Data classification (step iv)

The classification of results from scores was performed using the optimization method of Jenks (1967), which optimizes the difference in values between classes and maximizes the similarity of values in the same classes (Ramos et al., 2016). The classification of results in each dimension and in the MSWGI itself was done with the colorimetric variation defined according to the color standardization of Atlas Brasil (2020) (Table 2).

2.2.5 Visualization of the results (step v)

To visualize the results, QGIS software was used to generate maps and spreadsheets to produce graphs. Data visualization considered colorimetric differentiation according to the Jenks (1967) method based on the results obtained in each municipality. In addition, considering the non-normality of the data, Spearman (1904) correlation coefficient (r) was estimated to determine the linear association between (1) regulatory quality and voice and accountability and (2) regulatory quality and government effectiveness to assess convergence or divergence between dimensions.

3 Results and discussion

The study developed a theoretical framework and explored the challenges of proposing a municipal solid waste governance index in Brazil, potentially serving as an example for countries in the Global South. It aimed to demonstrate how an index can be generated, creating conditions and opportunities for adaptation to other contexts, considering the limited availability of data to all municipalities, which poses challenges to populating the index.

Given the challenges presented, the strategies employed in the five steps were outlined. In data selection (Step i), considering the data gap scenario, the strategies for identifying variables for each dimension, as defined by the theoretical framework, were presented based on existing databases. Additionally, the data selection strategy was described, which involved applying the data quality criteria. In Brazil, the MUNIC database (2019; 2020) was predominantly used.

In total, 59 variables, from Government of Brazil (2019a, 2020), Government of Brazil (2019c), and Núcleo de Pesquisa em Organizações, Sociedade e Sustentabilidade/University of São Paulo (NOSS/USP) (2021) databases, were relevant to the construction of the MSWGI and explored based on the dimensions of the theoretical framework and the logical model (see

TABLE 2 Classes of results of each dimension and the Municipal Solid Waste Governance Index (MSWGI) used to classify the 5.570 municipalities in Brazil.

Description	Regulatory quality (Dim1)	Voice and accountability (Dim2)	Government effectiveness (Dim3)	MSWGI (Dim1 + Dim2 + Dim3)
Very high	0.54–1	0.69–1	0.81–1	0.6–1
High	0.37–0.53	0.55–0.69	0.65–0.81	0.5–0.6
Medium	0.23–0.37	0.44–0.55	0.48–0.65	0.4–0.5
Low	0.11–0.23	0.33–0.44	0.3–0.48	0.3–0.4
Very low	0–0.11	0–0.33	0–0.3	0–0.29

Source: Elaborated by the authors (2022).

Supplementary Table S1), of which, after applying the data quality criteria, 25 variables were selected to compose the index (see Supplementary Table S2): seven for the Regulatory Quality dimension (related to the codes N_Leg_Mun, N_Leg_UF, MGOV01, MMAM201, MMAM21, MMAM225, and MMAM226), nine for Voice and Accountability (related to the codes MTIC251, MTIC254, MTIC271, MTIC272, MGOV0411/0415, MGOV06, MMAM10, MMAM102, and MMAM12), and nine for Government Effectiveness (related to the codes MREG062, MREG064, MREG174, MGOV186, MMAM01, MMAM06, MMAM08, MMAM16, and MMAM17). Most of the variables were extracted from a single public database (Government of Brazil, 2019a, 2020), which reached the data quality criteria. The response rate and consistency of the database were limitations of the analysis, as well as for Brazilian MSW governance.

Beyond the Brazilian context, basic data and information about waste streams, their quality, and quantities, are rarely collected in cities of the Global South (Beall et al., 2022). The Brazilian scenario reflects current data availability conditions and the difficulties of several countries to robustly understand MSW management (Alencar et al., 2022). Management is referred to as a proximate factor and governance as an ultimate factor when addressing environmental issues by solid waste (Szirmai, 2012). Despite this lack of information, in the Brazilian case study, the application of the MSWGI covered all 5,570 municipalities, considering the most recent data available (referring to the years 2019 and 2020) (see Supplementary Table S2).

The aggregation of the three dimensions in the MSWGI showed that Brazilian municipalities have MSW governance classified as very high (15.5%), high (24.8%), medium (26.5%), low (22.2%), and very low (11%) (Figure 4). South (S) and Southeast (SE) regions of Brazil exhibited the highest MSWGI, whereas the Northeast (NE) region exhibited the lowest MSWGI (Figure 4).

