Sustainable rural development in the Itapetininga Region: an emphasis on São Miguel Arcanjo (São Paulo, Brazil)

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Abstract

The Immediate Geographic Region (IGR) of Itapetininga, located in the state of São Paulo, Brazil, is notable for its production of fruits and vegetables, making it an important area for analyzing rural sustainable development. Among the six municipalities in the region, São Miguel Arcanjo was chosen for the implementation of an Agrotechnological District (AD) under the SemeAr Digital Project, coordinated by Embrapa Digital Agriculture, with the aim of fostering rural development. Our objective was to characterize and map the level of rural sustainable development across the six municipalities in the IGR, with a particular focus on São Miguel Arcanjo. We organized a set of 18 indicators into the economic, social, and environmental dimensions of sustainability. Using data from official databases standardized on a scale of 0 to 100, we developed indices for each sustainability dimension, culminating in the Sustainable Rural Development Index (SRDI). Our comparative analysis was based on quartile distribution, and spatial analysis was conducted using R and QGIS software. The results revealed disparities among the municipalities: Itapetininga had the highest SRDI, while Guareí recorded the lowest in the region. São Miguel Arcanjo excelled in the environmental dimension but showed signs of economic fragility. We demonstrated the effectiveness of composite indicators in identifying internal vulnerabilities and territorial disparities, serving as a tool for integrated diagnostics and territorial planning, thereby supporting public policies aligned

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with local realities. These findings highlight the need for cross-sectoral strategies that balance economic growth, social inclusion, and environmental conservation.

Keywords: Agro-technological Districts; Development Indicators; Rural sustainability; Territorial Development.

1. Introduction

The Immediate Geographic Region (IGR) of Itapetininga, situated in the state of São Paulo, consists of six municipalities and is renowned for its production of fruits and vegetables, including peas, pears, grapes, persimmons, and potatoes (IBGE, 2024). This makes the region a significant area for analyzing rural sustainable development, defined as the ability to meet present societal needs without compromising the capacity of future generations to meet their own (Hajian; Kashani, 2021). The increasing demand for a development model that harmonizes economic growth, social inclusion, and environmental conservation has led to the adoption of various tools for measuring rural sustainability. Among these, the Sustainable Rural Development Index (SRDI) stands out as it integrates economic, social, and environmental dimensions into a cohesive framework (Dourado Neto et al., 2021).

In this context, Digital Agriculture has emerged as a key focus, exemplified by initiatives such as the SemeAr Digital Project, which aims to enhance rural connectivity through the establishment of Agrotechnological Districts (ATD). These districts incorporate digital solutions designed to modernize production and improve sustainability in rural areas (Paiva et al., 2024). The selection of municipalities to host the ATD was conducted by Embrapa Digital Agriculture based on 34 socioeconomic indicators (Mondo et al., 2022). In São Paulo state, five municipalities were chosen, including São Miguel Arcanjo, which is part of the Itapetininga IGR. Consequently, our goal was to characterize and map the level of rural sustainable development across the six municipalities within the IGR, with a particular focus on São Miguel Arcanjo.

2. Method

The state of São Paulo consists of 645 municipalities, organized into 53 Immediate Geographic Regions (IGR). This study concentrated on the IGR of Itapetininga, which includes the municipalities of Alambari, Angatuba, Campina do Monte Alegre, Guareí,

Itapetininga, and São Miguel Arcanjo (Figure 1). The analytical scope included 637 municipalities in São Paulo, after excluding eight municipalities due to unavailability of data.
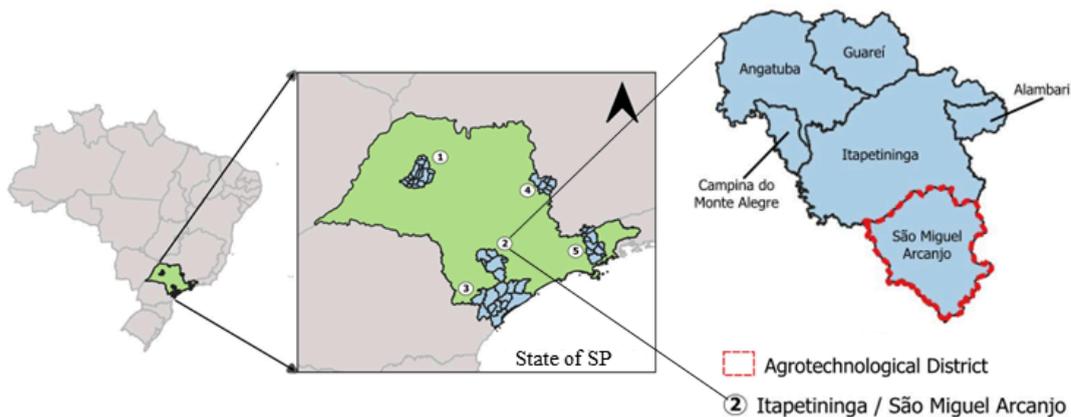
Figure 1. Map of the Immediate Geographic Regions selected within the SemeAr Digital Project, highlighting the Itapetininga IGR and the municipality of São Miguel Arcanjo (ATD).

