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Green Urban Infrastructure and the Potential for Offering Ecosystem Services for Climate Adaptation: Land Use Analysis of the Pinheiros District (São Paulo)

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ABSTRACT
Ecosystem services (ES) represent various benefits to society, especially those of climate regulation. An increasing number of recommendations are being made so that urban planning internalizes the concept of ES to objectively measure these benefits or for decision making. This paper intends to analyze the role of green infrastructure in urban land use to address the potential for providing climate regulation ES in urban green areas as measures of Ecosystem Based Adaptation (EbA). To this end, it was selected as a case study the land use analysis of the Pinheiros District in São Paulo. This region has a high degree of waterproofing, but has significant green areas and potential space to incorporate the expansion of green infrastructure, i.e., to promote EbA strategies, and consequently the offering of ES. For this purpose, geospatial analysis was used with the technical subsidies of a methodology proposed to measure the capacity of different extensions of vegetation coverage to promote ES regulation. The application showed that one of the district's four sub-districts revealed an existing and greater potential to mitigate climate change effects than the other three sub-districts. This discussion is considered timely given the recently released 2021 Climate Action Plan for the Municipality of São Paulo. The results of the work can be considered by public managers and decision makers on the role of urban green areas and their potential for climate adaptation.

KEY WORDS: Ecosystem services, Ecosystem-based Adaptation; Nature-based Solutions; Urban Planning.

1 INTRODUCTION

Increasing urbanization has been progressively demanding more space in the city to accommodate the population, contributing to a rise in impermeable areas in the urban environment (KABISCH et al., 2017). The negative effects of this rise in cities, such as heat islands (SIQUEIRA-GAY et al., 2017), have been worsening as a result of climate change. Urban planning and recent climate adaptation plans have an integrative role to organize the urban environment and provide guidelines for the city to mitigate (measures to reduce greenhouse gas emissions) and adapt (measures, actions, or opportunities to reduce the effects of these emissions) to such changes (COSTA AGUIAR et al., 2021).

In this context, Nature-based Solutions (NbS) represent a concept to integrate a range of ecosystem-based approaches to address growing societal challenges (BUSH; DOYON, 2019). Raymond et al. (2017) established a methodology for evaluating the benefits of NbS for ten major types of societal challenges, and one of these is represented by the maintenance of green areas. According to Kabisch et al. (2016), NbS have also been associated with other concepts such as ecosystem-based adaptation and green infrastructure. For Kabisch et al. (2014), these concepts represent systemic approaches in which particular interventions are used to address problems related to urban resilience and sustainability. Green infrastructure characterized by different types of green areas (urban trees, squares, parks, ecological corridors, among others) interwoven with urban gray infrastructure (buildings, roads and other infrastructure usually built in concrete and other non-natural materials) contributes with important benefits for life and health quality such as thermal comfort, improved air quality, leisure, among others (DEMUZERE, et al., 2014). According to Ferrari et al. (2019) both conservation and enhancement of green infrastructure can be considered a NbS to improve sustainability in urban planning.

Ecosystem-based Adaptation (EbA) is an adaptation strategy to the adverse effects of climate change and attempts to value green infrastructure and diverse range of associated ecosystem services to mitigate its negative effects on the urban environment (ROLO et al., 2019; ROLO et al., 2022). According to Geneletti and Zardo (2016), the maintenance and valuation of urban green areas also constitute EbA. EbA approaches additionally include management, conservation, and restoration of such green infrastructure that deliver relevant ecosystem services to society (MUNANG et al., 2013).

Therefore, EbA leverages the supply of ecosystem services (ES) in the urban environment that result from the functions that ecosystems perform in cities, such as climate regulation (FLAUSINO; GALLARDO, 2021). SE, meanwhile, can be regarded as a proxy to assess both the mitigation of negative externalities and positive ones such as green areas, associated with the urbanization effects (GAUDERETO et al., 2018). Public policies are more and more being proposed using the concept of ES to accurately measure these benefits (SOUZA et al., 2018). Multiple studies demonstrate that valuing ESs at a local scale increases urban resilience (AHERN, 2011, HAASE, et al., 2014) and thereby contributes to alleviating the effects of climate change (SCHWARZ, BAUER, HAASE, 2011).

