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Nexus Water-Energy-Food Approach as Decision-Making Support for Climate Resilience: A Case Study in the Mogi Guaçu River Basin

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Abordagem Nexus Água-Energia-Alimento como suporte à tomada de decisão visando a resiliência climática: estudo de caso na Bacia Hidrográfica do Rio Mogi Guaçu.

RESUMO

Objetivo - Analisar a segurança hídrica, energética e alimentar por meio da abordagem *Nexus* como subsídio à tomada de decisão visando a resiliência climática na Bacia Hidrográfica do Rio Mogi Guaçu.

Metodologia – Pesquisa dedutiva baseada em dados qualitativos publicados em plataforma *online* do governo brasileiro (AdaptaBrasil MCTI). O estudo foi conduzido em 3 etapas: i) coleta de dados; ii) análise das informações por meio de mapas georreferenciados; iii) propostas de medidas de adaptação com base na abordagem *Nexus*.

Originalidade/relevância – O estudo integra segurança hídrica, alimentar e energética sob a ótica das mudanças climáticas, em especial no contexto de bacias hidrográficas. Ao destacar medidas de mitigação com impactos intersetoriais, conecta as temáticas de governança e planejamento regional.

Resultados – O setor de recursos hídricos é o mais ameaçado durante os períodos de estiagem prolongada. As medidas propostas destacam ações de fomento à educação climática, melhorias na governança da água e a busca por alternativas para a produção agrícola.

Contribuições teóricas/metodológicas – Adoção da abordagem *Nexus* como ferramenta para análise integrada e auxílio na tomada de decisão. Contribuição metodológica no uso de dados disponibilizados em plataforma *online* de consulta pública para diagnóstico.

Contribuições sociais e ambientais - O estudo aponta medidas para o fortalecimento da cooperação entre os setores analisados e suporte à resiliência climática em bacias hidrográficas. Destaca a importância do planejamento integrado para segurança ambiental e qualidade de vida.

PALAVRAS-CHAVE: Mudanças climáticas. Planejamento urbano. Gestão colaborativa.

Nexus Water-Energy-Food Approach as Decision-Making Support for Climate Resilience: A Case Study in the Mogi Guaçu River Basin

ABSTRACT

Objective – To analyze water, energy, and food security through the Nexus approach as a decision-making support tool aimed at enhancing climate resilience in the Mogi Guaçu River Basin.

Methodology – Deductive research based on qualitative data published on the Brazilian government platform AdaptaBrasil MCTI. The study was conducted in three stages: data collection; analysis of information through georeferenced maps; and the proposal of adaptation measures based on the Nexus approach.

Originality/relevance – The study integrates water, food, and energy security within the context of climate change, particularly in river basins. By highlighting mitigation measures with intersectoral impacts, it connects governance and regional planning themes.

Results – The water sector was identified as the most threatened during drought periods. The proposed measures emphasize actions to foster climate education, improve water governance, and seek alternatives for agricultural production.

Theoretical/methodological contributions – The adoption of the Nexus approach as a tool for integrated analysis and decision-making support. Methodological contribution using data made available on a public consultation platform for territorial diagnosis.

Social and environmental contributions – The study proposes measures to strengthen cooperation between the analyzed sectors and to support climate resilience in river basins. It emphasizes the importance of integrated planning for environmental security and quality of life.

KEYWORDS: Climate Change. Urban Planning. Collaborative Management.

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Enfoque Nexus Agua-Energía-Alimento como apoyo a la toma de decisiones para la resiliencia climática: estudio de caso en la Cuenca Hidrográfica del Río Mogi Guaçu

RESUMEN

Objetivo – Analizar la seguridad hídrica, energética y alimentaria mediante el enfoque Nexus como herramienta de apoyo a la toma de decisiones orientada a la resiliencia climática en la Cuenca del Río Mogi Guaçu.

Metodología – Investigación de carácter deductivo basada en datos cualitativos publicados en la plataforma gubernamental brasileña AdaptaBrasil MCTI. El estudio se desarrolló en tres etapas: recolección de datos; análisis de la información mediante mapas georreferenciados; y propuestas de medidas de adaptación basadas en el enfoque Nexus.

Originalidad/Relevancia – El estudio integra la seguridad hídrica, alimentaria y energética en el contexto del cambio climático, especialmente en cuencas hidrográficas. Al destacar medidas de mitigación con impactos intersectoriales, establece conexiones entre la gobernanza ambiental y la planificación regional.

