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GEOPROCESSING APPLIED THE ENVIRONMENTAL ANALYSIS OF URBAN GREEN IN THE CITY OF ALEXANDRIA-RN/BRAZIL

Geoprocessamento aplicado à análise ambiental do verde urbano na cidade de Alexandria-RN/Brasil

Geoprocesamiento aplicado al análisis ambiental del verde urbano en la ciudad de Alexandria-RN/Brasil

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ABSTRACT

Urban greenery has been a recurring topic of discussion in several segments of civil organization, given the growing concern with quality of life in cities over the last decades. With this in mind, the objective of this paper is centered around the application of the Soil Adjusted Vegetation Index (SAVI) to analyze the green coverage in public open spaces (public squares) within the urban area of the municipality of Alexandria, in the state of Rio Grande do Norte (RN). For this purpose, the methodological procedures were structured in three stages: (i) bibliographic research, (ii) fieldwork, and (iii) digital processing of satellite images. The results suggest a low presence of vegetation in squares, neighborhoods, and in the surrounding urban area. In the urban perimeter and its surroundings, exposed soil and low vegetation prevail, which may result in thermal discomfort and reduced environmental quality for residents. In light of this scenario, it is recommended to expand and diversify urban afforestation, with emphasis in the introduction of native species and trees with urban canopies, capable of providing shade and promoting greater well-being for users of public spaces.

Keywords: Green Spaces; Geoprocessing; Vegetation Index; Public squares.

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O verde urbano vem sendo pauta de discussão recorrente em diversos segmentos da organização civil, dado que, nas últimas décadas, tem aumentado a preocupação com a qualidade de vida nas cidades. Pensando nisso, o objetivo deste trabalho centra-se em aplicar o índice de vegetação SAVI

(*Soil Ajusted Vegetation Index*), para fins de análise do verde nos sistemas de espaços livres (praças públicas) na área urbana do município de Alexandria, estado do Rio Grande do Norte (RN). Para esse fim, os procedimentos metodológicos fundamentaram-se em três etapas: (i) pesquisa bibliográfica, (ii) trabalho de campo e (iii) processamento digital de imagens de satélite. Os resultados indicaram uma vegetação pouco expressiva nas praças, nos bairros e no entorno da mancha urbana. No perímetro urbano e seu entorno, predominam áreas de solo exposto e vegetação de baixo porte, o que pode resultar em desconforto térmico e menor qualidade ambiental para os moradores. Diante desse cenário, recomenda-se a ampliação e diversificação da arborização urbana, com ênfase na introdução de espécies nativas e árvores de copas mais amplas, capazes de oferecer sombreamento e promover maior bem-estar aos usuários dos espaços públicos.

Palavras-chave: Espaços verdes; Geoprocessamento; Índice de Vegetação; Praças públicas.

RESUMEN

La vegetación urbana ha sido un tema recurrente de discusión en diversos segmentos de la organización civil, dado que en las últimas décadas ha aumentado la preocupación por la calidad de vida en las ciudades. En este sentido, el objetivo de este trabajo se centra en aplicar el Índice de Vegetación Ajustado al Suelo (SAVI) para el análisis de la cobertura verde en los sistemas de espacios libres (plazas públicas) del área urbana del municipio de Alexandria, en el estado de Rio Grande do Norte (RN). Para ello, los procedimientos metodológicos se estructuraron en tres etapas: (i) investigación bibliográfica, (ii) trabajo de campo y (iii) procesamiento digital de imágenes satelitales. Los resultados indicaron una vegetación poco significativa en las plazas, en los barrios y en el entorno de la mancha urbana. En el perímetro urbano y su entorno predominan las áreas de suelo expuesto y vegetación de bajo porte, lo que puede ocasionar incomodidad térmica y una menor calidad ambiental para los residentes. Ante este escenario, se recomienda la ampliación y diversificación de la arborización urbana, con énfasis en la introducción de especies nativas y árboles de copas más amplias, capaces de ofrecer sombra y promover un mayor bienestar a los usuarios de los espacios públicos.

Palabras clave: Espacios verdes; Geoprocesamiento; Índice de vegetación; Plazas públicas.

1 INTRODUCTION

Tree greenery has been a relevant and recurring topic of discussion in various civil society spaces—universities, NGOs, political centers, and others. And in urban spaces, the relevance of greenery is no different, given that, in recent years, there has been growing concern with maintaining the urban environment and the standard of living of people in cities, as pointed out by Cruz (2019).

The topic of urban green spaces has grown in the scientific community, including studies focused on planning areas to meet environmental, human, and aesthetic demands (Bezerra; Grígio; Pessoa, 2022). Nevertheless, several researchers use geoprocessing, especially remote sensing, to measure vegetation indices, as well as to identify, map, manage, and monitor green spaces.

The work of Bortolo, Rodrigues and Borges (2018) is an example of this. They apply specific concpts, methodologies and technical procedures to identify, classify, quantify and map the squares of the city of Monte Claros (MG) from WorldView-II satellite images. The authors also sought to define them in green or free space, based on ecological functions, aesthetic, leisure and a permeable area of 70%.

A similar theoretical and methodological situation, with the application of geoprocessing to urban greenery, is observed in the work of Barros, Farias, and Marinho (2020). The study analyzes the situation and characterization of vegetation cover in the municipality of Juazeiro do Norte in the state of Ceará, based on the NDVI (Normalized Difference Vegetation Index), as a subsidy to public management for decision-making related to local environmental planning.

Based on this perspective, it is believed that such studies contribute valuable information for the implementation, management, and monitoring of urban green spaces. Furthermore, it is a topic that aligns directly with the Sustainable Development Goals (SDGs) of the 2030 Agenda, especially Good Health and Well-being (SDG 3), Sustainable Cities and Communities (SDG 11), and Life on Land (SDG 15).

Given this, this research arises from the concern to analyze the quality of green spaces in areas free of buildings in a city in the interior of the state of Rio Grande do Norte (RN), namely Alexandria, also using geoprocessing techniques to develop a vegetation index, the SAVI (Soil Adjusted Vegetation Index).

The choice of SAVI is justified because it is an index that best fits the characteristics of the Caatinga vegetation, according to Diodato et al. (2021). The study area was selected because this city has a significant amount of open spaces (notably squares), which, despite this, lack adequate tree cover. Interestingly, according to the IBGE (2025), in 2022, 88.12% of Alexandria's public roads were tree-lined, yet, at the same time, it is observed that the afforestation of public squares is still deficient or completely absent.

It is worth noting that the Municipal Organic Law (Alexandria, 1990) makes it possible to address urban green areas, even if indirectly. The document ratifies the right to an ecologically balanced urban environment, for common popular use and enabling a good quality of life, with both the public authorities and society in general responsible for defending and preserving it. However, little effort is being made to insert and/or recover green areas in the city's open space systems, such as squares, beyond periodic pruning.