Initially, we calculated measures of central tendency and dispersion for the entire set of municipalities in the state. These statistical parameters were subsequently applied to the six municipalities within the Itapetininga IGR, facilitating a comparative analysis within the region. The indicators were organized according to the three dimensions of sustainability (Table 1).

Given the heterogeneity of measurement units, we standardized all indicators on a scale ranging from 0 to 100, utilizing the formula (1) for indicators representing environmental degradation (PPAd, LRd, and WSL), and the formula (2) for other indicators:

$$\beta_{i,m} = \frac{1 - I_{i,m} - Mn_i}{Mx_i - Mn_i} . 100 \quad \textbf{(1)} \qquad\qquad \beta_{i,m} = \frac{I_{i,m} - Mn_i}{Mx_i - Mn_i} . 100 \quad \textbf{(2)}$$

Where $\beta_{i,m}$ corresponds to the standardized value of the indicator $I_{i,m}$, $I_{i,m}$ to the absolute value of indicator i at municipality m, and Mn_i and Mx_i represent the minimum and maximum values of indicator i across all municipalities, respectively.

Table 1. Economic (Ec), Social (Sc), and Environmental (En) Dimensions (D): Indicators, Descriptions, and Data Sources for Sustainability Indicators.

| D	Indicator	Description	Source
Ec	Gross value added in agriculture	Contribution of agriculture to the municipal economy in 2021	IBGE (2025)
	Average income per establishment	Ratio between total average income and the number of rural establishments in the municipality	
	Market access	Percentage of rural properties whose main income derives from agriculture	
	Market integration	Proportion of establishments that commercialize the majority of their production	
	Access to credit	Percentage of establishments that obtained access to rural credit	
	Cooperativism	Proportion of establishments participating in cooperatives, at the municipal level	
	Technical assistance	Percentage of establishments receiving technical assistance	
	Mechanization	Average number of tractors, harvesters, and fertilizer applicators per rural establishment	
	Connectivity	Percentage of municipal area covered by 3G signal of medium, high, or very high intensity, over total area	Biomas […] (2022)
	Agricultural infrastructure	Average percentage of variables related to transportation, energy, storage, and proximity to slaughterhouses	
Sc	Life expectancy	Average population longevity, in years	Dourado Neto et al. (2021)
	Educational attainment	Average years of schooling, measured on a scale from 0 to 20 years	
En	Permanent preservation area deficit (PPAd)	Ratio between the pAPP of each municipality and the highest state value ($m^2 \, m^{-2}$); index ranges from 0 (greater preservation) to 1 (lower preservation)	Biomas […] (2022
	Legal reserve deficit (LRd)	Ratio between the pRL of each municipality and the highest state value ($m^2 \, m^{-2}$); index ranges from 0 to 1 (lower conservation)	
	Physical Environment Suitability Index (PESI)	Product of the Soil Quality Index (SQI), Relief Quality Index (RQI), and Climate Quality Index (CQI); higher values indicate better agro-environmental conditions	
	Water Stress Level (WSL)	Ratio between the municipal WSL and the highest state value ($m^3 \, m^{-3}$); ranges from 0 (lower) to 1 (higher water stress)	
	Soil preparation	Proportion of rural establishments adopting conventional and/or conservationist soil management practices	IBGE (2025)
	Agricultural practices	Proportion of establishments employing contour farming and/or crop rotation	

We calculated the Economic Development Index (EDI), Social Development Index (SDI), and Environmental Development Index (EnDI) as the arithmetic mean of their respective standardized indicators.

The Sustainable Rural Development Index was computed as the arithmetic mean of the three aggregated indices, which were also standardized. Based on quartile distribution, we classified municipalities into four performance categories: low, medium-low, medium-high, and high. The statistical analyses were performed using R software, while thematic maps were created with QGIS.

3. Results and Discussion

The analysis revealed contrasting territorial dynamics across the three aggregated indices among the municipalities within the Itapetininga IGR (Figure 2). Itapetininga recorded the highest value for the Sustainable Rural Development Index (SRDI) at 0.571, being the only municipality classified in the medium-high performance category (Figure 2D).

