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Sustainable urban mobility in climate emergency adaptation: the contested public space

Mobilidade urbana sustentável na adaptação à emergência climática: o espaço público em disputa

Movilidad urbana sostenible en la adaptación a la emergencia climática: el espacio público en disputa

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Abstract

The paper approaches the relationship between urban mobility, public space, and inequality in the climate emergency. Taking as a starting point the profound impact of Petrópolis' socio-environmental tragedies caused by extreme rains in summer 2022, it investigates how space production has led to an increase in extreme climate events vulnerability, underlying why and how these episodes have unequally affected different places and social groups. It points to the influence of private motor vehicle-centered mobility in cities' decision-making as an obstacle to the necessary changes. In opposition to this model, the study seeks to analyze the aspects that turn sustainable urban mobility into a powerful tool to reshape urban spaces and make cities environmentally safer and socially fairer.

Keywords: Urban Mobility; Climate crisis; Environmental justice; Petrópolis.

Resumo

O artigo aborda relações entre mobilidade urbana, espaço público e inequidades no contexto da emergência climática. Tomando como ponto de partida o profundo impacto das tragédias socioambientais que acometeram a cidade de Petrópolis, decorrentes de chuvas intensas ocorridas no verão de 2022, investiga-se como a produção do espaço vem agravando vulnerabilidades a eventos climáticos extremos ao analisar como distintos lugares e estratos sociais são afetados de forma desigual. A importância conferida aos deslocamentos por automóvel nos processos de decisão sobre a cidade é apontada como um entrave às mudanças necessárias. Em oposição à ela, busca-se analisar os atributos que fazem da mobilidade urbana sustentável uma ferramenta promissora para reconfigurar espaços públicos visando tornar a urbe ambientalmente mais segura e socialmente menos desigual.

Palavras-chave: Mobilidade Urbana; Crise climática; Justiça ambiental; Petrópolis.

Resumen

El artículo aborda las relaciones entre movilidad urbana, espacio público y desigualdades en el contexto de la emergencia climática. Se parte del profundo impacto de las tragedias socioambientales que afligieron la ciudad de Petrópolis, debido a la ocurrencia de lluvias extremas en el verano de 2022, para investigar cómo la producción del espacio ha agravado la vulnerabilidad a eventos climáticos extremos, además del hecho de que diferentes lugares y estratos sociales se afectan de forma desigual en estos episodios. La importancia de los desplazamientos en automóvil en los procesos de decisión acerca de la ciudad es señalada como un obstáculo a los cambios necesarios. En oposición a este modelo, se busca analizar los aspectos que convierten la movilidad urbana sostenible en una herramienta prometedora para reconfigurar espacios públicos y promover seguridad ambiental y justicia climática a las ciudades.

Palabras clave: Movilidad urbana; Crisis climática; Justicia ambiental; Petrópolis.

Introduction

The rise in the planet's average temperature, when compared to pre-industrial levels, caused mainly by anthropogenic greenhouse gas (GHG) emissions, needs to be understood and addressed with seriousness and urgency (IPCC, 2023). It is fundamental to qualify the problem, discussing its causes and effects, as well as naming it properly. Thunberg (2023) refers to a climate and ecological crisis, related to the development model imposed by the countries of the Global North upon the rest of the world, although each of them occupies a distinct position in sustaining it. Whether between countries or social strata, the problem must be analyzed through the lens of inequality, since, although leveraged by the paradigm of development, not all of humanity is responsible for the catastrophe. One example is CO_2 emissions: those released by the wealthiest 1% of the world's population are equivalent to those of the most impoverished 66% (Kartha et al., 2020).

Material wealth not only translates into greater responsibility for the worsening of the climate crisis, but also into a greater capacity to resist its damages. From the concept of environmental justice, Acselrad, Mello, and Bezerra (2009) highlight the uneven vulnerability among different social groups and regions, showing that those who contributed the least for the climate crisis are the most impacted by its effects, while the ones who contributed the most tend to suffer fewer impacts. The authors argue that climate emergency and extreme inequality are interlaced problems that can only be addressed combined, requiring a redistributive, compensatory, and participatory approach. The United Nations (UN), through the concept of climate justice, advocates that mitigation and adaptation actions be based on the guarantee of human rights and on the fair distribution of the benefits and losses generated by them. Thus, the countries that have least accessed the advantages of development should receive financial and technological support to reduce emissions and increase their resilience (UNFCCC, 2015; IPCC, 2023).