Herreros-Cantis et al. (2021) argue that urban planning policies should warrant investments in NbS via EbA. Zölch (2017) highlights NbS as EbA strategies through a focus on tree planting and green roof deployment. For Lehmann (2021), ES are becoming increasingly embedded in the urban planning agenda by planting trees on streets and avenues, gardens, parks, urban forests, green roofs, and living walls, and so forth. ES have been used as indicators that can be monitored to evaluate climate change coping strategies in urban planning (VAN OUDENHOVEN, 2018). Usage of geo-spatial analysis to measure ES-based approaches has been envisioned (LAFORTEZZA, 2018) and tested to appraise ES flow and demand by land cover analysis (BARÓ et al., 2016). Green infrastructure represents one of the measures for urban heat island attenuation, as confirmed by Wang et al. (2015) by studying the role of tree-covered areas in cooling the urban average temperature, setting up into EbA measures (LEHMANN, 2021).

This article is based on the premise that the valuation of NbS and EbA, considered in this context of analysis as equivalent concepts, through urban green areas, enables the broadening of ES offering as climate regulation, attenuating the effects of climate change in urban areas. Within this context of providing subsidies to urban planning, Zardo et al. (2017) proposed a method to assess the cooling capacity delivered by green infrastructure (ground cover, canopy cover) based on the evaluation of climate regulation ES. Therefore, this paper mainly aims to analyze the role of green infrastructure in urban land use to discuss the potential of offering climate-regulating SE in urban green areas as EbA measures.

As a case study, the Pinheiros district and its four sub-districts in the city of São Paulo were selected. The rationale for this territorial cutout relates to the high degree of waterproofing of this region, yet with space to receive the green infrastructure expansion, i.e., to promote EbA strategies, and consequently the supply of ES. Moreover, the Climate Action Plan of the City of São Paulo 2020-2050 (PlanClima SP), launched in 2021, establishes several goals to develop actions oriented to neutralize greenhouse gas emissions in São Paulo, based on NbS and EbA (COSTA AGUIAR et al., 2021). This study intends to provide technical contributions to support decisions on urban planning to face the effects of climate change.

2 METHOD

This research employed geospatial analysis and indicator analysis (ES) to apply analytical methods proposed in the literature (ZARDO et al., 2017), to be nationally used for urban planning.

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Geographic Information Systems (GIS) have been widely used as a tool in urban planning and land use characterization. Geospatial analysis supported by GIS has been applied to solve urban challenges in planning (MALCZEWSKI, 2006), propose indicators in urban planning (SIQUEIRA-GAY et al., 2019), and integrate SE in decision-making concerning green areas (PETRONI et al., 2022).

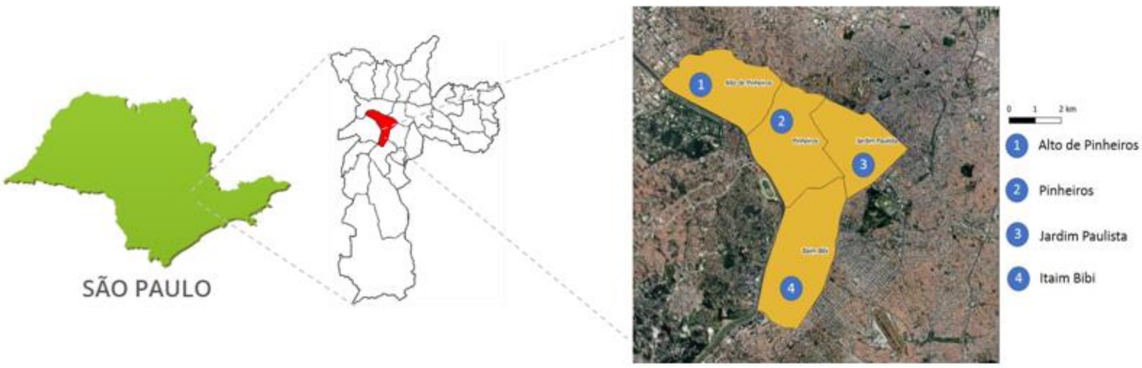
Technology use is an advancing trend for the mapping and land use modeling role, chiefly, in the GIS socio-political and participatory perspective, (MALCZEWSKI, 2004). Currently available tools mostly address only a portion of spatial readings (FERRETTI AND MONTIBELLER, 2016; GREENE et al., 2011; MALCZEWSKI AND RINNER, 2015). To do so, it is necessary to collect, classify, identify, and link large amounts of spatial and non-spatial data.

