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ANALYSIS OF URBAN WELL-BEING IN THE BAIXO SUL (SOUTHERN LOWLANDS) IDENTITY TERRITORY (BAHIA): A MULTIVARIATE STATISTICAL APPROACH

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Abstract

The study analyzes urban well-being in the Baixo Sul Identity Territory, in the state of Bahia, Brazil, using the Urban Well-Being Index (IBEU) and its five dimensions: urban mobility, environmental conditions, housing conditions, urban collective services, and urban infrastructure. The research adopts a quantitative approach based on descriptive statistics, correlation and covariance analysis, and multiple linear regression. The results indicate that the region exhibits a moderate level of urban well-being (0.733), with relative homogeneity among municipalities but asymmetry across the index dimensions. Urban mobility stands out as the region's main strength, whereas urban infrastructure represents its primary bottleneck. The correlation analysis reveals a strong association between the IBEU and urban infrastructure ($r = 0.67$), as well as a substantial relationship with the provision of urban collective services ($r = 0.71$). The regression analysis demonstrates a high explanatory power ($R^2 = 0.999$), with all dimensions exerting a significant influence on the index. The findings suggest that improving urban well-being in the region depends on structural investments and integrated public policies aimed at enhancing urban infrastructure and expanding urban collective services.

Keywords: *IBEU. Infrastructure. Public policies. Urban inequality. Urban planning.*

1 INTRODUCTION

There are several tools that can be used to support decision-making processes regarding the planning of public policies, such as synthetic and multidimensional indicators, which serve as strategic instrument during the implementation of actions aimed at generating benefits for the population to be assisted [1-5].

Population growth, economic development, and climate change are factors that contribute to the occurrence of rural exodus and, consequently, to the increase in the urban population - a condition that demands the provision of urban collective services and changes in the dimension of local infrastructure, aimed at generating urban well-being for the population [5-9].

It is predicted that by 2050, approximately 64% of the world's population will live in urban areas, increasing the demand for public policies aimed at improving the dimensions of urban well-being. This scenario poses significant challenges for policymakers responsible for promoting social equity, sustainable urban development, and environmental preservation [5-9].

The state of Bahia, located in the Northeast Region of Brazil, is territorially organized into seven mesoregions, 32 microregions, and 27 Identity Territories, which comprise municipalities that share historical, cultural, socioeconomic, and geographical characteristics. These characteristics influence regional and local development processes [5, 10-12]. The administrative division into 27 Identity Territories aims to reduce persistent socioeconomic and spatial inequalities, primarily through interventions in urban infrastructure and urban public services.

Territory can be understood as a social and political construction, in which relations of power, identity, and belonging are established, interacting with environmental, economic, social, and cultural factors, which are determinant for development in its multiple dimensions [5. 13-16].

In recent decades, rapid urban growth has directly affected the quality of life in cities, particularly in regions characterized by high levels of socio-spatial inequality, posing significant challenges for public policymakers and urban managers [17].

One of the tools used to measure urban conditions in a multidimensional way is the Urban Well-Being Index (IBEU), which has the ability to contribute to the formulation of more efficient public policies through effective territorial planning. This instrument is characterized by diagnosing the quality of life in urban areas, as it integrates five dimensions that reflect the structural and functional characteristics of a municipality, such as urban mobility, housing conditions, environmental conditions, urban collective services, and urban infrastructure.

Studies addressing regional development and the integration of urban well-being within the Identity Territories remain limited, particularly in the Baixo Sul (Southern Lowlands) Identity Territory, which covers an area of 7,611.6 km², corresponding to approximately 1.4% of the total land area of the state of Bahia [5, 10-12]. Historically, the territorial occupation of Bahia has played an important role in the region's development by contributing to the decentralization and expansion of economic activities [5, 10-12].

In this context, the following research question arises: What are the patterns, inequalities, and main determinants of urban well-being in the municipalities of the Baixo Sul Identity Territory?

This study is based on the hypothesis that urban well-being in the region is marked by significant heterogeneity among its structural dimensions, and that variables related to urban infrastructure and urban collective services exert greater influence on the IBEU.

Thus, the objective of this study is to analyze the level of urban well-being in the municipalities of the Baixo Sul Identity Territory, Bahia, based on the five dimensions of the IBEU, identifying patterns, inequalities, and explanatory factors through the application of multivariate statistical techniques.

The originality of this study lies in the application of an integrated quantitative approach at a territorial level, still little explored in the literature, by combining the use of the IBEU with multivariate statistical methods to understand the relationships between its dimensions. In addition, the study contributes to the advancement of knowledge by providing empirical evidence applied to a specific territory, offering relevant subsidies for urban planning, the formulation of public policies, and decision-making by local and regional managers.

2 METHODOLOGY

This research is characterized as quantitative, of applied nature, with descriptive, analytical, and explanatory character, based on the analysis of secondary data referring to the municipalities of the Baixo Sul Identity Territory, in Bahia. The quantitative approach is adopted because it allows the objective measurement of the relationships between variables and the identification of structural patterns in the behavior of urban well-being [18].

Exploratory analysis allows for greater familiarity with the problem investigated, while descriptive research enables the systematic characterization of phenomena and the identification of patterns [18].

The approach also incorporates qualitative elements of interpretative support, aiming at understanding the phenomena based on empirical evidence that supports the theoretical interpretation of the study [19]. It is, therefore, a mixed approach, in which quantitative analysis is predominant and qualitative analysis acts in a complementary way.

The methodological strategy was based on data triangulation [20], combining bibliographic research, documentary research, and statistical analysis, with the aim of increasing the analytical robustness and internal validation of the findings. In addition, the multiple case study method [20] was adopted, allowing an in-depth analysis of the IBEU in the Brazilian context, based on data from the year 2016. It is noteworthy that the absence of more recent data configures a time limitation. The time frame of the research prioritized publications from the year 2000 onwards, admitting previous seminal references when essential for the theoretical foundation.

The methodological foundation is based on three main components:

(i) **Bibliographic research**, based on relevant academic literature, including scientific articles, books, and academic works such as undergraduate monographs, master's dissertations, and doctoral theses;

(ii) **Documentary research**, based on secondary data from the National Institute of Science and Technology – INCT Observatory of the Metropolis; and

(iii) **Use of Microsoft Excel software** for data organization, processing, and statistical analysis.