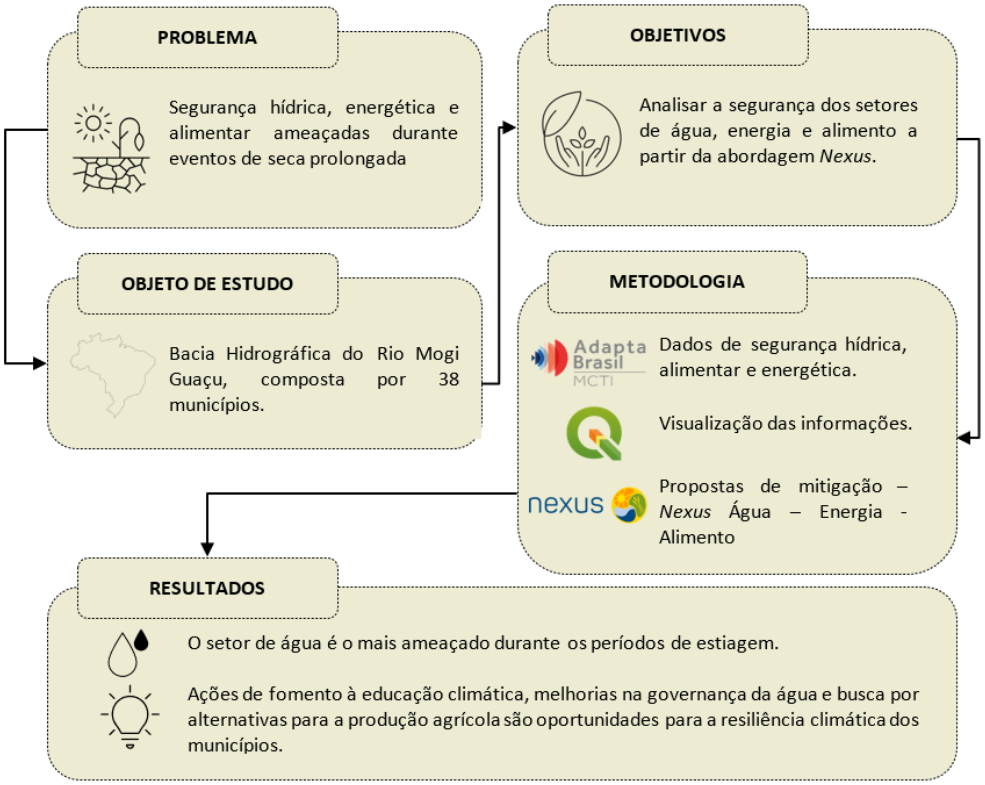
Resultados – El sector hídrico fue identificado como el más amenazado durante los períodos prolongados de sequía. Las medidas propuestas destacan acciones de fomento a la educación climática, mejoras en la gobernanza del agua y búsqueda de alternativas para la producción agrícola.

Contribuciones teóricas/Metodológicas – Adopción del enfoque Nexus como herramienta para el análisis integrado y apoyo en la toma de decisiones. Contribución metodológica mediante el uso de datos disponibles en plataformas de consulta pública para diagnóstico territorial.

Contribuciones sociales y ambientales – El estudio propone medidas para fortalecer la cooperación entre los sectores analizados y apoyar la resiliencia climática en cuencas hidrográficas. Se destaca la importancia de la planificación integrada para la seguridad ambiental y la calidad de vida.

PALABRAS CLAVE: Cambio Climático. Planificación Urbana. Gestión Colaborativa.

RESUMO GRÁFICO



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1 INTRODUCTION

In recent years, the terms “Resilient Cities” or “Urban Resilience” have come to represent the process of urban adaptation to climate change, as river basins have been increasingly pressured by the demands placed on their natural resources (Asefa et al., 2014; Oliveira & Silva, 2014; Godoy & Cruz, 2016; Tony et al., 2015). Resilience refers to the capacity to withstand, resist, and absorb disturbances, disruptions, and changes that negatively affect people's lives, urban infrastructure, and the economy (Ferreira, 2016; Tony et al., 2015). In this context, the notion that cities are subject to cumulative pressures capable of triggering systemic ruptures is central to resilience studies (Gonçalves, 2017).

Globally, the water, energy, and food sectors are the most vulnerable to climate change due to increasing demand for these resources. Given that natural resources are increasingly affected by anthropogenic interference, the demand for water, food production, and energy has also grown (Nascimento et al., 2022). Some studies highlight the need for interdisciplinary approaches that evaluate the interdependence between these three sectors, such as the Water–Energy–Food Nexus (WEF Nexus) (Páez-Curtidor et al., 2021).

The WEF Nexus is a framework aimed at supporting the management and planning of cities to reduce urban vulnerabilities without compromising quality of life and economic growth (Nascimento et al., 2022). This methodology emerged from concerns about global trends that negatively impact water, energy, and food resources, considering that current territorial management models may not effectively ensure water, food, and energy security (Guimarães and Souza, 2024; Zhang et al., 2021).

One of the strengths of the WEF approach lies in its broad and multidisciplinary nature, enabling the development of resilience indicators and monitoring tools. In addition, it requires a strong foundation in local and regional contexts. Challenges include the availability of data and essential information for understanding resource chains, which can affect the variables used in assessments (Nascimento et al., 2022).

Furthermore, socioeconomic disparities between municipalities may require the development of new indicators and research methodologies (Alvares and Ventura, 2024; Nascimento et al., 2022). In this regard, studies indicate that quantitative approaches dominate Nexus assessments, while qualitative methods from the social sciences remain limited.

The WEF framework supports the formulation of policies for integrated natural resource management and the identification of opportunities to increase resource efficiency and cross-sector collaboration, thereby directly impacting urban environments (Lazaro & Giatti, 2021; Páez-Curtidor et al., 2021).

This approach can be applied to assess and integrate different areas, such as wastewater management (Panagopoulos & Giannika, 2022), irrigation (Cui et al., 2022), communities and urban agriculture (Haitsma Mulier et al., 2022; Oviroh et al., 2023), forests and ecosystem services (Ding et al., 2023; Guimarães et al., 2024), among others.

Urban planning with a Nexus-based perspective can provide insights into achieving urban resilience in interconnected sectors, considering both ecological and built infrastructures (Nhamo et al., 2021). The approach incorporates fundamental factors for human survival, proposing integrated solutions and encouraging adoption across different levels of government.

