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Use of Variables for Implementing Compensatory Techniques in Urbanized Areas: Case Study in Araraquara - SP

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Use of variables for implementing compensatory techniques in urbanized areas: Case study in Araraquara - SP

Utilização de variáveis para implantação de técnicas compensatórias em meio já urbanizado: Estudo de caso em Araraquara – SP

RESUMO

Objetivo - Realizar demonstração da utilização de variáveis pré-selecionadas no auxílio da otimização da escolha de TC para serem implantadas com maior assertividade em meios já urbanizados, com estudo de caso em Araraquara - SP.

Metodologia - O estudo utilizou uma abordagem aplicada e empírica com base em revisão bibliográfica e análise de campo. A área escolhida foi a microbacia do Córrego da Servidão, localizada na região central de Araraquara-SP, onde ocorrem alagamentos frequentes. Foram definidas e aplicadas variáveis específicas para avaliar a viabilidade de implantação de diferentes TC em áreas urbanizadas, permitindo selecionar soluções mais adequadas ao contexto local.

Resultados - A partir dessa análise, foi possível observar que em locais sem disponibilidade de espaços, possibilidade de implantação em áreas públicas e privadas, interferência das obras de implantação com as atividades existentes e a possibilidade de dispersão dos lançamentos em diferentes pontos dos corpos receptores acabam sendo fatores relevantes a serem levados em consideração, antes de escolher a TC mais adequada.

Originalidade/Relevância - O estudo aborda a lacuna teórica e prática relacionada à dificuldade de implantação de TC em áreas urbanas já consolidadas. Contribui ao propor um conjunto de variáveis inéditas que orientam a seleção de técnicas de drenagem urbana sustentável, considerando limitações típicas de espaços urbanos densamente ocupados. A relevância reside na aplicabilidade prática para municípios que enfrentam problemas crônicos de alagamento.

Resultados - A análise mostrou que fatores como a falta de espaço disponível, interferência das obras com as atividades existentes, limitações de acesso a áreas públicas e privadas, e a possibilidade de dispersão dos lançamentos em diferentes pontos dos corpos receptores são cruciais na escolha da TC adequada. Técnicas que exigem grandes áreas ou interferem diretamente na circulação urbana se mostraram inviáveis, enquanto soluções mais flexíveis e integráveis ao sistema existente apresentaram maior viabilidade.

Contribuições Teóricas/Metodológicas - O trabalho propôs uma matriz de variáveis para avaliar a viabilidade de implantação de TC em áreas urbanas consolidadas, o que representa um avanço metodológico. A sistematização dessas variáveis permite uma análise mais criteriosa e padronizada na seleção das soluções técnicas, contribuindo com a literatura sobre drenagem urbana sustentável e planejamento urbano integrado.

Contribuições Sociais e Ambientais - As TC promovem benefícios como redução de alagamentos, melhoria da qualidade ambiental urbana e valorização dos espaços públicos. A aplicação dessas técnicas pode gerar melhorias significativas na mobilidade urbana, qualidade de vida da população e conservação dos corpos hídricos, desde que haja participação comunitária e apoio institucional. A conscientização e aceitação social são destacadas como pontos-chave para o sucesso dessas intervenções.

PALAVRAS-CHAVE: Drenagem urbana. Técnicas compensatórias. Águas pluviais.

Use of variables for implementing compensatory techniques in urbanized areas: Case study in Araraquara - SP

ABSTRACT

Objective - To demonstrate the use of pre-selected variables to optimize the selection of compensatory techniques (CT) for implementation with greater accuracy in already urbanized areas, through a case study in Araraquara-SP, Brazil.

Methodology - The study employed an applied and empirical approach based on bibliographic review and field analysis. The selected area was the micro-basin of the Servidão Stream, located in the central region of Araraquara-

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SP, where flooding occurs frequently. Specific variables were defined and applied to assess the feasibility of implementing different CTs in urbanized areas, allowing for the selection of solutions most appropriate to the local context.

Results - The analysis revealed that factors such as the unavailability of space, feasibility of implementation in public and private areas, interference of construction works with existing activities, and the possibility of dispersing runoff discharges to different receiving bodies are crucial considerations when selecting the most appropriate CT.