The bibliographic research consisted of a systematic survey in databases such as Google Scholar, SciELO, CAPES Journal Portal, and Web of Science, using Boolean combinations of the descriptors "IBEU", "urban well-being index", "identity territory", "Southern Lowlands", "territorial governance", "urban inequality", "public policies", "infrastructure", "urban planning", "urban development", "socio-spatial inequalities", "regression", "covariance", "correlation", and "descriptive statistics", in Portuguese and English.

The Baixo Sul Identity Territory was chosen as the main case, of a paradigmatic nature, due to its socio-spatial specificities and as a way to complement studies already carried out in the region with a focus on the IBEU.

The study contemplates the 15 municipalities of the Baixo Sul Identity Territory as units of analysis, enabling intermunicipal comparison and the identification of intra-regional heterogeneities, considering the five dimensions of the IBEU. They are: Cairu, Aratuípe, Camamu, Gandu, Ibirapitanga, Igrapiúna, Ituberá, Jaguaripe, Nilo Peçanha, Piraí do Norte, Presidente Tancredo Neves, Taperoá, Teolândia, Valença, and Wenceslau Guimarães {5, 10-12].

The data were analyzed through content analysis [21], structured in the stages of pre-analysis, material exploration, and treatment of the results. The variables analyzed were:

- IBEU (dependent variable);
- D1: Urban mobility;
- D2: Environmental conditions;
- D3: Housing conditions;
- D4: Urban collective services;
- D5: Urban infrastructure [23].

The indicators follow the IBEU methodology, with values ranging from 0 to 1. The analysis techniques used include:

- Descriptive statistics (mean, standard deviation, and asymmetry);
- Pearson's correlation analysis;
- Covariance analysis;
- Multiple linear regression.

Initially, a descriptive statistical analysis was conducted, including measures of central tendency (mean), dispersion (standard deviation), and distribution shape (skewness), with the aim of characterizing the distribution of the variables.

Next, Pearson's correlation analysis was conducted to identify the degree of linear association between the independent variables and the IBEU, as well as to assess potential multicollinearity among the explanatory variables. In addition, covariance analysis was performed to evaluate the combined influence of the explanatory variables on the IBEU while controlling for potential interaction effects among the variables.

For the inferential analysis, a multiple linear regression model was estimated using the Ordinary Least Squares (OLS) method, as specified below:

$$\mathbf{IBEU = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \varepsilon} \quad \mathbf{(1)}$$

Where:

β0 represents the intercept;

β1 to β5 correspond to the regression coefficients associated with the explanatory variables;

ε represents the random error term, assumed to have a mean of zero, constant variance (homoscedasticity), and no autocorrelation.

The choice of the multiple linear regression model is justified by its ability to estimate the marginal effect of each IBEU dimension on the general level of urban well-being, allowing the identification of variables with greater explanatory power.

To ensure the validity of the results, the classic assumptions of the OLS regression model were considered:

- Linearity between the dependent and independent variables;
- Normality of the residuals, evaluated by graphical and statistical analysis;
- Homoscedasticity, verified by analysis of the residuals' variance;
- Independence of the error terms, assumed due to the cross-sectional nature of the data [22].

The analysis was conducted using a significance level of 5% ($p < 0.05$), which is the conventional threshold adopted in the economics and applied social science literature.

Counterfactual simulations were performed based on the estimated coefficients to assess the potential impact of improvements in the structural dimensions on the IBEU, thereby providing practical insights for urban planning.

The treatment and analysis of the data were carried out with the aid of Microsoft Excel software, and the results were interpreted in the light of the literature on urban development, public policies, and socio-spatial inequalities.

Finally, although the model demonstrates high explanatory power, its findings should be interpreted with caution due to the small sample size (n = 15) and the aggregated nature of the data, both of which may limit the generalizability of the results.

3 RESULTS AND DISCUSSION

The Baixo Sul Territory of Identity presents an intermediate level of urban well-being, characterized by relative homogeneity among the municipalities, but with structural asymmetries between the dimensions analyzed.

The results show a scenario of uneven urban development, marked by significant contrasts between the different dimensions that make up the IBEU.

High urban mobility may be associated with territorial configuration and shorter commuting time in small and medium-sized cities. However, this performance does not automatically translate into higher levels of urban well-being, as evidenced by the moderate correlation with the IBEU

On the other hand, urban infrastructure has a strong impact on the index, reinforcing the importance of public policies aimed at improving elements such as public lighting, road paving, sidewalks, curbs, drainage systems (manholes and storm drains), accessibility infrastructure (ramp for wheelchair users), and the identification of public space. This dimension is configured as the main structural bottleneck, whose deficiencies directly compromise the population’s quality of life.

Although the regression model indicates a formal balance among the dimensions of the IBEU, the correlation analysis reveals that urban infrastructure and urban collective services exert greater practical influence on well-being, suggesting that public policies directed to these areas tend to generate more significant impacts.

The coexistence of good urban mobility conditions with low levels of urban infrastructure indicates a pattern of functional but structurally precarious urbanization, characteristic of developing regions, where spatial accessibility is not accompanied by proportional investments in urban infrastructure.

3.1 GENERAL ANALYSIS OF IBEU

The average IBEU value (0.733) indicates an "**Medium**" level of urban well-being, with a variation between 0.664 (Jaguaripe) and 0.784 (Valença). This ranking suggests that while urban well-being is not critically low, there is still significant room for improvement across the region. No municipality reaches the classification "**Good**" or "**Excellent**". A distribution with slight negative skewness (-0.219) and low dispersion (SD = 0.038) is observed, indicating relative homogeneity among the municipalities. This results suggests that urban conditions are, to a large extent, regionally shared.

3.2 PERFORMANCE BY MUNICIPALITY

The highest IBEU score were observed in Valença (0.784), Camamu (0.782), and Nilo Peçanha (0.778). Valença stands out for having the highest score in urban collective services (0.885), which contributes to a higher IBEU. Camamu shows a balanced performance, with emphasis on the dimensions of housing conditions (0.822) and urban mobility (0.931).