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Thus, it enables a better understanding of the causes and extent of population vulnerability in relation to food, energy, and water security, contributing to the development of preventive strategies for insecure scenarios (Chauhan et al., 2022).

In the Brazilian context, Cerezini and Castro (2024) report that all regions have experienced the impacts of climate change in varying intensities and dimensions, and they possess different levels of adaptive capacity. These authors emphasize that planning and implementing measures to strengthen adaptive capacity are essential to mitigate such impacts.

2 OBJECTIVES

Given the challenges faced by municipal management in the context of climate change, the objective of this study was to analyze water, energy, and food security through the Nexus approach as a decision-making tool to support climate resilience in the Mogi Guaçu River Basin.

3 METODOLOGY

3.1 Study Area Characterization

The Mogi Guaçu River Basin is located in the northeastern region of the State of São Paulo, encompassing an area of 15,004 km² and 59 municipalities, 38 of which have part or all of their territory within the basin. The region borders adjacent basins such as the Pardo River Basin and the Piracicaba/Capivari/Jundiaí River Basin, establishing itself as a strategic axis for water resource management in the state (Figure 1). The hydrography is dominated by the Mogi Guaçu River—its main watercourse—and its tributaries, such as the Peixe and Jaguari-Mirim rivers, as well as critical reservoirs for water supply and energy generation, including the Peixoto and Jaguará reservoirs.

The basin's total population is approximately 1.58 million inhabitants, with 95.1% living in urban areas, particularly in cities such as Mogi Guaçu, Sertãozinho, and Araras. Economically, the basin is sustained by agribusiness, notably sugarcane cultivation, citrus farming, and livestock production, in addition to industrial hubs (e.g., sugar mills, pulp and paper industries) and thermal tourism in municipalities such as Águas de Lindóia. Socioeconomically, the São Paulo State Social Responsibility Index highlights disparities within the region, with municipalities ranging from "equitable" (e.g., São João da Boa Vista) to "vulnerable" (e.g., Aguaí) (SEADE, 2019).

Historically, the basin has undergone several land use transformations. Initially covered by native vegetation, the area was gradually occupied by agricultural activities, particularly sugarcane plantations, citrus groves, and pasture lands. These changes in land use have led to significant environmental impacts, such as deforestation. The transformation has intensified erosion processes, especially in the Peixe and Jaguari-Mirim sub-basins, where erosion susceptibility is classified as "high" or "very high." Furthermore, according to the UGRHI 09 Water Resources Status Report, the presence of 1,877 dams—many of them irregular—has increased water use conflicts in the region.

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Figure 1 – Location map of the Mogi Guaçu River Basin

Source: The authors (2025).

Water availability in the Mogi Guaçu River Basin faces significant challenges due to increasing demand and the pressures caused by climate change. According to the National Water and Sanitation Agency (ANA, 2020), the basin has an average surface flow of 199 m³/s, in addition to exploitable groundwater reserves of 24 m³/s, found in aquifers such as Bauru and Guarani.

Despite this, the total granted water demand reached 39.30 m³/s in 2022, corresponding to 54.6% of Q95% (minimum reference flow) and 64.9% of Q7,10, indicating signs of water stress in critical sub-basins such as the Upper Mogi (ANA, 2020; SPAGUAS, 2023).

Agriculture accounts for 57% of total consumption (22.38 m³/s), followed by industry (22%) and public water supply (14%). Moreover, urban distribution systems experience significant losses, reaching up to 40% in cities like Jaboticabal. Projections from the 2016–2027 Basin Plan indicate that by 2040, water availability could decrease by up to 20% due to climate change, underscoring the urgent need for increased water use efficiency and improved water rights regulation (SIGRH-SP, 2023).

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The basin also faces water conflicts among user sectors, diffuse pollution from agrochemicals, and institutional vulnerabilities in enforcement and monitoring. To address these challenges, the 2016–2027 Basin Plan highlights the restoration of 20 km² of Permanent Preservation Areas (APPs) by 2023 and a 70% reduction in organic pollutant loads by 2027. The effectiveness of these measures depends on investments in sanitation, community engagement, and the strengthening of the Mogi Guaçu River Basin Committee (CBH-MOGI).

The Mogi Guaçu River Basin faces the tensions between development and sustainability, requiring coherent public policies and innovative water management strategies to balance human demands with environmental processes. In this context, the main hypothesis adopted in this study is that the water sector, compared to the energy and food sectors, is the most threatened during prolonged drought events due to the existing demand associated with this resource.

3.2 Theoretical Framework

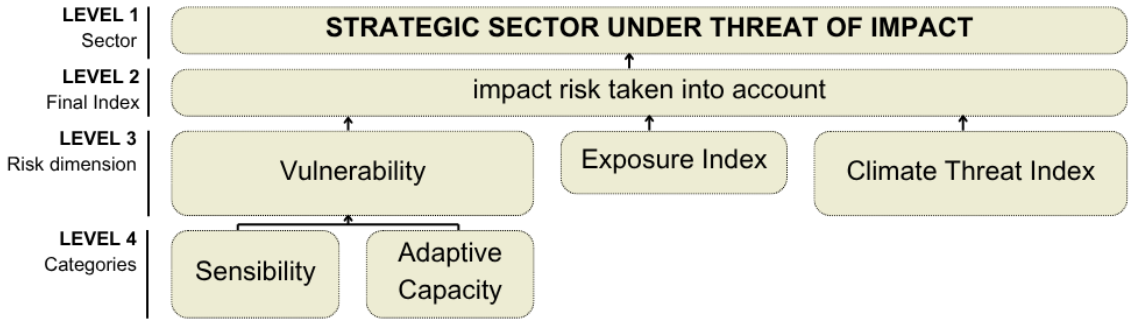
For the development of this study, a deductive research method was adopted, based on qualitative data published on the Brazilian government's online platform *AdaptaBrasil MCTI*, to describe observations related to climate resilience in the study area.

