

Mapping Ecosystem Services for proposing Nature-Based Solutions in urban planning

Amarilis Lucia Casteli Figueiredo Gallardo (amariliscfgallardo@gmail.com) – USP/Uninove; Mariella Midori Domingues Succi – USP; Roberta Consentino Kronka Mülfarth – USP; Miguel Luiz Bucalem – USP (Brasil).

Abstract: Achieving resilience and sustainability in cities has necessitated the use of geospatial analysis tools in urban planning for informed decision-making. In high socio-environmental vulnerability areas with a lack of green spaces, nature-based solutions (NbS) are proposed to address urban problems and generate environmental and quality-of-life benefits. The Brasilândia neighborhood in São Paulo city (Brazil) was chosen as a case study because it has a high percentage of favelas, scarcity of green spaces, and a high incidence of flooding. The municipal master plan mandates developing neighborhood plans for implementing community improvements. A geospatial analysis of the ecosystem services (ES) supply and demand was undertaken to identify areas for NbS implementation to mitigate flooding and increase green spaces. The InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) software was used for this purpose, utilizing the specific ES module for urban flood risk regulation. These ES were spatially analyzed in the territory, allowing us to identify the most appropriate NbS locations and typologies. These results guided the use of microscale NbS, such as rain gardens and bioswales, in areas with a lower ES availability. This analysis also allowed us to define specific projects aimed at increasing resilience in the territory and expanding the availability of other ES associated with the implementation of NbS in the Vila Brasilândia neighborhood plan. The conclusion is that support systems for solving climate-exacerbated phenomena in the urban environment can be used for improving sustainability in cities.

1. Introduction

São Paulo's city strategic master plan establishes the development of Neighborhood Plans as an instrument to strengthen urban planning and social control at the local scale, with the aim of promoting urban, environmental, landscape, and housing improvements through programmed actions, investments, and interventions. These plans are intended to enhance the quality of urban life in neighborhoods by considering their territorial and social specificities. Within the context of São Paulo's accelerated and unplanned urbanization process, the Brasilândia district is characterized by patterns of occupation marked by high social vulnerability, reflecting processes of socio-spatial segregation. This condition exacerbates the recurrence of socio-environmental risks, especially those associated with urban flooding.

One key for increasing urban resilience lies in expanding the provision of Ecosystem Services (ES), which can mitigate the negative impacts of poorly planned urbanization, often intensified by climate change. At the same time, these services provide benefits such as improvements in microclimate regulation, air quality, surface runoff retention, and urban biodiversity. The expansion of ES provision in urban environments can be achieved through the implementation of Nature-based Solutions (NbS), such as green roofs and rain gardens. These solutions comprise a set of actions aimed at the protection, management, and restoration of ecosystems, with the objective of addressing contemporary social challenges while simultaneously promoting human well-being and biodiversity conservation.

With regard to flood mitigation, the presence of vegetation associated with NbS can promote, when compared to impervious surfaces, greater water absorption by the soil, reducing infiltration time and the velocity of surface runoff (Moura, 2013). Furthermore, Wolch et al. (2014) emphasize that the allocation of NbS should be guided by principles of environmental justice, prioritizing areas marked by greater socio-environmental vulnerability. In this sense, the incorporation of urban planning strategies that value NbS and the provision of ES requires evaluation based on technical parameters in order to ensure their feasibility and effectiveness, both in reducing urban problems and in promoting quality of life and urban resilience.

Neighborhood Plans thus constitute instruments that, in articulation with the local population, enable the development of documents guided by demands and opportunities associated with small-scale initiatives. In this way, they represent a strategic tool to foster improvements in residents' quality of life and environmental quality, particularly by encouraging the expansion of ES provision resulting from the implementation of NbS.

In this context, the present study's objective is to discuss how geospatial analysis of Ecosystem Services can support the identification of Nature-based Solutions aimed at mitigating urban flooding, taking the neighborhood of Brasilândia, in the municipality of São Paulo, as a case study. Within this framework, it seeks to position itself as a decision-support tool with regard to the implementation of actions to mitigate urban problems and the formulation of public policies at the neighborhood scale. It

thus aims to contribute to the proposal of alternative solutions to socio-environmental challenges, while simultaneously encouraging the expanded use of NbS within the scope of Neighborhood Plans.

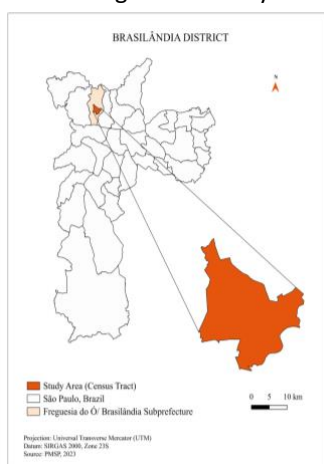
2. Methods

The method adopted in this study is based on the geospatial analysis of the supply and demand of ES aiming to identify priority areas for the implementation of NbS to mitigate urban flooding and enhance the provision of green spaces. The methodological approach is structured into three main stages.

