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Analysis of urban green spaces through remote sensing in a neighborhood of João Pessoa, Brazil

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Análise dos espaços verdes urbanos por sensoriamento remoto em um bairro de João Pessoa, Brasil

RESUMO

Objetivo: Quantificar os espaços com presença de vegetação, por meio de análises de NDVI e NDBI, no bairro de Tambaú, em João Pessoa/PB, bem como verificar as influencias e os benefícios desses espaços existentes para a qualidade de vida urbana.

Metodologia: Para atingir o objetivo proposto, foram empregados métodos de sensoriamento remoto, uma ferramenta que facilita a compreensão da fenologia da vegetação em diferentes resoluções, ajudando no planejamento local. Além disso, foram realizadas análises quantitativas com dados cartográficos e imagens do Google Earth, bem como qualitativas através de visitas e registros fotográficos na área estudada.

Resultados: Embora o bairro de Tambaú tenha áreas verdes públicas, elas são escassas e mal distribuídas, limitando o lazer dos moradores, concentrando-se na zona turística da orla marítima. A análise do NDVI e NDBI mostra a dinâmica da expansão urbana, resultando em baixa vegetação e conforto térmico. Além disso, a falta de planejamento urbano adequado compromete a qualidade de vida, evidenciando a necessidade de integrar mais espaços verdes. A revitalização da Área de Preservação Ambiental ao redor do Rio Jaguaribe é um ponto positivo, mas ainda insuficiente.

Contribuições sociais e ambientais: O estudo não apenas fornece dados importantes para o planejamento urbano, mas também promove uma abordagem holística que considera tanto os aspectos sociais quanto ambientais, contribuindo para um desenvolvimento mais equilibrado e sustentável.

PALAVRAS-CHAVE: Espaços Verdes Públicos. Qualidade de Vida. Planejamento Urbano.

Analysis of urban green spaces through remote sensing in a neighborhood of João Pessoa, Brazil

ABSTRACT

Objective: This study aims to quantify areas with vegetation cover in the Tambaú neighborhood of João Pessoa, Brazil, using NDVI and NDBI analyses, and to assess the influence and benefits of these green spaces on urban quality of life.

Methodology: To achieve this objective, remote sensing techniques were employed to better understand vegetation phenology at varying spatial resolutions, supporting local urban planning efforts. Quantitative analyses were conducted using cartographic data and Google Earth imagery, complemented by qualitative assessments through site visits and photographic documentation.

Results: Although the Tambaú neighborhood contains some public green spaces, they are limited and poorly distributed, restricting leisure opportunities for residents. These areas are mostly concentrated in the tourist zone along the coastline. NDVI and NDBI analyses highlight ongoing urban expansion processes, which have led to reduced vegetation coverage and diminished thermal comfort. Additionally, the lack of adequate urban planning negatively impacts quality of life, underscoring the urgent need for more integrated green infrastructure. The revitalization of the Environmental Preservation Area along the Jaguaribe River is a positive initiative, but remains insufficient.

Social and Environmental Contributions: This study provides valuable data to inform urban planning and promotes an integrated perspective that incorporates both social and environmental dimensions, contributing to more equitable and sustainable urban development

KEYWORDS: Public Green Spaces. Quality of Life. Urban Planning.

Análisis de los espacios verdes urbanos mediante teledetección en un barrio de João Pessoa, Brasil

RESUMEN

Objetivo: Cuantificar los espacios con presencia de vegetación, a través de análisis de NDVI y NDBI, en el barrio de Tambaú, en João Pessoa/PB, así como verificar las influencias y los beneficios de estos espacios existentes para la calidad de vida urbana.

Metodología: Para alcanzar el objetivo propuesto, se emplearon métodos de teledetección, una herramienta que facilita la comprensión de la fenología de la vegetación en diferentes resoluciones, ayudando en la planificación local. Además, se realizaron análisis cuantitativos con datos cartográficos e imágenes de Google Earth, así como evaluaciones cualitativas a través de visitas y registros fotográficos en el área estudiada.

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Resultados: Aunque el barrio de Tambaú cuenta con áreas verdes públicas, estas son escasas y están mal distribuidas, limitando el ocio de los residentes, concentrándose en la zona turística de la costa. El análisis de NDVI y NDBI muestra la dinámica de la expansión urbana, resultando en baja vegetación y confort térmico. Además, la falta de planificación urbana adecuada compromete la calidad de vida, evidenciando la necesidad de integrar más espacios verdes. La revitalización del Área de Preservación Ambiental alrededor del río Jaguaribe es un aspecto positivo, pero aún insuficiente.

Contribuciones Sociales y Ambientales: El estudio no solo proporciona datos importantes para la planificación urbana, sino que también promueve un enfoque holístico que considera tanto los aspectos sociales como los ambientales, contribuyendo a un desarrollo más equilibrado y sostenible.

