GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

Sustainable Spatial Development Index (SDI)

Vanessa Naomi Yuassa
PhD in Urban Engineering
Federal University of São Carlos, Brazil
vanessa.yuassa@gmail.com
ORCID ID 0009-0006-1215-9328

Luciana Márcia Gonçalves
Professor, PhD in Architecture and Urbanism
Federal University of São Carlos, Brazil
lucianamg@ufscar.br
ORCID ID 0000-0002-8206-239X

Thais de Cassia Martinelli Guerreiro
Professor, PhD in Transportation Engineering
Federal University of São Carlos, Brazil
tcmguerreiro@ufscar.br
ORCID ID 0000-0001-5795-8875

Submissão / Submission: 19/02/2025
Aceito / Acceptance: 20/02/2026
YUASSA, Vanessa Naomi; GONÇALVES, Luciana Márcia; GUERREIRO, Thais de Cassia Matinelli. Índice de Desenvolvimento Espacial Sustentável (IDES). **Revista Nacional de Gerenciamento de Cidades**, *[S. l.]*, v. 14, n. 92, p. e2553, 2026. DOI: 10.17271/23188472149220265513. Disponível em: https://publicacoes.amigosdanatureza.org.br/index.php/gerenciamento_de_cidades/article/view/5513.

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

Índice de Desenvolvimento Espacial Sustentável (IDES)

RESUMO

Objetivo - desenvolvimento de um índice para realizar a análise espacial urbana dos municípios, com enfoque na questão territorial urbana e esteja adequada à realidade brasileira e às legislações vigentes denominado índice de Desenvolvimento Espacial Sustentável (IDES).

Metodologia – o IDES foi desenvolvido a partir do referencial teórico e da análise bibliométrica em conjunto com a análise dos manuais existente.

Originalidade/relevância – atualmente há uma lacuna de estudo no desenvolvimento de um índice, que realize a análise espacial urbana, com base na Política urbana brasileira. Assim, a inovação é o desenvolvimento de um índice composto quantitativo, com número reduzido de indicadores, utilizando uma única base de dados para cada indicador e faixas de desempenho para todas as cidades brasileiras, independentemente do seu porte com enfoque na questão territorial urbana.

Resultados - a forma de arranjo das dimensões em conjunto com o tripé da sustentabilidade (meio ambiente, social e econômico) do IDES proporcionou a análise mais apurada entre os indicadores apontando possíveis indícios de necessidade dos municípios realizarem revisão ou desenvolvimento de Planos Diretor ou Planos setoriais (mobilidade, saneamento e habitação). Já o resultado global do IDES em conjunto com o IDH, evidencia que o desenvolvimento espacial é relevante dentro do contexto político, apresentando valores preocupantes em mais da metade das cidades analisadas.

Contribuições teóricas/metodológicas – a aplicação do IDES possibilita o fornecimento de subsídios para a proposição de políticas públicas e investimentos em Planos Diretores e Planos Setoriais em conjunto com a melhoria das políticas públicas voltados para habitação, saneamento, mobilidade e planejamento.

Contribuições sociais e ambientais – os gestores públicos poderão realizar o monitoramento do desempenho espacial urbano dos municípios ao longo do tempo, no âmbito de verificação da necessidade de revisão ou desenvolvimento de Planos de mobilidade, Plano diretor, Plano de Saneamento básico, Plano Habitacional ou de itens específicos dos documentos: hierarquia viária, sentido de via, perímetro urbano, gabarito, gestão de obra pública, realocação da população de baixa renda em área de risco e outros.

PALAVRAS-CHAVE: Análise espacial. Planejamento urbano. Índice.

Sustainable Spatial Development Index (SDI)

ABSTRACT

Objective - development of an index to carry out the urban spatial analysis of the municipalities, focusing on the urban territorial issue while remaining adequate to the Brazilian reality and to the current legislation, called the Sustainable Spatial Development Index (SDI).

Methodology – the SID was developed from the theoretical framework and bibliometric analysis, together with the analysis of the existing manuals.

Originality/Relevance – there is currently a study gap in the development of an index to perform urban spatial analysis, based on the Brazilian Urban Policy. Thus, the innovation is the development of a quantitative composite index, with a reduced number of indicators, using a single database for each indicator and performance ranges for all Brazilian cities, regardless of their size, focusing on the urban territorial issue.

Results - the arrangement of dimensions together with the three pillars of sustainability (environmental, social and economic) of the SID provided the most accurate analysis among the indicators, pointing out possible indications of the need for the municipalities to review or develop Master Plans or Sectoral Plans (mobility, sanitation and housing). The overall result of the SID together with the HDI, shows that spatial development is relevant within the political context, presenting worrying values in more than half of the cities analyzed.

Theoretical/Methodological Contributions – the application of the SID makes it possible to provide input for the formulation of public policies and investments in Master Plans and Sectoral Plans, together with the improvement of public policies aimed at housing, sanitation, mobility and planning.

Social and Environmental Contributions – public managers will be able to monitor the urban spatial performance of municipalities over time, in order to verify the need for revision or development of Mobility Plans, Master Plans, Basic

ISSN 2318-8472, v. 14, n. 92, 2026

Sanitation Plans, Housing Plans or specific items of the documents: road hierarchy, road direction, urban perimeter, building height limits, public works management, relocation of the low-income population in risk areas and others.
KEYWORDS: Spatial analysis. Urban Planning. Index.

Índice de Desarrollo Espacial Sostenible (IDES)

RESUMEN
Objetivo – desarrollo de un índice para realizar el análisis espacial urbano de los municipios, centrado en la cuestión territorial urbana y adecuado a la realidad brasileña y a la legislación vigente, denominado Índice de Desarrollo Espacial Sostenible (IDES).
Metodología – el IDES se desarrolló a partir del marco teórico y el análisis bibliométrico junto con el análisis de los manuales existentes.
Originalidad/Relevancia – actualmente existe una laguna en el estudio del desarrollo de un índice que realiza análisis espacial urbanos, basados en la Política Urbana Brasileña. Así, la innovación es el desarrollo de un índice compuesto cuantitativo, con un número reducido de indicadores, utilizando una base de datos única para cada indicador y rangos de desempeño para todas las ciudades brasileñas, independientemente de su tamaño, con enfoque en la cuestión territorial urbana.
Resultados - la forma de organizar las dimensiones junto con el trípode de sostenibilidad (ambiental, social y económica) del IDES proporcionó el análisis más preciso entre los indicadores, señalando posibles indicios de la necesidad de que los municipios revisen o desarrollen Planes Directores o Planes Sectoriales (movilidad, saneamiento y vivienda). El resultado global del IDES, junto con el IDH, muestra que el desarrollo espacial es relevante en el contexto político, presentando valores preocupantes en más de la mitad de las ciudades analizadas.
Contribuciones Teóricas/Metodológicas – la aplicación del IDES permite proporcionar subvenciones para la propuesta de políticas públicas e inversiones en Planes Directores y Planes Sectoriales, junto con la mejora de políticas públicas orientadas a la vivienda, el saneamiento, la movilidad y la planificación.
Contribuciones Sociales y Ambientales – los gestores públicos podrán supervisar el desempeño espacial urbano de los municipios a lo largo del tiempo, dentro del marco de verificar la necesidad de revisar o desarrollar Planes de Movilidad, Plan Directores, Plan Básico de Saneamiento, Plan de Vivienda o elementos específicos de los documentos: jerarquía vial, dirección del tráfico, perímetro urbano, límites de altura de edificación, gestión de obras públicas, reubicación de la población de bajos ingresos en zonas de riesgo y otros.

PALABRAS CLAVE: Análisis espacial. Planificación urbana. Índice.

ISSN 2318-8472, v. 14, n. 92, 2026

1 INTRODUCTION

The increasing predominance of human occupation in urban areas places the urbanization process among the most significant global trends of the twenty-first century. According to UN-Habitat (2022), a deceleration of urbanization rate has been observed globally over the last two years, largely due to the COVID-19 pandemic, which has triggered a search for sanitary security. As a consequence, there has been a large-scale migration process from major cities to the countryside or small towns in search of improved health security. It hasn't, however, changed the course of global urbanization: the urban population continues to grow, and the current forecast is that cities around the world will have an increment of 2.2 billion inhabitants by 2050, reaching the mark of 11.9 billion people.

The change has been more evident in urban spatial development, which has long been preoccupied with the managerial mode of policy making, ultimately aiming at efficiently managing the diverse spatial needs by land-use control and infrastructure provision (OECD, 2008). Therefore, urban planners must constantly monitor the impact that specific policies and planning tools – such as land use regulations, infrastructure investments, and taxation – have on the urban morphology. This, to ensure that what is being materialized is in accordance with what was once planned and envisioned by citizens, technicians, public managers, or other stakeholders. Spatial indicators can provide a way of monitoring the evolution of a city's spatial organization and allow a benchmark comparison with other cities. Making use of spatial indicators that allow comparing the structures of cities and monitoring the evolution over time of the spatial organization of individual cities (Bertaud, 2004). In this context, Sustainability Indicators have proven to be important instruments in performance assessment and goal setting, as well as rational and valuable tools to improve the availability of information (Leal *et al.*, 2022).