Given the above, the main objective of this study is to apply SAVI to the analysis of urban greenery in open space systems (public squares) in the city of Alexandria. Specifically, in addition to observing tree spatialization, we seek to identify the dominant species and the uses associated with the locations.

2 GREEN AREAS AND VEGETATION INDICES: THEORETICAL CONTEXT

Green zones, spaces, areas, or facilities are places with a predominance of tree vegetation in urban environments. This greenery commonly persists in cities' open space systems, which are understood as a set of outdoor environments for public use for rest, walking, sports activities, and leisure in general, such as squares, public gardens, and urban parks (Loboda; De Angelis, 2009).

Far beyond their strictly ecological function, vegetation in urban centers contributes directly to the regulation and moderation of temperatures, in addition to providing options for leisure and lending landscape essence to properties and historical and cultural value to municipalities (Bortolo; Rodrigues; Borges, 2018).

In this context, growing urbanization further highlights the need for planning focused on the incorporation of green areas. In Brazil, 87.4% of the population (177.5 million people) live in urban areas, according to the 2022 Census by IBGE (2024). On a global scale, more than half of the population already lives in cities, and this proportion is estimated to reach 68% by 2050, according to the World Cities Report (UN-Habitat, 2024). This scenario highlights the urgency of public policies that prioritize squares, parks, and other green spaces, not only as environmental infrastructure but also as essential components of urban resilience, sociability, and collective well-being (Loboda; De Angelis, 2009).

The importance of green spaces in urban areas is also justified by their influence on quality of life, as well as people's physical and mental health. Vidal et al. (2020) explain that the presence of green spaces in cities is fundamental to promoting the psychological well-being of those who frequent them. This is because the lifestyle and social organization — individualistic, indifferent to socio-affective relationships, replaceability of the materializable by excessive digital consumption — accentuate human emotional instability. Therefore, green areas emerge as therapeutic and accessible spaces, since it is not always possible to escape urban life and go to eminently natural spaces.

The World Health Organization (WHO) in Europe confirms that access to quality green spaces promotes the physical and mental well-being of visitors, in addition to improving their cognitive and immune performance, a fact that will also lead to a reduction in overall mortality rates. Furthermore, it emphasizes that the entire population should have access to these areas, especially socially and economically vulnerable groups (WHO, 2017).

According to the WHO (2017), the effects of urban green spaces can be perceived from three perspectives. First, regarding use and function, they promote active mobility, food production, gardening, physical activity and sports, relaxation and leisure, and social interaction. Second, they add territorial value, impacting residential quality, land prices, and rental levels of nearby properties. Third, they provide environmental regulatory services supporting biodiversity, carbon storage, pollution control, soil protection, as well as temperature and water regulation.

For a better understanding of tree cover, vegetation indices based on geotechnologies can be used to visualize and understand the concentration and conservation status of these spaces. The indices are obtained from the mathematical ratio of different spectral bands that quantify vegetation activity and its seasonal variation, based on the reflectance of the red and near-infrared regions (Bandeira; Cruz, 2021).

According to Diodato et al. (2021), geotechnologies are reliable and relevant tools, widely applied in several fields, with particular emphasis on obtaining information about vegetation and land use. Their use has therefore expanded not only in the academic-scientific domain but also in the business sector. These technologies facilitate both the assessment of natural resources and the monitoring of terrestrial vegetation cover. This process involves the use of indices, defined as mathematical models developed to evaluate vegetation cover, by relating the spectral signature to field-measurable parameters, both quantitatively and qualitatively (Diodato et al., 2021).

The most frequently used is the Normalized Difference Vegetation Index (NDVI). According to Huang et al. (2021), the NDVI is an attractive resource because it enables rapid delineation of vegetation and vegetative stress through digital technologies, i.e., it provides information on vegetation with remotely sensed data. According to these authors, the NDVI is efficient in recognizing typical savanna vegetation, dense forests, non-forested and agricultural fields, evergreen versus seasonal forests, for determining plant properties, etc.

However, for Diodato et al. (2021), when it comes to semi-arid areas with caatinga-type vegetation cover, as is the case in the municipality of Alexandria, SAVI is one of the indicators that best suits the characteristics of this vegetation (deciduous, low-growing, and sparsely dense plants). These authors explain that SAVI, in addition to being an improvement on NDVI, is a type of hybrid index obtained by band ratio and with adjustment aimed at minimizing the contrast of the background soil amid the vegetation.

In short, with the strong urbanization of cities, the presence of greenery is indispensable in compensating for damage to the environment, balancing artificial gray (concrete) and natural green, as well as making places healthier and more conducive to the integration of humans and nature (Scheuer; Neves, 2016). For these and other situations, vegetation indices can contribute directly to the planning of urban green areas and land use planning (Barros; Farias; Marinho, 2020).

3 METHODOLOGICAL PROCEDURES

The procedures used to achieve the proposed objectives are based on three main stages: (i) bibliographic survey, (ii) fieldwork, and (iii) digital processing of satellite images.

3.1 Bibliographic survey

Initially, a survey of literature providing theoretical and methodological support for the topic under investigation was conducted. To this end, free searches were conducted for articles announcing the topic, either in the form of articles (in the Google Scholar database, the *Portal Periódicos Capes* with *CAFe* access, event proceedings, journals, etc.) or in master's dissertations and doctoral theses (searches in institutional repositories). The same procedure was also replicated in the collection of secondary data from the study area.

In the survey of these materials, descriptors were used that should be included cumulatively in the body of the texts, such as: green areas – urban environment – afforestation – vegetation – mapping – identification – vegetation index – Caatinga – Semi-arid – SAVI – Rio Grande do Norte – Alexandria.

3.2 Fieldwork

In carrying out the fieldwork, we first conducted office-based activities to observe satellite images using Google Earth ProTM, seeking to preliminarily visualize the spatial distribution of trees in urban spaces (squares) and then recognize them in situ. During the field visits, the survey sheet (Table 01) by Pivetta and Silva Filho (2002) was used to collect information related to the tree survey, cataloging data related to the identification and location of the area, biological aspects, surroundings and interferences, and definition of actions.