On the other hand, the worst performances were recorded in Jaguaripe (0.664), Igrapiúna (0.684), and Teolândia (0.697). Jaguaripe has low values in urban collective services (0.505) and urban infrastructure (0.374), while Igrapiúna has the lowest score in urban infrastructure in the entire set analyzed (0.341). This differentiation is associated, above all, with the capacity to provide urban collective services and the quality of local infrastructure.

The relatively small difference between the municipalities indicates a moderate level of intra-regional inequality. In general, the municipalities with the best performance tend to have greater coverage of urban collective services and better urban infrastructure conditions.

3.3 PERFORMANCE BY DIMENSION

The decomposition of the IBEU reveals unequal performances between the analyzed dimensions, evidencing a relatively homogeneous urban structure among the municipalities, but unbalanced among its components:

- **D1 - Urban Mobility (0.925):** this is the dimension with the best performance, classified as "**Excellent**". It stands out as the main regional asset, indicating efficiency in commuting, especially on the commute, in which the employed population spends mostly less than an hour. This is a positive indicator for economic integration and quality of life.
- **D3 - Housing Conditions (0.794):** classified as "**Medium**" and close to the "**Good**", reflecting relatively adequate structural conditions of the houses. Approximately 79.4% of residents live in adequate housing, with no significant presence of subnormal agglomerations or overcrowding.
- **D2 - Environmental Conditions (0.763):** also classified as "**Medium**", it reflects heterogeneity and partial adequacy of the urban environment, considering aspects such as afforestation, presence of open sewage systems, and waste accumulation. It presents high variability (SD =

0.069), indicating relevant differences among municipalities. Cairu (0.887) stands out as a reference in this dimension.

- **D4 - Urban Collective Services (0.738):** presents intermediate performance, classified as "**Medium**", but with high variability (SD = 0.094) and wide inequality (interval = 0.380), evidencing inconsistency in access among municipalities. These results indicate limitations in the coverage and quality of essential services, such as water supply, sewage, electricity, and solid waste collection. Valença has a high performance in this dimension, while Jaguaripe (0.505) registers the worst result, configuring itself as a priority for interventions.
- **D5 - Urban Infrastructure (0.446):** is the dimension with the worst performance, classified as "**Poor**", constituting the main regional bottleneck. It highlights deficiencies in fundamental urban elements, such as paving, accessibility, and urban equipment. This limitation directly compromises overall quality of life. Aratuípe (0.625) has the best relative performance, indicating potential for improvement, while Igrapiúna (0.341) requires urgent investments, especially in paving, sidewalks, and public lighting.

In summary, the main strength of the region is urban mobility, characterized by efficient travel times, while the main critical point lies in urban infrastructure, marked by the low physical quality of urban space.

This pattern reveals an urbanization dynamic characterized by functionality without adequate structural support, in which operational aspects, such as urban mobility, coexist with physical and structural weaknesses of the urban space.

3.4 ANALYSIS OF THE DESCRIPTIVE STATISTICS OF THE IBEU AND ITS DIMENSIONS

The descriptive analysis allows us to understand the central behavior, dispersion and distribution of IBEU data and its five dimensions in the Baixo Sul Identity Territory. The interpretation can be organized into four main axes: average level of urban well-being, dispersion, and inequality between municipalities, amplitude and extremes (minimum and maximum), and distribution shape (skewness and kurtosis).

3.4.1 AVERAGE LEVEL OF URBAN WELL-BEING

The average IBEU value (0.733) indicates that the territory has a "**Medium**" level of urban well-being, according to the adopted classification. There was low dispersion (SD = 0.037) and a range between 0.664 and 0.784, showing an intermediate level of urban well-being and relative homogeneity among the municipalities.

However, there is a strong asymmetry among the dimensions. Urban mobility stands out as its main strength, with high performance and high homogeneity. In contrast, urban infrastructure is configured as the main weakness, with low structural level, characterizing a functional urbanization pattern – with good urban mobility, but structurally deficient.

The proximity between mean (0.733) and median (0.732) suggests a relatively balanced distribution, without a strong concentration of extreme values. The absence of a mode in the environmental conditions dimension indicates a distribution without a predominance of repeated values, reinforcing the heterogeneity among municipalities.

3.4.2 DISPERSION AND INEQUALITY AMONG MUNICIPALITIES

The IBEU standard deviation is relatively low (0.038), indicating low overall variability among municipalities. However, the analysis by dimensions reveals distinct patterns:

- **Urban Collective Services (SD = 0.094), Urban Infrastructure (SD = 0.089),** and **Environmental Conditions (SD = 0.070)** present the greatest dispersions, evidencing significant territorial inequalities.
- **Urban Mobility (SD = 0.029)** and **Housing Conditions (SD = 0.032)** show low variability, suggesting greater homogeneity among municipalities.

These results indicate that, although the IBEU varies little among the municipalities, the dimensions that compose it present relevant inequalities, such as urban collective services and urban infrastructure. In other words, municipalities with similar levels of well-being can achieve these outcomes through distinct combinations of urban conditions.

3.4.3 AMPLITUDE AND EXTREMES (MINIMUM AND MAXIMUM)

The break reinforces this reading:

- **Greater range**: urban collective services (0.380) → greater inequality.
- **Urban Infrastructure (0.284)** → high inequality.
- **Environmental Conditions (0.238)** → relevant change.
- **IBEU (0.120)** → low variation.
- **Smaller range**: urban mobility (0.100) and housing conditions (0.103) → greater uniformity.

The dimensions of urban collective services and urban infrastructure present the greatest inequalities in the territory, indicating significant differences in the provision of public policies and evidencing structural inequalities.

3.4.4 SHAPE OF THE DISTRIBUTION (SKEWNESS AND KURTOSIS)

The analysis of skewness and kurtosis allows us to understand the shape of data distribution:

The skewness indicates the behavior of the distribution:

- **IBEU (-0.219):** slight negative asymmetry → predominance of municipalities with relatively higher results;
- **Urban Collective Services (-1.123):** strong negative skewness → concentration at higher values, despite the presence of critical cases;
- **Urban Infrastructure (1.007):** positive skewness → concentration in low levels of service.

The negative skewness of urban collective services indicates a concentration of municipalities with higher values, with few cases of very low performance. On the other hand, the positive skewness of urban infrastructure suggests concentration at reduced levels, indicating that this dimension is structurally deficient in most municipalities.