PALABRAS CLAVE: Espacios Verdes Públicos. Calidad de Vida. Planificación Urbana.

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1. INTRODUCTION

The rapid changes in the natural environment, driven by unplanned urban expansion, have led to changes in land use and the fragmentation of natural areas, compromising both the quality of the physical environment and human well-being (Maciel; Barbosa, 2015, p. 30). Accelerated population growth has intensified urbanization, relegating urban nature to a secondary role in territorial planning. Rivers and green areas have been neglected, often not considered essential components of urban infrastructure and planning (Lyra; Constantino, 2024, p. 28). In this context, natural spaces in cities not only contribute to the conservation of fauna and flora, but also provide important aesthetic and recreational benefits (Rubira, 2016, p. 138).

In the context of urban quality of life, green areas not only enhance the environment and promote ecological balance, but also contribute to social development and support both the physical and mental health of the population (Londe; Mendes, 2014, p. 265). They serve as strategic elements in addressing environmental issues, improving air quality, mitigating the urban heat island effect, and helping to reduce urban flooding (Vasquez *et al*., 2019, p. 333).

Public green spaces are defined as areas with continuous vegetation and no buildings, although they may include paths, walkways, or equipment for children's play and other recreational activities, provided they are designated for public use. Ideally, such areas should exceed 200 m² and include spaces such as squares, public gardens, and urban parks (Leite, 2021). These spaces provide essential environmental and social benefits, acting as gathering points and fostering community interaction. When properly planned, they attract residents for physical activities or rest.

João Pessoa, the capital of Paraíba, was awarded the title “Cidade Verde” (Green City) in 1999 due to its high tree density and the presence of Mata do Buraquinho, a forested area of approximately 515 hectares containing one of the largest remnants of Atlantic Forest within an urban perimeter. The city also includes several well-vegetated areas, such as Praça da Independência and Parque Zoobotânico Arruda Câmara (Bica), which are regularly used for leisure and nature appreciation.

The Brazilian Society of Urban Arborization (SBAU) recommends a minimum of 15 m² of green space per inhabitant to fulfill the functions of socialization and climate regulation (Silva *et al.,* 2016, p. 354). According to ICES (2014), João Pessoa has 30.67% of its territory classified as green area, corresponding to an average of 47.11 m² of green space per inhabitant. However, these spaces are unevenly distributed, and many neighborhoods lack adequate public green areas to benefit both the environment and the local population. For example, Ilha do Bispo has 254 hectares of green space for approximately 6,020 residents, while the Funcionários neighborhood, with around 16,000 residents, lacks significant green areas (Andrade; Jeronimo, 2015, p. 205).

In this context, it is essential to analyze the relevance of these areas, considering that the integration between nature and urban populations is also a public health issue, as the disconnection can negatively impact both human and environmental well-being (Pinheiro; De Souza, 2017, p. 71). Therefore, this study aims to quantify vegetated spaces through NDVI and NDBI analyses in the Tambaú neighborhood of João Pessoa, Paraíba, and to examine the influence and benefits of these spaces on urban quality of life.

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2. METHODOLOGY

This study focuses on the Tambaú neighborhood, located in the municipality of João Pessoa, Paraíba (PB), Brazil. The neighborhood was selected due to its high population density and proximity to the coastal zone. The research is classified as exploratory and descriptive, as it seeks to familiarize the researchers with the problem and gather relevant information aboutthe object of study (Gerhardt; Silveira, 2009, p. 38).

2.1. STUDY AREA

Tambaú (Figure 1) is located in the eastern zone of João Pessoa, bordered by the neighborhoods of Miramar, Cabo Branco, and Manaíra. It covers an area of 84.63 hectares and had a population of approximately 10,163 inhabitants in 2010. The neighborhood is predominantly characterized by buildings over ten stories high, used for both residential and mixed purposes (PDMU/JP, 2020). Currently, it is considered an upper-middle-class area of the capital of Paraíba, situated along the city's coastline, but it also exhibits characteristics of a central neighborhood due to its commercial development and the substantial flow of people from diverse backgrounds on a daily basis (Souza, 2004, p. 2).

Tambaú is also considered central in terms of being João Pessoa's hub for both daytime and nighttime leisure, offering a variety of natural and built attractions that draw individuals with different profiles, lifestyles, preferences, intentions, cultures, and origins. Since its early formation, Tambaú has been a site of significant commercial activity, catering to both tourists and local residents. Originally founded as a fishing community, the neighborhood has undergone intense social and cultural transformations to become what it is today (Souza, 2004, p. 3).