As observed by Sáez, Heras-Saizarbitoria and Rosríguez-Núñez (2020), there has been a notable proliferation of City Rankings in the last decades.Such rankings were developed by consulting firms, non-profit organizations, public institutions, academic institutions, business groups and even the media, aiming to analyze problems related to Urban an Spatial Planning. In Brazil, many tools have been developed in order to assess and track urban sustainability, such as the Urban Sustainability Index (SISU), the Quality of Urban Life Index for Brazilian Municipalities (IQVU-BR), the National City Information System (SNIC), the Integrated Urban Environment Management System (SIGAU), the Sustainable Development Index for Municipalities (IDSM) and the Sustainable Cities Program (PCS) (Silva, *et al.*, 2025).

In addition to the findings of Sáez, Heras-Saizarbitoria and Rosríguez-Núñez (2020), other researchers emphasize the importance of the diversity of thematic approaches related to urban spatial analysis, developed by the following studies such as: Lafortune *et al.* (2018), Un-Habitat (2016), Arcadis (2018), Sun *et al.* (2018), Kotharkar, Pallapu and Bahadure (2019), Bhattacharya, *et al.* (2020), Steiniger, S. *et al.* (2020), Zulaica (2019), IESE (2020), Fu, *et al.* (2020) and Hassan and Kotval-K (2019).

The study carried out by the United Nations Statistical Commission in 2018, as described by Lafortune *et al.* (2018), considers several approaches related to urban spatial issues such as: housing (adequate; safe and accessible housing); sanitation (access to sanitation

ISSN 2318-8472, v. 14, n. 92, 2026

services); mobility (access to the public transport system and reduction in the number of deaths); resilience (number of people affected by disasters); air pollution (PM 2.5 concentration level) and public space (access universal to public spaces - green and safe areas). Another example is the study developed by Un-Habitat (2016) called the Prosperity Index, that pushes the analysis even further, introducing fields as: energy source (electricity access); communication (internet access); land-use efficiency (population density and land use mix), length of public transport network, street intersection density, street density, average daily travel time) and pollution (number of pollution monitoring stations and CO_2 emissions). It is also possible to find studies in the literature such as Arcadis (2018) emphasize the use of technology, such as the number of culture-oriented items advertised on TripAdvisor; access to the digital system of the public transport service; access to *Wi-Fi*, access to the bike-sharing system; congestion and metro/rail infrastructure. It is also important to highlight approaches that emphasize the "mobility field", such as: area of paved roads per capita (Sun *et al.*, 2018), mode of travel (Kotharkar, Pallapu and Bahadure, 2019) and the Kilometers of bicycle path and lanes (Bhattacharya, *et al.*, 2020), as well as access to public facilities: sports and culture area (Steiniger, *et al.*, 2020) and education and medical facilities (Zulaica, 2019). In addition, fields related to the Master Plan are also addressed, addressed in: property value (IESE, 2020), percentage of built area by the total urban area (Fu, *et al.*, 2020), percentage of area (residential, commercial, industrial, and tourism), and population growth (Hassan and Kotval-K, 2019).

Given the complexity due to the variety of thematic approaches, it is necessary to seek the efficiency of this measuring tool, so it is adequate to the Brazilian reality and current legislation, and not simply a copy or adaptation of existing indices, while still being easy to use. Since the Constitution of the Federative Republic of Brazil of 1988, in its 2nd Chapter, 21st. Art., Item XX (Brasil, 1988), dictates that one of the competences of the Union is to establish guidelines for urban development, including housing, basic sanitation and urban transport, it reaffirms the importance to develop a tool that allows carrying out an urban spatial analysis to serve as support for the development of public policies that benefit the entire urban population.

However, measuring the urban spatial development of Brazilian municipalities is not an easy task, due to the various realities of existing municipalities, in which it must be analyzed in an integrated manner with national policies aimed at urban planning, through reliable indicators. This challenging reality brings a question up: Would it be possible to develop a succinct and efficient index that aims to analyze urban territory based on Brazilian urban policy?

In this sense, this research aims to develop a Sustainable Spatial Development Index (SDI) in order to capture the current spatial portrait of the urban area of the municipalities today and over time, allowing the federal, state and municipal governments to diagnose and assist in public policies and urban management. The focus on urban spatial analysis can be carried out through the use of scientific methods with simplifying logic of the real phenomenon, such as indices. Currently, there is a study gap in the development of an index, which performs urban spatial analysis, as shown in syudy by Yuassa *et al*. (2025). Additionally, based on the Brazilian Urban Policy, composed of a reduced number of indicators, using a single database for each indicator and performance parameters for all Brazilian cities, regardless of their size.

2 OBJECTIVES

ISSN 2318-8472, v. 14, n. 92, 2026

The following study aims to develop an index to carry out the urban spatial analysis of the municipalities, focusing on the urban territorial issue and adapted to the Brazilian reality and current legislation. Whose objective is the evaluation of urban spatial development at the local level, based on appropriate indicators, composed of a reduced number of indicators, using a single database for each indicator that can be applied to municipalities of different sizes. This allows for an understanding of the reality of Brazilian municipalities through performance ranges, dimensions and the final index generated for each municipality. Enabling the comparison between the results of the Human Development Index - HDI (2010) and the SDI (2022).

3 METHODOLOGY

This section presents a summary of some existing methodologies for developing composite indices. Three methodologies were chosen: two international (OECD and ESRI) and one national (ENAP). Following this, the methodology of the Sustainable Spatial Development Index (SDI) is presented.

3.1 Existing methodologies for developing indices

The OECD manual (2008) is widely used as a reference for conceptual and methodological systematization in the development of a composite index, and has been cited in several studies (Neves; Melo; Sampaio, 2011; Founda; Elkhazendar, 2018; Hansan; Kotval-K, 2019; Kotharkar; Pallapu; Bahadure, 2019; Araújo, De Almeida; Santos, 2021; CLP, 2022). Other great reference, more related to the subject of this study (urban spatial development), is the manual developed by ESRI (2023), which also includes the possibility of collecting and analyzing primary data through the Geographic Information System (GIS) in the composition of the indicators. Finally, the Manual developed by ENAP (2021) aims to disseminate knowledge and provide resources to support agencies and entities in their institutional missions.

Table 1 shows the differences and similarities between them, the result of the analysis was important for the structuring of the index proposed in this study: the Sustainable Urban Development Index (SDI).

ISSN 2318-8472, v. 14, n. 92, 2026

Table 1 - Summary table of existing methodologies for the elaboration of the SDI

Steps	OECD (2008)	ESRI (2023)	ENAP (2021)	SDI
Theoretical framework	x		x	Theoretical framework
Study scale		x		Study scale
Identify the objective		x	x	Identify the objective
Definition of dimensions		x		Definition of dimensions
Choose the study area		x		Choose the study area
Survey of indicators	x	x	x	Survey of indicators
Imputation missing data	x			Imputation missing data
Selection of indicators	x	x	x	Selection of indicators
Statistical analysis	x		x	Statistical analysis
Formula construction			x	Formula construction
Normalization	x	x		Normalization
Weighting	x	x		Weighting
Aggregation	x	x		Aggregation
Goal setting			x	Goal setting
Visualize and investigate results	x	x		Visualize and investigate results
Viewing the results	x	x		Viewing the results
Defining those responsible			x	-
Final validation			x	-
Performance measurement			x	-

Source: Authors (2025).

Understanding the methodologies was fundamental to the development of the Sustainable Spatial Development (SDI) index structure, based on the following characteristics observed in each methodology: (1) The ESRI (2023) raises important issues related to the analysis of the spatial phenomenon, such as the need to specify the spatial unit and the study area together with the use of the Geographic Information System (GIS) to help create more effective variables. (2) The OECD (2008) emphasizes the importance of the robustness of the final index by using statistical analysis, especially multivariate data analysis, to assess the adequacy of the dataset and explain the methodological choices. (3) ENAP (2021) differs in its structure by including two stages (construction of formulas for each indicator and the establishment of goals to ensure the effective implementation of the strategy).