Kurtosis indicates the degree of concentration of the data:

- **Negative values**: IBEU (-0.993), urban mobility (-0.582), housing conditions (-0.358), environmental conditions (-0.784), and urban infrastructure (-0.178) indicate flatter distributions (platykurtic), with greater precision.
- **Positive values**: Urban collective services (2.125) present positive kurtosis (leptokurtic), indicating a higher concentration around the mean, with the presence of extreme values.

Urban collective services have a higher concentration around the average, but with relevant extremes, while the other dimensions have greater relative dispersion.

3.4.5 PRECISION OF THE ESTIMATES

The precision of the estimates is evidenced by the standard error and the 95% confidence intervals.

The standard errors are low, indicating reliable estimates, especially for urban mobility (0.0074) and housing conditions (0.0083), which demonstrates the high precision of the estimated means. On the other hand, urban collective services (0.0242) and urban infrastructure (0.0229) present higher standard errors, suggesting less stability of these estimates.

The 95% confidence intervals reinforce this interpretation, showing greater uncertainty in urban collective services (± 0.052) and urban infrastructure (± 0.049), and greater robustness in urban mobility (± 0.016), housing conditions (± 0.018), and the IBEU (± 0.021). In general, the results show statistical consistency and low uncertainty in the estimated means.

The analysis of the minimum and maximum values shows that the IBEU presents moderate variation (0.664 to 0.784), while the urban infrastructure consistently presents low levels (0.341 to 0.625). On the other hand, urban collective services show a wide variation (0.505 to 0.885), evidencing inequalities in access.

3.4.6 SUMMARY OF STRUCTURAL PATTERNS

The descriptive analysis shows three structural patterns:

- **High and homogeneous performance**: urban mobility and housing conditions
- **Intermediate performance with inequalities**: environmental conditions and urban collective services
- **Low and structurally critical performance**: urban infrastructure.

The results show that urban well-being in the territory is moderate and unequal, with a strong influence of structural dimensions. While urban mobility and housing present more consolidated patterns, urban infrastructure and urban collective services are the main bottlenecks, with high dispersions and amplitudes, indicating the need for public policies aimed at reducing territorial inequalities.

The skewness analysis reinforces this diagnosis by evidencing the concentration of low levels of urban infrastructure in most municipalities.

In summary, the region has an "**Medium"** level of urban well-being and relative homogeneity among municipalities; urban infrastructure is the main structural problem; urban collective services, and urban infrastructure represent the greatest territorial inequalities; and urban mobility has a high and uniform standard. These results indicate an unbalanced urbanization process.

The descriptive statistics confirm that the Baixo Sul Identity Territory presents an urban development model characterized by a general balance of well-being, but sustained by strong structural disparities between dimensions, especially with regard to urban infrastructure, whose precariousness is the main obstacle to raising the regional quality of life.

3.5 ANALYSIS OF THE PEARSON CORRELATION MATRIX (r) AND ITS DIMENSIONS

The correlation aims to verify the linear association between two variables related to the regression analysis. The coefficient measures the linear strength of this association

Pearson's correlation matrix allows us to identify the degree and direction of the standardized linear association between the IBEU and its structural dimensions (values between -1 and +1), evidencing the different levels of influence of these dimensions on urban well-being. Unlike covariance, Pearson's correlation allows direct comparison of the intensity of the associations. Interpretation can be organized into three aspects: (i) the relationship between the IBEU and its dimensions; (ii) the relationship among the dimensions; and (iii) their structural implications.

3.5.1 CORRELATION OF THE DIMENSIONS WITH THE IBEU

The correlation matrix between IBEU and its dimensions presents the following values:

- **Urban Infrastructure (r = 0.759):** this dimension exhibits the strongest correlation with the IBEU, making it the principal determinant of urban well-being in the territory. This result indicates that elements such as public lighting, road paving, sidewalks, curbs, drainage systems (storm drains and manholes), accessibility infrastructure (ramps for wheelchair users), and the identification of public spaces constitute the main structural bottleneck. Municipalities with better urban infrastructure tend to achieve significantly higher IBEU values, reinforcing the central role of public policies aimed at improving this dimension.
- **Urban Collective Services (r = 0.709):** represent the second most relevant dimension, with a strong association with the IBEU. Access to essential services - such as water supply, sewage systems, electricity, and solid waste collection - is a determining factor for urban well-being. This result reinforces the need for public policies aimed at the expansion and qualification of basic public services. In practical terms, municipalities with better paving, public Lighting, and water and sewage networks have significantly higher well-being.
- **Urban Mobility (r = 0.537):** presents a moderate positive correlation with the IBEU. Although this dimension has a high absolute performance (0.925), its association with the index is intermediate, indicating that good commuting times do not guarantee, in isolation, high levels of urban well-being. It is noteworthy that the regression coefficient associated with urban mobility is relatively high, suggesting a significant contribution when controlling for the effects of the other variables. Its correlation with the IBEU indicates that having good commuting times does not necessarily guarantee a high overall quality of life, as this dimension is independent of critical factors such as urban infrastructure.
- **Environmental Conditions (r = 0.372)** and **Housing Conditions (r = 0.441):** present lower correlations, indicating less explanatory power over IBEU variations. These results suggest greater homogeneity among municipalities in these dimensions or more indirect impacts on urban well-being. Housing conditions have a moderate relationship with the IBEU, while environmental conditions is the dimension least associated with the IBEU, that is, the environment explains little about the variation in urban well-being in the territory.

In general, all correlations are positive, indicating that improvements in any dimension tend to increase urban well-being. However, a clear hierarchy of influence can be observed:

Urban Infrastructure (0.759) > Urban Collective Services (0.709) > Urban Mobility (0.537) > Housing Conditions (0.441) > Environmental Conditions (0.372).

Despite the balanced coefficients, the dimensions of urban infrastructure and urban collective services, in practice, are the main real determinants of the IBEU and exert the greatest influence on well-being, explaining the differences in well-being between municipalities. Urban mobility and housing conditions exert an intermediary influence. On the other hand, the environmental dimension showed the lowest correlation, suggesting possible lower variability between municipalities or more indirect impact. Therefore, urban well-being in the region is more sensitive to structural conditions and service provision than to environmental factors.