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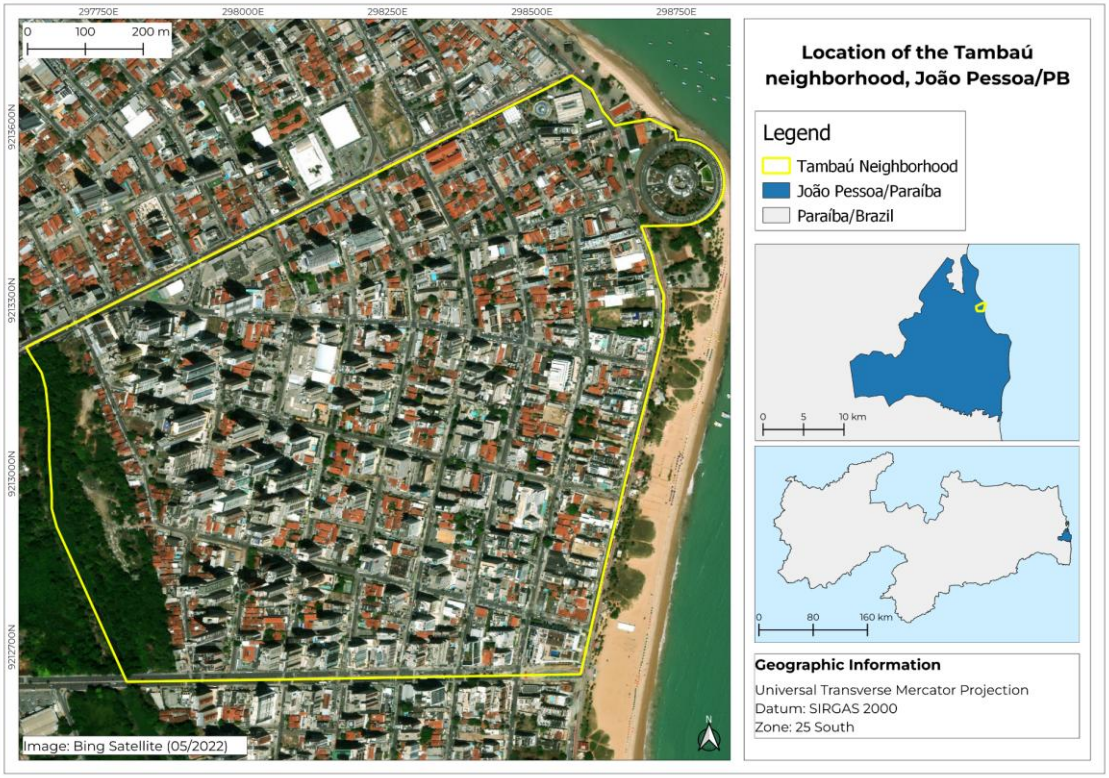
Figure 1. Location map of the Tambaú neighborhood.



Source: Authors, (2024).

According to Silveira and Silveira (2014, p. 291), Tambaú is one of the areas in the city that has undergone significant changes in its construction patterns, primarily characterized by the rise of vertical buildings. Due to the high commercial and residential value of the area, the neighborhood began to develop vertically. In response to market demands and interests, construction companies started investing in the region, seeking to occupy all available spaces. Vacant lots were progressively converted into buildings or reserved for future construction (Souza, 2004, p. 5).

Figure 2 presents the building distribution in the Tambaú neighborhood. Approximately 9.4% of the housing units have ten or more floors, while around 2.2% exceed twenty floors, suggesting that the area may still undergo changes in its current building height regulations (Dos Santos *et al.,* 2023, p. 6).

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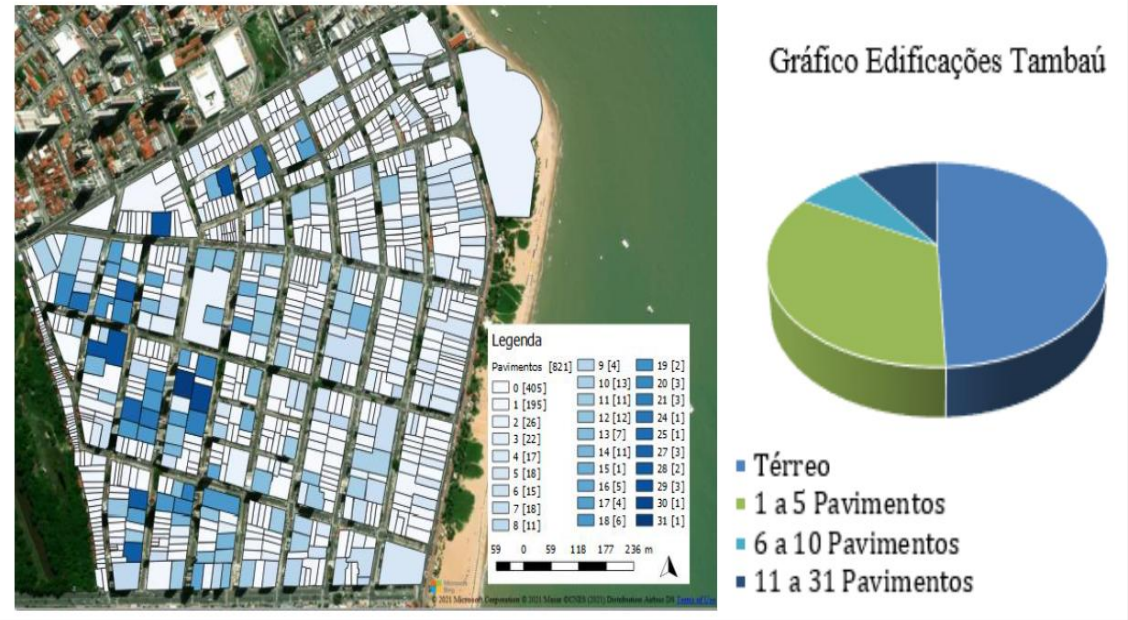
Figure 2. Building map of the Tambaú neighborhood.