The methodological approach was structured in three stages: (i) data collection; (ii) analysis of the information through the construction of georeferenced maps; and (iii) formulation of adaptation measures based on the Nexus approach.

- **Stage 1 – Data Collection:** The information was obtained from the *AdaptaBrasil MCTI* platform, established in 2020 by the Brazilian Ministry of Science, Technology, and Innovations, with the aim of consolidating, integrating, and disseminating data to support the advancement of analyses on the impacts of climate change (AdaptaBrasil MCTI, 2025).

  Considering the Nexus – WEF approach, indices and indicators related to the water, energy, and food sectors were collected to support the analysis of climate resilience within the study area. The indices considered included levels of vulnerability, climate threat, and exposure. Additionally, the categories of sensitivity and adaptive capacity — components of the vulnerability index as proposed by Gallopín (2006) — were also included, as illustrated in Figure 2.

Figure 2 – Indices considered for the analysis of the study area in the water, energy, and food sectors.



Fonte: Elaboração própria com base em AdaptaBrasil MCTI (2025).

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- **Stage 2 – Data Analysis:** The collected data were organized into georeferenced maps using the open-source software QGIS, specifically the Long Term Release for Windows (version 3.34 LTR). Maps were produced to represent the impact risk index, vulnerability index (including the corresponding categories of sensitivity and adaptive capacity), exposure index, and climate threat index.
- **Stage 3 – Proposal of Adaptation Measures:** Based on the information obtained and the identification of the main challenges to climate resilience within the study area, mitigation measures were proposed guided by the Nexus – WEF approach. The proposals were developed using the 5W2H management tool, which supports the organization of information for planning and decision-making processes within an action plan (Ventura & Suquisaqui, 2020). The tool involves answering seven guiding questions to structure the proposals: (i) What?; (ii) When?; (iii) Why?; (iv) Where?; (v) Who?; (vi) How?; and (vii) How much does it cost? The cost-related question was excluded from the analysis as it falls outside the scope of this study.

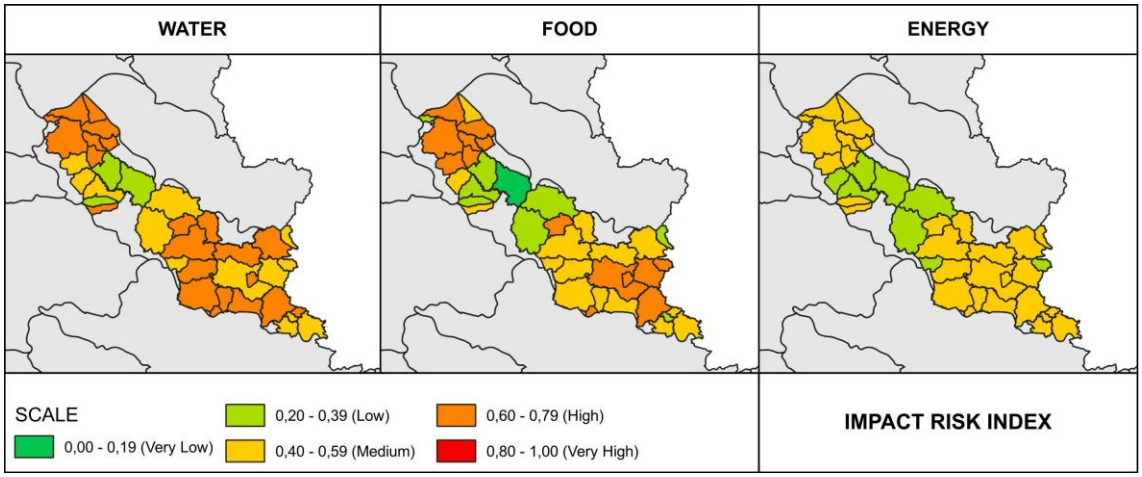
4 RESULTS

4.1 Analysis of Water, Food, and Energy Security

4.1.1 Impact Risk Index – Periods of Prolonged Drought

For the extreme drought event, data related to the water, food, and energy sectors were collected at Level 2 – Impact Risk Index (Figure 3). This index results from the combination of vulnerability, exposure, and climate hazard indices for each sector.

Figure 3 – Impact Risk Index for drought in the water, food, and energy sectors.



Source: The authors based on AdaptaBrasil MCTI (2025).

Among the sectors analyzed, the water sector shows the highest number of municipalities at risk during prolonged drought periods (Figure 3). In total, 22 municipalities exhibit high impact risk (0.60–0.79), 13 are classified as having medium impact risk (0.40–0.59),

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and 3 municipalities (Guatapará, Luís Antônio, and Santa Lúcia) have low impact risk (0.20–0.39). None were classified as having very high or very low risk in this sector.