Originality/Relevance - This study addresses both theoretical and practical gaps regarding the challenges of implementing CTs in already consolidated urban areas. It contributes by proposing a novel set of variables that guide the selection of sustainable urban drainage techniques, considering typical limitations of densely occupied urban spaces. Its relevance lies in the practical applicability for municipalities facing chronic flooding problems.

Theoretical/Methodological Contributions - The study proposes a matrix of variables for evaluating the feasibility of implementing CTs in consolidated urban areas, representing a methodological advancement. The systematization of these variables enables a more rigorous and standardized analysis in the selection of technical solutions, contributing to the literature on sustainable urban drainage and integrated urban planning.

Social and Environmental Contributions - CTs provide benefits such as flood reduction, improvement of urban environmental quality, and enhancement of public spaces. Their implementation can significantly improve urban mobility, population quality of life, and preservation of water bodies, provided there is community participation and institutional support. Public awareness and social acceptance are emphasized as key factors for the success of such interventions.

KEYWORDS: Urban Drainage. Compensatory Techniques. Rainwater.

Utilización de variables para la implementación de técnicas compensatorias en un medio ya urbanizado: Estudio de caso en Araraquara – SP

RESUMEN

Objetivo - Demostrar el uso de variables preseleccionadas para optimizar la elección de técnicas compensatorias (TC) a ser implementadas con mayor precisión en áreas ya urbanizadas, mediante un estudio de caso en Araraquara-SP, Brasil.

Metodología - El estudio adoptó un enfoque aplicado y empírico basado en revisión bibliográfica y análisis de campo. El área seleccionada fue la microcuenca del arroyo Servidão, ubicada en la región central de Araraquara-SP, donde se producen inundaciones frecuentes. Se definieron y aplicaron variables específicas para evaluar la viabilidad de implementar distintas TC en áreas urbanizadas, permitiendo seleccionar soluciones más adecuadas al contexto local.

Resultados - El análisis permitió observar que factores como la falta de espacio disponible, la posibilidad de implementación en áreas públicas y privadas, la interferencia de las obras con las actividades existentes y la posibilidad de dispersión de los vertidos en diferentes puntos de los cuerpos receptores son elementos cruciales que deben considerarse antes de seleccionar la TC más adecuada.

Originalidad/Relevancia - El estudio aborda vacíos teóricos y prácticos en relación con las dificultades de implementación de TC en áreas urbanas ya consolidadas. Contribuye proponiendo un conjunto inédito de variables que orientan la selección de técnicas de drenaje urbano sostenible, considerando las limitaciones típicas de espacios urbanos densamente ocupados. Su relevancia radica en la aplicabilidad práctica para municipios que enfrentan problemas crónicos de inundaciones.

Contribuciones Teóricas/Metodológicas - El estudio propone una matriz de variables para evaluar la viabilidad de implementar TC en áreas urbanas consolidadas, lo cual representa un avance metodológico. La sistematización de estas variables permite un análisis más riguroso y estandarizado en la selección de soluciones técnicas, contribuyendo a la literatura sobre drenaje urbano sostenible y planificación urbana integrada.

Contribuciones Sociales y Ambientales - Las TC generan beneficios como la reducción de inundaciones, la mejora de la calidad ambiental urbana y la valorización de los espacios públicos. Su implementación puede generar mejoras significativas en la movilidad urbana, la calidad de vida de la población y la preservación de los cuerpos hídricos, siempre que exista participación comunitaria y apoyo institucional. La concienciación y aceptación social son aspectos clave para el éxito de estas intervenciones.

PALABRAS CLAVE: Drenaje Urbano. Técnicas Compensatorias. Agua de Lluvia.

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1 INTRODUCTION

With the increasing urbanization of cities, conventional stormwater drainage systems face challenges due to soil impermeabilization and the extinction of local vegetation due to housing developments. Thus, the use of Compensatory Techniques (CT) is becoming more common in Brazil and worldwide.