Bringing this debate to the scale of cities is crucial, as they are situated at both ends of the problem: they hold the biggest part of emissions that accelerate global warming — 60% according to UN-Habitat — and it is in them that the effects are most extremely felt by people. Therefore, the fight against the climate crisis requires profound urban changes (Andrés, 2020).

In Brazilian cities, public spaces express quite well the relationship between urbanization, inequality, and its contribution to the socio-environmental crisis. Since the 1940s, road-oriented development has driven urbanization, spreading the territorial occupation and progressively claiming more space for motor vehicle traffic (Andrés, 2020). As a result, the hydrological ecology of each territory has been obliterated by burying, channeling, and all sorts of technical solutions that have impermeabilized the soils, but also, in a wider manner, the sensitive relationships of urban life with the earth and the water. Road infrastructures created to improve traffic have worsened flooding and tragedies related to intense rainfall,

as they reduce spaces for gradual infiltration and the natural variation of river volumes. Moreover, they have reconfigured the morphology of urban landscape, suppressing spaces for pedestrian sociability and non-motorized circulation, and distancing city dwellers from riparian forests and rivers. The bonus, therefore, is to the privileged social classes and their motorized lifestyles; and the onus is to the lower classes, who tend to inhabit the most vulnerable pieces of land and move around by active (human-powered) and collective transportation through public spaces that lack environmental quality.

Sustainable urban mobility presents itself as a suitable concept for addressing the issue, as it is structured around three pillars, listed here in order of importance: avoiding the need for and the distance of travel; adopting the least polluting modes of transportation; and reducing vehicles energy demand and emissions (ITDP Brasil, 2019). This order is essential, since solutions such as the electrification of personal vehicles do not always contribute to climatically resilient and socially just cities. Therefore, studies like this one are fundamental in supporting the characterization of truly sustainable mobility, that does not just mitigate GHG emissions, but also promotes equity and contributes to increasing urban resilience in the face of extreme climate events.

To deepen this discussion, the article analyzes the case of Petrópolis/RJ. The socio-environmental tragedies that occurred in 2022 were followed by reconstruction efforts that reinforced the road-oriented model of infrastructure, without questioning the impact of car-centered mobility on progressively more sensitive natural dynamics. The reconfiguration of street space to enhance the capacity of hydrological infiltration, conveyance, and retention—which would demand prioritizing active and collective transportation, since they are spatially more efficient—was not even taken into consideration by public authorities. By analyzing these aspects, the study aims to demonstrate how sustainable urban mobility can contribute to climate adaptation and reduce socio-spatial inequalities.

The article is organized into three main parts. The first one discusses the role of sustainable mobility in the environmental security of Brazilian cities, highlighting the need for integrated planning with other policies, such as housing. Subsequently, the article analyzes the vulnerability to extreme events in the urban planning of Petrópolis, considering historical aspects related to urban expansion and environmental injustice. For this, it uses cartographies and data that address the occupation of risk areas from a racial perspective. The third part examines the prominence of the personal motor vehicle in institutional decisions for urban recovery after the 2022 tragedies, revealing its incompatibility with contemporary environmental challenges. The study concludes by advocating for a model of urban planning that encompasses the present and the future, pointing to the social and spatial benefits of mobility centered on active transport and public transit.

Sustainable urban mobility and environmental security in cities

The potential of sustainable urban mobility for adapting cities to the effects of the climate crisis is still barely considered in public debate within Brazilian municipalities. Likewise, little attention has been given to the need for its integration with social housing policies in the Serrana Region of the state of Rio de Janeiro. A fragmented planning model has become consolidated, which fails to connect housing with displacement conditions and denies a more complex perspective on mobility.

When the current practice of producing housing complexes in distant areas is associated with precarious transit services, the availability of individual motorized transportation comes to determine each individual's degree of access to urban opportunities, reinforcing inequalities. In addition to this, this model increases the operational cost of the transportation system, since the need for expanding it in order to serve dispersed populations burdens its financing. In Brazil, where public transport is commonly funded by fares, this increase creates two tendencies: the rise in the value paid by users, aiming to boost revenue, and the deterioration of the service in order to reduce costs (Gregori *et al.*, 2024).

This scenario highlights the importance of a housing policy that prioritizes dwellings in urban areas with proper infrastructure, featuring diverse land uses and services. Proximity reduces the need for motorized travel, allowing everyday life to occur with less expenditure of time and money on transportation. Thus, urban planning must be the starting point for sustainable mobility, as the most efficient strategy is to shorten travel distances. In addition, sustainable mobility must promote modal shift through a diverse range of policies involving investment, facilitation, and promotion of active and collective transport use, while regulating and discouraging the use of personal motor vehicles (ITDP Brazil, 2019). It is important to emphasize that the inclusive dimension of the transport modes to be encouraged must ensure both financial and physical accessibility, as a means of overcoming various social barriers. Transit and public spaces must allow for broad, safe, and autonomous movement to people with disabilities and reduced mobility, as well as to people across diverse income levels.