In contrast, Guareí registered the lowest SRDI in the sample at 0.103, placing it in the low-performance category. The other municipalities - Angatuba (0.255), São Miguel Arcanjo (0.272), Campina do Monte Alegre (0.376), and Alambari (0.486) - were all classified within the medium-low performance tier.
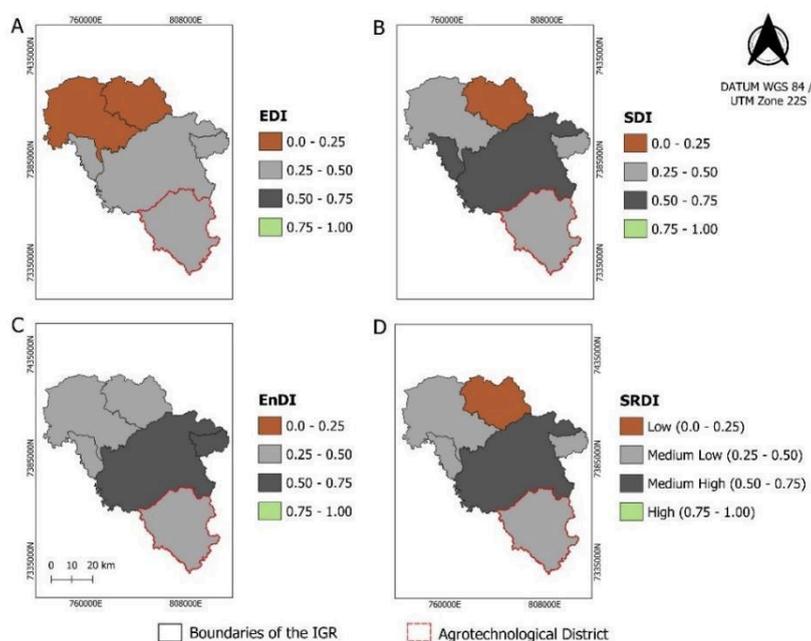
Figure 2. Spatial distribution of the: (A) Economic; (B) Social; (C) Environmental; (D) Sustainable Rural Development Indices of the municipalities located in the Itapetininga IGR.

Despite São Miguel Arcanjo's medium-low Sustainable Rural Development Index (SRDI), the municipality stood out in the environmental dimension, achieving an index of 0.496 (Figure 2C). This was in contrast to its lower performance in the economic dimension, which recorded an index of 0.257 (Figure 2A). The relatively positive environmental outcome can be attributed to a lower incidence of environmental liabilities and reduced levels of water stress. Conversely, the Economic Development Index (EDI) approached the lower boundary of its quartile, indicating the fragility of individual economic indicators in this municipality.

The articulation of composite indices has proven effective for territorial analysis, allowing for the identification of internal vulnerabilities and facilitating intermunicipal comparisons from the perspective of rural sustainability. São Miguel Arcanjo's intermediate position in the regional ranking underscores the diversity of conditions within rural territories and the necessity for integrated strategies that address both opportunities and challenges. In this context, the SemeAr Digital Project emerges as a

promising initiative aimed at strengthening these dimensions and promoting advancements in the municipality's rural sustainability.

4. Conclusion

The assessment of rural sustainability relies on the integration of its constituent dimensions. The contrast observed between environmental performance and limitations in economic and social aspects emphasizes the necessity for integrated strategies. The development and application of the Sustainable Rural Development Index (SRDI) facilitated a comparative analysis of rural sustainability across municipalities, revealing territorial asymmetries and identifying potential areas for future policy focus. This comprehensive approach allows for targeted interventions that can enhance overall sustainability and address specific local challenges.

Acknowledgements

References

BIOMAS brasileiros: potencialidades e limitações para o uso agropecuário. Piracicaba: FEALQ, 2022. 60 p.

IBGE. **Tabela 9923 -** p**opulação residente, por situação do domicílio**. 2024. Available at: https://sidra.ibge.gov.br/tabela/9923. Accessed on: April 13, 2025.

IBGE. **Censo agropecuário 2017**: resultados definitivos. Available at: https://sidra.ibge.gov.br/pesquisa/censo-agropecuario/censo-agropecuario-2017/resulta dos-definitivos. Accessed on: April 12, 2025.

DOURADO NETO, D.; DELFINO, A.; COUTINHO, P. A. Q.; RIZZO, R.; ARAUJO, M. A. de; BARRETO, A. G. de O. P.; VIEIRA JÚNIOR, P. A.; RODRIGUES, R.; PAOLINELLI, A. Índice de desenvolvimento rural sustentável. In: PAOLINELLI, A.; DOURADO NETO, D.; MANTOVANI, E. C. (org.). **Diferentes abordagens sobre agricultura irrigada no Brasil:** técnica e cultura. Piracicaba, ESALQ - USP. 2021. cap. 7, p. 327- 350.

HAJIAN, M.; KASHANI, S.J. Evolution of the concept of sustainability. From Brundtland Report to sustainable development goals. **Sustainable Resource Management:** Modern Approaches and Contexts, p. 1-24, 2021. DOI: https://doi.org/10.1016/B978-0-12-824342-8.00018-3.

MONDO, V. H. V.; LUCHIARI JUNIOR, A.; BOLFE, E. L.; SILVA, V. J. da; FREDO, C. E. Projeto SemeAr: mapeamento das condições para viabilização da agricultura digital no município de Caconde, Estado de São Paulo. **Textos Para Discussão**, n. 42/2091, p. 1-25, fev. 2022. Available at: https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/1153664/1/AP-Projeto-SemeAr -2022.pdf. Accessed on: April 21, 2025.

PAIVA, C. M. N.; QUINTINO, D. D.; MORAIS, T. B. C. de; COZADI, E. G.; COSTA, J. S. da; LEME, P. H. M. V.; SCOLFORO, J. R. S. Pathways to rural sustainability: opportunities and challenges in the creation of an Agrotechnological District in Ingaí City, Brazil. **Agriculture**, v. 14, n. 12, 2185, 2024. DOI: https://doi.org/10.3390/agriculture14122185.