The first stage consisted of defining the study area in order to ensure its compatibility with the proposal of actions within the scope of Neighborhood Plans. The Brasilândia District, located in the municipality of São Paulo (Figure 1), covers, approximately, 21 km² and is divided into 103 census tracts. Of this total area, about 14 km² correspond to urbanized areas, while the remainder comprises portions of the Serra da Cantareira, an important forest remnant of the Atlantic Forest biome. According to data from the Brazilian Institute of Geography and Statistics (IBGE, 2022), the district has a population of 52.277 inhabitants.

Based on this territorial framework, a census tract within the Brasilândia District was selected, from GeoSampa (2024), as the study area. The selected unit is characterized by high social vulnerability, recurrent flooding events, and low tree canopy cover, yet exhibiting significant potential for urban greening actions, as illustrated in Figure 1.

Figure 1 – Study Area.



The second stage aimed to map the ES present in the territory using secondary land use and land cover data (LULC). The ES mapping followed the methodology proposed by Lourdes et al. (2022). This procedure made it possible to identify the spatial distribution of ES, assess opportunities for their expansion, and understand their relationship with the social, economic, and environmental conditions of the analyzed area. For this purpose, the InVEST software (Integrated Valuation of Ecosystem Services and Tradeoffs) was employed, using the specific module focused on urban flood risk mitigation, given the high degree of imperviousness and the frequent occurrence of flooding in the selected area. This tool estimates the reduction in surface runoff on a per-pixel basis relative to the precipitation event volume (NATURAL CAPITAL PROJECT, 2024). To this end, for each pixel, surface runoff is calculated for each precipitation event based on the assigned soil characteristics, using the Curve Number (CN) method, a parameter associated with the physical properties as well as land use and land cover of the watershed (COLLISCHONN & DORNELLES, 2013).

The rainfall depth data were obtained from records 2010 to 2024 provided by the Centro de Gerenciamento de Emergências Climáticas. Land use and land cover for the study area were derived from the European Space Agency (ESA) WorldCover Version 2 dataset. Additionally, the HYSOGs250m dataset of soil hydrologic groups developed by Ross et al. (2018) was used to model surface runoff using the Curve Number (CN) method. Finally, the relationship between the CN parameter and each land use type in urban watersheds was obtained from Collischonn & Dornelles (2013, apud Tucci, 1993). The modeling results enabled the spatialization of ES supply, the analysis of its correspondence with existing demand, and the support of the identification of NbS capable of more effectively addressing the needs identified in the territory.

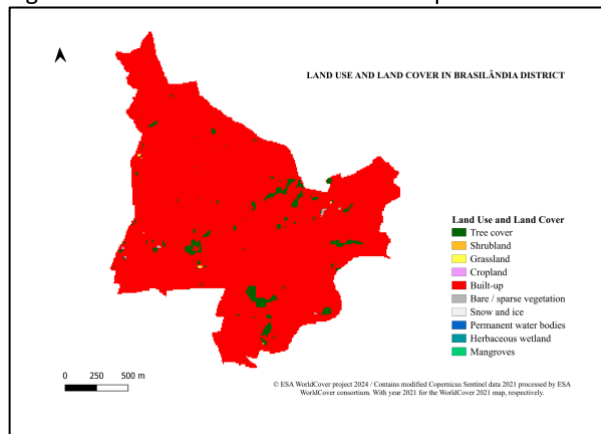
The third stage of the study focused on identifying suitable locations and typologies for the allocation of NbS, with the aim of mitigating the diagnosed problems and increasing the provision of ES

within the selected census tract of the Brasília District. To this end, areas with the greatest deficits in ES, particularly those related to urban flood mitigation, were analyzed in order to identify priority zones for intervention. The definition of NbS typologies was primarily based on the studies by Cortinovis and Geneletti (2018), Ronchi and Arcidiacono (2018), and Chen, Lin, and Chiueh (2023), considering their applicability in urban contexts characterized by high density and high levels of soil imperviousness. The results obtained from these stages are intended to provide technical and methodological inputs that can be incorporated into the Neighborhood Plan of the Brasília District, contributing to sustainable urban planning and to the reduction of socio-environmental vulnerabilities at the local scale.

3. Results

The LULC map of the study area is presented in Figure 2. Five land cover classes can be identified, with built-up areas constituting as the predominant land use, accounting for approximately 96.89% of the Brasília territory under some form of impervious cover, while only 3.11% is covered by vegetation.