Beyond being safer and more energy-efficient (Figure 1), these modes benefit equity, both because they are more affordable and because they optimize the use of public space, occupying smaller area for urban mobility (Figure 2). This allows the recovery of spaces that, in addition to social purposes, can serve environmental functions. This approach has been adopted by various cities around the world, where the reduction in car dependence has paved the way for a more creative and flexible use of public space. The city of Utrecht, for example, has successfully implemented sustainable mobility policies, promoting active travel, social encounters, and social engagement where cars were once predominant. A recent step was the renaturalization of a canal that had been buried by road

infrastructure, significantly enhancing environmental quality and contributing to traffic calming (Figure 3).

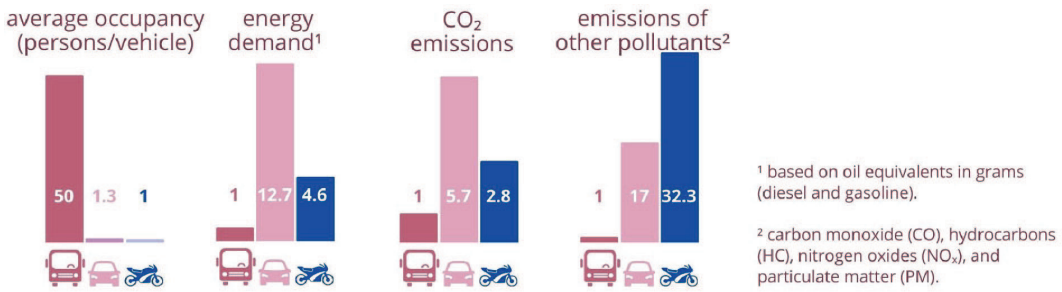

Figure 1: Average occupancy and relative indices per person/km in road transport modes.
Source: Paiva (2022).

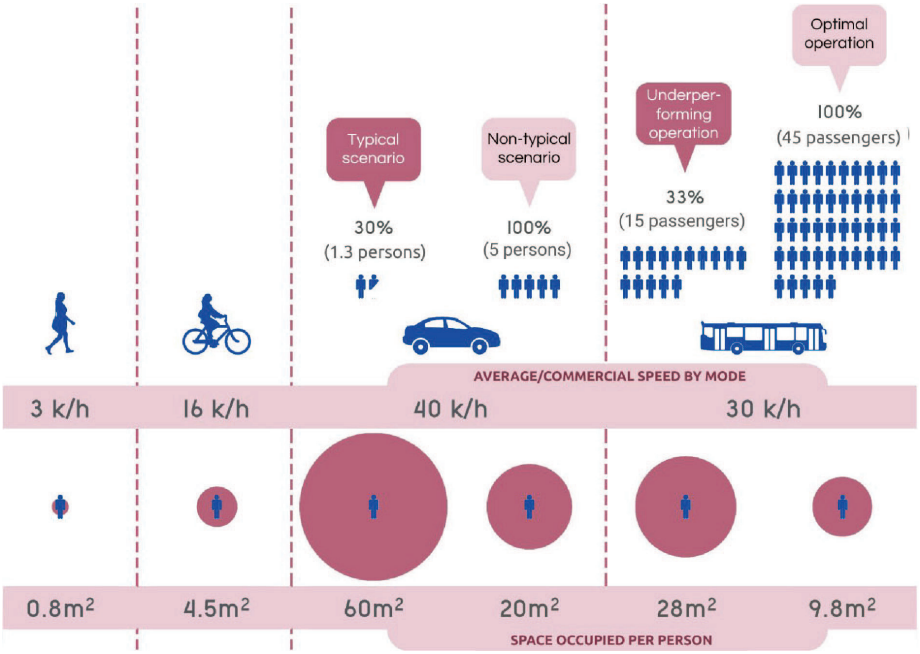

Figure 2: Efficiency in the use of space by mode of transport.
Source: ITDP Brasil (2015), adapted by authors.

Figure 3: Renaturalization of the Catharijnesingel Canal in Utrecht.
Source: Utrecht Archive and Antoine Thevenet apud OKRA (2024).