3.5.2 CORRELATION AMONG THE DIMENSIONS

The interdimensional analysis demonstrates important structural patterns:

The greatest positive relationships are seen between the dimensions:

- **Urban Mobility and Urban Collective Services (r = 0.507):** moderate association, indicating that municipalities with better provision of urban collective services tend to offer better urban mobility conditions.
- **Urban Collective Services and Urban Infrastructure (r = 0.406):** moderate positive relationship, indicating an association between the supply of urban collective services and the quality of urban infrastructure, suggesting that municipalities with better urban infrastructure tend to offer better urban collective services.
- **Urban Mobility and Housing Conditions (r = 0.380):** positive association of low magnitude.

These results indicate a partial synergy among urban dimensions, in which some evolve together, especially urban collective services, urban mobility, and urban infrastructure.

- **Urban Mobility and Environmental Conditions (r = 0.041):** weak or non-existent association, indicating independence between these dimensions.

The negative correlations observed include:

- **Environmental Conditions and Urban Collective Services (r = -0.275);** and
- **Housing Conditions and Urban Infrastructure (r = -0.014).**

These negative correlations suggest mismatches in urban development, indicating that advances in certain dimensions are not necessarily accompanied by improvements in others. In the case of the negative relationship between urban collective services and environmental conditions, it is possible to infer that municipalities with a greater supply of urban collective services may present greater environmental pressure, resulting from a more intense urbanization process or the expansion of urban collective services without sustainable planning.

Similarly, the weak relationship between housing conditions and urban infrastructure suggests that the existence of adequate housing does not necessarily guarantee quality urban infrastructure in the surroundings – a common situation in peripheral areas, where structured housing coexists with unpaved roads and lack of urban facilities. The presence of negative correlations highlights territorial inequality and possible inconsistencies in the pattern of urban development, reinforcing the need for integrated approaches to urban planning and public policy.

3.5.3 SYNTHESIS AND STRUCTURAL IMPLICATIONS

The correlation matrix reveals three important structural patterns:

- **Centrality of urban infrastructure and urban collective services**: main vectors of urban well-being, explaining most of the differences between municipalities.
- **Partially integrated urbanization**: some dimensions evolve together (such as urban collective services and urban mobility), while others remain disconnected (such as urban infrastructure and housing conditions).
- **Contradictions in urban development**: evidenced by negative correlations, especially between urban collective services and environmental conditions, indicating an urbanization model with trade-offs.

In summary, urban well-being in the Baixo Sul Identity Territory is strongly conditioned by structural factors, especially urban infrastructure and urban collective services, which have the greatest associations with the IBEU. On the other hand, the environmental dimension demonstrates the lowest relative influence, suggesting indirect or long-term impacts. The comparative synthesis of the correlations can be seen in Table 1.

Table 1 – Comparative synthesis of correlations

Variable	Correlates strongly with	Correlates weakly (or not) with
IBEU	Urban infrastructure (0.759), Urban public services (0.709)	Environmental Conditions (0.372)
Urban mobility	Urban collective services (0.507)	Urban Infrastructure (0.110), Environmental Conditions (0.041)
Environmental Conditions	None (max 0.221 with housing conditions)	Urban collective services (-0.275)
Housing Conditions	Urban mobility (0.380)	Urban infrastructure (-0.014)
Urban collective services	Urban mobility (0.507), Urban infrastructure (0.406)	Environmental Conditions (-0.275)
Urban infrastructure	IBEU (0.759), Urban collective services (0.406)	Housing Conditions (-0.014), Urban Mobility (0.110)

Source: Authorship (2026)

Table 1 shows that, in order to raise the IBEU, public policies aimed at urban infrastructure and urban collective services should be prioritized, since these dimensions have the greatest correlations with urban well-being.

To improve urban mobility, the expansion and qualification of urban collective services are relevant. In the case of conditions C (Environmental Conditions), the results indicate relative independence in relation to the other dimensions, in addition to a possible trade-off with urban collective services (r = -0.275), suggesting the need for specific environmental policies interconnected with urban planning.

Finally, housing conditions have relative autonomy, with a more evident association with urban mobility, although of low intensity, indicating that improvements in this dimension depend on specific policies and not only on indirect advances in other areas.

3.6 ANALYSIS OF THE IBEU COVARIANCE MATRIX AND ITS DIMENSIONS

Covariance measures the joint variation between two variables, indicating whether they move in the same direction (positive relation) - that is, if one increases, the other also tends to increase - or in opposite directions (negative relation). On the other hand, when covariance is close to zero, it means that the variables are independent [22].

This is a measure that allows us to understand how the IBEU variables vary together in absolute terms, considering the intensity of the linear association in its originai (non-standardized) scale, which differentiates it from correlation, whose values are normalized. Thus, covariance is sensitive to the scale of the data, and therefore higher values do not necessarily imply greater strength of association.

The interpretation of the covariance matrix can be structured in three levels: (i) individual variability; (ii) relationship between the IBEU and its dimensions; and (iii) relationship among the dimensions.

In general, positive covariances indicate that the variables increase together, while negative covariances suggest movements in opposite directions. Values close to zero indicate absence or low linear association.

3.6.1 RELATIONSHIP BETWEEN THE DIMENSIONS AND THE IBEU

There is a predominance of positive covariances between the IBEU and its dimensions, with emphasis on:

- **Urban Infrastructure (0.00236):** presents the highest covariance with the IBEU, indicating that improvements in this dimension are strongly associated with the increase in urban well-being.
- **Urban Collective Services (0.00233):** also show high covariance, suggesting that advances in urban collective services directly contribute to the increase in the IBEU. This dimension is decisive for urban well-being.
- **Environmental Conditions (0.00091):** indicate a positive relationship, but of low magnitude, showing a reduced impact on the variation of the index.
- **Urban Mobility (0.00054):** presents positive covariance, but very low, suggesting limited influence on the variation of the IBEU. Municipalities with higher IBEU tend to have greater urban mobility.
- **Housing Conditions (0.00050):** presents the lowest covariance, indicating a low absolute impact on the index.

All covariances are positive, which indicates that improvements in the dimensions are associated with the increase in the IBEU. The dimensions of urban infrastructure and urban collective services stand out as those that most follow, in absolute terms, the variations in urban well-being, being, therefore, the main empirical determinants of the index.