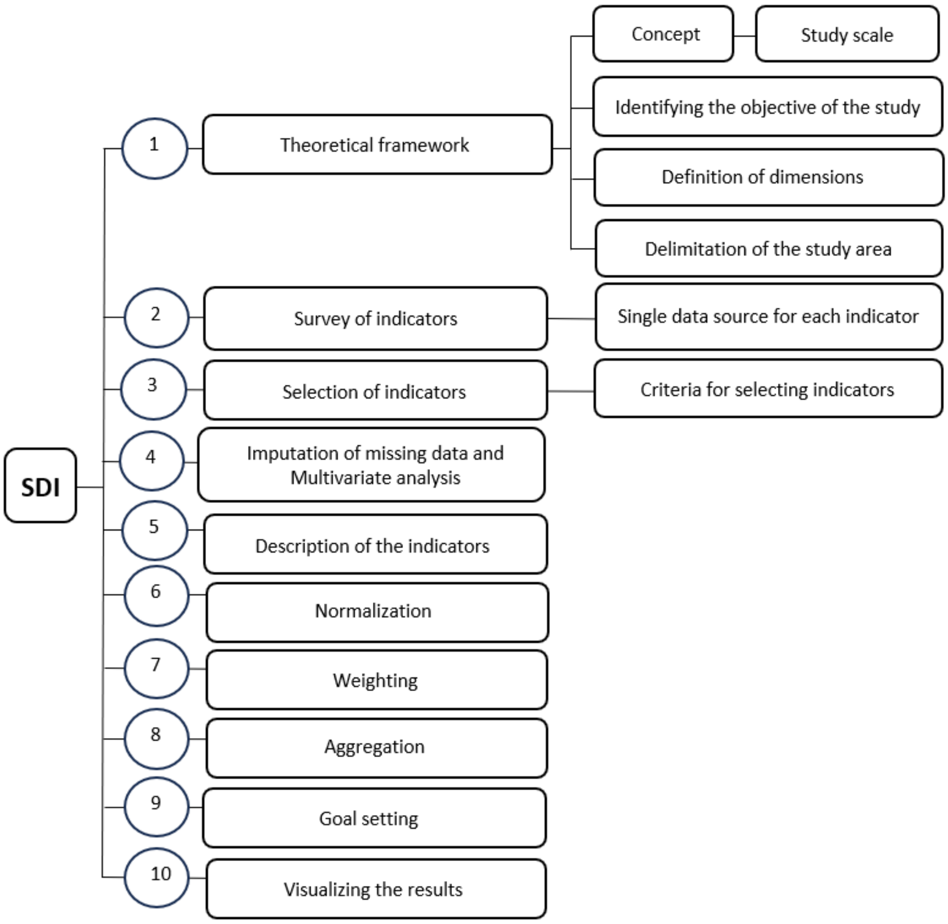
3.2 Structure of the SDI

The structure of the SDI is composed of 10 main steps (Figure 1), the steps are dynamic, and can occur concomitantly or, if necessary, revert to previous phases for revision. Each of the steps will be further detailed in the following sub-items.

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

Figure 1 – Structure of the Sustainable Spatial Development Index (SDI)



Source: Authors (2025).

According to the OECD (2008), the definition of the concept of the should provide clarity to the reader on what is being measured. Therefore, the concept of Sustainable Spatial Development was obtained through other existing concepts. The adopted concept is in accordance with the provisions of the City Statute[1].

Sustainable spatial development is defined as the ability: the ability to plan urban occupation, linked to the equitable distribution of infrastructures and services with access to housing, basic sanitation and mobility. In this way, contemplating four dimensions: housing, mobility, sanitation and planning, according to the City Statute.

These dimensions (housing, mobility, sanitation and planning) are composed of indicators that reflect environmental, social and economic issues, that is, the tripod of sustainability. By promoting sustainable spatial development planning, through the creation of a permeable urban fabric, adequate population density, responsible use of natural resources, predicting and reducing potential damage from natural and economic hazards, avoiding marginalization and segregation of the low-income population, and providing democratic

[1] The City Statute gained prominence in the international context among urban development and financing agencies, such as UN-Habitat and the World Bank, by becoming an instrument for urban planning and management in Brazil, particularly regarding urban land.

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

management through public participation in spatial development approaches. This also promotes cooperation between the government and the monitoring of spatial development plans, programs and projects.

3.3 Data and Delimitation of the study area

The choice of state capitals was because the 2022 Census had not published the variables necessary for calculating the housing deficit on its official website until 11/25/2024. Currently, data is available from the Continuous National Household Sample Survey (PNAD-C) for the year 2022. However, PNAD-C does not collect data from all Brazilian municipalities. It is important to note that it is not possible to identify the code or the name of the municipalities in the sample, except for the state capital cities. There is the possibility of analyzing the capital cities and/or metropolitan regions as a whole.

3.4 Dimensions

The SDI is composed of 4 dimensions, each dimension is related to a theme addressed in the City Statute (housing, sanitation, mobility and urban planning). Considering that, each dimension will be composed of indicators focused on the environment, social and economic (tripod of sustainability). The dimensions were aggregated according to the City Statute and the concept of Sustainable Spatial Development; each dimension is described below in Table 2.

Table 2 - Description of each dimension

 Mobility	 Housing	 Sanitation	 Planning
Ease of urban mobility, through the connectivity density of the road network and the vehicle fleet. Together with the growth of the urban area, it ensures road safety by mitigating accidents and traffic fatalities.	Linked to access to housing through the housing deficit (composed of cohabitation, rent burden and precarious housing) for the low-income population, along with the existence of stalled projects aimed at education, health and urbanism.	Equitable distribution of infrastructure and services related to basic sanitation (drinking water, sewage and drainage).	More compact cities through population density, ensuring more rational city growth by mitigating the presence of vacant housing.

Source: Authors (2025).

3.5 Indicators

As detailed in Yuassa *et al.* (2025), an extensive literature review was carried out on the Urban Development Index. According to the authors, the most commonly used way to select

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

indicators is through selection criteria, which include: availability, relevance, coverage/coverage, comparability and measurability.

In this study, the aforementioned selection criteria were used and the indicators that did not fit all the criteria were discarded, with the objective of ensuring data quality, same data source and the same data collection period.

The SDI is composed of indicators, each utilizing a single data source (database). Enabling data analysis with the same methodological basis for the municipalities analyzed. The data sources of each indicator are described in Table 3. It should be noted that some data do not have stratification between urban and rural areas, such as: Fleet growth rate, Percentage of stalled construction projects, Growth rate of traffic accidents and Percentage of households at risk of flooding. Therefore, values encompassing both urban and rural areas were used.

In general, the base year of the data collected for the 12 indicators is 2022, preferably using nationally available secondary data in conjunction with primary data from Open Street Map, as previously described. It is important to point out that, for some indicators, data from the period between 2011 and 2020 were used, as shown in Table 3.

Table 3 - Base year and source of each SDI indicator

Dimension	N.	Indicator	Year	Source
Mobility	1	Fleet growth rate	2011 and 2020	SENATRAN
	2	Traffic accident growth rate	2011 and 2020	DATASUS
	3	Connectivity density of the urban road network		OpenStreetMap
	4	Urban sprawl growth rate	2011 and 2020	MAPBIOMAS
Housing	5	Urban housing deficit rate	2022	PNAD-C
	6	Percentage of stalled construction projects	2022	TCU
Sanitation	7	Percentage of households served by urban drinking water supply	2022	SNIS
	8	Percentage of urban households connected to the urban sewage network	2022	SNIS
	9	Percentage of the population served by the urban drainage network	2022	SNIS
Planning	10	Percentage of households at risk of flooding	2022	SNIS
	11	Urban population density	2022	Census
	12	Rate of vacant urban private households	2022	Census

Source: Authors (2025).

3.6 Imputation of missing data and multivariate analysis

Imputation is the choice of which method to use to fill empty data spaces. In the following study, the multiple imputation method was used, using the IBM SPSS version 2.0 software. SPSS uses the EM (Expectation-Maximization) method, which assumes a distribution for partially omitted data and bases inferences on the probability of this distribution.

Before imputing missing data, it is important to perform the Roderick J. A. Little chi-square test to determine if the values are randomly missing (Missing Complete At Random - MCAR). For this test, the null hypothesis is that the data are randomly missing, and the p-value

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

is set at the 0.05 significance level. If the value is less than 0.05, the data are not randomly missing. The data may be randomly missing (Missing At Random - MAR) or not randomly missing (Not Missing At Random - NMAR).

It is important to note that it was necessary to perform the urban population projection due to the unavailability of data on the IBGE website. The method used for the population projection is arithmetic growth.

Population growth is calculated at a constant rate according to the formulas described below. Knowing that dP/dt is the population growth rate over time. P0, P1, and P2 are the populations in the years t0, t1, and t2. Pt is the estimated population for year t and Ka is the coefficient.

$$P_t = P_0 + K_a * (t - t_0)$$

$$\frac{dP}{dt} = K_a$$

$$K_a = \frac{P_2 - P_1}{t_2 - t_0}$$

Factor Analysis, which includes Principal Component Analysis, is a statistical approach that can be used to analyze interrelationships between a large number of variables and explain these variables in terms of their common inherent dimensions (factors). The goal is to find a way to condense the information contained in several original variables into a smaller set of statistical variables (factors) with minimal loss of information (Hair, 2009).

In the following study, the IBM SPSS version 2.0 software was used. SPSS was used to perform Factor Analysis and Analysis, through the Varimax rotation method. This method is one of the most popular orthogonal factorial rotation methods, focusing on simplifying the columns into a factorial matrix. Generally considered superior to other orthogonal factorial rotation methods to achieve a simplified factorial structure (IBM, [n.d.]).

The variables obtained were tested, and the value of the significance level was 0.024, which is less than 0.05. Therefore, the Bartlett sphericity test is statistically significant.

When analyzing the distribution of the values in the factorial matrix (Table 4), factor loadings of ± 0.50 or higher, as mentioned above, were used as a reference. When verifying the factor loading values of the 13 indicators, it was noted that 5 indicators had values higher than 0.7 (38%), 7 indicators with values between 0.50 and 0.70 (54%) and 1 indicator had a value between 3.0 and 5.0 (8%). It should be emphasized that factor loadings in the range of ± 0.30 to ± 0.40 are considered to meet the minimum level for interpreting the structure.

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

Table 4 - Factorial matrix of SDI indicators (continues)...