For the food sector, the observed pattern was more heterogeneous. Only one municipality (Luís Antônio) was classified as having a very low impact risk, 8 municipalities showed low impact risk, 15 had medium impact risk, and 14 were classified as having high impact risk. Similarly, no municipalities were classified as having a very high risk in the food sector.

Finally, the energy sector presented the most homogeneous pattern, with 30 municipalities under medium impact risk and 8 municipalities under low risk. These results highlight the need for a more detailed analysis of the components within each sector to identify critical points requiring attention. This approach can support resource management strategies at both the municipal and watershed levels.

4.1.2 Vulnerability Analysis

Vulnerability can be understood as the predisposition of a system to suffer damage when exposed to a hazard, being directly linked to the system's sensitivity and adaptive capacity. Sensitivity refers to the degree to which a system is affected by climatic stimuli, while adaptive capacity refers to its ability to adjust to disturbances or potential damages (AdaptaBrasil MCTI, 2025; IPCC, 2014).

In this context, data related to the vulnerability of the water, energy, and food sectors within the Mogi Guaçu River Basin are presented in the maps in Figure 4.

For the water sector, in terms of vulnerability, one municipality showed a very high index (Pitangueiras – 0.80), four municipalities presented high vulnerability (Aguaí, Américo Brasiliense, Conchal, and Porto Ferreira), 22 municipalities were classified with medium vulnerability, and the remaining 11 municipalities were categorized as having low vulnerability. The results for the sensitivity and adaptive capacity categories vary.

Among all municipalities, three (Aguaí, Pitangueiras, and Porto Ferreira) exhibited high sensitivity, and three had low adaptive capacity (Américo Brasiliense, Conchal, and Leme). An overlap was observed among municipalities with poor performance in both categories and in overall vulnerability, highlighting critical areas for sectoral management. This overlap signals the need for targeted actions to enhance system resilience.

Regarding the vulnerability of the food sector, four municipalities presented high vulnerability indices (0.60–0.79), and 13 showed medium vulnerability. The majority of municipalities (21 – 55.26%) had low vulnerability, indicating the need for greater focus on those with weaker performance. Public policies should prioritize diversification of food production, cultivation of drought-resistant crops, planning and management of food and nutritional security, and strengthening the socioeconomic capacity of families to access safe food (Berardy & Chester, 2017; Prefeitura de Campinas, 2024).

A similar pattern is observed in the sensitivity category, with 22 municipalities showing low sensitivity. Only four municipalities (Barrinha, Jaboticabal, Pitangueiras, and Santa Cruz da Conceição) exhibited high sensitivity, and one municipality (Aguaí) showed very low sensitivity. As for adaptive capacity, notable variations were found among municipalities, with six showing low adaptive capacity and requiring increased attention. Therefore, it is essential to assess public

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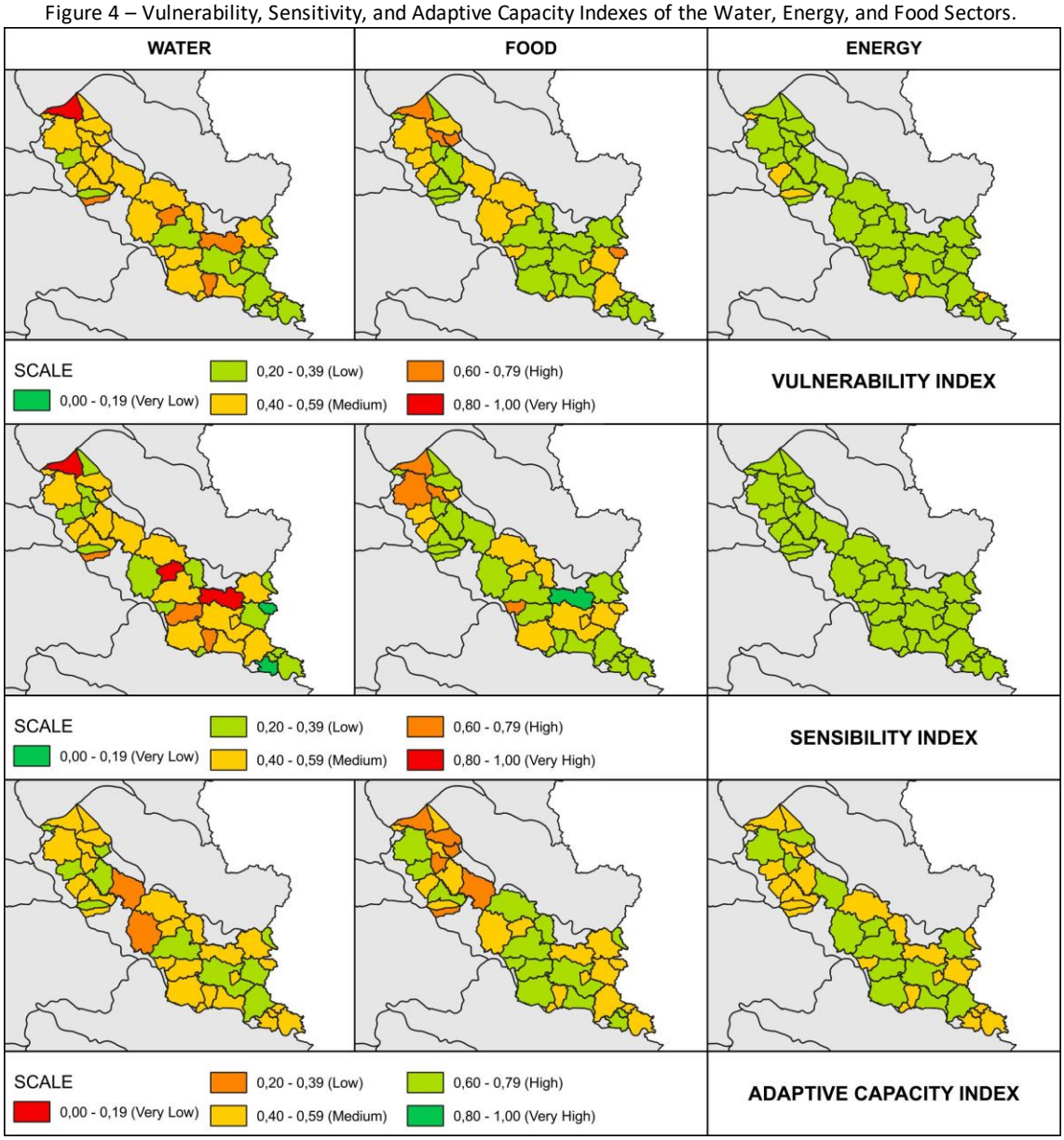
policies in municipalities that are less vulnerable to drought to inform and support the development of policies for those facing greater challenges during extreme events.