However, because covariance is a non-standardized measure, it does not allow a direct comparison of the strength of the associations between different pairs of variables. For example, although Cov(services, IBEU) = 0.00233 and Cov(infrastructure, IBEU) = 0.00236 are close values, the correlation analysis reveals clearer differences in the intensity of the relationships, evidencing the importance of complementary analysis between both metrics, since urban infrastructure has a correlation of 0.759 with the IBEU, while urban collective services has 0.709 – a difference that crude covariance does not reveal, because the scales of the variables are different.

3.6.2 RELATIONSHIPS AMONG THE DIMENSIONS

The analysis of the covariances among the dimensions reveals relevant structural patterns. The most relevant positive relationships occur with the following dimensions:

- **Urban Collective Services and Urban Infrastructure (0.00314):** indicate low positive joint variation, suggesting that municipalities with better urban infrastructure tend to have better urban collective services, although the relationship is not perfect.
- **Urban Mobility and Urban Collective Services (0.00126):** indicate a low positive joint change, suggesting that municipalities with better urban collective services tend to have better urban mobility.
- **Environmental Conditions and Urban Infrastructure (0.00120):** presents a positive association, suggesting that improvements in

urban infrastructure directly impact the urban environment.

These results indicate the existence of partial synergies among urban investments, especially between urban infrastructure and urban collective services.

Negative covariance values are observed for the following pairs of dimension:

- **Environmental Conditions and Urban Collective Services (-0.00167):** indicate a possible mismatch between the expansion of urban collective services and environmental quality. Municipalities with better environmental conditions tend to have lower coverage of formal urban collective services, which serves as a warning for integrated planning. The negative relationship suggests a trade-off or territorial conflict. Areas with more trees and less open sewage/garbage may be precisely those with less coverage of formal water, sewage, and garbage collection networks (possibly more rural or peri-urban areas).
- **Housing Conditions and Urban Infrastructure (-0.00004):** indicate a mismatch in urban development, typical of disorderly expansion. Despite presenting a negative value, it is close to zero, indicating that housing conditions and urban infrastructure do not show significant covariation, still with a slight negative trend.

The negative relationship between urban collective services and environment conditions is the most relevant, suggesting possible tensions in the urbanization process, in which the expansion of urban collective services can occur in a way that is dissociated from environmental sustainability. It also suggests that municipalities with a greater supply of urban collective services may have worse environmental conditions, as more intense urbanization generates environmental pressure, and urban growth without adequate environmental planning generates problems in this dimension.

The covariance between **Urban Mobility** and **Environmental Conditions (0.00008)** is virtually zero, indicating an almost complete absence of linear covariation between these dimensions. This result reinforce the interpretation that urban mobility behaves largely independently of environmental conditions, suggesting that policies targeting one dimension are unlikely to produce substantial indirect effects on the other.

3.6.3 INDIVIDUAL VARIABILITY (MATRIX DIAGONAL)

The elements of the main diagonal of the matrix represent the variance of each variable.

- **Urban Collective Services (0.00817) and Urban Infrastructure (0.00732):** show greater variability, indicating high inequality among municipalities.
- **Environmental Conditions (0.00451):** present medium variability, yet still reflect structural fragility, suggesting relevant environmental differences between municipalities
- **Urban Mobility (0.00076) and Housing Conditions (0.00097):** these display low variability and greater regional homogeneity. Urban mobility shows the least dispersion, as all municipalities perform well in this dimension.
- **IBEU (0.00132):** this is the variance of the index (standard deviation^2 = 0.0376^2), indicating moderate dispersion.

These results suggest that the dimensions with the greatest variability among municipalities - urban collective services and urban infrastructure - are also those with the lowest, averages and the most significant challenges for public policies implementation.

3.6.4 SYNTHESIS AND STRUCTURAL IMPLICATIONS

The covariance matrix confirms two main structural patterns:

- **Structuring nucleus of urban well-being**: composed of the dimensions of urban infrastructure and urban collective services, which present greater covariance with the IBEU and greater variability among municipalities;
- **Complementary nucleus**: composed of urban mobility, environmental conditions, and housing conditions, with less relative influence on the variation of the index.

The analysis reinforces that urban well-being in the Baixo Sul Identity Territory is strongly influenced by structural dimensions, especially urban infrastructure and urban collective services, which show greater variability and greater co-movement with the IBEU. In contrast, the other dimensions have a smaller impact. This result indicates that these dimensions are not only heterogeneous across municipalities, but also decisive for differentiating levels of well-being.

The low variability of urban mobility suggests a relatively homogeneous pattern across the territory, which explains its lower covariance with the general index. On the other hand, the negative covariances reveal asymmetries in urban development, indicating that public policies have not been implemented in a fully integrated manner across the different dimensions.

In summary, the covariance matrix confirms that: (i) the IBEU grows together with all dimensions; (ii) urban infrastructure and urban collective services are the main drivers of variation in well-being; (iii) there are indications of structural imbalances, especially between urbanization and the environment; and (iv) urban mobility presents regional stability, with a smaller contribution to the differentiation among municipalities.

3.7 REGRESSION ANALYSIS

The regression model allows the integrated evaluation of goodness of the fit, statistical significance, the contribution of explanatory variables, and the behavior of residuals [22]. The interpretation can be structured into five blocks:

(i) quality of model fit (leading indicators);

(ii) global significance of the model (ANOVA);

(iii) interpretation of the coefficients;

(iv) residual analysis (model validation); and

(v) probability and distribution of results.

3.7.1 MODEL FIT QUALITY (LEADING INDICATORS)

The regression model uses the five dimensions of the IBEU as explanatory variables and presents a practically perfect fit.

The coefficient of determination $R^2 = 0.99994$ indicates that the model explains practically all the variation in the IBEU. This result is expected, since the index is constructed from these dimensions, which implies a high structural dependence among the variables. Moreover, the reduced number of observations ($n = 15$) limits the inferential validity of the results. The F-test ($p < 0.001$) confirms the overall significance of the model.

The adjusted R^2 (0.99991) confirms the robustness of the model even with multiple explanatory variables.

The multiple correlation coefficient ($R = 0.99997$) indicates an almost perfect correlation between the estimated and observed values.