Source: Dos Santos et al (2023).

Its growth is reflected in the appreciation of the real estate market, with the number of households increasing significantly from 1,873 in 2000 to 3,457 in 2010, of which 84.7% correspond to vertical housing units (De Araújo *et al.,* 2023, p. 3). In this context, due to the extensive occupation of vacant lots and the absence of prior urban planning, the neighborhood lacks public green spaces that could serve as areas for rest, recreation, or physical activity. The few existing spaces are primarily located along the coastal zone and are mainly designed to attract tourists.

2.2. DATA COLLECTION AND PROCESSING

To achieve the objectives of this study, remote sensing methods were employed, as they facilitate the understanding of vegetation phenology at various resolutions. These methods provide detailed spatial information that can support the planning of urban green areas in both residential and public contexts. Additionally, remote sensing serves as an effective communication tool for authorities involved in urban and environmental planning at the local level

In this context, the Normalized Difference Vegetation Index (NDVI) is one of the most widely used tools for assessing vegetation cover in a given region using satellite imagery (Aburas *et al.,* 2015, p. 239). The NDVI, originally proposed by Rouse *et al.* (1974), produces values normalized on a scale from -1 to 1, where values closer to 1 indicate dense and healthy vegetation, while values near -1 suggest the absence of vegetation, typically corresponding to non-vegetated surfaces such as exposed soil. NDVI is also applied to detect various types of land cover and changes caused by human activities, such as construction and other forms of urban development (Ahmad; Sharif, 2016).

The Normalized Difference Built-up Index (NDBI), proposed by Zha *et al*. (2003, p. 585), is used to highlight the density of built-up areas and urban features. This index also ranges from

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-1 to 1, with values closer to 1 indicating the presence and intensity of urban structures or exposed soil.

For this study, data from the LANDSAT series (Land Remote Sensing Satellite), Collection 2, Level 1, calibrated to top-of-atmosphere (TOA) reflectance, were obtained via Google Earth Engine (GEE). These images offer a spatial resolution of 30 meters, which is suitable for urban-scale analyses. To cover the time frame addressed in this research, scenes from the period between 2007 and 2024 were selected. Landsat 7 imagery was used for 2007, while Landsat 8 was selected for 2024 to ensure higher image quality due to sensor improvements and updates.

Subsequently, images were filtered based on cloud cover, with the scene showing the lowest cloud percentage selected to minimize atmospheric interference in the results. To isolate the study area, the images were clipped using a shapefile corresponding to the boundaries of the Tambaú neighborhood.

For the calculation of NDBI, the near-infrared (NIR) band (0.77–0.90 µm) Band 4, and the shortwave infrared (SWIR) band (1.55–1.75 µm) Band 5, from Landsat 7 were used. For Landsat 8, the corresponding bands were the SWIR band (1.57–1.65 µm) Band 6, and the NIR band (0.85–0.88 µm) Band 5, which match the spectral ranges required for the index.

The NDBI was calculated using Equation 1:

$$\mathrm{NDBI} = \frac{(\mathrm{SWIR} - \mathrm{NIR})}{(\mathrm{SWIR} + \mathrm{NIR})} \qquad \text{(Equation 1)}$$

Where:

SWIR = Surface reflectance in the shortwave infrared wavelengths;
NIR = Surface reflectance in the near-infrared wavelengths.

For the NDVI calculation, the red band (0.63–0.69 µm) and NIR band (0.77–0.90 µm) from Landsat 7 were used. For Landsat 8 and 9, the red band (0.64–0.67 µm) and NIR band (0.85–0.88 µm) were employed.

The NDVI was computed using Equation 2:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})} \qquad \text{(Equation 2)}$$

Where:
NIR = Surface reflectance in the near-infrared wavelengths;
RED = Surface reflectance in the red wavelengths.