Table 01 - Tree recognition survey sheet

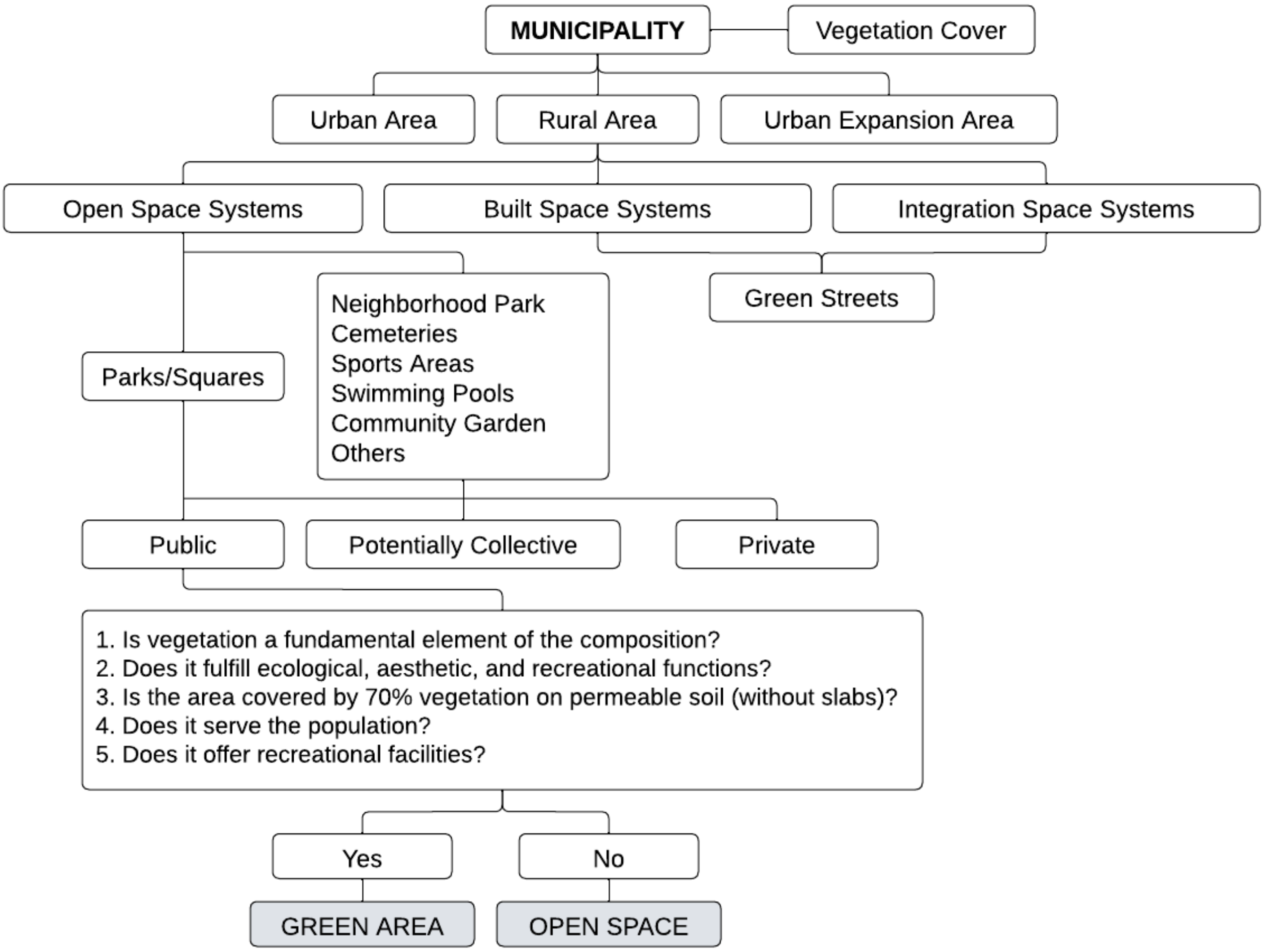
<table>
<tr><th colspan="7">I – LOCATION AND IDENTIFICATION</th></tr>
<tr><td>Date:</td><td colspan="3">Public Road:</td><td>Number:</td><td colspan="2">Neighborhood:</td></tr>
<tr><th colspan="7">II – DIMENSIONS</th></tr>
<tr><td colspan="3">Common/scientific name of the species:</td><td colspan="2">Crown diameter:</td><td colspan="2">Stem diameter:</td></tr>
<tr><th colspan="7">III – BIOLOGY</th></tr>
<tr><th>General Condition</th><th>General Balance</th><th>Phytosanitary Condition</th><th>Intensity</th><th>Location</th><th>Injuries</th><th>Ecology</th></tr>
<tr><td>( ) Excellent
( ) Good
( ) Average
( ) Terrible
( ) Dead</td><td>( ) Yes
( ) No

( ) Stem
( ) Crown</td><td>( ) Aphid
( ) Borer
( ) Insect
( ) Ant
( ) Termite
( ) Caterpillar</td><td>( ) Light
( ) Medium
( ) Heavy
( ) Absent</td><td>( ) Stem
( ) Root
( ) Fruits
( ) Flowers
( ) Branches
( ) Leaves</td><td>( ) Serious injury
( ) Moderate injury
( ) Minor injury
( ) Absent
( ) Vandalism</td><td>( ) Insects
( ) Nests
( ) Lichens
( ) Epiphytes
( ) Parasites</td></tr>
<tr><th colspan="7">IV – ENVIRONMENT AND INTERFERENCES</th></tr>
<tr><th>General Location</th><th>Relative Location</th><th>Pavement</th><th>Root Outcrop</th><th>Participation</th><th>Type of Wiring</th><th>Traffic</th></tr>
<tr><td>( ) Median strip
( ) Sidewalk
( ) Square
( ) Public road</td><td>( ) Next to curb
( ) Centered</td><td>( ) Soil
( ) Cement
( ) Stone
( ) Ceramic
( ) Grass</td><td>( ) Sidewalk
( ) Flower Bed
( ) Construction</td><td>( ) Isolated
( ) Two or more</td><td>( ) Electricity
( ) Telephone</td><td>( ) Light
( ) Heavy
( ) Medium</td></tr>
<tr><td>( ) Setback?</td><td colspan="2">( ) Adequate situation</td><td colspan="2">( ) Paved road</td><td colspan="2">( ) Tree inside the property</td></tr>
<tr><th colspan="2">Posting</th><th colspan="3">Lighting</th><th colspan="2">Wall/Construction</th></tr>
<tr><td colspan="2">( ) Current
( ) Potential
( ) Absent</td><td colspan="3">( ) Current
( ) Potential
( ) Absent</td><td colspan="2">( ) Current
( ) Potential
( ) Absent</td></tr>
<tr><th colspan="7">V – DEFINITION OF ACTIONS</th></tr>
<tr><th colspan="3">Action taken</th><th colspan="4">Recommended action</th></tr>
<tr><td colspan="3">( ) Light pruning ( ) Heavy pruning ( ) Planting ( ) Damage repair
( ) Control ( ) Replacement ( ) Bed Expansion
Quality of action: ( ) Excellent ( ) Good ( ) Fair ( ) Poor</td><td colspan="4">( ) Light pruning ( ) Heavy pruning ( ) Planting
( ) Damage repair ( ) Control
( ) Replacement ( ) Expansion of the planting bed
( ) Other ____________________________</td></tr>
</table>

Source: Pivetta e Silva Filho (2002)

The field stage also enabled photographic records to be taken and the points visited to be georeferenced using GPS (Global Positioning System) devices. In this stage, the Urban Green Classification Key (Figure 01) was also used, as listed in the work by Buccheri Filho and Nucci (2006). In summary, the key provides support for the recognition of urban vegetation cover in open spaces or green areas.