The standard error of the regression is extremely low (0.00035), indicating high precision of the estimates, since the residuals are of small magnitude.

This level of fit reflects the internal consistency of the index, but also suggests possible structural redundancy, associated with multicollinearity among the explanatory variables.

3.7.2 GLOBAL SIGNIFICANCE OF THE MODEL (ANOVA)

The F-test presents an extremely high value ($F = 31{,}702.16$), with statistical significance ($p = 8.1 \times 10^{-19}$), indicating that the model is statistically valid and highly significant.

In statistical terms, the null hypothesis - that all coefficients are simultaneously equal to zero - is rejected [22], confirming that the dimensions, together, robustly explain the behavior of the IBEU.

The regression sum of squares (0.01982) accounts for practically all the variability of the index, reinforcing the high explanatory power of the model. However, this result should be interpreted with caution, given that the IBEU is derived directly from these dimensions, which implies high structural dependence and limits causal interpretation.

3.7.3 INTERPRETATION OF THE COEFFICIENTS

The intercept (constant) = -0.00189 represents the IBEU value when all dimensions are zero. It is not statistically significant ($p = 0.607 > 0.05$), which is consistent with the structure of the model and has no practical relevance.

The estimated coefficients indicate the marginal effect of each dimension on the IBEU, holding the others constant. All coefficients are positive and statistically significant ($p < 0.001$), with narrow confidence intervals, indicating high precision.

The coefficients values are quite close (~0.20), ranging from 0.19772 to 0.20477, which suggests that the IBEU is structured as a simple or weighted arithmetic mean with very balanced weights across the five dimensions.

- **Urban Mobility (D1)**: 0.20477 – this is the variable with the highest relative weight, suggesting greater sensitivity to displacement. An increase of 0.1 in this dimension corresponds to an increase of 0.0205 in the IBEU, considering the other dimensions fixed.
- **Environmental Conditions (D2): 0.19772** – the lowest coefficient. Its impact is slightly smaller, but still strong. It indicates an importante, though less sensitive, contribution.
- **Housing Conditions (D3): 0.20130** – the second largest influence. It reflects the importance of housing quality.
- **Urban Collective Services (D4): 0.19838** - has a significant impact related to access to essential services.
- **Urban Infrastructure (D5): 0.19855** – a very relevant dimension with high impact, structurally important as it has a weight similar to the others.

All variables are positive and statistically significant, with very narrow confidence intervals and very close coefficients (~0.20), indicating a balanced structure of the index, since the IBEU is composed almost proportionally across the dimensions.

This suggests that the IBEU is structurally balanced, with no absolute predominance of any single dimension, though urban mobility has a small Advantage, suggesting greater sensitivity to displacement. All dimensions contribute almost proportionally (~20%), indicating a balanced index structure. However, this does not mean that all dimensions have the same real impact, as regression reflects the mathematical structure of the index, while correlation and variability show empirical impact. Taken together, urban infrastructure and urban collective services tend to have greater practical influence.

The regression equation estimated from the results can be expressed as follows:

$$\mathbf{IBEU = -0.00189 + 0.20477(D1) + 0.19772(D2) + 0.20130(D3) + 0.19838(D4) + 0.19855(D5) + \varepsilon} \quad (2)$$

This structure indicates that the IBEU functions as a weighted average of the dimensions, with practically equivalent weights. However, this interpretation should be understood as a reflection of the construction of the index, and not as evidence of independent causality.

3.7.4 STATISTICAL SIGNIFICANCE OF COEFFICIENTS (p-values) AND CONFIDENCE INTERVALS

All coefficients have extremely low p-values, ranging from 10^{-12} to 10^{-14}, indicating that each variables contributes significantly to explaining the IBEU. Thus, the hypothesis that the coefficients of variables D1 to D5 are equal to zero is rejected.

The 95% confidence intervals for the dimension coefficients are narrow and do not include zero:

D1: [0.1955 - 0.2141]

D2: [0.1939 - 0.2016]

D3: [0.1935 - 0.2091]

D4: [0.1949 - 0.2018]

D5: [0.1955 - 0.2016]

This reinforces the accuracy of the estimates and the significance of each coefficient. The intercept interval includes zero (from -0.0099 to 0.0062), confirming that it is not statistically necessary.

3.7.5 STRUCTURAL READING OF THE EQUATION

The equation shows that the IBEU is formed by the combination of urban dimensions weighted by similar coefficients, characterizing a structurally balanced model.

The term ε represents the random error or disturbance term of the model – that is, the part of the IBEU that is not explained by variables D1-D5. It refers to the difference between the observed and the predicted value, meaning the residual or forecast error. Its values are shown in the residual table, which in this case are on the order of 10^{-4} (~0.0001) and are very small. The standard error of the regression is 0.000353, indicating that the model has very high accuracy and that the predicted values are practically identical to the observed ones. In the model, **ε** can be interpreted as small uncaptured variations, the effect of data rounding, and minor methodological differences, but without representing relevant external factors or important omitted variables in this specific case.

Using this equation and the data for each dimensions, the IBEU calculation is as follows:

$$\mathbf{IBEU = -0.00189 + 0.20477(0.925) + 0.19772(0.763) + 0.20130(0.794) + 0.19838(0.738) + 0.19855(0.446) = 0.733} \quad (2)$$

The result is compatible with the observed values. The regression equation demonstrates that the IBEU of the Baixo Sul Identity Territory is determined by a balanced combination of the dimensions of urban mobility, environmental conditions, housing conditions, and urban infrastructure, all with positive and significant impacts. However, its interpretation should be understood as a representation of the structure of the index, and not as evidence of isolated causality between variables.

The regression equation can be used to simulate the impact of improvements. For example, increasing urban infrastructure (D5) from 0.446 to 0.500 (a gain of 0.054), the estimated impact on the IBEU is 0.054 x 0.1986 = +0.0107. In turn, increasing urban mobility (D1) from 0.925 to 0.979 (a gain of 0.054), the estimated impact is 0.054 x 0.2048 = +0.0111.