Dimension	Indicator	Factor Load			
		1	2	3	4
Mobility and urban planning	Fleet growth rate	-.660	.247	.310	.537
	Traffic Accident Growth Rate	.227	.200	.367	.494
	Percentage of households at risk of flooding	.001	-.058	-.120	.867
Sanitation	Percentage of households served by urban drinking water supply	.648	-.207	.348	.165
	Percentage of urban households connected to the urban sewage network	.504	-.389	.478	.020
	Coverage rate for municipal solid waste collection	.575	-.177	.220	.260
	Percentage of urban households served by the urban drainage network	.834	.024	-.145	-.085

Table 4 - Factorial matrix of SDI indicators

Dimension	Indicator	Factor Load			
		1	2	3	4
Housing	Urban housing deficit rate	-.037	.023	.885	-.084
	Percentage of stalled construction projects	.083	.304	.592	.148
Planning	Rate of vacant urban private households	-.048	.724	-.108	-.156
	Urban sprawl growth rate	-.068	.798	.189	-.020
	Urban population density	.142	-.598	-.206	-.229
	Connectivity density of the urban road network	.400	-.611	-.017	-.222

Source: Authors (2025).

When segmenting the indicators into four parts, some indicators can be used both in the mobility and planning dimensions (Table 4), such as the indicator "Percentage of households at risk of flooding" and "Connectivity density of the urban road network".

3.7 Normalization

According to Yuassa *et al.* (2025) the most commonly used normalization method is the linear interpolation method, also known as minimum-maximum normalization. Therefore, the minimum-maximum normalization method was adopted for the study.

However, before normalizing the data, it is necessary to analyze the presence of outliers. Outliers can strongly influence the results, distorting and masking reality. There are several methods for identifying outliers, the most common are the control chart (using the 95th and 5th percentiles values, as well as 97.5th and 2.5th percentiles) in conjunction with R^2.

When analyzing the original data (Table 5), it is observed that 7 indicators present the highest values (54%), while with the replacement of the values located in the 2.5th and 97.5th percentiles, there is 1 indicator with the highest value (8%) and finally, with the replacement of the values located in the 5.0th and 95th percentiles, there are 5 indicators with the highest values (38%).

ISSN 2318-8472, v. 14, n. 92, 2026

Table 5- R^2 values for the 2.5 and 97.5 percentiles together with 5 and 95

Indicators	R2	R2 Percentile 2.5 and 97.5	R2 5th and 95th Percentile
Fleet growth rate	0,0197	0,0228	0,0241
Traffic Accident Growth Rate	0,0069	0,0089	0,0096
Urban housing deficit rate	0,1677	0,196	0,1766
Rate of vacant urban private households	0,0006	0,0004	0,003
Percentage of households served by urban drinking water supply	0,1289	0,1199	0,1196
Percentage of urban households connected to the urban sewage network	0,0367	0,0367	0,037
Percentage of coverage of municipal solid waste collection	0,0242	0,0242	0,019
Percentage of the population served by the urban drainage network	0,088	0,0872	0,0859
Percentage of stalled construction projects	0,0094	0,0089	0,0075
Urban sprawl growth rate	0,0057	0,0046	0,004
Urban population density	0,0405	0,0365	0,0199
Connectivity density of the urban road network	0,0002	0,0022	0,0029
Percentage of households at risk of flooding	0,0004	0	0

Source: Authors (2025).

Thus, due to the highest R^2 values being present in the values in the original indicators, outliers replacement will not be performed.

The SDI will be normalized between 0 and 1.0, using the minimum-maximum normalization method to preserve magnitude differences, because the goal is to identify locations that are high in terms of absolute values. The calculation formula is shown below.

Each indicator for a generic country "c" and time "t" is transformed into:x_{qc}^{t}

$$I_{qc}^{t} = \frac{x_{qc}^{t} - min_c(x_q^t)}{max_c(x_q^t) - min_c(x_q^t)}$$

Where, are the minimum value and the maximum value of in all countries "c" at time "t". Thus, the normalized qc indicators have values between 0 and 10.$min_c(x_q^t)\ e\ max(x_q^t)\ \ x_{qc}^{t}$ 13

After data normalization a non-parametric Spearman correlation analysis was performed, because the sample was considered small (less than 30). The correlation analysis was performed between indicators of the same dimension. The correlation parameters used are those of Cohen (1992):

- τ = 0.10: weak correlation;
- τ = 0.30: moderate correlation;
- τ = 0.50: strong correlation.

Table 6 shows that the indicator "Percentage of coverage of municipal solid waste collection" along with the other indicators of the sanitation dimension, shows a correlation of less than 0.10. Thus, due to the lack of correlation with any of the indicators of the same dimension, the indicator was discarded from the SDI composition. Regarding the indicator "Percentage of households at risk of flooding" there is no correlation with "Rate of vacant urban unoccupied private households" (0.056), however, in relation to "Urban population density" there is a weak correlation (0.134). In this case, the indicator will be maintained in the SDI

ISSN 2318-8472, v. 14, n. 92, 2026

composition. This condition may be due to the low number of samples. As seen previously, the minimum sample size recommended in the literature is 50.

It is important to highlight that Spearman's correlation analysis was important for decision-making on the location of the indicators in the mobility and planning dimensions. The indicator " Urban sprawl growth rate" shows a high correlation with the indicators in the mobility dimension (Fleet growth rate, Traffic accident growth rate and Connectivity density of the urban road network) with values of -0.349, 0.322 and 0.493, respectively. Meanwhile, the indicator "Urban population density" shows a moderate correlaion when analyzed together with "Traffic accident growth rate" (0.210). This is because the indicators for the sanitation and housing dimensions have already been allocated in the factor matrix.

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

Table 6 – Correlation matrix between the indicators

Dimension	Mobility				Sanitation				Housing		Planning		
Indicator	**Fleet growth rate**	**Traffic Accident Growth Rate**	**Connectivity density of the urban road network**	**Growth rate of the urban sprawl**	**% of households served by urban drinking water supply**	**% of urban households connected to the urban**	**% population served with solid waste collection**	**% population served with the urban drainage network**	**Urban housing deficit rate**	**% of stalled construction projects**	**% of households at risk of flooding**	**Rate of vacant urban private households**	**Urban population density**
Fleet growth rate	**1,0**	-,232	-,631	-,349	-,258	-,205	-,377	-,543	-,256	-,182	-,048	-,173	-,495
Traffic Accident Growth Rate		**1,0**	,157	,322	-,145	-,010	-,233	-,100	,244	,402	,025	-,112	,210
Connectivity density of the urban road network			**1,0**	,493	,221	,387	,145	,230	-,014	,099	-,053	,115	,649
Growth rate of the urban sprawl				**1,0**	,012	,128	,125	,225	,016	-,002	-,300	,071	,412
% of households served by urban drinking water supply					**1,0**	,525	,086	,422	-,294	-,205	,035	,088	,077
% of urban households connected to the urban sewerage system						**1,0**	,049	,322	-,377	,021	,380	,296	,164
% of coverage of municipal solid waste collection							**1,0**	,516	-,241	-,028	-,046	,231	-,019
% of the population served by the urban drainage network								**1,0**	-,159	,079	-,044	,316	,094
Urban housing deficit rate									**1,0**	,305	-,103	0,000	,142
% of stalled construction projects										**1,0**	,058	,210	,176
% of households at risk of flooding											**1,00**	,056	-,288
Rate of vacant urban private households												**1,00**	,134
Urban population density													**1,00**

Source: Authors (2025).

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

3.8 Weighting

Among the normalization methods found, 51% of the selected documents use the linear interpolation method (Yuassa *et al.*, 2025). Therefore, for this study, the linear interpolation method was adopted for weighting the data.

The selected aggregation method is the arithmetic mean, both for the indicators in their dimensions as well as for each dimension.

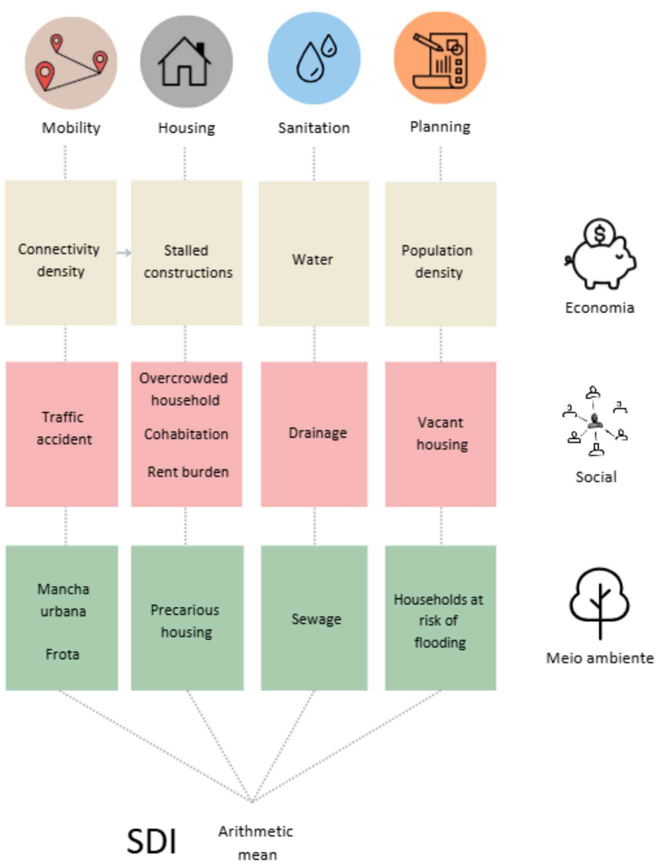
$$SDI = \sum_{i=1}^{n} \frac{DIM_i}{n}$$

Where SDI is the value of the Sustainable Spatial Development Index, DIM is the value of the arithmetic mean of the dimensions and "n" is the number of dimensions.