As the analysis cutout is an urban area, one should emphasize that the urban fabric is composed of multiple land uses that delineate the main characteristics or typologies of existing infrastructure in the city, such as buildings, open areas and spaces, green areas, squares, sidewalks, waterways, among others. The purpose of this study is to analyze the land use of the existing infrastructure, focusing on distinct typologies of green areas.

2.1 CASE STUDY

The spatial analysis study was carried out in São Paulo's Pinheiros district, which covers 31.70 km2 of the area of the municipality of São Paulo, and is divided into 4 subdistricts: Alto de Pinheiros, Itaim Bibi, Jardim Paulista and Pinheiros. Figure 1 and Table 1 below present, respectively, the area location and some socioeconomic data.

Figure 1 - Map of Pinheiros Sub-Districts



Source: Authors, 2022.

Table 1 - Data from the sub-districts that comprise the Pinheiros district.

Pinheiros sub-districts	Demographic Density Hab/ Km²	Population (2010)	Surface Area (Km²)
Alto de Pinheiros	5.600	43.117	8.207
Itaim Bibi	9.351	92.570	10.970
Jardim Paulista	14.540	88.692	6.826
Pinheiros	8.171	65.364	9.059
Pinheiros District	**9.140**	**289.743**	**35.062**

Source: Authors, 2022, based on IBGE data (2012).

2.2 GEOSPATIAL DATA ANALYSIS

The spatial analysis was done using the open source software QGIS 3.26.3 and with GRASS7.6.1 as accessory plugin for map reading from open shape databases and public domain census spreadsheets (IBGE, 2012). The OSM - Open Street Maps, with gray coloring (ESRI Gray Light), WGS84 Datum coordinate system with background image made with district boundaries (SDMU,2015) was used as the map base. To elaborate the vegetation cover map, it was used classification raster image based on NDVI (Normalized Difference Vegetation Index), which measures the green area and density of vegetation captured in satellite image. Non-vegetated objects from the digital terrain model, such as buildings, roads, vehicles, and others, were removed from this image. The vegetation cover map was composed of the sum of tree and ground vegetation covers (lawns) in each sub-district that comprises the Pinheiros district.

The geospatial analysis encompassed the mapping of existing vegetation cover or green infrastructure, associated with the potential offer of ES, as advised by Zardo et al. (2017).