Reclaiming part of the vast urban area dedicated to car traffic and parking can be an effective strategy to reduce flooding susceptibility in Brazilian cities, enhancing their adaptation to the climate crisis. Enabling the implementation or expansion of areas dedicated to water infiltration, retention, and conveyance would be a central aspect of a climate-responsive urbanism, aiming to progressively reverse soil sealing, as well as mangrove landfilling, river channeling, and the suppression of vegetation. Breaking with car dominance and dependence opens space (literally) for an urban design that respects the dynamics of hydrological agents, rather than taming them.

The relevance of sustainable urban mobility is amplified when embedded in integrated territorial planning. Through the lens of environmental and climate justice, it is essential that policies take into consideration the socio-economic determinants of each context, ensuring that their restrictions do not penalize vulnerable groups, but, instead, help reduce historical inequalities.

Petrópolis: production of space and vulnerability in climate events

In February and March of 2022, two episodes of intense rainfall hit Petrópolis. The combination of their magnitude and the physical characteristics of the city led to landslides and floods that resulted in the death of 242 people, condemnation of thousands of buildings—most of them residences—, along with profound impacts on urban infrastructure, economy, and people's mental health. These deaths account for 54% of all rainfall-related fatalities in the city between 1988 and February 14, 2022, the day before the first tragedy (Paiva, 2022).

The site where Petrópolis is located presents ecological dynamics that make it sensitive to extreme weather events. Even so, to link floods and landslides only to the biophysical characteristics of the location would be imprecise, nor would it be accurate to justify the subsequent losses with this factor. Anthropogenic action in

distinct scales — from global GHG emissions to the impact of the urban insertion within the local river basin — is, undoubtedly, co-responsible for the tragedies.

Petrópolis was one of the first cities in the country to feature a planned layout, with a level of detail that was unusual at the time. The Koeler Plan (1846), developed by the engineer Julius Friedrich Koeler, demonstrated greater-than-usual attention to the natural environment for the period. Koeler used the topography and rivers as guiding principles for positioning the streets and structuring the occupation, which would take place in valley bottoms (Martins; Barcellos; Drach, 2022). He implemented streets and lot frontages facing water courses, giving them a prominent position in the urban landscape. Nevertheless, although he valued them as landscape elements, the Plan reproduced relationships of control over nature, compressing the river system by straightening and channeling its courses, and by occupying floodplains with streets and buildings (Figure 4). Indeed, the local topography, with its steep slopes and narrow floodplains within concave-bottom valleys, limited the viable and secure options for the layout of the settlement. Koeler was aware that the interventions would increase flood susceptibility, and, aiming to mitigate such risk, envisioned two retention tanks to reduce the speed and accommodate water volumes in flooding situations (Neves, 2021).

Figure 4: Current Koeler Avenue and the straightened Quitandinha River.
Source: Klumb (ca. 1870) apud Instituto Moreira Salles (n.d.).

Although prone to floods, the settlement, which was restricted to the riverbanks, preserved the slopes and the vegetation that protected them from soil erosion, thus preventing landslides. This premise of the Plan, however, was more difficult to ensure as Petrópolis became more urbanized. Its strategic location and transportation infrastructure that connected it to the states of São Paulo, Minas Gerais, and the capital of Rio de Janeiro drove population growth, leading the city beyond the original purpose of serving as a summer retreat for the nobility (Martins; Barcellos; Drach, 2022).

Starting in the 1940s, the parceling of lots has densified consolidated areas, while new paths and subdivision of lots moved toward middle sections of slopes. Since the 1970s, the informal occupation on hills, following the trend of the favelas in Rio de Janeiro, expanded into steeper areas, hilltops, and natural drainage lines (Petrópolis, 2017). This process has increased landslide susceptibility of slopes and the vulnerability of the local population, who, without access to the formal housing market or to efficient public policies, had no alternative but to live at risk.

It is worth noting that Petrópolis mirrors the Brazilian pattern of concentrating disadvantages on marginalized segments of the population, but with specificities related to its history. Meanwhile, families who came from Europe to perform paid labor in the construction of the future city were settled in the Colonial Blocks and were exempted from the tax charged for land occupation for 8 years (Ribeiro; Amorim; Abad, n.d.), Black people received no reparation, support, or policies ensuring access to housing and land when slavery was abolished in 1888. On the contrary, the Land Law, enacted in 1850, established purchase as the sole legal means of accessing vacant land, thereby denying land access to formerly enslaved people (Brasil, 1850).

With formal housing concentrated in the real estate market and access to opportunities denied to socially marginalized groups, it would not be surprising if the areas most at risk of landslides in Petrópolis were predominantly inhabited by Black people, even though they make up only 41.1% of its population (Brazil, 2024). The intersection of racial distribution data and susceptibility to mass movements support this correlation (Figure 5).