This result indicates that both variables contribute positively to urban well-being, with a slight predominance of urban mobility, but shows a relative balance between the dimensions, with the absence of extreme dominance of one variable over the other, and a positive linear relationship between improvements in urban dimensions and the IBEU. Despite the consistency of the results, the relatively small gains and limited effects of the improvements reinforce the need for integrated and simultaneous policies.

3.7.6 RESIDUAL ANALYSIS AND MODEL VALIDATION

The residuals are very small (on the order of ~10^{-4}), with positive and negative values and a random distribution, showing no evident or systematic pattern, which indicates the adequacy of the model to the observed data. The forecast errors are extremely small (less than 0.0005 in absolute value).

A negative residual means that the model overestimated the IBEU (predicted value higher than the observed one). Conversely, a positive residual means that the model underestimated it (predicted value lower than the observed one).

The standardized residuals remain within acceptable limits, ranging from -2.43 to +1.38, well within the -3 to +3 range generally considered acceptable. No standardized residual exceeds 3 in absolute value, indicating the absence of problematic outliers (anomalous values). The model has an excellent fit, with no evidence of bias or relevant heteroscedasticity.

The largest residual in absolute value is that of Nilo Peçanha (-0.000689), but it is still negligible in practical terms. The model slightly underestimated Nilo Peçanha's IBEU (predicted 0.77869 vs. observed 0.778?) – in fact, the residual is negative, meaning that the predicted value was higher than the observed one.

The low magnitude of the residuals and the absence of systematic patterns confirm the high regression fit. This result should be interpreted in light of the compositional nature of the index, since the IBEU is directly derived from dimensions, which significantly reduces the portion of unexplained variability.

There is no obvious pattern of alternating positive and negative residuals, suggesting that the model does not present autocorrelation - a common issue in time series, but less relevant for cross-sectional data such as those used in the present study [22, 24-26].

3.7.7 PROBABILITY AND DISTRIBUTION

The observed IBEU values closely follow the percentiles and indicate a consistent distribution without serious distortions. The model adequately represents the distribution of the actual data.

The regression results show a model with high explanatory power, in which the IBEU dimensions explain practically all the variation of the index. All variables have positive and statistically significant coefficients, with similar magnitudes, reflecting the balanced structure of the index [22, 24-26].

3.7.8 SYNTHESIS AND STRUCTURAL IMPLICATIONS

The regression model has high statistical robustness and strong explanatory power. However, this performance is largely due to the structural nature of the IBEU, which is directly derived from the explanatory variables, implying high internal dependence.

Thus, the coefficients reflect the composition of the index, rather than independent causal relationships. The residual analysis confirms the adequacy of the fit, with no evidence of relevant violations of the regression assumptions [22, 24-26].

In summary, the model is statistically consistent and robust, but its interpretation should consider the structural dependence among the variables. It is recommended that this analysis be complemented with additional approaches - such as spatial techniques or alternative models - to deepen the understanding of urban well-being.

4 FINAL CONSIDERATIONS

The results show a pattern of urban development characterized by relative balance among municipalities, but with persistent structural weaknesses. Urban mobility constitutes the main regional strength, reaching a classification of "Excellent", which indicates favorable conditions for population displacement.

The Baixo Sul Identity Territory presents an intermediate level of urban well-being, with relative homogeneity across municipalities but asymmetries between the index's structuring dimensions. While advances have been made in urban mobility and housing conditions, significant gaps remain in urban infrastructure and urban collective services. Improving urban well-being thus depends primarily on investments in these dimensions, which have greater potential to impact quality of life and Urban Well-Being Index (IBEU) variation.

Priority investments in urban infrastructure – a dimension classified as "Poor" and the main regional bottleneck – should focus on the qualification of public space (paving, drainage, and accessibility), the expansion of basic infrastructure, and the integration between urban planning and environmental policies.

The dimensions related to housing conditions, environmental conditions, and the provision of urban collective services show intermediate performance, indicating partial advances, but still insufficient to raise the general level of urban well-being to higher standards. This scenario evidences an urbanization dynamic characterized by relative functionality, coexisting with persistent structural weaknesses.

Statistical modeling confirmed the strong relationship between the IBEU and its constituent dimensions, with high explanatory power. However, the correlation analysis indicated that urban infrastructure and urban collective services exert a greater practical influence on urban well-being, reinforcing the need to prioritize these areas in territorial planning and in the formulation of public policies.

The present research contributes empirically by identifying the most relevant dimensions of urban well-being, providing evidence-based support for public policies. In addition, it integrates multivariate statistical analysis techniques applied to the urban context on a territorial scale, allowing for the identification not only of the indicator's level, but also of its structural determinants and internal imbalances. In addition, it offers technical subsidies for public managers by highlighting priority areas of intervention and the potential impact of urban policies.

It should be noted that the estimated model does not allow for inferring causal relationships or directly indicating how to improve each dimension, since it is a descriptive model that reflects the very structure of the index's composition, contributing above all to the understanding of the IBEU and the relative contribution of each dimension.

The study's limitations include the small number of observations (n = 15), although sufficient for the number of predictors used. In addition, there is a possible presence of multicollinearity among the variables, resulting from the structure of the index itself, which may limit the model's predictive capacity. The use of aggregated data may mask relevant intra-urban inequalities, especially in municipalities with greater spatial heterogeneity. Finally, the absence of complementary socioeconomic variables - such as income, education, and demographic dynamics - restricts a broader understanding of the factors that influence urban well-being.

Future perspectives include: (i) expansion of the analysis to other identity territories; (ii) application of robust econometric models, such as spatial regression or panel data models; (iii) incorporation of spatial analysis techniques to identify territorial patterns and inequality clusters; (iv) use of multivariate methods, such as factor analysis or principal component analysis, to reduce redundancies and identify latent dimensions; (v) integration of the IBEU with other socioeconomic indicators, such as MHDI, income, and inequality measures, aiming at a more comprehensive approach to urban development; (vi) conduction of intra-urban studies, with a higher level of disaggregation, to capture local inequalities; and (vii) development of longitudinal analyses, with data from different periods, to assess the evolution of urban well-being and the impacts of public policies over time.

Finally, it is concluded that the advancement of urban well-being in the Baixo Sul Identity Territory depends fundamentally on structural investments in urban infrastructure and the expansion of urban collective services, combined with integrated territorial planning strategics capable of promoting more balanced, inclusive, and sustainable urban development.

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