Finally, to assess the evolution of NDBI and NDVI over the study period, the difference between the values obtained for the years 2024 and 2007 was calculated using the Raster Calculator tool in QGIS 3.28, based on the images previously exported from Google Earth Engine (GEE). The temporal variation was determined using Equation 3 and Equation 4, respectively:

$$\Delta NDBI = NDBI_{(2024)} - NDBI_{(2007)} \qquad \text{(Equation 3)}$$

$$\Delta NDVI = NDVI_{(2024)} - NDVI_{(2007)} \qquad \text{(Equation 4)}$$

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Based on the results obtained, it was possible to observe the presence of vegetation in the study area, as well as quantify the extent of vegetation loss resulting from building densification and the expansion of the urban footprint over the analyzed period. To achieve this, a Python script was developed to identify the number of pixels with values greater than 0.01 in the NDBI, corresponding to urbanized areas, and pixels with values greater than 0.30 in the NDVI, corresponding to vegetated areas. Considering the spatial resolution of 30 m × 30 m for each Landsat image pixel, the total areas were calculated and expressed in square kilometers (km²).

Subsequently, public green spaces and leisure areas within the Tambaú neighborhood were mapped, with an evaluation of their distribution in relation to population density. For the quantitative analysis, cartographic data from the João Pessoa City Hall database (Filipéia, 2024) were used, along with imagery obtained from Google Earth. For the qualitative analysis, field visits were conducted for photographic documentation and direct observation of spatial distribution, in order to provide a better understanding of the local urban landscape.

It is important to note that all maps used in this research were produced using the open-source software QGIS 3.28.

3. RESULTS AND DISCUSSION

The Tambaú neighborhood contains three identified public green spaces (Figure 3). Largo Tambaú covers an area of 3,876 m² and is located along the waterfront, adjacent to private commercial establishments. It is a well-known tourist site in the city, bordering the Cabo Branco neighborhood, and is frequented both by residents for physical activities and by visitors as a leisure and social gathering space. The other two locations designated by the city government as public green areas are also squares: one situated at the Tambaú Market (Praça Professor Vicente Trevas Filho) and the other next to Tambaú Refeições (Praça Santo Antônio). Both are positioned in front of the former Hotel Tambaú, another historical and touristic landmark of the city.

The spatial analysis reveals a clear scarcity of public green areas in the Tambaú neighborhood. The limited green spaces theoretically available for leisure and recreation are concentrated in the tourist zone, which does not serve the entire local population but rather those who frequent the coastal area. Due to intense urban development and a lack of integrated planning, green infrastructure has not been prioritized. Additionally, the main green area observed in the neighborhood is part of the Environmental Protection Area (EPA) surrounding the Jaguaribe River, while the central urban areas remain largely devoid of vegetated public spaces.

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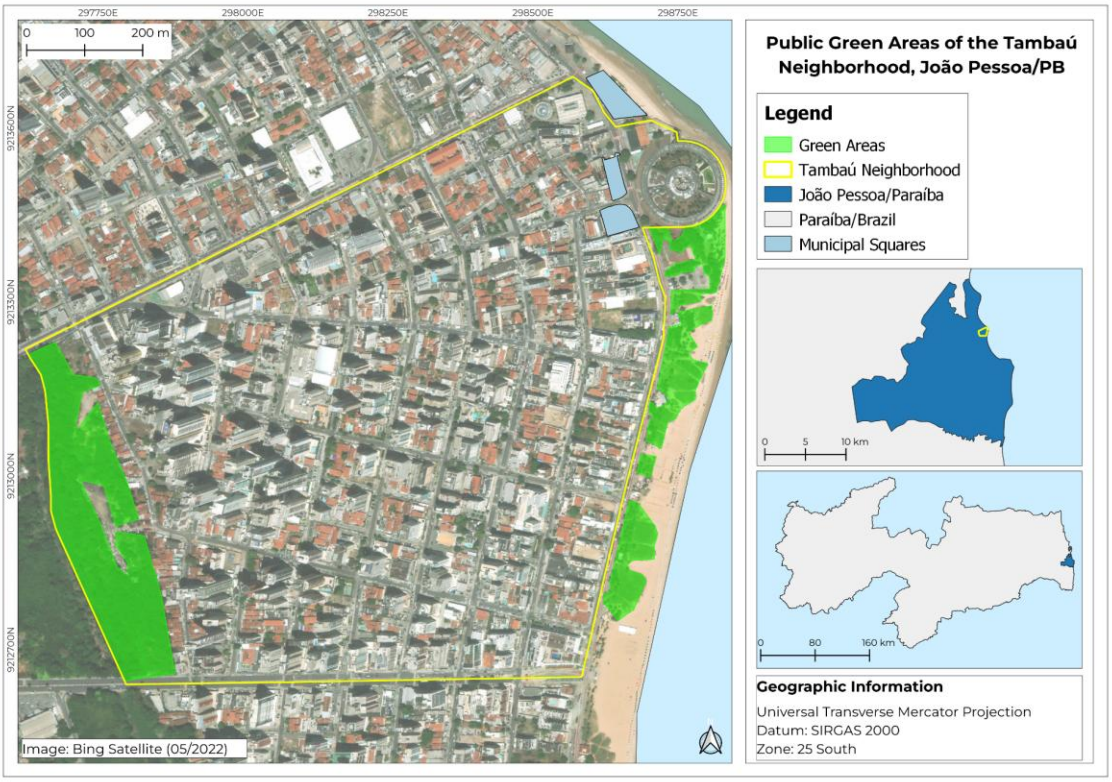
Figure 3. Map of public green areas in the Tambaú neighborhood, João Pessoa, Paraíba (PB), Brazil.