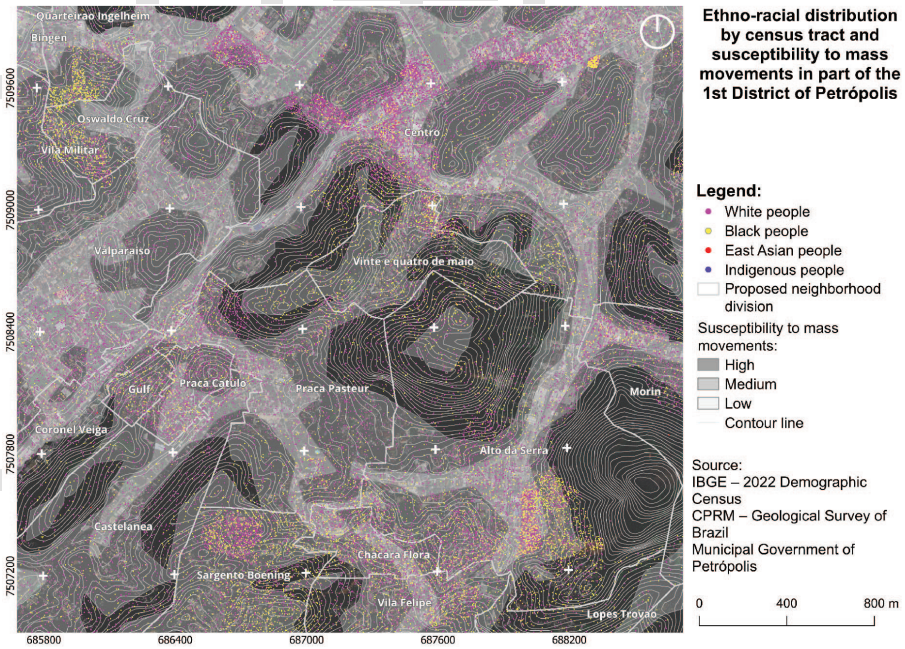

Figure 5: Racial distribution and susceptibility to mass movements in part of the 1st District of Petrópolis.

Source: Elaborated by the authors.

In areas of high flood risk — which have constituted the formalized city since the 19th century — the presence of white residents has been predominant (Figure 6). Although this data may lead to the perception that risks are distributed between the two groups, each being more susceptible to a different type of risk, there is a condition of environmental injustice that is revealed in the technical dimensions and fatality statistics. Sites with predominance of white people and groups with greater purchasing power are the ones equipped with infrastructure and housing in better condition to withstand flooding. On the other hand, those in which Black and lower-income people are predominant, located on hillsides and largely self-built, present more fragile and precarious infrastructure and housing, being thereby less likely to withstanding landslides. The comparison is reinforced by data indicating that mass movements are the deadliest geological processes in Brazil, with more than 4 thousand fatalities between 1988 and 2022 (Macedo; Sandre, 2022).

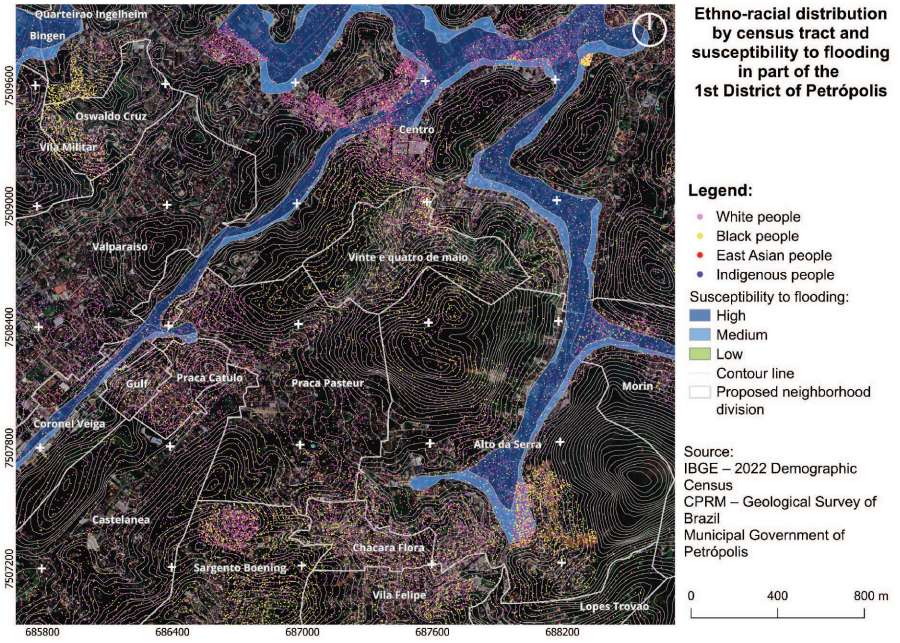

Figure 6: Racial distribution and susceptibility to flooding in part of the 1st District of Petrópolis. Source: Elaborated by the authors.