MSW management systems are better established in the South and Southeast regions of Brazil (Government of Brazil, 2019b), both of which encompass the majority of municipalities that exhibit the highest socioeconomic indices in the country (Government of Brazil, 2020). This is because cities' performance on MSW can be associated with socioeconomic development indices (Velis et al., 2023). However, it was observed that low and very low governance scores were also attributed to some municipalities in the South and Southeast regions, even though in a smaller proportion than in the North (N) and Central-West (CW) regions (Figure 4). The Northeast region, a lower income portion of Brazil, concentrated most of the very low MSWGI values and requires special attention due to the strong association between waste management systems and the low level of socioeconomic development (Velis et al., 2023). Very high MSWGI values were generally observed in the South and Southeast, but also in many municipalities of the North region.

The Regulatory Quality dimension of Brazilian municipalities also varied among and within country regions (Figure 5). It is possible to notice that this dimension is also mostly high (31.4%) and very high (23.7%) in Brazilian municipalities. These results point to the existence of normative and legal apparatus for MSW management, which are fundamental for structuring local governance, as highlighted by Buta and Teixeira (2020). However, it is worth mentioning that, despite being the dimension with the highest weighting of the MSWGI, the Regulatory Quality does not necessarily guarantee high-quality governance and, therefore, may not be reflected on mechanisms of participation, accountability, and quality of public services performed in municipalities, as shown by results in other dimensions. Spearman's correlation analysis (1904) revealed the statistically significant ($p < 0.05$) but poor correlation between regulatory quality and voice and accountability ($r = 0.297$) and between regulatory quality and government effectiveness dimensions ($r = 0.325$).

Mechanisms for municipal participation and accountability were represented by the Voice and Accountability dimension of the MSWGI. The results of this dimension indicate that 32.4% of Brazilian municipalities have a low level of Voice and Accountability (Figure 6), followed by high (25.4%), medium (19.2%), very low (13.1%), and very high (9.98%) values in MSW governance. Municipalities in the Northeast (NE) region of the country presented the lowest levels of voice and accountability (Figure 6). These may indicate that most Brazilian municipalities still have conditions to be improved, regarding access to information and participation of actors in MSW governance. It is important to highlight that waste pickers are an integral part of MSW management, not only in Brazil, but in the Global South (Velis, 2017). The waste informal workers have often been 'invisible': they may belong to marginalized groups; and may have no opportunity to collect, use, and report data (Velis, 2024), constituting a limitation of the analysis. Availability and accessibility of information on MSW is a fundamental aspect for various actors in formal and informal systems to be able to monitor and influence the development of governmental actions and the provision of municipal services related to MSW management.