Figure 2 – Land Use and Land Cover Map



The processed datasets on land use and land cover, soil hydrologic group, rainfall depth, and the biophysical table were analyzed using the InVEST software. This step enabled the spatialization of surface runoff values for the modeled rainfall event, as illustrated in Figure 3. The analysis of Figure 3 indicates that the areas exhibiting the highest surface runoff values, reaching up to 100.451 mm, are predominantly associated with the convergence of built-up areas. Another result derived from the InVEST simulation is presented in Figure 4, which complements Figure 3 by spatially illustrating surface runoff retention in cubic meters. As expected, areas characterized by moderate to high surface runoff potential exhibit low water retention capacity, due to soil imperviousness and intrinsic soil properties.

Figure 3 – Surface runoff values in Brasília district

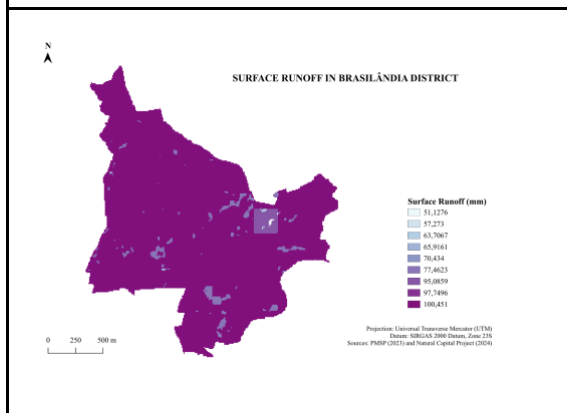
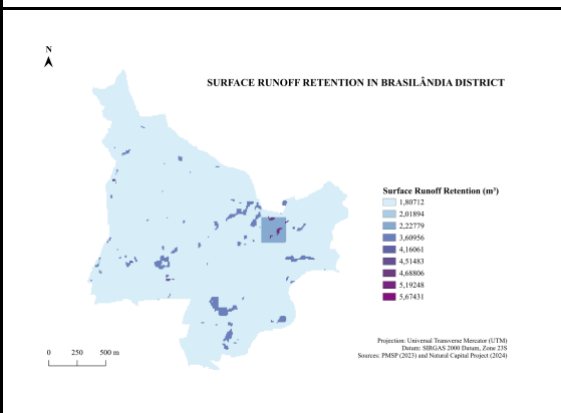


Figure 4 – Surface runoff retention in the study area



For the spatial analysis of the provision of hydrological regulation ES urban flood risk mitigation, based on surface runoff retention values (m^3), average retention values were calculated for each census tract within the study area, as shown in Figure 5. A comparison between Figure 5 and the data presented

in Figure 1 reveals a higher provision of average surface runoff retention ES in non-impervious areas. Consequently, locations with lower retention values exhibit higher runoff volumes and are therefore more susceptible to flooding.

In order to better understand whether areas with higher ES provision effectively coincide with vegetated areas, an additional source of green space mapping was employed. To this end, the average values of surface runoff retention ES were overlaid with a vegetation map by sub-municipality produced in 2020 and obtained from the GeoSampa platform. It is important to note that this dataset was not used in the model simulation, as land use and land cover files with the required level of detail were not available. The result of this spatial overlay is presented in Figure 6.