Less road space, more water space: toward a Petrópolis less susceptible to flooding

In addition to the many lives lost and traumas left behind, the 2022 disasters caused a severe economic loss. According to an estimate from the Industry Federation of the State of Rio de Janeiro at the time, the impact of the February 15 rainfall would have caused a reduction of 665 million reais (2%) in the city's gross domestic product (Paiva, 2022). As a consequence of the same rainfall, the municipal transit sustained damage to 70 vehicles — 20.4% of the total fleet —,

6 of which were declared total losses. By September 2022, public funds allocated to the urban infrastructure affected by the February and March rainfall events had already surpassed 44.5 million reais (Paiva, 2022) (Figure 7).

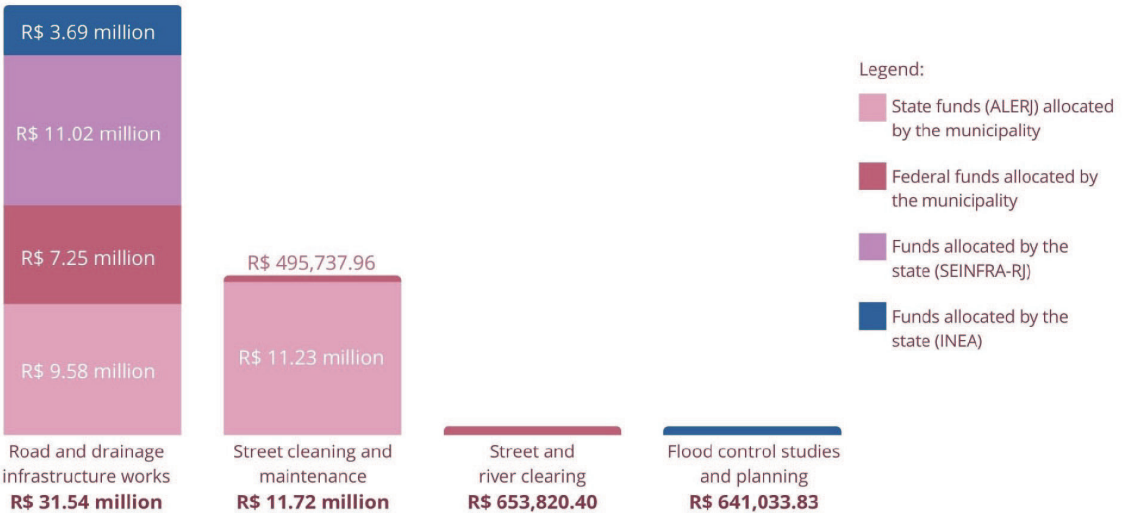

Figure 7: Public funds allocated to urban infrastructure following the 2022 disasters (as of September 7, 2022).
Source: Paiva (2022), using data from Petrópolis (2022) and Rio de Janeiro (2022).

It should be natural to have a profound debate about the necessary changes in the urban environment so that what happened does not recur. But if this discussion gains broader attention just when the topic is the landslides, floods still seem to be perceived as something inevitable, a consequence of misguided urbanization, but difficult to reverse. From this limited perspective, only pragmatic actions would be left, such as issuing meteorological warnings during moments of risk, restricting access to flooded regions, and assisting affected people (Petrópolis, 2020). Barriers blocking highly flood-susceptible roads and the demarcation of safe areas, where whoever is on the streets during heavy rains could go, constituted the limited urban infrastructure preparation after the disasters (Paiva, 2022).

As necessary as such measures may be to preserve lives and reduce losses, keeping certain areas equally susceptible to flooding could, in the medium or long term, condemn them to abandonment, especially in relation to activities that are located on ground floors, which are more likely to be affected. It is reasonable to imagine, for example, that business owners would have little interest in remaining in or migrating to properties located in areas subject to frequent and severe flooding.

Beyond these measures and efforts to maintain the current drainage infrastructure, it is necessary to acknowledge that the historical process of altering floodplains—spaces naturally occupied by the variations of the fluvial system—plays a central role in the responsibility for the city's floods and, in the context of climate emergency, must be target of critical restoration through bold

and creative proposals. The confinement of watercourses and the sealing of soil surfaces must be urgently reconsidered in Brazilian cities. In Petrópolis, due to its urban morphology, this is not feasible without reallocating part of the road space to new uses and functions.