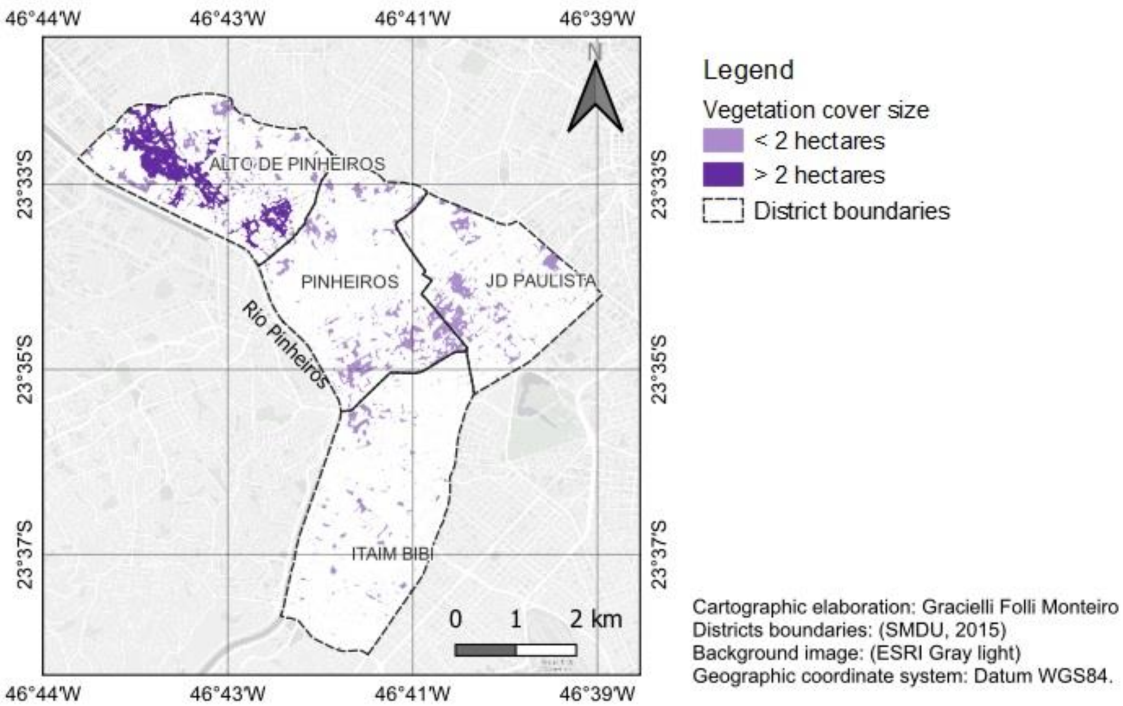
For the analysis of the green infrastructure cooling capacity indicator, for the vegetation cover typologies, the provision of areas with cooling capacity was evaluated according to the size of these areas. According to Zardo et al. (2017), apart from the relative contribution of shading and evapotranspiration, the size of green areas directly influences their climate cooling capacity, with the threshold around 2 hectares of green areas being considered representative to distinguish small (less than 2 hectares, can cool up to 1 oC) or large (greater than 2 hectares, can cool between 2 oC and 4 oC) areas. In this way, using QGIS, the areas larger and smaller than 2 hectares that correspond to the climate regulating ES were identified.

The spatial assessment of this indicator enables to examine and spatially measure ES provision indicators and to compare these areas, for example, to evaluate current conditions and to establish priorities to receive NbS and EbA in an urbanistic intervention project plan in a city planning effort.

3 RESULTS AND DISCUSSION

The figure below (Figure 2) displays the vegetation cover map prepared as recommended by Zardo et al. (2017) in which the Pinheiros district zones with areas over and under 2 hectares were mapped.

Figure 2 - Vegetation Cover Map - Cooling Capacity



Source: Authors, 2022.

According to Figure 2, only the sub-district of Alto de Pinheiros, in the Pinheiros district, has areas of vegetation cover greater than 2 hectares. This indicates that, in terms of provision of climate regulation services, cooling the urban temperature, this sub-district stands out compared to the others. The extent of the vegetation cover area determines the climate regulation benefits in urban areas, for as pointed out by Chang et al. (2007), vegetation contributes to shading processes on the ground. The larger the area of ES offering, the better climate regulation performance, as these areas help in increasing air humidity and boost evapotranspiration, as pointed out by Munang et al. (2013).