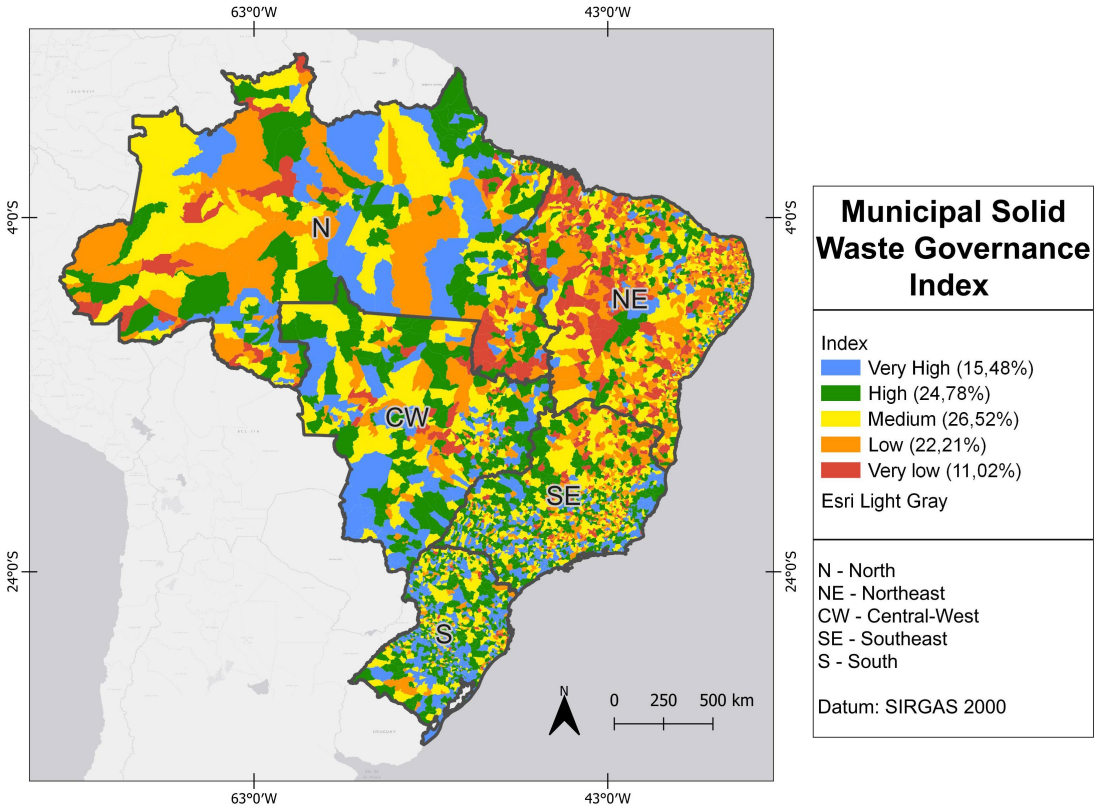

FIGURE 4
Municipal Solid Waste Governance Index (MSWGI) application for each of the 5.570 municipalities in the Brazilian case study (Brazilian regions: N—North, NE—Northeast, CW—Central-West, SE—Southeast, and S—South).

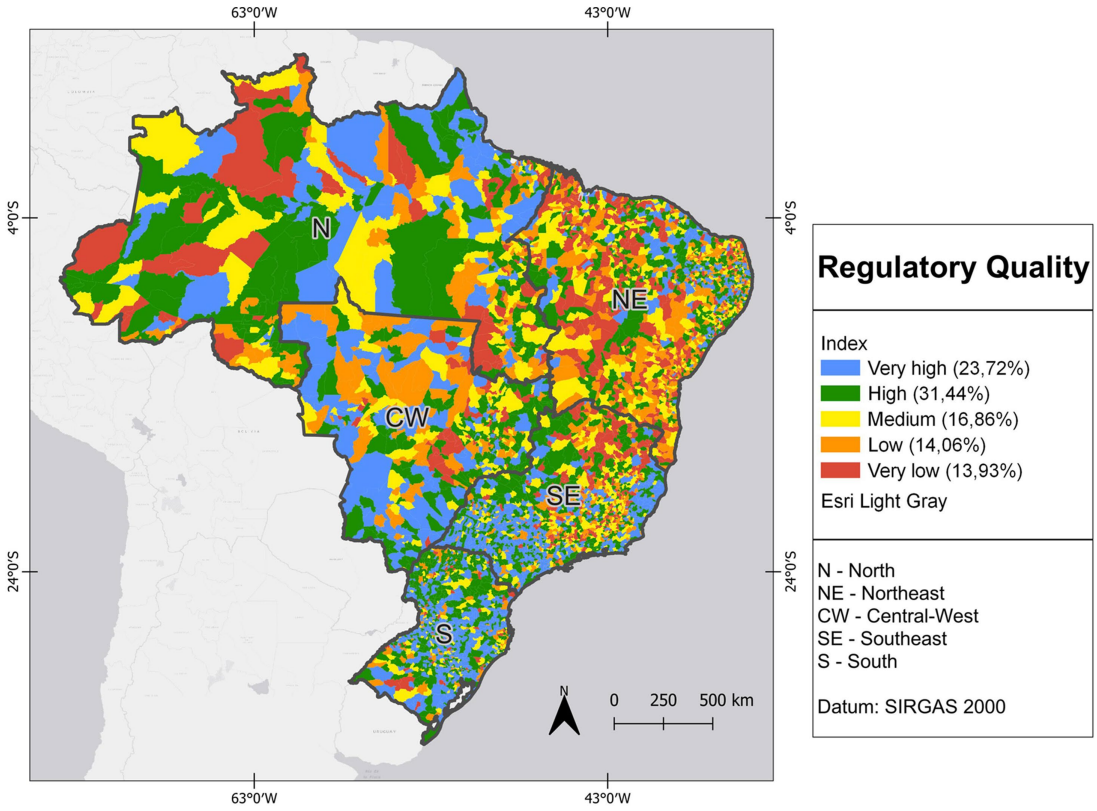

FIGURE 5
Dimensions of the Municipal Solid Waste Governance Index (MSWGI) applied to the 5.570 Brazilian municipalities: Regulatory Quality.