However, going beyond the maintenance of the existent drainage system seems unimaginable to those who look at the city's streets and see no possibility of rethinking them. It is common to compare Petrópolis' urban morphology and road dimensions to those of other cities in traffic-related debates. The notion that the narrow streets would be the main cause of congestion in this city is deeply embedded in the collective imagination and is frequently expressed, in a tone of resignation and impotence, when discussing the topic. In a context where the car dominates road space, public transit remains precarious and investments in and incentives for active mobility are lacking; another widely held belief is that, in Petrópolis, it is necessary to have an automobile". Numbers confirm the persistence of this notion: "there are 539.1 individual motor vehicles per 1,000 inhabitants, a proportion that is 32.3% higher than in the city of Rio de Janeiro, 38.3% higher than in the state of Rio de Janeiro, and 15.5% above the Brazilian average (Schvarsberg; Paiva; Rocha, 2025).

Therefore, the proposal to replace spaces dedicated to motor vehicle circulation with areas designed for a less flood-prone urban environment should be preceded by a shift in the culture and experience of urban mobility. It should occur gradually, beginning with the reclamation of space, investments and a growing public interest in more efficient transportation modes — active, collective, and public transportation. The pressing question for this and many other cities today is whether they will choose to maintain car space untouched and endure frequent flooding, or whether they would be willing to reduce it in an effort to become safer.

There is, for Petrópolis, a range of collective and environmental benefits to gain if it chooses this path. Limiting the car-dedicated space may be key to reversing a scenario of pollution, traffic congestion, environmental vulnerability, and other impacts caused by its current mobility. An alternative reality is possible: characterized by resilience against rain, shorter travel distances, and daily time savings, as well as commercial and tourism prosperity. Among many other advantages, new ways of appropriating public space would emerge.

It is worth highlighting that improving the experience of using transportation modes other than the personal motor vehicle—by restricting the space allocated to it—is a way of reducing social inequalities in mobility. In Brazil, while 62% of white families have at least one car in their household, 70% of Black families have none (Pereira, 2021). From a gender perspective, experiences with implementing bicycle infrastructure in various cities–such as São Paulo, Buenos Aires, and Paris–confirm that they are key elements in promoting cycling mobility among women[1]

1 In addition, these policies have led to a reduction in GHG emissions and an improvement in the overall quality of life for the population.

(Paiva, 2022). Providing this group with greater comfort and safety in the use of a versatile vehicle, which facilitates route changes and stopping at destination points, is also a way of recognizing and valuing their needs and travel patterns, which tend to be multipolar due to the accumulation of reproductive tasks—related to care—socially and culturally imposed on them (ITDP Brasil, 2021). Optimizing the conditions for carrying out these activities should, however, be part of a broader agenda to confront patriarchy, one that involves a fair distribution of the responsibilities currently placed on women.

While efforts are underway to initiate the necessary shift in mobility culture, it is worth reflecting, from an urban planning and design perspective, on where Petrópolis should begin reviewing its relationship with water bodies. Santos, Antunes, and Fernandes (2019) offer valuable insights in this regard. By analyzing the basins of the main rivers that guided the Koeler Plan—Piabanha, Palatino, and Quitandinha—, using cartographic data from 1846 and 1999, they reveal changes in riverbeds and green areas. The reduction in sinuosity, the elimination of river islands, and the narrowing of riverbed over time make the Quitandinha the most significantly altered river, followed by the Piabanha and the Palatino. Its basin also experienced the greatest loss of vegetation coverage (56.8%), ahead of the Palatino's (34.5%) and the Piabanha's (31.6%) (Figure 8).