Source: Authors, (2024).

On-site photographic records show that even the areas officially classified by the João Pessoa city government as public green spaces exhibit low vegetation density, with sparse tree cover and an absence of grassy surfaces (Figure 4). In addition to nearby paved roads, these areas themselves are largely covered in impermeable surfaces, which may contribute to thermal discomfort due to the limited capacity of compacted soil to absorb solar radiation. Furthermore, the neighborhood streets have limited arborization, with most trees and plants confined to private properties. This results in a lack of shade along sidewalks, thereby increasing the thermal sensation experienced by pedestrians.

Notably, the most vegetated portion of the neighborhood is located along the coastal strip, possibly making it the most thermally comfortable and visually pleasant area.

Silveira and Silveira (2014) investigated the impact of verticalization on the quality of life in Tambaú using the Residential Space Quality (QER) assessment tool. Their study identified two key variables that influence residents' well-being: vertical development and high population density. The authors argue that these factors can significantly alter traffic patterns, increase the demand for parking infrastructure, and reduce the amount of vegetation in the urban environment. They observed that streets with greater verticalization tend to have less vegetation cover. Thus, the study emphasizes the importance of urban planning, as unchecked verticalization may lead to problems such as traffic congestion, pollution, and a shortage of public green and recreational spaces—factors that collectively diminish the overall quality of life for residents.

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Figure 4. Photographic records of various locations within the Tambaú neighborhood.

Source: Authors, (2024).

3.1. Normalized Difference Vegetation Index (NDVI)

With ongoing urban expansion, there is a noticeable increase in built-up areas, which typically leads to the reduction or complete loss of native vegetation. According to Medeiros *et al*. (2010, p. 10), the encroachment on vegetated zones is often associated with the expansion of urbanization. In NDVI analyses, values close to 1 represent higher vegetation density, making

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it possible to clearly observe, through spatial mapping, the dynamics of urban growth and its impact on green cover within the neighborhood.

A comparison of NDVI results from 2007 and 2024 indicates that the Tambaú neighborhood exhibits limited vegetative cover, with the exception of the Environmental Protection Area (EPA) located near the border with the Miramar neighborhood (Figure 5). This trend is largely explained by the area's accelerated urban growth. The construction of Avenida Epitácio Pessoa in 1930 facilitated the movement of populations from the city center toward the coastal zone, which initiated the rapid and unplanned development of the Tambaú neighborhood (Filipéia, 2024, p. 64; Silveira *et al*., 2007). As a result, almost all available land was occupied, leaving only a few fragmented green spaces remaining.

The neighborhood continues to experience development, albeit in a verticalized form, with single-family homes increasingly being replaced by multi-story buildings to accommodate urban growth. According to Silveira (2007), the construction of the Tambaú Hotel accelerated the expansion process along the coastline, contributing significantly to the transformation of the natural landscape. This verticalization is part of a broader process of population densification, driven by the real estate market, which continuously supplies new residential units. As noted by Souza (2013, p. 24), formerly horizontal residences have been demolished and replaced by vertical structures, evidencing a shift in the neighborhood's spatial morphology. These patterns are consistent with the observed data, which indicate only a slight variation in NDVI values between 2007 and 2024—likely due to the prevalence of vertical, rather than horizontal, urban growth.

Regarding the Environmental Protection Area (EPA) located within the neighborhood, a positive change was observed between the years 2007 and 2024. According to NDVI-based spatial analysis, the vegetated area expanded from 0.1782 km² in 2007 to 0.2025 km² in 2024, suggesting a process of ecological revitalization. This observation is supported by visual comparisons shown in Figure 6, which presents imagery from 2013 and 2024, confirming the improvement in vegetative cover. It is important to note that this EPA recorded the highest NDVI values in the neighborhood, making it the most densely vegetated and ecologically relevant zone in the study area.