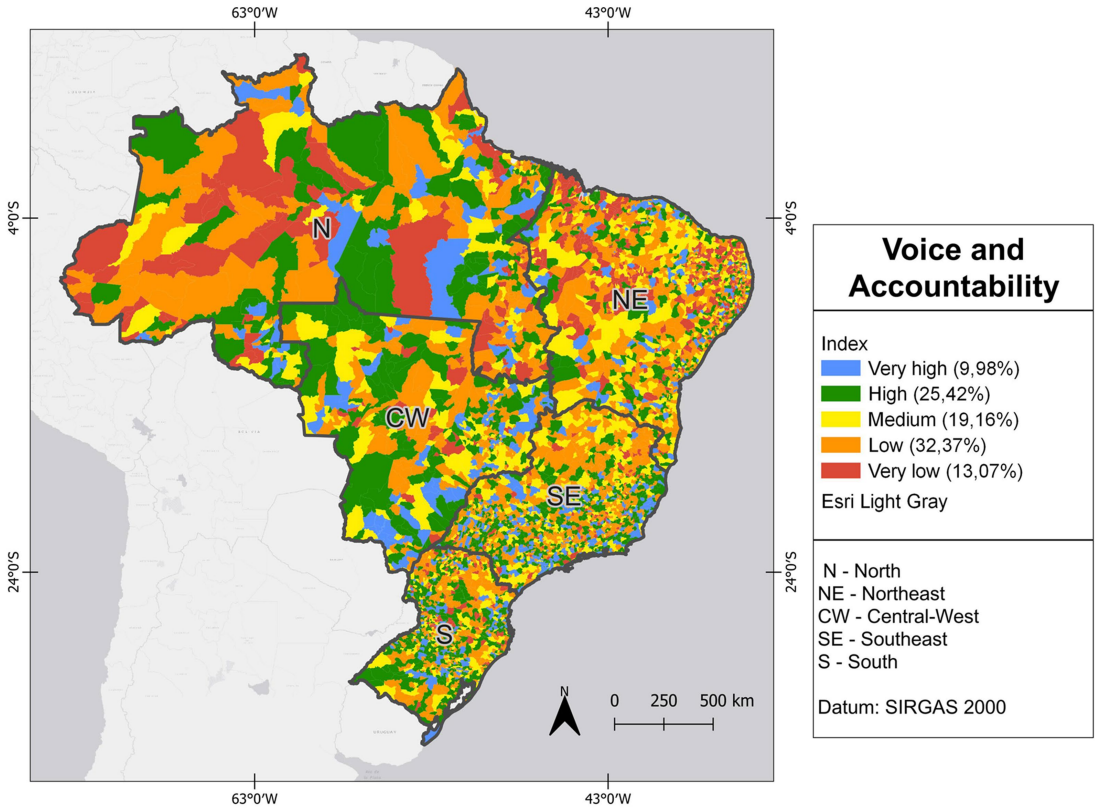

FIGURE 6
Dimensions of the Municipal Solid Waste Governance Index (MSWGI) applied to the 5.570 Brazilian municipalities: Voice and Accountability.

The last dimension that integrates the MSWGI is the Government Effectiveness and most Brazilian municipalities were classified as medium (27.8%), low (24.5%), and high (24.1%) effectiveness regarding the government's commitment to provide MSW management public services, followed by the very high (14.5%) and very low (9.1%) levels (Figure 7). There was a predominance of medium government effectiveness in Brazil, with a higher incidence of municipalities rated as very high in the South region and very low in the Northeast portion of the country, mirroring the level of socioeconomic development.

These results reveal that there is a need to improve the provision of MSW services in municipalities, by developing and implementing better actions regarding hiring and controlling human, financial, and administrative resources. However, waste management systems in the Global South suffer from a chronic inability to secure the financing required to deploy infrastructure. Operational costs have been unaffordable for parts of the population, and the willingness to pay is very low, especially in neglected places where there is no prior experience of waste management services. Product stewardship systems, such as the extended producer responsibility, may not be in place or are still not effective, and in any case, do not fully/suitably include waste pickers in their provisions (Velis, 2024).