3.9 Calculation of the SDI

The construction of the SDI calculation aimed to be simple and easy to understand the results. Thus, the dimensions and the final index of the SDI are calculated by the arithmetic mean (Figure 2).

Figure 2 – SDI calculation structure



Source: Authors (2025).

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

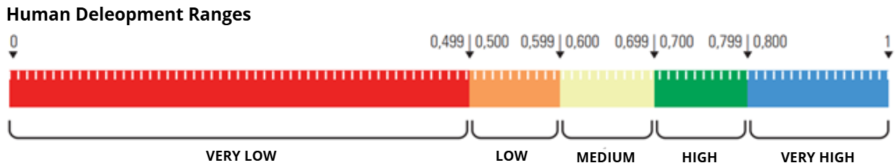
ISSN 2318-8472, v. 14, n. 92, 2026

3.10 Goals

In this study, some reference ranges of values proposed by the United Nations will be used, through the Municipal Human Development Index (HDI-M), as shown in Figure 3.

This study, undertaken by Ipea and the João Pinheiro Foundation, involved adapting the methodology of the Global HDI to calculate the Municipal HDI (HDI-M) of the 5,565 Brazilian municipalities (Atlas of Human Development in the Brazilian Metropolitan Regions, n.d.).

Figure 3 – Human Development Ranges



Source: Atlas of Human Development in Brazilian Metropolitan Regions (n.d.) 2

3.11 Aggregation

One of the most important concepts to consider when selecting an aggregation method is whether high values in one variable should compensate for low values in other variables, a concept known as compensability, as defined by ESRI (2023).

Problems of correlation and compensability issues among indicators need to be considered and either be corrected for or treated as features of the phenomenon that need to be retained in the analysis (OECD, 2008).

While the linear aggregation method is useful when all individual indicators have the same measurement unit, provided that some mathematical properties are respected. Geometric aggregations are better suited if the modeller wants some degree of non-compensability between individual indicators or dimensions. Furthermore, linear aggregations reward base-indicators proportionally to the weights, while geometric aggregations reward those countries with higher scores (OECD, 2008, p. 32).

It should be noted that the compensability between the indicators was mitigated by analyzing the presence of outliers, as previously described.

The most commonly used aggregation methods are the weighted mean (27.1%) and the arithmetic mean 20.8% (Yuassa *et al.*, 2025). Thus, the selected aggregation method is the arithmetic mean, both for the indicators in their dimensions as well as for each dimension.

$$SDI = \sum_{i=1}^{n} \frac{DIM_i}{n}$$

Where SDI is the value of the Sustainable Spatial Development Index, SDI is the value of the arithmetic mean of the dimensions, and "n" is the number of dimensions.

[2] Available at: <http://www.ipeadata.gov.br/doc/Metodologia%20ADH.pdf>. To be accessed on 02 Dec. 2024.

ISSN 2318-8472, v. 14, n. 92, 2026

4 RESULTS

This chapter will present the results of the pilot study of the SDI in the state capitals and the Federal District. First, calculations were performed to normalize the indicator values, as well as to calculate the dimensions and the final index for each municipality. The results will be presented in the form of a table and a graph.

4.1 Case Study

The Brazilian federation is composed of three federated entities, the Union and two subnational levels, the state governments (26) together with the Federal District and the municipalities (5,570) (Santos *et al.*, 2020). With regard to the states and their capitals, Brazil is composed of 26 capitals of the Brazilian states and the Federal District.

In 2010, the population of the 26 Brazilian capitals, together with the Federal District, was 45,466,045 inhabitants (23.8% of the total Brazilian population). The 2022 census reveals an increase in the total population of 12 million people between 2010 and 2022. This represents a heterogeneous population composition, ranging from 302,692 to 11,451,245 inhabitants.

4.2 Normalized values

In the mobility dimension (Table 7), there is a marked growth in the fleet in most state capitals, except for the city of Campo Grande. It is noteworthy that many of these municipalities also have low performance in relation to urban connectivity density, except Curitiba, Natal and São Paulo.

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

Table 7 - Normalized values of each indicator

City	Mobility				Housing		Sanitation			Planning		
	Connectivity density	Accident number	Urban population density	Vehicle fleet	Housing deficit	Paralyzed works	Urban water service	Urban sewage service	Rainwater networks or channels	Vacant private households	Emergency Situation	Growth rate of the urban sprawl
Rio Branco	0.0	0.6	0.1	1.0	0.6	0.7	0.6	0.2	0.1	0.3	0.0	0.8
Maceió	0.2	0.7	0.4	1.0	0.5	0.5	0.0	0.7	0.2	0.4	0.9	0.6
Macapá	0.0	0.7	0.2	1.0	0.8	0.8	0.2	0.0	0.0	0.4	0.8	0.8
Manaus	0.2	0.7	0.3	1.0	0.7	0.3	1.0	0.2	0.0	0.4	0.6	0.7
Salvador	0.5	0.9	0.7	1.0	0.9	0.7	1.0	1.0	0.0	0.1	0.8	0.5
Fortaleza	1.0	0.7	0.7	0.9	0.5	0.8	0.7	0.5	0.0	0.3	1.0	0.9
Brasília	0.3	0.7	0.0	0.9	0.4	1.0	1.0	0.9	0.6	0.4	0.9	0.5
Vitória	0.6	0.2	0.3	1.0	0.8	1.0	1.0	0.9	0.6	0.5	0.9	1.0
Goiânia	0.3	0.3	0.3	0.9	0.4	0.2	1.0	0.9	0.5	0.4	1.0	0.7
São Luís	0.2	0.6	0.2	1.0	0.7	0.3	0.9	0.5	0.2	0.5	0.9	0.6
Cuiabá	0.1	0.5	0.2	1.0	0.8	0.6	1.0	0.8	0.9	0.4	1.0	0.2
Campo Grande	0.2	0.6	0.2	1.0	0.5	0.4	1.0	0.9	0.0	0.3	0.7	0.6
Belo Horizonte	0.5	0.8	0.6	0.9	0.7	0.8	0.9	0.9	0.2	1.0	0.7	1.0
Belém	0.3	0.9	0.4	1.0	0.7	0.2	0.7	0.1	0.4	0.3	1.0	0.7
João Pessoa	0.4	0.5	0.3	1.0	0.0	0.0	1.0	0.8	0.4	0.2	0.7	0.4
Curitiba	1.0	0.7	0.3	0.8	0.5	0.4	1.0	1.0	1.0	0.6	0.8	1.0
Recife	0.6	0.5	0.6	1.0	1.0	0.8	1.0	0.4	0.9	0.4	1.0	0.8
Teresina	0.1	0.3	0.2	1.0	0.6	0.5	1.0	0.4	0.0	0.3	1.0	0.0
Rio de Janeiro	0.4	0.8	0.4	0.7	0.6	0.6	1.0	0.7	0.7	0.3	0.9	0.9
Natal	0.6	0.7	0.4	1.0	0.5	0.4	0.9	0.4	0.0	0.2	0.8	0.8
Porto Alegre	0.3	0.8	0.2	0.9	0.6	0.4	1.0	0.9	0.9	0.2	0.9	0.8
Porto Velho	0.0	0.3	0.2	1.0	0.8	0.8	0.2	0.0	0.0	0.0	0.8	0.5
Boa Vista	0.1	0.4	0.2	1.0	0.2	0.5	1.0	0.9	0.1	0.7	0.9	1.0
Florianópolis	0.2	0.8	1.0	1.0	0.5	0.8	1.0	0.7	1.0	0.5	0.7	0.7
São Paulo	0.6	1.0	1.0	0.0	0.5	0.6	1.0	1.0	0.3	0.4	0.9	1.0
Aracaju	0.4	0.4	0.3	1.0	0.0	0.6	1.0	0.5	0.3	0.3	0.8	0.5
Palmas	0.1	0.0	0.1	1.0	0.3	0.6	0.9	0.9	0.6	0.3	1.0	0.3

Source: Authors (2025).

The same table shows that in municipalities with high fleet growth rates and low fleet connectivity density (Maceió, Macapá, Manaus, Brasília, Goiânia, São Luís, Cuiabá, Belo Horizonte, Belém, Rio de Janeiro, Porto Alegre, Porto Velho, Florianópolis and Aracaju), it is necessary to review the road hierarchy and create new road connection alternatives to improve mobility, regardless of the mode of transport. This also includes verifying the feasibility of achieving a balanced modal split through improvements to the public transport system and infrastructure geared towards active modes (walking and cycling).

ISSN 2318-8472, v. 14, n. 92, 2026

In addition, in municipalities with low urban connectivity and higher rates of growth in traffic accidents, it is important to review the direction of traffic flow in order to mitigate conflict points, in municipalities such as: Maceió, Manaus, Campo Grande, João Pessoa, Rio de Janeiro, Boa Vista and Palmas.

Also noteworthy is the analysis of the relationship between the high growth of urban areas and low connectivity (Cuiabá, João Pessoa, Teresina, Porto Velho, Aracaju and Palmas), which can lead to the phenomenon known as urban sprawl, that is, the emergence of urban voids. In this context, the revision of the urban perimeter would be a key point, in order to mitigate the process of urban expansion, thus rationalizing urban infrastructure.