According to Tucci (1999), urban development alters vegetation cover, affecting the natural hydrological cycle. Urbanization changes the basin cover to impermeable pavements and introduces conduits for stormwater runoff, altering its cycle. Various techniques have emerged, offering solutions to integrate water, ecological, and urban environments, improving the feasibility and aesthetics of municipalities with multifunctional uses. These can be inserted in already urbanized areas, planned for urbanizing areas, or rearranged in re-urbanizing environments (LI *et al*., 2024).

According to Fletcher *et al.* (2021), the term Alternative Techniques began to be used to indicate a new approach to traditional urban drainage, aiming to neutralize the impacts of urban expansion, optimize urban land use, and limit investment financial resources. The authors discussed the development and integration of terms to describe stormwater management in urban environments, highlighting concepts such as Water Sensitive Urban Design (WSUD), Low Impact Development (LID), and Best Management Practices (BMP).

CTs come in various sizes and shapes, aiming to minimize the impacts of urbanization on the urban hydrological cycle, thus benefiting the population's quality of life and environmental preservation (Baptista *et al*., 2015). CTs are generally divided into structural and non-structural types and can be associated with each other or even with the existing conventional drainage system.

According to the Maryland LID manual (1999), various CT types aid stormwater drainage, which can be combined and linked to the existing system, facilitating their application.

CTs are socio-ecological technical systems that can improve the ecosystem and urban drainage technologies, incorporated into urban planning, management, and design (Mcphearson *et al*., 2022). These urban systems can provide multiple benefits to the population and local aesthetics.

According to McPherson *et al.* (2022), the resilience of drainage systems like CTs in urban environments can be improved by providing multiple ecosystem services, offering various functions, and adapting their flexibility to handle future uncertain conditions, which usual infrastructures cannot. The use of CTs in urban areas can explore better perspectives in urban planning, urban ecology, urban design, landscape architecture, improvement of local climatic conditions, among others, maximizing benefits for people, the environment, and reducing costs from local flooding and inundations.

The use of CTs in urban areas, such as implementing green roofs, retention basins, or other sustainable urban drainage systems, has the potential to generate significant socio-economic benefits in the short, medium, and long term (Maes; Jacobs, 2017). These nature-based solutions can help the population have safe operational spaces, improve local ecological and social sustainability, and provide long-term economic returns.

The most commonly used CTs are Detention/Retention Basins (DB/RB), Rain Gardens

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(RG), Infiltration Trenches (IT), Infiltration Ditches (ID), Permeable Pavements (PP), Infiltration Reservoirs (IR), Green Roofs (GR), and Grass Strips (GS).

Although CTs are an alternative to the conventional drainage system, some problems in their implementation need to be analyzed before their execution, often taking time to be evaluated, especially in already urbanized areas.