Figure 4 – Vulnerability, Sensitivity, and Adaptive Capacity Indexes of the Water, Energy, and Food Sectors.



Fonte: The authors based on AdaptaBrasil MCTI (2025).

Similar to the pattern observed in Section 4.1.1 regarding the overall impact risk index, the energy sector showed the greatest homogeneity among municipalities. In terms of vulnerability, only five municipalities (Águas de Lindóia, Conchal, Motuca, Santa Lúcia, and Taquaral) exhibited medium risk, while the remaining 33 municipalities were classified as having low risk.

Regarding the sensitivity category, all municipalities were assessed as having low risk. The greatest variation was observed in adaptive capacity: 13 municipalities showed a high adaptive capacity index (including Araras, Mogi Guaçu, and Sertãozinho—the three largest municipalities in the Mogi Guaçu River Basin), while 25 municipalities had a medium index.

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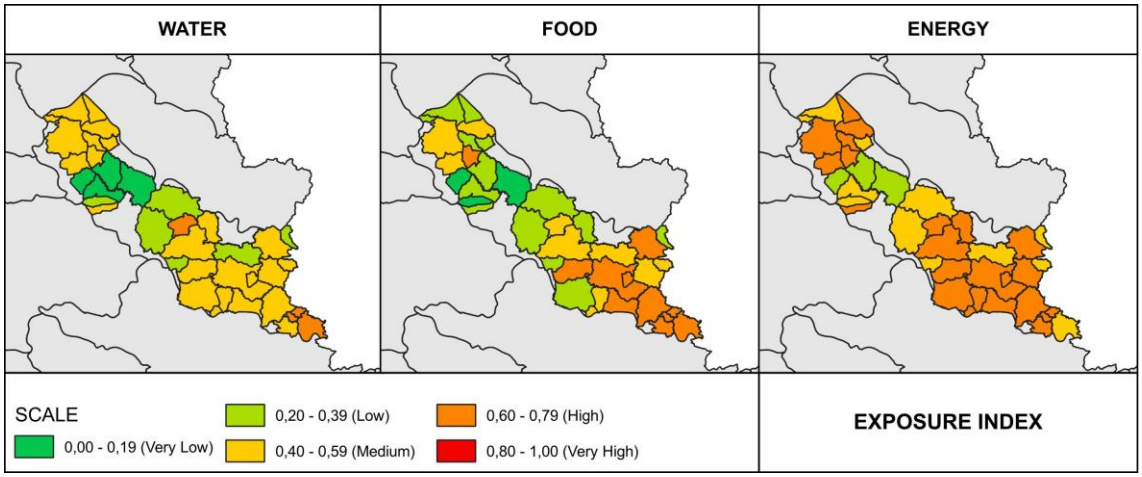
4.1.3 Exposure Analysis

The exposure dimension relates to the degree of susceptibility of the system when exposed to the climate hazard (in terms of duration and/or extent), and it is determined independently from vulnerability (AdaptaBrasil MCTI, 2025). Figure 5 presents the data collected for the 38 municipalities under study.

Figure 5 – Exposure Index for the Water, Energy, and Food Sectors.



Fonte: The authors based on AdaptaBrasil MCTI (2025).

In the water resources sector, four municipalities (Guatapará, Luís Antônio, Motuca, and Rincão) exhibit a very low exposure index and may serve as examples for planning efforts in other municipalities facing greater challenges. Overall, 24 municipalities (63.16%) presented a medium exposure index, while four municipalities (Águas de Lindóia, Lindóia, Porto Ferreira, and Socorro) were classified with a high exposure index.

In contrast, the food sector showed greater variation among the results: three municipalities (Luís Antônio, Motuca, and Santa Lúcia) were classified with a very low exposure index, 14 with low exposure, 10 with medium exposure, and 11 with high exposure.