Figure 02 – Urban Green Classification Key



Source: Buccheri Filho e Nucci (2006)

3.3 Geoprocessing and SAVI

The cartographic representations were prepared in a GIS (Geographic Information System), more precisely in QGIS version 3.16.11 Hannover. The location map of Alexandria used grids provided by IBGE (2022) and Google Satellite images from 2022. The land cover map was based on data from the MapBiomas Project (2022). It should be noted that the delimitation of what constitutes the urban area of Alexandria was done arbitrarily by creating polygons in Google Earth Pro, since no official delimitation of the municipal district for the neighborhoods was found.

To calculate the vegetation index for the study area, SAVI, satellite images were digitally processed, mainly from Bands 4 (B4) and Bands 5 (B5). The image used was from Landsat 8-9 sensor OLI/TIRS C2 L2, path 216, line 064, captured on 09/21/2022, from the United States Geological Survey (USGS) portal. As it is a level 2 (L2) product, the image has already been atmospherically corrected and is available in surface reflectance values. Thus, the procedures applied were limited to radiometric transformation, coordinate reprojection, and cropping of the scene corresponding to the study area.

The vegetation index was based on the calculation of the raster file using the equation:

$$SAVI = \frac{(NIR - RED)}{(NIR + RED + L)} X\ (1 + L)$$

where "NIR" refers to the near-infrared band (B5), 'RED' to the red band (B4), and "L" to the soil brightness correction factor in relation to vegetation. Thus, the value of L for caatinga-type vegetation is generally 0.5 (Diodato *et al.*, 2021). The result will indicate locations with values between -1 (little or no vegetation) and 1 (dense vegetation).

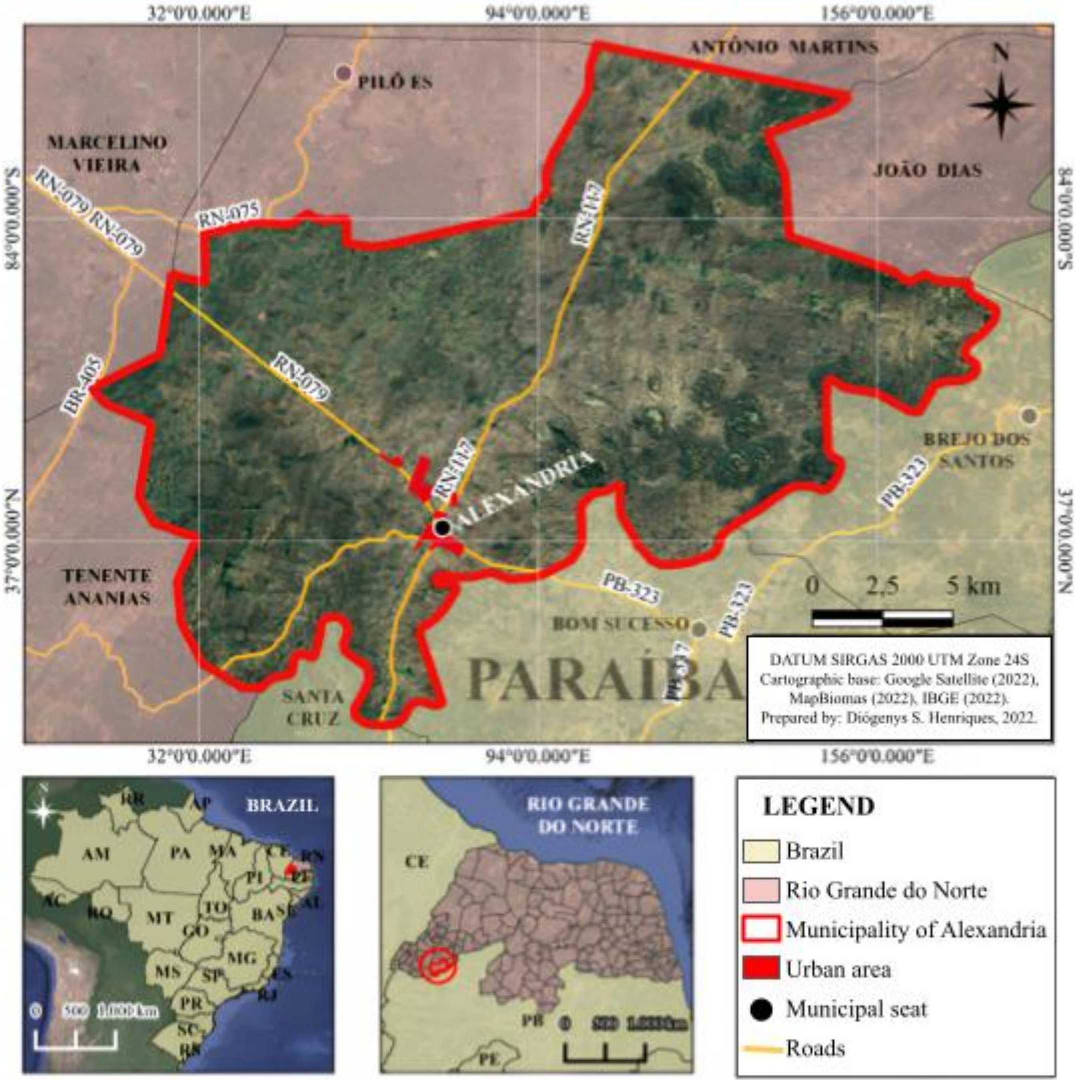
4 CHARACTERIZATION OF THE STUDY AREA

The municipality of Alexandria is located in the western part of the state of RN, in the northeastern region of Brazil. According to the Brazilian Institute of Geography and Statistics - IBGE (2017), it is located in the immediate geographical region of Pau dos Ferros and intermediate to Mossoró. It borders the municipalities of João Dias, Antônio Martins, Pilões, Marcelino Vieira and Tenente Ananias in RN, as well as others in the state of Paraíba (Santa Cruz, Bom Sucesso, and Brejo dos Santos) (Figure 02).

According to IBGE (2021), it is estimated that around 13,529 inhabitants resided in Alexandria in 2021, with 9,200 people living in urban areas (68%) and the remaining 4,329 in rural areas (32%). The municipal territory covers an area of 381.205 km², resulting in a population density of 35.43 inhabitants per km². Regarding the Municipal Human Development Index (IDHM), where values ranging from 0 to 1 are assigned to each locality, Alexandria has a score of 0.606, which places it in the "average" range and in 83rd position among the municipalities of RN (Atlas Brasil, 2017).

In terms of the economy, in 2019, Alexandria had a per capita Gross Domestic Product (GDP) of R$10,712.92, derived from agricultural, industrial, commercial, and service activities associated with administration, defense, education, public health, and social security (IBGE, 2021). Agriculture is the most significant activity in the economic arrangement and, according to MapBiomas (2022), occupies approximately 19,351 hectares or 50.76% of Alexandria's territory, surpassing the natural vegetation formations that covered 17,355 hectares (45.53%) (Figure 03).