In the housing dimension (Table 7), it is evident that the social issue of access to housing remains a major challenge for municipalities. It is observed that 30% of municipalities show the worst performance (Fortaleza, Goiânia, Campo Grande, João Pessoa, Boa Vista, São Paulo, Aracaju and Palmas). In addition, 6 municipalities (22%) showed a low performance (Maceió, Fortaleza, Curitiba, Rio de Janeiro, Natal and Florianópolis). Totaling more than 50% of the cities with low or very low performance.

Nevertheless, when analyzing the existence of a high rate of housing deficit together with the percentage of paralyzed works (Table 7), the municipalities with the worst performances are: Goiânia, Campo Grande and João Pessoa. There is a need to review public policies related to stalled public facilities, as well as social housing policies. It is important to emphasize that stalled construction projects generate burdens for the municipality, prevent the population from accessing planned services, and lead to urban problems such as areas for drug consumption, areas for carrying out acts of sexual violence and others. Of the 27 municipalities analyzed, 10 show a very low performance (37%): Manaus, Vitória, Goiânia, São Luís, Campo Grande, Belém, João Pessoa, Curitiba, Natal, and Porto Alegre.

In the Planning dimension (Table 7), he presence of cities with low performance in relation to both population density and the rate of vacant private dwellings is observed (Rio Branco, Maceió, Macapá, Manaus, Brasília, Goiânia, São Luís, Cuiabá, Campo Grande, Belém, João Pessoa, Teresina, Rio de Janeiro, Natal, Porto Alegre, Porto Velho, Aracaju and Palmas). This allows for the development of extensive areas with low population density and a significant proportion of vacant dwellings, generating a burden on the provision of infrastructure and services by the public entity, when compared to cities with higher population densities. Given the complexity of planning issues, it would be important to verify the need to revise or develop the master plan by increasing building heights in certain regions, increasing the extent of mixed uses in conjunction with the road hierarchy.

Regarding households at risk of flooding (Table 7), the vast majority of cities had good performance, with a low flood risk rate in 85% of the municipalities. However, when verifying the cities with a low percentage of stormwater drainage service together with significant values of households at risk of flooding (Macapá, Boa Vista, Porto Velho, Salvador, Teresina, Fortaleza and Natal), it becomes clear that it is important to review or develop the sanitation plan, particularly focusing on urban drainage.

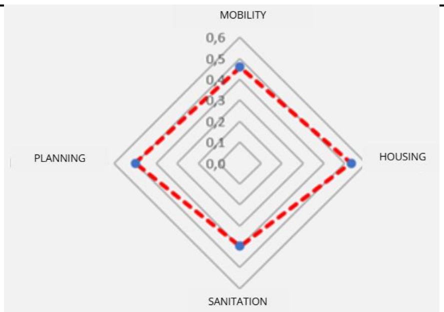
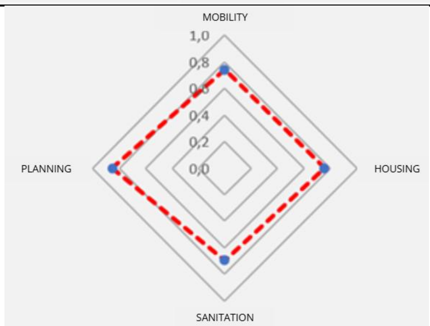
4.4 Dimension values

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

From the normalized values, the arithmetic mean was calculated to obtain the values for the four dimensions: planning, mobility, sanitation and housing. The results by SDI dimensions are presented in Table 7 for the 27 Brazilian municipalities.

In order to better understand the performance of the municipalities in relation to the dimensions, Figures 4 through 7 show the radar graphs referring to each of the municipalities studied, in which the closer to the extremities (value one), the better the performance and the closer to the center (value zero), the worse the performance. Some cities show more balanced development between the four dimensions (Manaus, São Luís, Belo Horizonte and Belém), but rather suggests a lack of targeted public policy or resources in those dimensions.

City	Dimensions radar chart	City	Dimensions radar chart
Figure 4 - Manaus		Figure 5 – São Luís	
Figure 6 – Belo Horizonte		Figure 7 - Belém	

Source: Authors (2025).

4.5 SDI Values

To measure the comparative levels of sustainable urban spatial development of cities, reference values were established. This facilitates the assessment of progress towards achieving these goals by managers and the population, allowing visualization of the cities' positioning in relation to the reference value, as shown in Figure 8.

Figure 8, together with the spatial development bands, clearly shows that no city can yet be classified as having a very high level of urban spatial development. In contrast, Belo Horizonte is the closest city to achieving this level. At the other extreme, it is visible that many municipalities are still at a very low or low level.

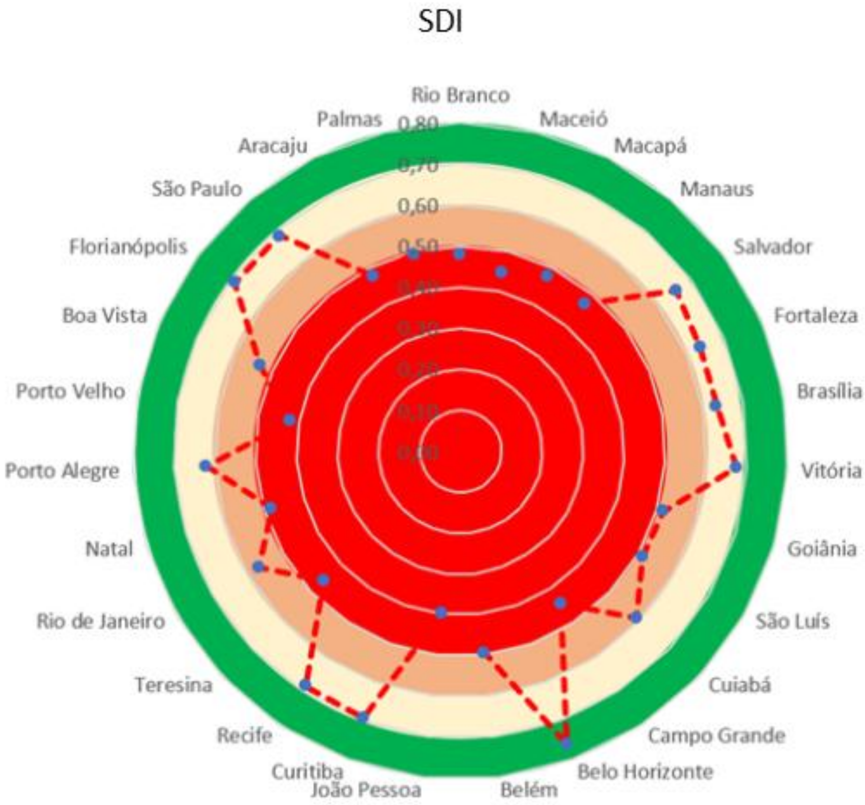
An unbalanced spatial development is evident between the capital cities and the Brazilian Federal District, showing a regional imbalance. Notoriously, the northern region of Brazil shows a higher concentration of cities with values considered very low, except Roraima, which was classified as low. In the northeast and central-west regions, there were cities evaluated as very low (Teresina, Natal, João Pessoa, Maceió, Aracaju and Campo Grande), low

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

(Maranhão, Cuiabá and Goiânia) and medium (Fortaleza, Recife, Salvador and Brasília). In the southeast and south regions, a discrepancy is observed in the scenario compared to the other regions, with a predominance of municipalities evaluated as low (Rio de Janeiro), medium (Vitória, São Paulo, Curitiba, Florianópolis and Porto Alegre) and high (Belo Horizonte).

Figure 8 - Radar graph with the final values of the SDI for each municipality



Source: Authors (2025).

The final result of the values obtained from the SDI for each municipality is presented in Table 8. The SDI values were also calculated using the weighted average of the four dimensions (mobility, housing, planning and sanitation), composed of twelve indicators for the 26 capital cities and the Federal District. It can be observed that the values range from 0.4 (João Pessoa) and 0.76 (Belo Horizonte). It should be noted that in addition to Belo Horizonte, other cities also had a similar performance (0.6 to 0.7): Salvador, Fortaleza, Brasília, Vitória, Curitiba, Recife, Porto Alegre, Florianópolis and São Paulo. Intermediate values (0.5 to 0.6) were observed in the following municipalities: Goiânia, São Luís, Cuiabá, Rio de Janeiro, Boa Vista and Palmas. Cities with SDI values lower than 0.5 are: Rio Branco, Maceió, Macapá, Manaus, Campo Grande, Belém, João Pessoa, Teresina, Natal, Porto Velho and Aracaju.

When we observe the SDI and HDI values, with reference years of 2022 and 2010, respectively (Table 8), it is noticeable that the issue of spatial development in relation to the HDI is presented disparately. Thus, the results obtained with these indices show that spatial development is relevant within the political context, presenting worrying values in more than

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 14, n. 92, 2026

half of the cities analyzed. This is because the urban area is not just a backdrop for everyday situations, but rather, it interferes with how we move, live, and access urban services and infrastructure. The performance of urban spatial development thus assists the government in adopting policies and strategies that guide sustainable development. This is especially important given that education and health currently have mandatory funds allocated to these purposes by the Union, States, and municipalities.