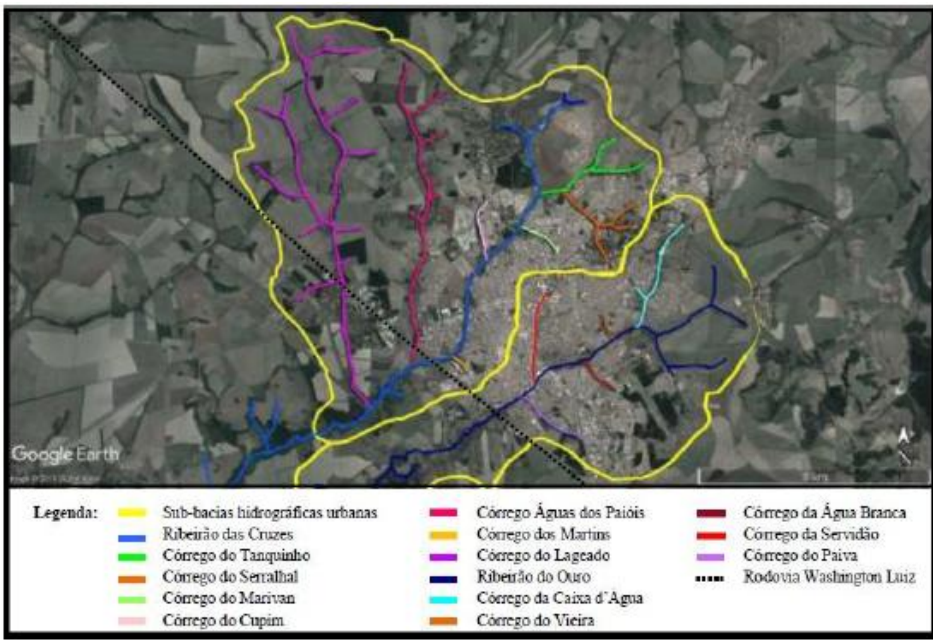
2 OBJECTIVES

Demonstration of the use of pre-selected variables to optimize the choice of CTs for more effective implementation in urbanized environments with a case study in Araraquara-SP.

3 METHODOLOGY

The municipality of Araraquara-SP was chosen for having several microbasins, some within the urban area, the focus of this study. Lopes (2021) studied the Córrego da Servidão microbasin, shown in red on the map (Figure 1), which runs under one of the main roads in the city.

Figure 1 – Sub-watersheds in the Urban Area of de Araraquara – SP



Source: Peroni (2018).

The microbasin is located almost in the central part of the city's urban area, as shown in more detail in Figure 2.

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Figure 2 – Córrego da Servidão Microbasin

Source: Araraquara, 2013.

According to Peroni *et al.* (2017), it is important to highlight that during the implementation of the Via Expressa in the 1980s, the canalization and covering of the Córrego da Servidão were carried out in sections, at different times, resulting in sections of different shapes and sizes throughout its course, causing flooding problems at certain points.

To apply the variables in already urbanized areas, a region with frequent flooding during rainy seasons were selected. This area is also in the city's central region, below the Central Bus Integration Terminal (Figure 3), on Avenida Maria Antônia de Camargo Oliveira, popularly known as Via Expressa, as shown in Figures 4 and 5.

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Figure 3 – Location Map of Central Integration Terminal

Source: Google Maps, 2021.

Figura e – Aerial View of the Central Integration Terminal in Araraquara – SP

Source: Lopes (2021, p. 76).

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Figure 5 – Area below the Termimal were flooding occurs

Source: Lopes (2021, p. 77).

Despite the availability of catch basins and partially draining pavement in the bus and vehicle parking area, the devices are insufficient to conduct the generated surface runoff, which concentrates in the lowest points and causes recurring flooding.

It is worth noting that the Córrego da Servidão is completely canalized and covered, running exactly under this road, further complicating the drainage of rainwater and suffering contamination issues.

When flooding occurs, this entire stretch of the Via Expressa needs to be closed until the water volume decreases, causing local traffic problems and requiring professionals to guide an alternative route and others to temporarily solve the drainage problem, as shown in Figure 6.

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Figura 6 – Flooding on Via Expressa

Source: G1 São Carlos e Araraquara, 2014.

In this type of situation, it is important to note that conventional techniques are no longer effective in rainwater drainage, requiring the use of CT combined with possible local replanning. Unfortunately, being a high-access area, major construction work would have significant impacts.

4 RESULTS AND DISCUSSION

4.1 4.1 Application of Variables in Flood-Prone Areas

Given the variety of CTs, Lopes (2021) developed new variables after a literature review of manuals and municipal master plans to optimize the choice of CTs for specific urbanized environments, as shown in Table 1. The author was able to identify relevant variables related to urbanized environments to facilitate the elimination of CTs that posed implementation difficulties.

Table 1 – Proposed Variables for Applying CTs in Urbanized Areas

PROPOSED VARIABLES FOR APPLYING CTS IN URBANIZED AREAS
Superficial area occupied by CT
Need for continuous surface areas
External efforts and vibrations
Interference with underground installations
Possibility of integration with existing drainage system

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Possibility of implementation in private areas
Availability of public areas
Interference with existing activities
Population acceptance
Use of circulation and parking areas
Possibility of multiple Uses
Re-urbanization of the area
Possibility of fraud or improper use
Discharge dispersion in receiving bodies

Source: Lopes (2021, p. 51), translated.

Lopes (2023) noted that there are more considerations for implementing a CT in an already urbanized environment than in one being urbanized or yet to be urbanized. Existing structures need to be considered, along with validating their dimensions to match the chosen location.