In summary, the results of the MSWGI and its dimensions indicate possibilities for improvements in MSW governance in municipalities, as an academic exercise with potential practical consequences, by collecting and providing relevant information. The index proposed in this paper allows the identification of potential critical points, such as the association of waste management systems with the level of socioeconomic development; social participation, and the informal system, as well as the lack of information. While database inconsistency and incompleteness may be potential sources of bias for applying the index in other contexts, other existing data can be utilized following the model presented. Associated with the local monitoring and assessment of governance of MSW, this can guide the path for the implementation of improvements, investments, and corrective actions.

One of the limitations of developing the MSWGI using mixed weighting methods, was the participation of specialists, given the low response rate. Granting additional response time could enhance the form's response rate, with time constraints having been a limiting factor in the study's progress. To apply the proposed index, the Brazilian case study was used, achieving results comparable to other contexts of the Global South. In Brazil, the possibility of analyzing the quality of MSW services and management policies, incorporating aspects of governance efficiency and effectiveness, is restricted due to the lack of availability and accessibility of adequate data for such an evaluation, as well as in cities of the Global South (Velis, 2024). In this study, a large part of the data on MSW used was categorical and, above all, dichotomous (yes/no), which limits its use and application. Despite the existence of public databases, which gather municipal information on MSW, the absence of data is recurrent, which led to the selection of databases that had variables with complete and reliable responses for all Brazilian municipalities.

In addressing such constraints, this study presented an innovative proposal for monitoring local MSW governance, incorporating dimensions that allowed the identification of critical points for improving MSW governance at the local level. Efforts were directed

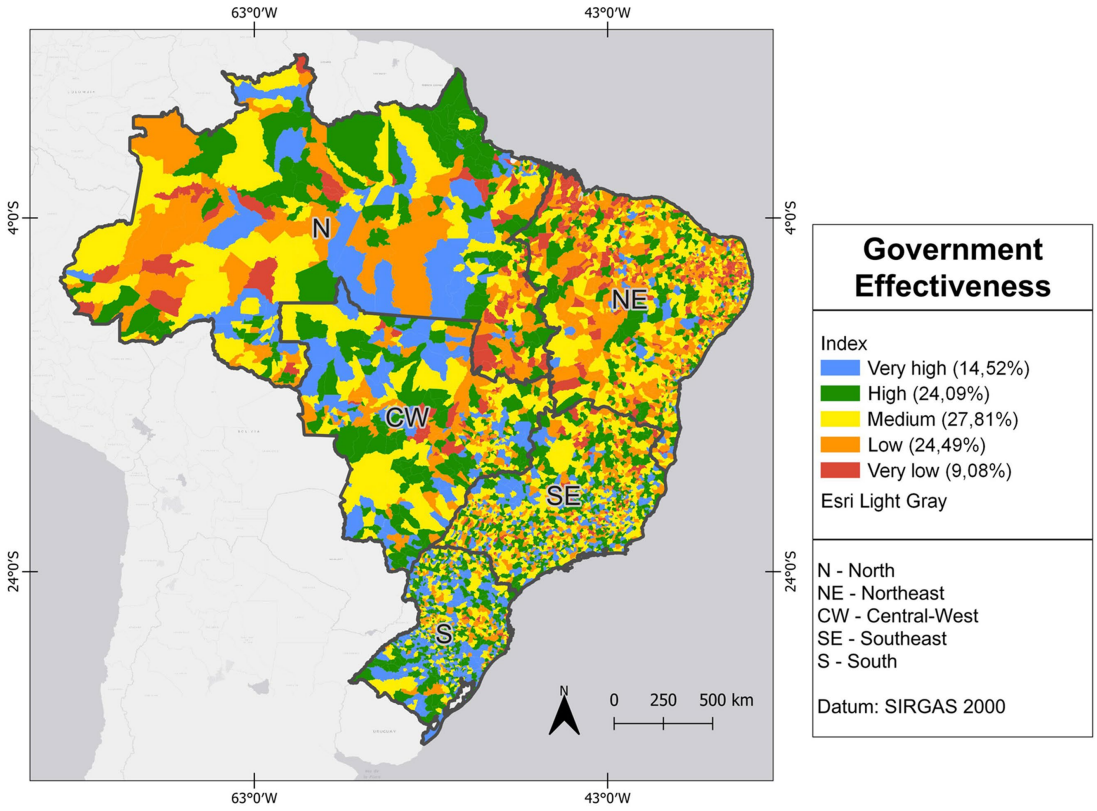

FIGURE 7
Dimensions of the Municipal Solid Waste Governance Index (MSWGI) applied to the 5.570 Brazilian municipalities: Government Effectiveness.

toward improving the functioning of formal social participation structures, as well as integrating informal systems, with reliable and complete databases, to achieve solid waste governance that considers socioeconomic aspects, and the complexities associated with the context of the Global South.