Finally, differing from the patterns observed in Sections 4.1.1 and 4.1.2, the energy sector exhibited a greater number of municipalities threatened by drought events. A majority of 23 municipalities (60.53%) showed a high exposure index, 12 municipalities presented a medium index, and only three (Guatapará, Luís Antônio, and Motuca) were classified with low exposure. Therefore, it is crucial to consider a comprehensive planning strategy aimed at reducing the sector's exposure throughout the basin.

No very high exposure index was identified in any of the sectors, directing attention primarily to municipalities with high and medium exposure. Additionally, it is important to highlight that Luís Antônio and Motuca achieved consistently favorable results across all sectors in terms of exposure. A more detailed investigation into the factors contributing to this performance is recommended to assess the presence (or absence) of intersectoral collaboration.

4.1.4 Climate Threat Analysis

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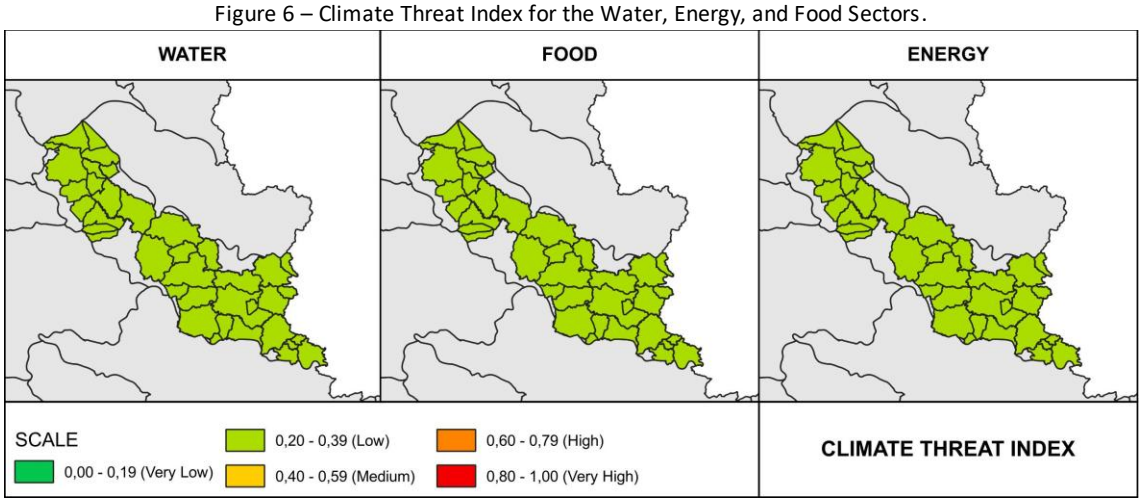
Climate threat can be defined as the losses and damages experienced by both society and ecosystems resulting from extreme climatic events. These events are characterized by intensity and/or duration exceeding the normal range of thermal variability (e.g., heat waves, intense rainfall, prolonged droughts, among others). Thus, in simplified terms, the Climate Threat Index reflects the external climatic factors that have the potential to significantly impact the system when interacting with each other (AdaptaBrasil MCTI, 2025).

The data collected regarding climate threat for the water, energy, and food sectors in the study area are presented in Figure 6.

Figure 6 – Climate Threat Index for the Water, Energy, and Food Sectors.



Fonte: The authors based on AdaptaBrasil MCTI (2025).

Unlike the findings presented in Sections 4.1.1 to 4.1.3 of this study, the climate hazard did not pose significant challenges for any of the municipalities in the Mogi Guaçu River Basin across the evaluated sectors.

For water, energy, and food sectors, all municipalities exhibit low climate hazard indices, which include assessments of consecutive dry days and the standardized evapotranspiration index. This indicates that planning efforts, whether at the municipal or regional level, should focus on reducing vulnerability and exposure of municipalities to drought events.

Moreover, it is important to highlight that climate hazard was the only dimension that showed no significant discrepancies among the analyzed sectors. This suggests that management probably does not occur in an intersectoral manner, resulting in impacts at different levels on water, food, and energy.

Therefore, exploring synergies among the sectors is essential to enhance decision-making effectiveness and accuracy, thereby contributing to security across all three evaluated pillars.

4.1.5 Mitigation Measures Based on the Nexus Approach – Water, Energy, Food

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Based on the information collected for the watershed under study, intervention measures were proposed that consider regional-level actions to support decision-making by responsible authorities.

Using the Water–Energy–Food Nexus methodology, three intervention measures were selected for detailed analysis following the 5W1H management tool. These measures are presented in Tables 1, 2, and 3. For each measure, the potential impact on all three sectors (water, energy, and food) was considered with the aim of fostering more collaborative management.

Chart 1 – Mitigation Measures for Climate Resilience in the Municipalities of the Mogi Guaçu River Basin: Promoting Climate Education Actions.