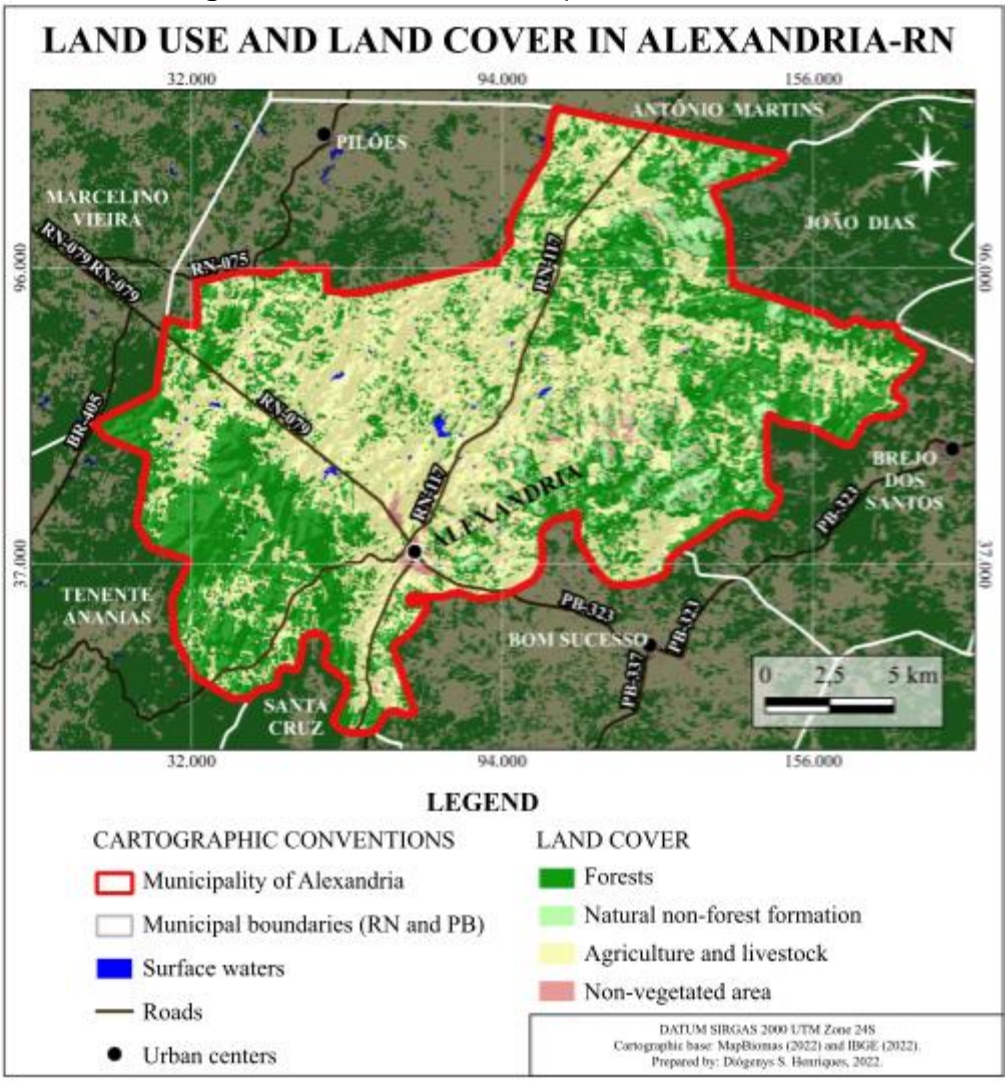
Figure 02 – Location map of the municipality of Alexandria-RN.



Source: Prepared by the authors, 2022.

In terms of climate, Alexandria is located in a semi-arid area. The average annual temperature is 28°C and rainfall is 770.0 mm, with the rainy season lasting from February to May (Mascarenha et al., 2005). Hydrographically, the municipality is part of the Apodi-Mossoró River Basin, where the water drainage channels consist of intermittent streams and creeks, with torrents of water only during the winter months.

Figure 03 – Land cover map of Alexandria-RN



Source: Prepared by the authors, 2022.

Physiographically, the territory of Alexandria has a rich natural landscape related to both biodiversity and geodiversity. The mountainous terrain in Alexandria, a notable feature of the regional hinterland landscape, protects a seemingly well-preserved, if not entirely natural, vegetation cover. In these environments, the diversity of plant species supports typical local fauna, including birds, amphibians, reptiles, and mammals (Henriques; Medeiros, 2021).

The vegetation cover is typical of the Hyperxerophytic Caatinga (drier with cacti and scattered low-growing plants) and Deciduous Forest (species with small, deciduous foliage that falls during the dry season). Common examples of this vegetation are *Combretum leprosum Mart* (mufumbo), *Mimosa tenuiflora* (jurema preta), *Pilosocereus pachycladus* (facheiro), *Pilosocereus gounellei* (xique-xique), and *Cydonia oblonga* (Marmeleiro) (Mascarenhas et al., 2005).

5 RESULTS AND DISCUSSION

The results will be presented below, initially providing data on SAVI focused on the urban area of Alexandria, followed by the characterization to greenery and the urban environmental quality of open spaces.