The green areas extension analysis considered as areas that provide climate regulation ES for the Pinheiros district, as highlighted by Munang et al. (2013) and Geneletti (2016) can support the decision making in urban planning. The quantitative data and spatial distribution of green areas among the subdistricts of the Pinheiros neighborhood enable the urban planner to examine the ES supplied and define priority locations to include EbA. To achieve better results in implementing EbA, it is important to prioritize creating green areas larger than 2 hectares. For, as highlighted by Geijzendorffer et al. (2015), if the urban planner's goal is to reduce urban heat islands, these guidelines should be considered not only to increase the amount of urban green areas, but also as to their location. Thereby, for example, densifying existing green areas may allow to reach extensions greater than 2 hectares and to actually maximize the benefits of ES in this respect. For use in planning, these data have been stressed by Cortinovis and Geneletti (2018; 2020) to be considered as EbA strategies in urban areas. This also aligns with the proposal by Andersson et al. (2019), for whom ES can be used in urban planning processes, helping to incorporate multifunctional ES into cityscapes and contributing to promote urban sustainability. As outlined by Cortinovis and Geneletti (2018), ES consideration is crucial to foster sustainable urban development, once urban land use decisions will affect the availability of provision of these services that are essential to population well-being.

Considering the adoption of EbA strategies in the urban environment can fulfill the needs of local temperature decrease to face heat islands, as explained by Siqueira-Gay et al. (2017). The subdistricts of the Pinheiros district with green areas smaller than 2 hectares are the ones that present the greatest demands for the expansion of these climate regulation strategies.

Such analysis adds to what is foreseen in the Planclima (PLANCLIMA, 2021), in its Action 22, related to the usage of EbA and NbS to expand the permeable area in public spaces through the increase of green areas. Therefore, by considering the extension of green areas greater than 2 hectares, it is possible to contribute more effectively to ensure the resilience not only of the Pinheiros district, but also to contribute to the city of São Paulo.

Investment in the expansion of green areas is an important strategy to achieve urban sustainability and reduce climate change (MARÓSTICA et al., 2021). A well-balanced environment promotes an improved mental and physical quality of life among citizens, as well as city benefits and a more inclusive development, complying with Article 225 of the Federal Constitution, as well as with the Climate Action Plan of the City of São Paulo.

4 CONCLUSIONS

The land use analysis concerning infrastructure, in particular green infrastructure, of the four sub-districts of the Pinheiros district in the city of São Paulo confirms that the provision of climate regulation ES in urban green areas constitute EbA actions that can be used for decision making in urban planning aimed at climate adaptation.

It was evidenced that the assessment of the extension of urban green areas by land use analysis allows considering both in terms of administrative cut (sub-districts) and spatial cut (location) the current ES provision, subsidizing decisions on the increase of green areas. The method revealed results for the Pinheiros district, in which one of its four sub-districts (Alto de Pinheiros) revealed an existing and greater potential to soften the effects of climate change than the three other sub-districts (Pinheiros, Itaim Bibi and Jardim Paulista).

It is also possible to ascertain that, should the strategy be to direct the provision of ES towards climate regulation services, it is worth considering areas larger than 2 hectares that presently contribute to tackling the problem and areas smaller than this extension. One possible strategy is to pursue the broadening of areas with vegetation cover smaller than 2 hectares so that they can surpass this threshold and contribute more effectively to the coping of heat islands in the urban environment.

This paper, treated as a first local contribution for testing a methodology employed in another context, contains some limitations and can be improved. It is recommended that other databases such as the Geosampa be used to compare the results obtained in this study and, occasionally, to promote adjustments as it considers recent surveys of vegetation cover in the city of São Paulo not considered in the IBGE database. Further research should also be undertaken to confirm how, in a tropical environment, the extensions of areas covered by vegetation cover influence the cooling of climate effects, since a study carried out in a European city was used as basis.

Other evaluation methods can also be tested both for the different territorial clippings discussion and for the more specifically consideration of park areas, which have a larger extension, for EbA decision making considering the entire city.

Additional analyses that consider EbA measures such as green walls and green roofs, expansion of urban ecological corridors, increasing tree planting and expansion of urban gardens, which also provide shading and boost evapotranspiration, contributing to amplify the offer of ES in climate regulation, can also be carried out.

Considering all the above, it is possible to state that this work contributes with analytical data and quantitative basis to operationalize some strategies proposed in Planclima for the city of São Paulo. Hopefully, the results of this article can be evaluated by public managers and decision makers to ensure that the EbA guidelines discussed here can be implemented in the changes and updates foreseen in climate adaptation plans and in the revision of urban master plans.

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