Action	Promoting Climate Education Actions	
What	Promoting climate education actions with a special focus on the maintenance of water bodies (quantity and quality).	
Why	Most municipalities in the Mogi Guaçu River Basin face challenges related to security in the water, energy, and food sectors during prolonged drought periods. Climate education actions can generate positive impacts, such as:	
	WATER	Reduction in per capita water consumption. Increased water availability for supply.
	ENERGY	Increased water availability for energy production
	FOOD	Increased water availability for food production.
	ECOSYSTEM	Conservation of the ecosystem, maintenance of vegetation, and enhancement of climate resilience.
Where	These actions are targeted at primary and elementary schools (both municipal and private) and institutions involved in municipal management (e.g., city hall, sanitation companies/autarchies).	
When	Semiannual. Plan the actions to be carried out in schools and institutions every six months with the aim of informing and updating the population about municipal indicators and the existing possibilities to increase the city's climate resilience.	
Who	Implementing agents: Municipal public authorities and members of the Watershed Committee representing the Mogi Guaçu River Basin. Target audience: General population.	
How	1) Fiscal incentive campaigns to reduce per capita water consumption. 2) Workshops with activities emphasizing the importance of maintaining water bodies (e.g., vegetation conservation, reduction of solid waste disposal, increasing soil permeability in residential areas, among others). 3) Monitoring through management indicators: annual percentage of vegetated area, average annual per capita water consumption, volume of solid waste collected, water quality parameters, among others deemed necessary by management for municipal performance verification.	

Source: The authors based on Lapa et al. (2018), Prefeitura de Campinas (2024).

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Chart 2 – Mitigation Measures for Climate Resilience in the Municipalities of the Mogi Guaçu River Basin: Enhancing Water Governance

Action	Enhancing Water Governance	
What	Improving water governance based on principles such as effectiveness, efficiency, and trust and engagement.	
Why	The water resources sector is the most threatened during drought periods when compared to the other sectors (energy and food) evaluated in this study. Risk indicators for this sector identify 23 municipalities with high impact risk (0.60 – 0.79) and 12 municipalities classified with medium impact risk (0.40 – 0.59).	
	WATER	Reduction of per capita water consumption. Increased water availability for supply.
	ENERGY	Increased water availability for energy production.
	FOOD	Increased water availability for food production.
	ECOSYSTEM	Increased water availability for various uses.
Where	At the Mogi Guaçu River Basin Committee and at the municipal-level agency (and/or autarchy, private concession) responsible for water resources management in each of the 38 municipalities comprising the basin under study.	
When	Immediate.	
Who	Implementing agents: Municipal public authorities and members of the Mogi Guaçu River Basin Committee. Target agents: General population.	
How	1) Establish clear sustainable policy goals at all levels of government. 2) Maximize the benefits of sustainable water resource management at the lowest cost to society. 3) Build public trust and mobilize involved stakeholders through institutional measures and fair procedures.	

Source: The authors based on Ferro *et al.* (2025); Lal (2015), Nouri *et al.* (2021), Rasul; Sharma (2016), Roo *et al.* (2021).

Chart 3 – Mitigation Measures for Climate Resilience in the Municipalities of the Mogi Guaçu River Basin: Alternatives for Agricultural Production

Action	Seeking Alternatives for Agricultural Production	
What	Pursuing alternatives to diversify agricultural production and reduce water and energy consumption during irrigation processes.	
Why	The analysis of the Adaptive Capacity Index for the food sector in the evaluated municipalities revealed that 7 municipalities exhibited a low adaptive capacity index, while 15 municipalities presented a medium index. Together, these represent 57.89% of the Mogi Guaçu River Basin municipalities, indicating a need for focused attention.	
	WATER	Reduced water consumption compared to conventional solutions
	ENERGY	Decreased energy demand for irrigation system operation
	FOOD	Ensured food production – food security
	ECOSYSTEM	Reduction in greenhouse gas emissions
Where	These measures should be prioritized in the 38 municipalities comprising the Mogi Guaçu River Basin, especially those with medium and low adaptive capacity indices.	
When	Immediate.	
Who	Implementing agents: Municipal public authorities and members of the Mogi Guaçu River Basin Committee. Target agents: General population.	
How	1) Cultivation of drought-tolerant crops. 2) Replacement of current crops with varieties better suited to future temperature and precipitation patterns. 3) Exploration of alternatives such as micro-irrigation, the use of solar-powered pumps, and other agricultural techniques like hydroponics.	

Source: The authors based on Lal (2015), Mpandeli et al. (2018), Rasul; Sharma (2016), Kropf; Schmid; Mitter (2021), Torres et al., (2024), Wu; Elshorbagy; Helgason (2023).

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5 CONCLUSIONS

The information survey, based on data available online through the AdaptaBrasil MCTI platform for the municipalities of the Mogi Guaçu River Basin, and its organization into georeferenced maps proved to be an effective tool in supporting the identification of opportunities and challenges for management at both regional and municipal levels.

The data reveal intersectoral divergences, indicating a likely lack of collaboration among sectors during the planning process. Thus, this study emphasizes the need to consider the potential synergies between the water, energy, and food sectors in decision-making.

Limitations were identified during the research development, including reliance on online data sources that are often outdated and the transparency of information provided by municipal agencies.

Finally, the Nexus framework serves as a model to assist in identifying these synergies. Among the possibilities, the study highlights climate education actions, improvement of water governance, and the search for alternatives in agricultural production as potential measures to support municipalities in enhancing climate resilience, especially during prolonged drought periods.

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DECLARAÇÕES

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DECLARAÇÃO DE CONFLITOS DE INTERESSE

Nós, **Laura de Oliveira Battistini Pestana, Jacqueline Priscila Olmedo, Keila Camila da Silva e Katia Sakihama Ventura,** declaramos que o manuscrito intitulado "**Abordagem *Nexus* Água-Energia-Alimento como suporte à tomada de decisão visando a resiliência climática: estudo de caso na Bacia Hidrográfica do Rio Mogi Guaçu** ":

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