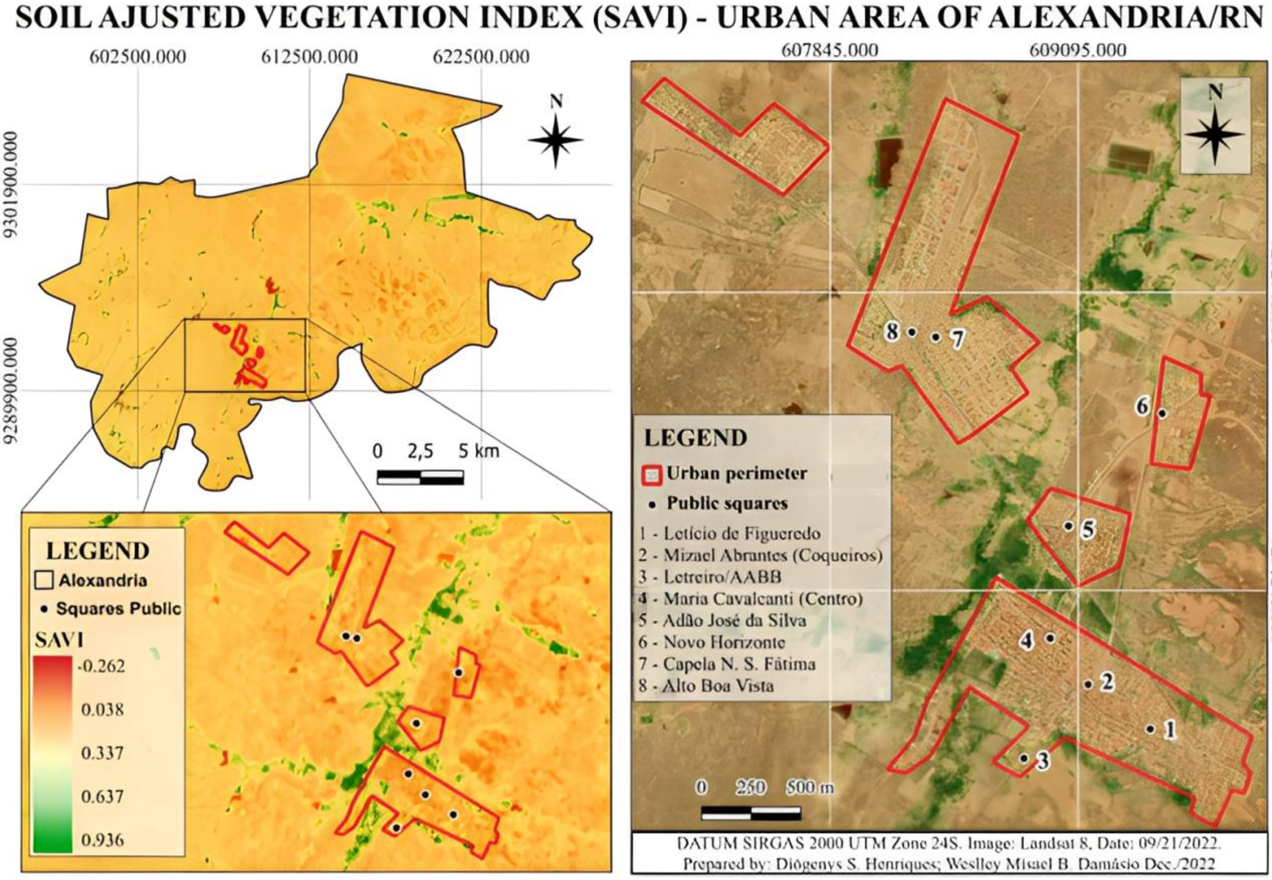
5.1 SAVI Applied to the Urban Green Areas in Alexandria

Obtaining the SAVI for the urban area of the municipality of Alexandria made it possible to identify locations with greater and lesser amounts of vegetation cover. As can be seen in the map in Figure 04, it was possible to generate five classes for SAVI, with values ranging from -0.262, corresponding to water bodies, to 0.936, referring to denser vegetation. It should be noted that these values reflect the recording period and the resolution of the satellite image used.

The orbital image used for the index has a spatial resolution of 30 meters and was captured on September 21, 2022, during the dry season, when vegetation loses its foliage as an adaptation to the region's climatic characteristics, especially low rainfall. In general, the SAVI results reveal low vegetation indices in all neighborhoods of Alexandria, with values ranging from -0.100 to 0.337. It is clear that vegetation appears sporadically and in isolation within the polygons representing the neighborhoods and even in the vicinity of public squares. This is also true in areas outside these quadrants (surrounding the urban area).

To explain these values, it is important to consider two aspects. First, the presence of various urban buildings and facilities tends to stand out and inhibit not only the scarce vegetation present in squares but also the trees along the streets. Second, there is the possibility that the scarcity of urban vegetation could make it impossible to capture, due to the cartographic scale or resolution of the satellite image.

Figure 04 – Map of the Soil-adjusted Vegetation Index (SAVI) of the urban area of Alexandria/RN



Source: Prepared by the authors, 2022.

It is worth noting that there is a discrepancy with the IBGE (2025) data, which indicates that, in 2022, 88.12% of public roads had trees. However, this vegetation was not represented in the mapping obtained from SAVI. In the urban perimeter, the SAVI map (Figure 03) did not reveal any significant difference in values, even though there is no “concrete” to inhibit the green vegetation. In this case, despite the low values, this does not mean that there is no vegetation cover or that everything is exposed soil. The index only interprets the vegetation as low-growing, shrubby, herbaceous, or simply vegetation without foliage, since the image was captured during the dry season.

Alexandria is an agricultural municipality, predominantly rural, which is reflected in the extensive areas of exposed soil around the urban area (Figure 2). This type of land use and occupation contributes directly to soil exposure and degradation, intensified by natural and climatic factors, and requires a long time for the remaining vegetation to regenerate.

Finally, the map also shows a linear green patch cutting across the urban area in a southwest-northeast direction. This type of vegetative strip, with values ranging from 0.500

to 0.936, refers to the riparian forest along the Alexandria River and some of its tributaries, which, due to its more preserved tree composition, intensifies chlorophyll activity, allowing the area to be captured in the vegetation index.

This identified tree composition represents the dispersion of species from the Caatinga Arbórea, which has trees up to 20 meters high and which, in the rainy season, form a continuous canopy that provides shade inside. As shown in the image used for SAVI, the vegetative strip of the Alexandria River remains green not only in the rainy season but also in the dry season, even though the river is intermittent, i.e., with water flowing only in the rainy months.