Table 8 - Final result of the values obtained from the SDI (2022) and the HDI (2010) for each municipality (continues)

Municipality	SDI	HDI
Belo Horizonte	0,76	0,81
Curitiba	0,69	0,82
Recife	0,69	0,77
Florianópolis	0,69	0,85
São Paulo	0,69	0,81
Vitória	0,68	0,85
Salvador	0,66	0,76
Fortaleza	0,64	0,75
Brasilia	0,63	0,82
Porto Alegre	0,62	0,81
Cuiabá	0,59	0,79
Rio de Janeiro	0,57	0,80
Boa Vista	0,53	0,75
Goiânia	0,52	0,80
São Luís	0,51	0,77
Palmas	0,50	0,79
Belém	0,49	0,75
Rio Branco	0,48	0,73
Macapá	0,48	0,73
Natal	0,48	0,76
Aracaju	0,48	0,77
Manaus	0,47	0,74
Teresina	0,46	0,75
Maceió	0,45	0,72
Campo Grande	0,44	0,78
Porto Velho	0,42	0,74
João Pessoa	0,40	0,76

Source: Authors (2025).

5 CONCLUSION

This study essentially contributes to the development of the structure focused on spatial development in the urban context, but can also be extended to the development of state and federal policies. It is necessary to seek efficiency in this tool, so that it focuses on the urban territorial issue and is adapted to the Brazilian reality and current legislation.

Therefore, the innovation is the development of a quantitative composite index, with a reduced number of indicators focused on the urban territorial issue, whose objective is the evaluation of urban spatial development at the local level, applicable to municipalities of varying sizes. Allowing a better understanding of the spatial reality of Brazilian municipalities through performance ranges. In this context, public managers can monitor the urban spatial performance of municipalities over time, verifying the need to revise or develop Mobility Plans,

ISSN 2318-8472, v. 14, n. 92, 2026

Master Plan, Basic Sanitation Plan, Housing Plan or specific items within these documents: road hierarchy, road direction, urban perimeter, building height limits, public works management, relocation of the low-income population in risk areas and others.

The SDI structure was developed based on the study of methodologies aimed at developing existing indices, as well as the bibliometric analysis carried out by Yuassa *et al.*, 2025. The results of this research demonstrate that the SDI is an applicable index at the municipal level. The pilot study was carried out in the state capitals together with the Federal District, which are the subject of case studies, comprising a total of 27 municipalities. The data used in the SDI present the base year of 2022 or the period between 2011 and 2022.

The result of the research revealed that in the mobility dimension, in municipalities that have a high rate of fleet growth and low density of fleet connectivity, it is necessary to verify the need to review the road hierarchy and the creation of new alternatives for road connections, to facilitate easier mobility, regardless of the mode of transport. This also includes verifying the feasibility of balancing the modal split through improvements to the public transport system and active modes (walking and/or cycling).

Furthermore, for municipalities with low urban connectivity and higher rates of traffic accident growth, it is important to review the direction of traffic flow to mitigate conflict points.

Also noteworthy is the analysis of the relationship between the high growth of the urban area and low connectivity, which can lead to the phenomenon known as urban sprawl, that is, it can lead to the creation of urban voids. In this context, revising the urban perimeter would be a key point to mitigate the process of urban expansion.

However, when analyzing the housing dimension, a high rate of housing deficit is observed, along with a high percentage of stalled construction projects. There are indications of a need to review public policy regarding stalled public facilities, as well as the social housing policy. It is important to emphasize that the existence of stalled construction projects generates burdens for the municipality, prevents the population from accessing planned services, and creates urban problems such as areas for drug use, areas for acts of sexual violence, and others, thus demonstrating the inefficiency of public management.

In the Planning dimension, it is observed the presence of cities with low performance both in relation to population density, as well as the rate of vacant private households. This enables the development of extensive areas with low population density and a significant portion of vacant dwellings. This generates a burden on the provision of infrastructure and services by the public entity when compared to cities with higher population densities. In view of the complexity of planning issues, it would be important to verify the need to revise or develop the master plan by increasing building heights in certain regions, increasing the extent of mixed uses in conjunction with the road hierarchy.

In general, within the sanitation dimension, the percentage of households served by the urban stormwater drainage network shows the worst performance among the indicators of this dimension, while the percentage of households served by the urban drinking water supply shows a large proportion of municipalities with very high performances. Even so, the universalization of sanitation according to Federal Law No. 14,026/2020 is a great challenge. Especially for infrastructures aimed at drainage and sewage.

ISSN 2318-8472, v. 14, n. 92, 2026

Regarding the results obtained from the SDI of the municipalities, it is observed that the values vary between 0.4 (João Pessoa) and 0.76 (Belo Horizonte). There is an unbalanced spatial development between the capital cities and the Federal District. Notoriously, the northern region of Brazil presents a higher concentration of cities with values considered very low, except Roraima, which was classified as low. In the northeast and central-west regions, there were cities evaluated as very low, low and medium. In the southeast and south regions, a discrepancy is observed in the scenario compared to the other regions, with a predominance of municipalities evaluated as low, medium, and high.

Finally, a comparative analysis was carried out between the results of the SDI and the HDI, revealing that spatial development is relevant within the political context, presenting worrying values in more than half of the cities analysed. This is because the urban area is not merely a backdrop for everyday situations, but rather influences how we move, live, and access urban services and infrastructure. Currently, education and health have mandatory funding allocated to these purposes by the federal, state, and municipal governments. Investments in Master Plans and Sectoral Plans, along with the improvements in public policies aimed at housing, sanitation, mobility and planning, are crucial for the survival of urban areas and the populations that inhabit them.

This study presented some limitations, such as the availability of official data in public databases, given that some indicators were not available on public platforms, such as sidewalk with wheelchair ramp and average travel time, according to the IBGE. It is also important to develop a single, easily accessible database, fed by the municipalities with information on land use (distinguishing the percentage of areas destined for residential, mixed, commercial, industrial, and leisure use), green areas and land areas parcels. Another limitation to be pointed out is the need to stratify data from urban and rural areas, such as the percentage of stalled construction projects and the proportion of households at risk of flooding. It is important to initially present consensual definitions for each of these areas, so that this information can be stratified later. The sample size is also a limitation; it is important to apply the SDI to a larger number of municipalities, especially small ones (there was no representativeness).

Other research could apply SDI in the same cities as the case study, to verify and adapt SDI over time.

REFERENCES

ARAÚJO, L. T.; ALMEIDA, G. V. A. De; SANTOS, B. N. M. Dos. O ambiente de negócio nos municípios do Espírito Santo visto por um indicador composto. **Revista de Desenvolvimento Econômico**, v. 3, n. 50, 2021. Disponível em: https://revistas.unifacs.br/index.php/rde/article/download/7300/4558. Acesso em: 24 dez. 2023.

ARCADIS. **Citizen Centric Cities: The sustainable Cities Index**. 2018. Disponível em: https://www.arcadis.com/campaigns/citizencentriccities/images/%7B1d5ae7e2-a348-4b6e-b1d7-6d94fa7d7567%7Dsustainable_cities_index_2018_arcadis.pdf. Acesso em: 23 ago. 2021.

BAHIA, L. O. **Guia referencial para construção e análise de indicadores**. Brasília: ENAP, 2021. Disponível em: https://www.gov.br/economia/pt-br/centrais-de-conteudo/publicacoes/guias-e-manuais/defeso/gr-construindo-e-analisando-indicadores-final.pdf/view. Acesso em: 08 de jul. 2023.

BHATTACHARYA, T. R.; BHATTACHARYA, A.; MCLELLAN, B. C.; TEZUKA, T. Sustainable smart city development framework for developing countries**. Urban Research and Practice**, 2020. Disponível em:

ISSN 2318-8472, v. 14, n. 92, 2026

https://www.researchgate.net/publication/329260650_Sustainable_smart_city_development_framework_for_developing_countries. Acesso em: 31 ago. 2021.

COHEN, J. A power primer. **Psychological Bulletin**. 1992, Vol.112, 155-159.

DATASUS. **TABNET**. [S. l.], 2022. Disponível em: http://tabnet.datasus.gov.br/cgi/tabcgi.exe?logtabnet/log.def. Acesso em: 18 nov. 2024.

CENTRO DE LIDERANÇA PÚBLICA (CLP). **Ranking de competitividade dos Estados**. 2022. Disponível em: https://www.clp.org.br/wp-content/uploads/2022/09/Relatorio_tecnico_2022_set_22.pdf. Acesso em: 24 dez. 2023.

ECONOMIC COMMISSION FOR EUROPE (OECD). **Spatial Planning: Key Instrument for Development and Effective Governance with Special Reference to Countries in Transition**. Nova York e Geneva, 2008. Disponível em: https://unece.org/sites/default/files/2022-01/spatial_planning_e.pdf. Acesso em: 09 dez 2023.

ESRI. **Creating Composite Indices Using ArcGIS: Best Practices**. [*S. l.*], 2023. Disponível em: https://www.esri.com/content/dam/esrisites/en-us/media/technical-papers/creating-composite-indices-using-arcgis.pdf. Acesso 31 out. 2023.

FOUNDA, Y. E.; ELKHAZENDAR, D. M. A Criterion for modelling the 'live-and-work' city index using sustainable development indicators. **International Journal of Urban Sustainable Development**, 2018, Volume 11, 2018 - Issue 1. Disponível em: https://www.researchgate.net/publication/329754465_A_criterion_for_modelling_the_'live-and-work'_city_index_using_sustainable_development_indicators. Acesso em: 13 jan. 2022.