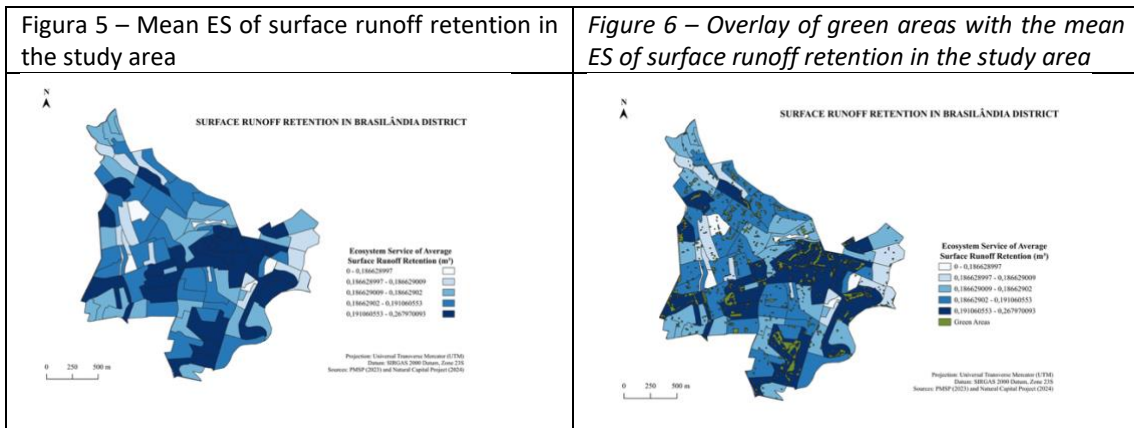
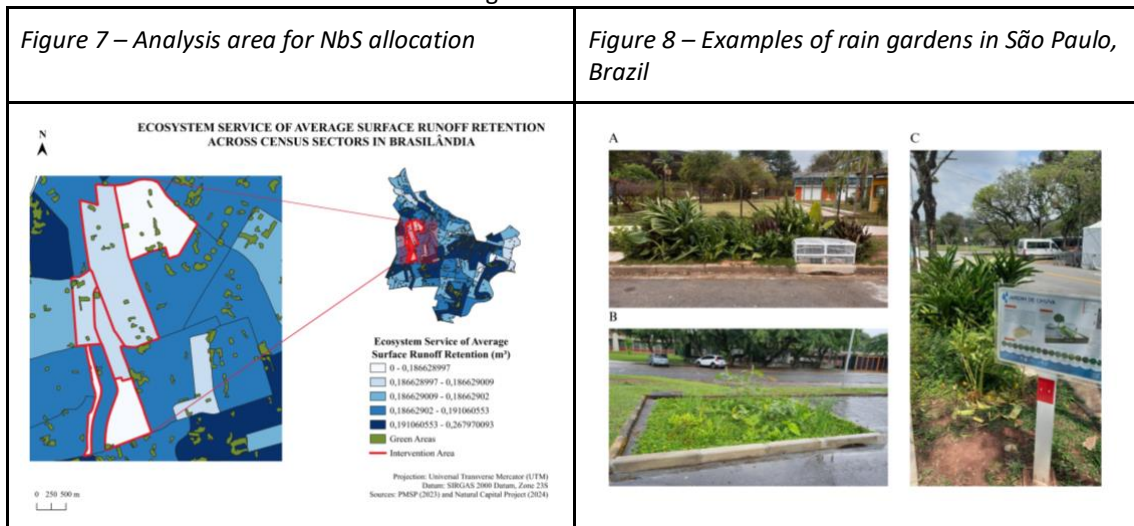


Figure 6 allows for the identification of higher concentrations of green areas within the classes exhibiting greater average ES provision for surface runoff retention, which constitutes an indication that the simulation results are plausible. Conversely, areas with a lower provision of hydrological regulation ES showed reduced occurrences of vegetation. The identification of suitable locations for the allocation of NbS was based on census tracts exhibiting the lowest levels of surface runoff retention Ecosystem Services. The selected area is illustrated in Figure 7.



Given that the selected area is characterized by high urban density and extensive soil imperviousness, the choice of NbS must consider the limited availability of vacant or underutilized land, as it represents a consolidated fragment of the metropolitan fabric. Furthermore, the proposed infrastructure should exhibit flexibility in response to the intense flow of pedestrians and vehicles in the area. In addition, the low ratio between vegetated and built-up areas highlighted in Figure 7 underscores the need to prioritize infrastructure solutions capable of increasing green space coverage within the region.

For these reasons, the implementation of micro-scale NbS was selected, including rain gardens, bioswales, and vegetated curb extensions. It is worth noting that such solutions can be deployed in

constrained urban spaces, for instance in areas where rain gardens can be implemented within footprints smaller than those of two parking spaces

5. Conclusions

The present study examines how the geospatial analysis of ES can be employed to mitigate urban flooding problems through the implementation of NbS with a focus on the neighborhood of Brasilândia, in São Paulo. The spatialization of ES enabled a more comprehensive understanding of the phenomenon across the territory, making it possible to identify areas with greater vulnerability to flooding and, consequently, to propose solutions that are more suitable to the local context.

The processing of the data allowed for the generation of surface runoff and runoff retention maps, as well as for the assessment of the provision of the ES related to Urban Flood Risk Mitigation. The results indicate that built-up areas exhibit higher levels of surface runoff, reaching values up to 46.23% greater than those observed in vegetated areas.

Based on these findings, the study supports the allocation of NbS in areas with lower ES provision, through the implementation of typologies such as rain gardens, vegetated curb extensions, and bioswales, given their applicability in limited spaces and their effectiveness in mitigating urban flood risks.

Although NbS typologies can be preliminarily recommended for a given location, it is important to emphasize the relevance of conducting detailed, site-specific analyses. This process enables the development of tailored projects that are more efficient and better aligned with the particular characteristics and demands of the territory. Furthermore, continuous monitoring of the implemented initiatives is essential in order to evaluate their outcomes and to ensure the long-term effectiveness and sustainability of the interventions.

In this regard, dialogue with local residents is crucial to assess whether the mapped es are consistent with on-the-ground conditions and to foster discussions regarding the potential implementation of mitigation infrastructure. The maps produced in this study may be used in the future to support this process of aligning expectations with the community, as well as to strengthen community-driven policies, such as Neighborhood Plans.

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