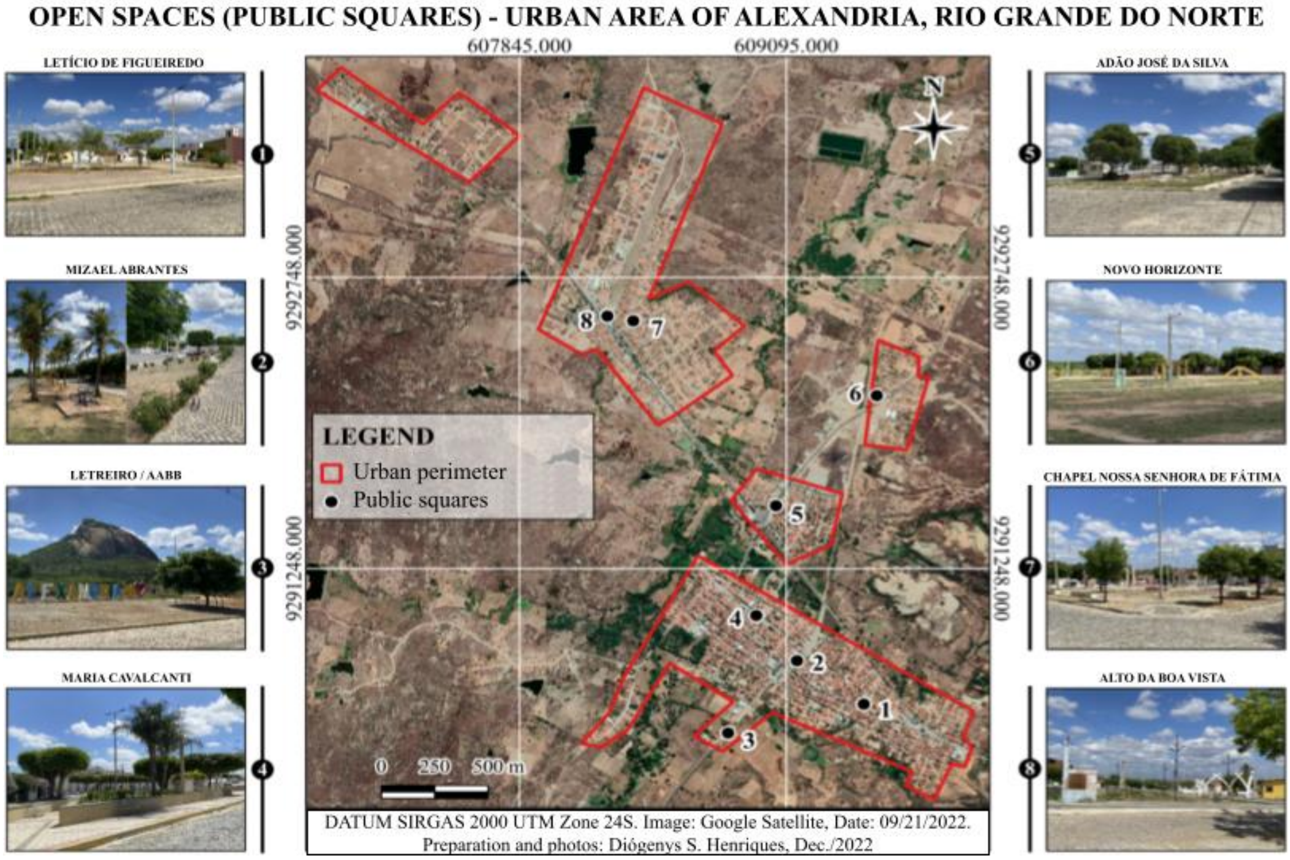
5.2 Uses and Environmental Quality of Public Squares in Alexandria

According to Ecker (2020), squares are spaces for collective use found in any city. They are characterized by an open architectural form, surrounded by buildings and framed by facades. Initially, they were places dedicated to culture, but over time, they began to incorporate multiple sectors (social, commercial, recreational, sports).

Based on this concept, it can be said that the urban center of the municipality of Alexandria has a total of eight public squares, namely Nossa Senhora de Fátima Chapel, Neighborhood Alto Boa Vista, Neighborhood Novo Horizonte, Letício de Figueredo, Mizael Abrantes, Letreiro, Maria Cavalcanti, and Adão José da Silva (Figure 05). In summary, in these squares, exotic species predominate over native species, with *Azadirachta indica* (*nim*) and *Prosopis juliflora* (*algaroba*) being the most common species, but there are also other species that occur more sporadically.

Of these spaces, those with the highest daily flow of people are Mizael Abrantes Square and Maria Cavalcanti Square, as they are located on streets where urban centrality occurs. Therefore, for the purposes of this study, specific focus will be given to these two squares. The other squares do not have good tree coverage, except for Adão José da Silva Square, in the Santo Amaro neighborhood, which, despite not having many trees, has large trees that are in good physical condition and provide good local shade. The others generally have fewer than 10 small trees, and one of them has no trees, only shrubs.

Figure 05 – Map showing the location of public squares in the urban area of Alexandria/RN



Source: Prepared by the authors, 2022.

5.3 Mizael Abrantes Square

Mizael Abrantes Square (PMA), also called Praça dos Coqueiros, is located in the city center and close to the old train station, the Joaquina Queiroz Maternity Hospital, and the 7 de Novembro State School (Figure 06).

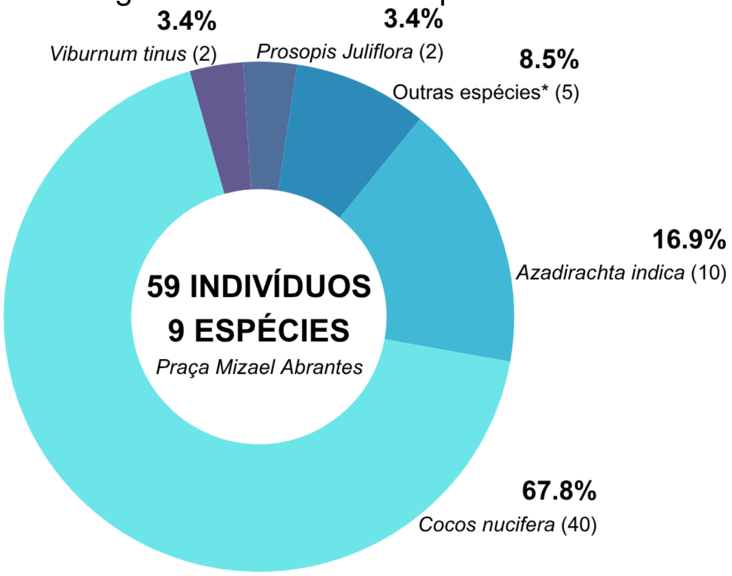
Using the Urban Green Classification Key by Buccheri Filho and Nucci (2006), the PMA is characterized as an open space, since vegetation is not the main element, nor does it cover 70% of the square's area. It covers approximately 2,600 m² and is home to 60 trees, most of which are between 3 and 8 meters tall, as well as others with a shrubby appearance, typical of non-woody gardening (flowers). Of this number, the field identified trees of short stature (≥1.50 m or ≤1.90 m), which, given their good condition, suggest recent planting (seedlings).

Of the trees identified in the field (Graph 01), the following can be mentioned: *Prosopis juliflora* (algaroba), *Azadirachta indica* (nim), *Cocos nuciferas* (coqueiros), *Viburnum tinus* (sempre-verde), *Citrus limon* (limoeiro), *Licania rigida* (oiticica), *Mangifera* *indica* (magueira), *Terminalia catappa Linn* (castanhola), and *Schinus terebinthifolia* (aroeira).

Figure 06 – Mizael Abrantes Square. A and B – View of Quadrant 1 with a predominance of *Azadirachta indica* and other isolated species; C and D – Quadrant 2 with *Cocos nucifera* and equipment from the Health Academy Program

Source: Fieldwork. Authors' collection, Dec./2022.

Graph 01 – Percentage distribution of tree species in Mizael Abrantes Square



Source: Fieldwork. Prepared by the authors, 2022.

The PMA experiences a large flow of people and motor vehicles, both day and night, especially since it is located on one of the city's main streets, Dr. Rafael Fernandes Street. The square can be divided into two non-continuous quadrants, separated by a street (Dix-Sept Rosado Street). Quadrant 1 (see Figures 6-A and 6-B) contains shorter trees (4-5 meters tall), predominantly Azadirachta indica (10 trees, corresponding to 17% of the total trees identified at the site), as well as solitary trees (young species of *Licania rigida* and *Schinus terebinthifolia*).