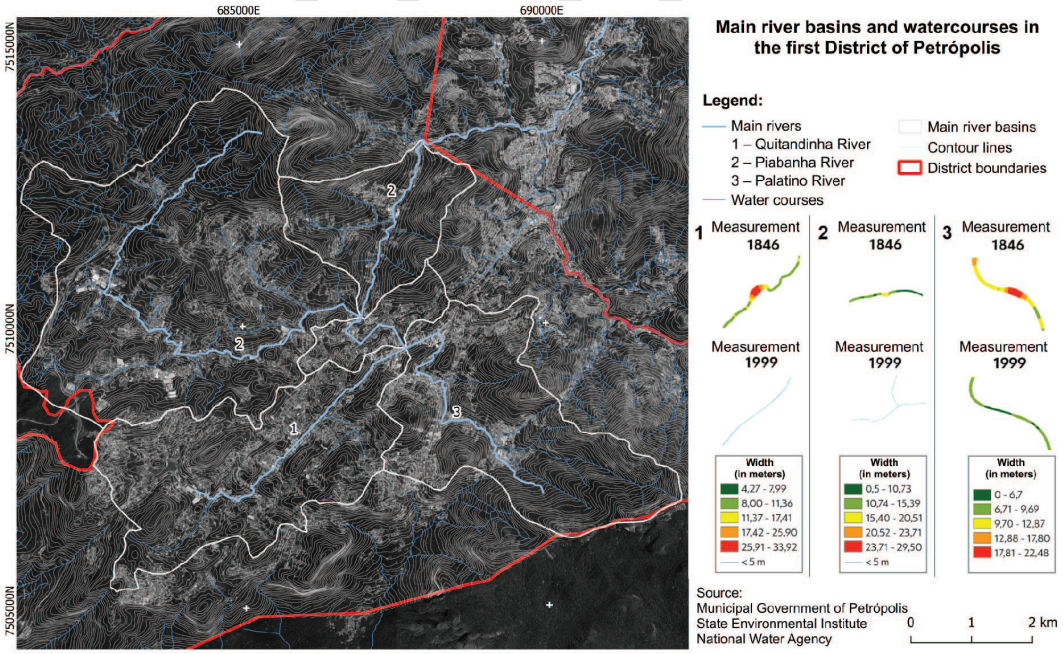

Figure 8: Main river basins and watercourses in the 1st District of Petrópolis.
Source: Authors, based on Santos, Antunes and Fernandes (2019).

In São Paulo, between 2007 and 2017, the number of bicycle trips increased by 43.59%, resulting in a reduction of approximately 6 tons of $CO_{2\ per}$ day (Reis, 2024). The city of Buenos Aires, committed to become carbon neutral by 2050, expanded its cycling network by 277 km between 2010 and 2022, enhancing connectivity within and beyond its center, where there is a high concentration of work and study commutes (C40 Cities, 2022). Paris, driven by the COVID-19 pandemic, implemented 52 kilometers of temporary bike lanes that became permanent, enabling bicycle trips to surpass those made by cars by a factor of two (González, 2024).

Consequently, the Quitandinha river axis accounted for 93.1% of the floods recorded across the three watercourses between 2011 and 2019 (Santos; Antunes; Fernandes, 2019). The vulnerability of this river calls for the renaturalization of its banks and an increase in soil permeability throughout the entire basin, in order to reduce surface runoff. Within the logic of mobility as a tool for climate-responsive urbanism, this region should be prioritized for investments in spatially efficient travel routes. Accordingly, dedicated lanes for buses, cycling infrastructure, bicycle-sharing systems, and restrictions on car traffic would constitute measures capable of freeing up as much space as possible for these interventions.

Concluding Remarks

Sustainable urban mobility can be a key policy in addressing the urgent challenge of adapting Brazilian cities to the climate crisis. Its main advantage in this regard is the efficiency of urban space usage, as the area required for active and collective transportation is significantly smaller than that for proper circulation and parking of cars. Taking Petrópolis as a paradigmatic case, this study argues that *regenerating the relationship between cities and rivers, adopting sustainable urban mobility as the core strategy, is a critical path that must be further developed technically, politically, and culturally.*

From a technical perspective, achieving this requires adopting *nature-based solutions* in an integrated manner *with the redesign of public and circulation spaces*. From a political perspective, in addition to prioritizing investments in management, improving service offerings, and developing infrastructure dedicated to these transportation modes, it is necessary to *overcome the pattern of sector-specific policies* that barely communicate. Sustainable urban mobility will only be effective when aligned to the decentralization of urban opportunities, bringing them closer to households of different socio-economic strata. From a cultural perspective, it is fundamental that all aforementioned actions be accompanied by *communication and education strategies aimed at changing collective perspectives of urban life*. The dominance of the personal motor vehicle, which reflects social distinctions as well as class and racial privileges, must also be addressed in the realm of desires.

The goal of this article was not to present definitive strategies for formulating actions related to sustainable urban mobility to address the climate crisis, but rather a set of reflections on this topic that, although generally applicable to Brazilian cities, is particularly relevant in the case of Petrópolis. Any proposals resulting from these reflections should consider complementing the perspectives presented here with approaches embedded with qualitative research and morphological studies at various scales (street, district, river basins, etc.) in order to provide adaptive responses at the municipal level, encompassing the redesign of public open spaces as well as actions integrated into an urban planning sensitive to the climate emergency.

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