Rather than presenting an index to be directly transposed and applied to other locations, the steps of a strategy for generating an MSWGI from existing data in each Global South country, where data gaps are a limiting factor, were outlined. It also constituted a strategy for, based on the development of the MSWGI, identifying gaps in relevant information for improving indices, which can be enhanced as new and better data become available. Within the Plastic Treaty (UNEP, 2022) there are expectations for a global comparison of governance to address solid waste issues with standardized data across all locations; however, this remains a distant reality. In this sense, this study creates mechanisms to refine these indicators within the context of data lack, presenting strategies that can be utilized by other Global South countries.

4 Final considerations

This study sought to develop a MSWGI that can be used by municipalities located in the Global South, with its application demonstrated through a case study of Brazil. Although there are other synthetic indicator initiatives for evaluating and monitoring municipal waste management, there is a lack of specific governance indexes toward MSW to all municipalities on a national scale. In this sense, this paper innovates by addressing a strategy for developing an MSWGI tailored to the data limitations prevalent in countries in the Global South, and by employing an interdisciplinary approach that includes both quantitative and qualitative analyses in the development of the index.

The approach developed and applied in Brazil can be adapted, tested, and improved in other countries, aiming not to establish a standard but to provide guidance for constructing a solid waste governance index in a context characterized by lack of data. The data were analyzed, with the selection of variables that could represent the three dimensions of the index. The results can contribute to the development of complementary approaches that also use variables and indicators that can be studied and deepened in greater detail, specifically in the process of identifying critical points for improving MSW governance. Additional data sources can be utilized, but the logical framework for constructing a governance index from available databases can serve as an enabling strategy for enhancing MSW government and addressing associated critical issues. Thus, the study delves deeper into the theme of solid waste governance, exploring its construction and underlying issues comprehensively, systematically, and structurally.

As perspectives for future studies, the following aspects are highlighted: improvement of MSW data availability and quality; understanding the articulation between different actors involved in MSW governance and the decision-making process; definition of institutional arrangements for MSW management, including the informal system; and developing validation methods for the MSWGI, its results and the possibility of incorporating other variables and dimensions, according to available data to feed the index indifferent realities. Thus, the strategies presented in this study can be utilized by other Global South countries, as well as in an incremental way toward the complete implementation of the Plastic Treaty (UNEP, 2022).

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

CS: Conceptualization, Writing – original draft, Writing – review & editing, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Validation. LSR: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. TBC: Conceptualization, Formal Analysis, Writing – review & editing. BGG: Conceptualization, Formal Analysis, Writing – review & editing. MVA: Conceptualization, Formal Analysis, Funding acquisition, Writing – review & editing. CIE: Conceptualization, Formal Analysis, Project administration, Supervision, Writing – review & editing. NMC: Conceptualization, Supervision, Writing – review & editing. SLFGD: Conceptualization, Methodology, Project administration, Resources, Supervision, Writing – review & editing. LAC: Conceptualization, Writing – review & editing. VMS: Conceptualization, Writing – review & editing. AT: Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing, Conceptualization.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This research was funded by the Blue Keepers Program of the UN Global Compact of Brazil. This study was also financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES)—Finance Code 001.

Acknowledgments

The present study resulted from a partnership carried out by the authors within the Blue Keepers Program of the UN Global Compact of Brazil. We would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES; Programa de Excelência Acadêmica—PROEX—Brasil) for financial support to CS (Grant # 88887.820395/2023-00) and for covering the publication fee for our article, as well as the journal's fee program. We also thank the Brazilian National Council for Scientific and Technological Development for the scholarship grant to AT (CNPq; 310553/2019-9; 316837/2023-7) and to TBC, Grant 2023/13182-1, São Paulo Research Foundation (FAPESP). Translation by Nathalia Silva de Souza Lima Cano.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The present study resulted from an academic agreement between University of São Paulo and the UN Global Compact Brazil within the Blue Keepers Program. The partners had no role in the design, execution, interpretation, or writing of the study.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsus.2024.1409418/full#supplementary-material

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