FU, S.; ZHUO, H.; SONG, H.; WANG, J.; REN, L. Examination of a coupling coordination relationship between urbanization and the eco-environment: a case study in Qingdao, China. **Environmental Science and Pollution Research,** 2020. Disponível em: https://www.researchgate.net/publication/340719201_Examination_of_a_coupling_coordination_relationship_between_urbanization_and_the_eco-. Acesso em: 01 set. 2021.

HASSAN, A.; KOTVAL-K, Z. A framework for measuring urban sustainability in an emerging region: The city of Duhok as a case study. **Sustainability** (Switzerland), v. 11, n. 19, 2019. Disponível em: https://www.mdpi.com/2071-1050/11/19/5402. Acesso em: 31 ago. 2021.

IBGE **Censo demográfico brasileiro 2022**. [*S. l.*], 2022. Disponível em: https://www.ibge.gov.br/estatisticas/sociais/trabalho/22827-censo-demografico-2022.html. Acesso em: 18 nov. 2024.

IBGE. **Pesquisa Nacional por Amostra de Domicílios Contínua**. [*S. l.*], 2022. Disponível em: https://www.ibge.gov.br/estatisticas/sociais/trabalho/9171-pesquisa-nacional-por-amostra-de-domicilios-continua-mensal.html. Acesso em: 20 ago. 2023.

IESE. **City in Motion Index**. 2020. Disponível em: https://media.iese.edu/research/pdfs/ST-0542-E.pdf. Acesso em: 24 ago. 2021.

KOTHARKAR, R.; PALLAPU, A. V.; BAHADURE, P. Urban Cluster-Based Sustainability Assessment of an Indian City: Case of Nagpur. **Journal of Urban Planning and Development**, v. 145, n. 4, 2019. Disponível em: https://www.researchgate.net/publication/336217710_Urban_Cluster-Based_Sustainability_Assessment_of_an_Indian_City_Case_of_Nagpur. Acesso em: 02 set. 2021.

LAFORTUNE, G.; FULLER, G.; SCHIMIDT-TRAUB, G.; ZOETERMAN, K.; MULDER, R.; DAGEVOS, J. **European cities: SDG Index and dashboards report**. 2019. Disponível em: https://s3.amazonaws.com/sustainabledevelopment.report/2019/2019_sdg_index_euro_cities.pdf. Acesso em: 27 ago. 2021.

LEAL, T. L. M. De C.; SILVA, T. B..; FIGUEIRÊDO, S. Da S. M.; LOPES, W. G. R.; ZANELLA, M. E. Sustentabilidade urbana no Brasil e suas aplicações: uma revisão sistemática. **Revista Nacional de Gerenciamento de Cidades**, 2022. V. 10, n. 76. Disponível em:

ISSN 2318-8472, v. 14, n. 92, 2026

https://publicacoes.amigosdanatureza.org.br/index.php/gerenciamento_de_cidades/pt_BR/article/view/3181/3097. Acesso em: 17 jan. 2026.

MAPBIOMAS. **Estatísticas 2022**. [*S. l.*], 2022. Disponível em: https://brasil.mapbiomas.org/estatisticas/. Acesso em: 18 nov. 2024.

NEVES, J. A.; MELO, S. DE B.; SAMPAIO, E. V. S. B. **Um índice de suscetibilidade ao fenômeno da seca para o semiárido nordestino**. 2011. Disponível em: https://www.sbagro.org/files/biblioteca/3671.pdf. Acesso em: 24 dez. 2023.

SÁEZ, L.; HERAS-SAIZARBITORIA, I.; RODRÍGUEZ-NÚÑEZ, E. Sustainable city rankings, benchmarking and indexes: Looking into the black box. **Sustainable Cities and Society**, v. 53, 2020. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S2210670719321754. Acesso em: 10 maio 2021.

SENATRAN. **Registro Nacional de Estatísticas e Sinistros de Trânsito** 2022. [*S. l.*], 2022. Disponível em: https://www.gov.br/transportes/pt-br/assuntos/transito/arquivos-senatran/docs/renaest. Acesso em: 18 nov. 2024.

SILVA, M. L. G. Da.; CÂNDIDO, G. A.; LIMA, E. R. V. De. Priorizando Indicadores de Sustentabilidade Urbana: Uma Análise Participativa com Base na Metodologia do Programa Cidades Sustentáveis. **Revista Nacional de Gerenciamento de Cidades**, 2022. V. 13, n. 88. Disponível em: https://publicacoes.amigosdanatureza.org.br/index.php/gerenciamento_de_cidades/pt_BR/article/view/5775/5746. Acesso em: 17 jan. 2026.

SNIS. **Série histórica 2022**. [*S. l.*], 2022. Disponível em: https://www.gov.br/cidades/pt-br/acesso-a-informacao/acoes-e-programas/saneamento/snis. Acesso em: 07 out. 2024.

STEINIGER, S.; WAGEMANN, E.; BARRERA, F. De La; MOLINOS-SENANTE, M.; VILLEGAS, R.; FUENTE, H. De La.; VIVES, A.; ARCE, G.; HERRERA, J.-C.; CARRASCO, J.-A.; PASTÉN, P. A.; MUÑOZ, J.-C.; BARTON, J. R. Localizing urban sustainability indicators: The CEDEUS indicator set, and lessons from an expert-driven process. **Cities**, v. 101, 2020. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S0264275118305523. Acesso em: 02 set. 2021.

SUN, X.; LIU, X.; LI, F.; TAO, Y.; SONG, Y. Comprehensive evaluation of different scale cities' sustainable development for economy. **Journal of Cleaner Production**, v. 163, 2018. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S0959652615012238. Acesso em: 02 set. 2021.

TCU. **Painéis de informações TCU 2022**. [*S. l.*], 2022. Disponível em: https://paineis.tcu.gov.br/pub/?workspaceId=8bfbd0cc-f2cd-4e1c-8cde-6abfdffea6a8&reportId=013930b6-b989-41c3-bf00-085dc65109de&filterPaneEnabled=false&navContentPaneEnabled=false. Acesso em: 18 nov. 2024.

UN HABITAT. **Measurement of city prosperity: methodology and metadata**. 2016. Disponível em: https://unhabitat.org/sites/default/files/2019/02/CPI-METADATA.2016.pdf. Acesso em: 23 ago. 2021.

UNITED NATIONS HUMAN SETTLEMENTS PROGRAMME (UN-HABITAT). **Envisaging the future of cities**. 2022. Disponível em: https://unhabitat.org/sites/default/files/2022/06/wcr_2022.pdf. Acesso em: 26 nov. 2023.

YUASSA, V. N.; GONÇALVES, L. M.; GUERREIRO, T. De C. M. Revisão sistemática da literatura sobre índices voltados à sustentabilidade urbana. **Revista Nacional de Gerenciamento de Cidades**, [S. l.], v. 13, n. 88, 2025. DOI:10.17271/23188472138820255599. Disponível em: https://publicacoes.amigosdanatureza.org.br/index.php/gerenciamento_de_cidades/pt_BR/article/view/5599. Acesso em: 15 fev. 2025.

ZULAICA, L. Is Mar del Plata (Argentina) a sustainable city? An evaluation of the sustainability of urban and peri-urban areas using indicators. **Sustentabilidade em Debate**, v. 10, n. 2, 2019. Disponível em: https://periodicos.unb.br/index.php/sust/article/download/20646/23447/55314. Acesso em: 31 ago. 2021.

ISSN 2318-8472, v. 14, n. 92, 2026

STATEMENTS

CONTRIBUTION OF EACH AUTHOR

When describing each author's participation in the manuscript, use the following criteria:

- **Conception and Study**: **Design**: Vanessa N. Yuassa, Luciana M. Gonçalves, Thais de C. M. Guerreiro.
- **Data Curation**: Vanessa N. Yuassa.
- **Formal Analysis**: Vanessa N. Yuassa, Luciana M. Gonçalves, Thais de C. M. Guerreiro.
- **Funding Acquisition**: None.
- **Investigation**: Vanessa N. Yuassa.
- **Methodology**: Vanessa N. Yuassa, Luciana M. Gonçalves, Thais de C. M. Guerreiro.
- **Writing - Original Draft**: Vanessa N. Yuassa.
- **Writing - Critical Review**: Vanessa N. Yuassa, Luciana M. Gonçalves, Thais de C. M. Guerreiro.
- **Review and Final Editing**: Vanessa N. Yuassa, Luciana M. Gonçalves, Thais de C. M. Guerreiro.
- **Supervision**: Luciana M. Gonçalves, Thais de C. M. Guerreiro.

DECLARATION OF CONFLICTS OF INTEREST

We, Vanessa Naomi Yuassa, Luciana Márcia Gonçalves and Thais de Cassia Martinelli Guerreiro**, declare that the manuscript entitled "Sustainable Spatial Development Index (SDI)"**:

1. **Financial Relationships**: Has no financial relationships that could influence the results or interpretation of the work. No institution or funding entity was involved in the development of this study.
2. **Professional Relationships**: Has no professional relationships that may impact the analysis, interpretation or presentation of the results. No professional relationship relevant to the content of this manuscript has been established.
3. **Personal Conflicts**: Has no personal conflicts of interest related to the content of the manuscript. No personal conflicts related to content were identified.