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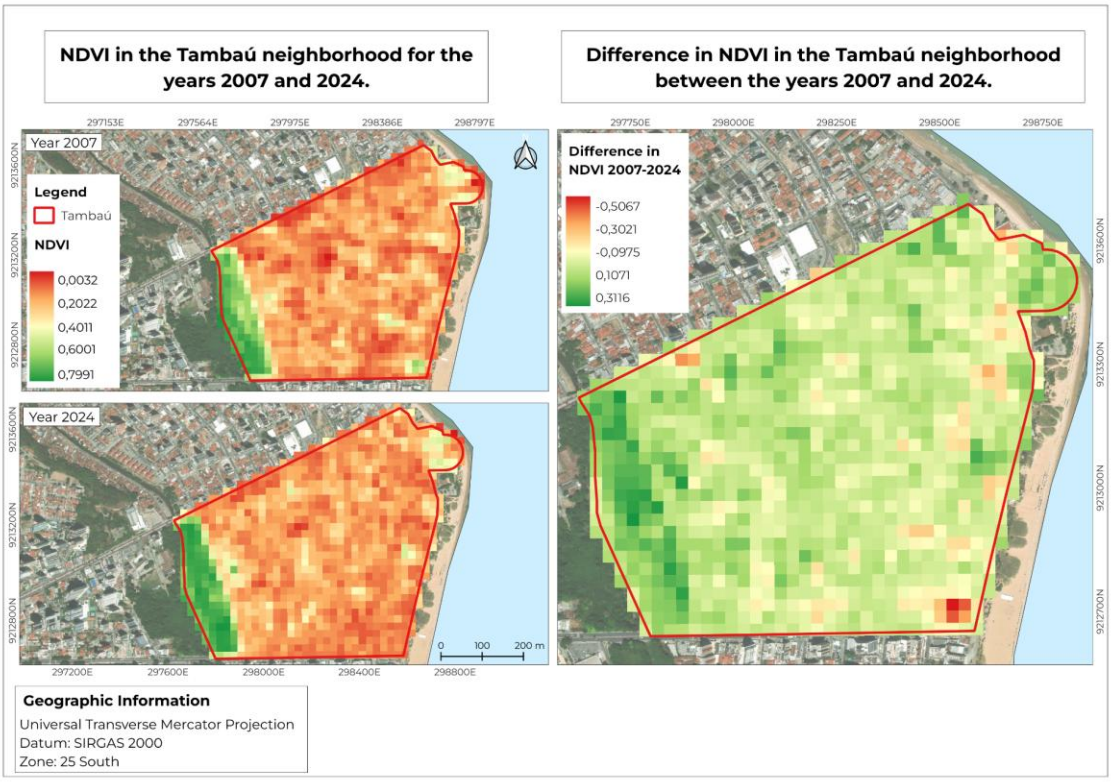
Figure 5. Spatiotemporal analysis of NDVI in the Tambaú neighborhood for the years 2007 and 2024.



Source: Authors, (2024).

Figure 6. Images of the Environmental Protection Area (EPA) along the Jaguaribe River in 2013 and 2024, respectively.

EAP (Jaguaribe River – border between the neighborhoods of Tambaú and Miramar)

Source: Authors, (2024).

3.2. Normalized Difference Built-up Index (NDBI)

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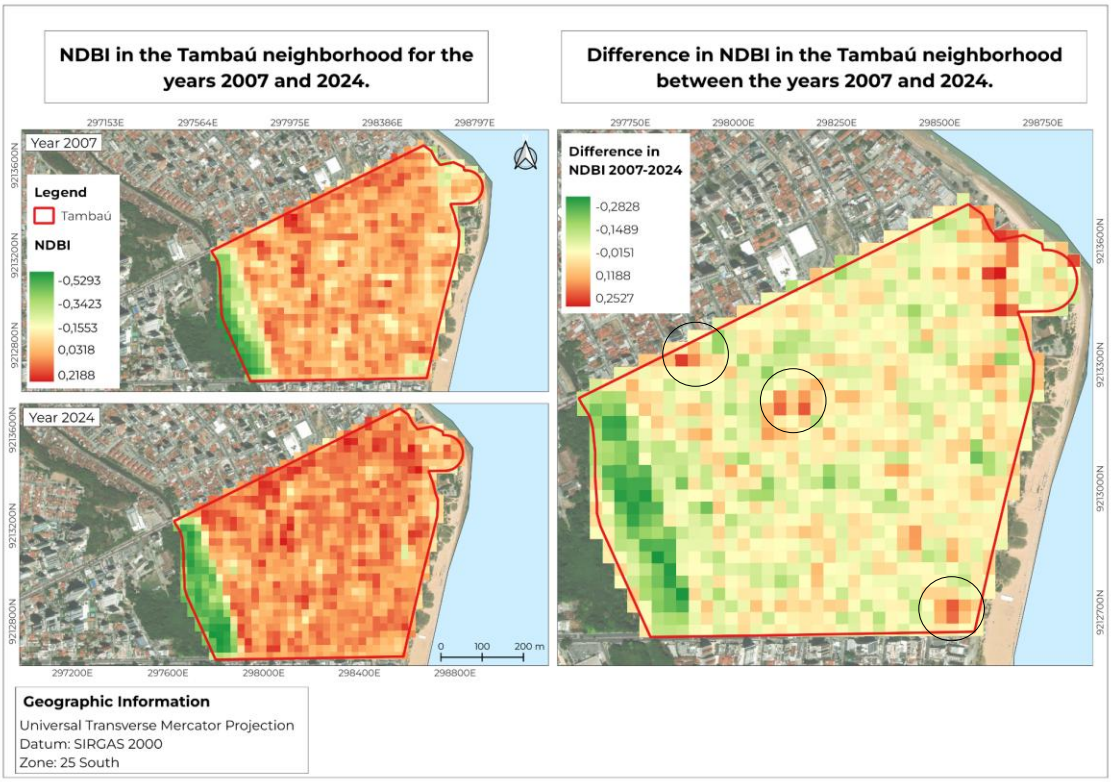
NDBI values closer to 1 indicate a higher density of built-up areas. A clear increase in such values is observed between 2007 and 2024, with the latter year showing more locations with values equal to or exceeding 0.22. This trend reflects the vertical growth of the neighborhood, characterized by a greater extent of built environments compared to 2007 (Figure 7). As previously discussed, the urban expansion of Tambaú accelerated after the construction of Avenida Epitácio Pessoa in 1930, and this growth has since intensified vertically, with single-family homes being replaced by multi-story buildings, consistent with the neighborhood's highly urbanized profile.