This analysis of variables, along with explanatory observations, justified the difficulties in these locations, including high impermeability due to urban density and local social and economic conflicts.

The evaluation of these variables for flood-prone areas allowed the creation of Table 2, outlining possible CTs for implementation in a residential area without open spaces.

Table 2 – Application of Variables in Flood-Prone Areas

VARIABLE	DESCRIPTION
Superficial area occupied by CT	Surface area needed for the CT implementation
Need for continuous surface areas	Requirement of large continuous surface areas
External efforts and vibrations	External forces and vibrations affecting the CT
Interference with underground installations	Impact on existing underground installations
Possibility of integration with existing drainage system	Ability to connect with the current drainage system
Possibility of implementation in private areas	Feasibility of implementation on private property
Availability of public areas	Availability of public spaces for CT implementation
Interference with existing activities	Impact on ongoing activities during CT construction
Population acceptance	Public acceptance of the CT
Use of circulation and parking areas	Use of vehicles circulation and parking areas for CTs
Possibility of multiple Uses	Potential for multiple uses of the implemented CT
Re-urbanization of the area	Potential for area redevelopment
Possibility of fraud or improper use	Potential of CT misuse or vandalism
Discharge dispersion in receiving bodies	Ability to disperse discharges to various points

Source: Lopes (2021, p. 80), translated.

The analysis showed that the variables have significant weight in CT implementation, often.

The assessment of variables for flood-prone areas allowed the creation of Table 3, evaluating the applicability of each CT in this studied situation. The analysis compared Favorable

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conditions for Implementation (•), Unfavorable conditions for Implementation (•), or those that do not apply (•)

Table 3 – Variables x CT Matrix for Flood-Prone Areas

	COMPENSATORY TECHNIQUES								
VARIABLE	BD/BR	JC	TI	VL	PP	PI	RI	TV	FG
Superficial area occupied by CT	red	red	green	red	green	green	green	green	green
Need for continuous surface areas	red	red	green	red	green	green	green	green	green
External efforts and vibrations	red	red	green	green	red	green	green	green	green
Interference with underground installations	green	red	red	green	green	red	red	green	green
Possibility of integration with existing drainage system	green	green	green	green	green	green	green	green	green
Possibility of implementation in private areas	red	red	red	red	red	red	green	green	red
Availability of public areas	red	green	green	red	green	red	red	blue	red
Interference with existing activities	red	green	green	red	red	red	green	red	green
Population acceptance	red	blue	green	green	green	green	green	red	green
Use of circulation and parking areas	blue	blue	green	green	green	red	red	blue	green
Possibility of multiple Uses	red	green	green	green	green	green	red	red	green
Re-urbanization of the area	blue	blue	blue	blue	blue	blue	blue	blue	blue
Possibility of fraud or improper use	red	red	green	red	red	red	green	green	red
Discharge dispersion in receiving bodies	red	red	red	red	red	red	red	red	red

Source: Lopes (2021, p. 81), translated.

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Being a fully concreted and paved location, space availability for CT implementation is scarce, making it difficult to use CTs like basins or rain gardens.

The implementation of any CTs cannot be done directly on the avenue due to heavy traffic, necessitating evaluation in curbs, sidewalks, or local medians. The avenue lacks a central median, only having a narrow strip separating opposite lanes.

Finally, this area is at the lowest point of the basin, limiting CT effectiveness as the runoff water will have accumulated, reducing concentration time.

4.2 General Analysis of Variables

All selected variables for different situations were considered within an urbanized area, evaluating their main characteristics and challenges.

Besides drainage issues, impermeability suggests a lack of available spaces, complicating the implementation of new technologies to solve existing problems. Large-scale CT implementation is more di1ficult without available spaces, requiring expropriation and potential demolitions.

Considering soil occupation, CT implementation in non-continuous areas, dividing and placing them in various pails of the basin instead of one large area, is more favorable. Traffic-related e0orts and vibrations, especially from large vehicles at high speeds, influence CT choice, as some are fragile and may deteriorate over time.