The difference map of NDBI between 2007 and 2024 highlights key areas of significant built-up area expansion (Figure 7). Three specific zones stand out, where this increase is particularly pronounced, suggesting the probable replacement of green spaces by construction activities.

Quantitatively, the built-up area expanded as evidenced by the reduction in vegetated surface from 0.2367 km² in 2007 to 0.2261 km² in 2024, indicating ongoing urban densification and land use change.

These findings underscore the urgent need to implement more efficient and sustainable urban development strategies, especially given the evident population growth and resulting increased demands on urban infrastructure. To progress toward the status of a smart city, it is essential to explore innovative urban development alternatives that leverage technology and sustainable practices (Ravache *et al.*, 2024, p. 121).

Figure 7. Spatiotemporal analysis of NDBI in the Tambaú neighborhood for the years 2007 and 2024



Source: Authors, (2024).

An analysis of these specific locations using Google Earth reveals a significant transformation along Avenida Senador Ruy Carneiro, as shown in Figure 8. In 2013, the area consisted of permeable soil with scattered trees; however, it is currently fully impermeabilized

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due to the construction of a warehouse. This site could be repurposed as a green space to provide ecological balance to the surrounding paved surfaces, potentially mitigating urban heat island effects and serving as an important public green area for the community.

Figure 8. Images of the land on Avenida Senador Ruy Carneiro in 2013 and 2024, respectively.

Av. Sen. Ruy Carneiro, nº 1635, neighborhood: Tambaú

Source: Google Earth (2013) **Source:** Google Earth (2024)

Source: Authors, (2024).

Figure 9 highlights another significant change located along the waterfront, in an area of approximately 6,000 square meters, as identified on the NDBI map. This block, adjacent to the well-known "*Busto de Tamandaré*" monument, has been entirely compacted, with construction covering the entire site and incorporating minimal vegetation limited to landscaping. The third notable area of change was not captured by Google Earth, as the modification occurred prior to 2013, and the platform does not provide imagery before that year.

Figure 9. Images of the land on Avenida Almirante Tamandaré in 2013 and 2024, respectively.

Av. Alm. Tamandaré, 1710, neighborhood : Tambaú

Source: Google Earth (2013) **Source:** Google Earth (2024)

Source: Authors, (2024).

Additionally, it is important to note that due to the neighborhood's relatively small size and its already advanced stage of development prior to the analyzed period, the results did not show significant changes except for specific locations. Satellite imagery suitable for such analyses is generally available only from the year 2000 onwards, by which time Tambaú was already a consolidated urban area.

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4. CONCLUSION

Urban planning plays a crucial role in the sustainable development of cities, aiming to balance built environments and green spaces. Green areas are essential not only for aesthetics and urban beautification but primarily for the physical, psychological, and social well-being of residents.

The rapid urban growth of João Pessoa has led to considerable population densification and significant transformations in the urban landscape. In this context, the Tambaú neighborhood clearly lacks adequate green spaces to meet the needs of its population. The predominance of built-up areas and insufficient urban planning have resulted in limited vegetation cover, contributing to thermal discomfort and reducing residents' quality of life.

The analysis of NDVI and NDBI indices highlights the urgent need for urban planning strategies that prioritize the integration of green spaces. The absence of such areas can exacerbate environmental and social problems, including increased urban heat islands, air pollution, and adverse effects on mental and physical health. Therefore, investing in green infrastructure equates to investing in the health and well-being of the urban population.

Finally, it is recommended that future research extend to additional neighborhoods or consider the entire municipality of João Pessoa to provide a broader understanding of urban quality of life and facilitate comparative analyses across different urban contexts.

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