Since this microbasin is within an urbanized area, interference with existing underground installations is inevitable, always evaluating less impacted locations or relocating existing ones. Integration with the existing drainage system is essential, reducing costs and utilizing existing infrastructure.

Studying a private area doesn't always mean CT implementation is possible, requiring space evaluation, construction type (e.g., green roofs), and local resident acceptance. Similarly, public area availability doesn't guarantee CT feasibility, requiring structure evaluation, available space, potential expropriations, among other factors.

The challenge in urban areas is ensuring local population movement, especially for residence and work access, evaluating CT construction impacts. This is more significant in commercial areas and larger or longer-term CTs. Logistical considerations are essential.

5 FINAL CONSIDERATIONS

For CT implementation in private or public areas, population acceptance is crucial, ensuring proper use, comfort, and well-being. Consideration of pre-existing uses and clear, participatory planning can prevent rejection or misuse.

Some CTs can be implemented in parking or low-traffic areas, curbs, and street medians. CTs can have multiple uses, adapting existing parks and squares, adding value beyond drainage.

Implementing CT in re-urbanizing areas is almost a new project, allowing greater flexibility and planning from the start. Re-urbanization is seen as a new available area, increasing CT implementation possibilities.

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Without public policies and environmental education, CT fraud and misuse are possible in private or public areas, including improper use, solid waste disposal, dismantling

post-approval, among other issues. Government incentives are crucial for the population to see CTs as valuable and sustainable.

Classified variables for CT implementation in urbanized areas should be analyzed before construction to avoid future issues, providing better logistics and strategy, and choosing the most appropriate CT depending on the location.

All CTs have advantages and disadvantages, but the primary need is evaluating the existing urban environment for the best association with the CT.

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DECLARAÇÕES

CONTRIBUIÇÃO DE CADA AUTOR

Ao descrever a participação de cada autor no manuscrito, utilize os seguintes critérios:

- **Concepção e Design do Estudo**: O seguinte artigo foi elaborado através de uma parte da dissertação de mestrado de Bruna Lamorea Veiga Lopes.
- **Curadoria de Dados**: Todos os dados foram analisados em conjunto de ambos os autores.
- **Análise Formal**: Bruna desenvolveu o método de análise a partir da revisão bibliográfica de diversos manuais e livros sobre o tema.
- **Aquisição de Financiamento**: Todo o estudo foi feito durante a dissertação de mestrado de Bruna, pleiteada com bolsa de estudo pela CAPES e ajuda financeira para a publicação do mesmo pelo Programa de Pós-Graduação em Engenharia Urbana da UFSCar.
- **Investigação**: A coleta de dados foi feita por Bruna, com auxílio de Bernardo.
- **Metodologia**: A metodologia foi desenvolvida por pelos autores juntos.
- **Redação - Rascunho Inicial**: Bruna escreveu, com supervisão de Bernardo.
- **Redação - Revisão Crítica**: Bruna escreveu, com supervisão de Bernardo..
- **Revisão e Edição Final**: O artigo foi revisado pela Baum Soluções Informacionais.
- **Supervisão**: Prof. Doutor Bernardo Arantes do Nascimento Teixeira garantiu a supervisão do estudo.

DECLARAÇÃO DE CONFLITOS DE INTERESSE

Nós, **Bruna Lamorea Veiga Lopes e Bernardo Arantes do Nascimento Teixeira** declaramos que o manuscrito intitulado **Utilização de variáveis para implantação de técnicas compensatórias em meio já urbanizado: estudo de caso em Araraquara – SP:**

1. **Vínculos Financeiros**: Não possuímos vínculos financeiros que possam influenciar os resultados ou interpretação do trabalho. Nenhuma instituição ou entidade financiadora esteve envolvida no desenvolvimento deste estudo.
2. **Relações Profissionais**: Não possuímos relações profissionais que possam impactar na análise, interpretação ou apresentação dos resultados. Nenhuma relação profissional relevante ao conteúdo deste manuscrito foi estabelecida.
3. **Conflitos Pessoais**: Não possuímos conflitos de interesse pessoais relacionados ao conteúdo do manuscrito. Nenhum conflito pessoal relacionado ao conteúdo foi identificado.