In this same quadrant, the trees are centrally placed, with cement paving on the sides, and the interior varies from exposed soil to sparse (dry) grass. Also in this quadrant are benches/seats in the square, as well as some informal businesses (food, textiles, and crafts).

In quadrant 2 of the PMA (Figures 5-A and 5-B), there are trees ranging from young to mature, ranging in height from 3 to 8 meters. This location has a distinctive plant characteristic: the predominance of *Cocos nucifera* over other species (approximately 67%) and the fact that it also houses sports equipment for the outdoor gym, funded by the Federal Government's Health Academy Program (PAS). Therefore, in addition to being a place for social interaction, it is an environment that promotes the physical health of residents.

In this quadrant, it can be observed that the planting of *Cocos nuciferas* complies with the guidelines of Pivetta and Silva Filho (2002) for columnar trees. The authors point out that these species are suitable for streets or avenues with central reservations wider than 3 m, and can be planted in two rows, as observed in the field. The authors also recommend that, preferably, the same species be maintained in the median strip. However, it was found that residents introduced other species to the site (*Citrus limon, Mangifera indica, Terminalia catappa Linn*), a fact that may lead to competition for space and even the death of the species.

In terms of biological aspects, the PMA trees are in fair overall condition, with no damage or signs of vandalism on the trunk or crown. Ecological indicators are also present, such as traces of insects, mainly ants (*Formicidae*). Bird nests are more common in *Prosopis juliflora*, while they are rare in other species. This is because Cocos nuciferas do not have a branch and canopy system suitable for holding nests, and *Azadirachta indica* are considered abortive plants for birds (and other animals such as bees), as they cause sterility (Silva, 2019).

Finally, the PMA trees, which are small and have sparse, irregular, and sparse canopies, even with constant irrigation, offer limited shade. It was found that none of the quadrants provide good shade for visitors to the site, such as students, merchants, motorcycle taxi drivers, gym users, and others.

5.4 Maria Cavalcanti Square

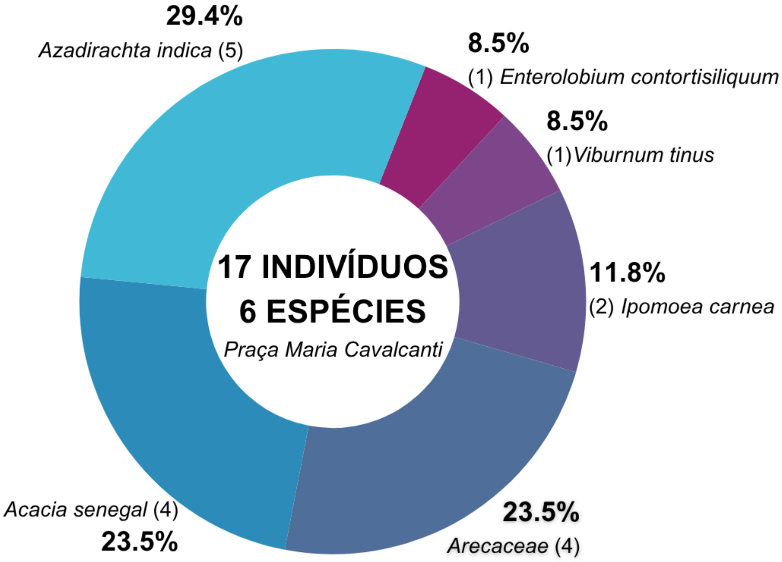
Maria Cavalcanti Square (PMC), Mother Church Square, or Downtown Square (Figure 7), is the most frequented of all the city's squares and is located in the area with the highest urban centrality, commercial traffic, and flow of people and cars. In addition to the landmarks mentioned above, it is also located off Dr. Gregório de Paiva Street, and other well-known points of interest nearby are the Municipal Pavilion, the Pátio da Folia, and the Waldemar de Sousa Veras State School.

Figure 07 – Maria Cavalcanti Square. A, B, and C – Species of *Acacia senegal* (acacia), *Enterolobium contortisiliquum* (Timbaúba), and *Arecaceae* (palm tree) in Quadrant 1; D – Species of *Azadirachta indica* in Quadrant 2.

Source: Fieldwork. Authors' collection, Dec./2022.

The PMC covers an area of approximately 3,758 m², with 17 trees ranging in height from 4 to 10 meters, distributed across two main non-contiguous quadrants (separated by Travessa Agostinho and Trecho Luiz Gonzaga). Of the tree units identified in the field, six different species can be mentioned in this square, namely: Azadirachta indica (neem), *Acacia senegal* (acacia), *Arecaceae* (palm tree) Ipomoea carnea (wild cotton), Virbunum tinus (evergreen), and *Enterolobium contortisiliquum* (Timbaúba) (Graph 02). In addition to these, there are other shrubby and herbaceous species for decorative purposes, such as seedlings and flowers.

Gráfico 02 – Percentage distribution of tree species in Maria Cavalcanti Square



Source: Fieldwork. Prepared by the authors, 2022.

With regard to biological aspects, it was found that the trees are in good condition, as they are watered daily and pruned frequently. It should be noted that, during the period visited, the trees showed no signs of damage or injury to any part of the plant, only rotten and dry branches. In terms of ecological indicators, it was noted that some trees have abandoned bird nests (in *Enterolobium contortisiliquum*) and insects, mainly ants (*Formicidae*), but in a way that does not compromise them.

In general, despite its cultural, economic, and social relevance, the PMC has a tree deficit in relation to the PMA, being classified as open space, according to the classification key. In quantitative terms, even with a larger area, the PMC has 43 fewer trees than the PMA, which represents about three times less or 70% fewer tree units.

In qualitative terms, because some trees are taller, with more spread out and closed canopies, there is greater shade coverage, with *Acacia senegal* (about 7 meters) and *Enterolobium contortisiliquum* (approximately 10 meters) being the species that provide the most shade in the area and together account for 30% of the total tree units in the PMC. However, this better coverage is restricted to only one quadrant of the PMA.

In this same quadrant, there is a presence of *Arecaceae* (24% of total species) which, despite also being taller (6-8 meters), are not decisive in terms of shading the area, as they do not have large, open canopies for this function. Therefore, this species has only a decorative effect and, probably, an ecological effect for some birds. It should be noted that, as columnar trees, they do not meet the recommendation of being planted in rows or in a zigzag pattern, as recommended by Pivetta and Silva Filho (2002). These are arranged in a scattered and isolated manner in the PMC.

In the second quadrant are the species Azadirachta indica, Ipomoea carnea, and Viburnum tinus, which together represent 47% of the trees in the PMC. These species, with heights between 4 and 6 meters, have more closed crowns but offer little shade and are distributed sporadically.

Finally, the uses associated with the PMC go beyond leisure and socialization. It is common to see people using it for sports (free walking, outdoor exercise at the nearby gym), food (snack bars, restaurants, pizzerias, ice cream parlors, bars, etc.) commercial purposes (open-air markets, handicraft sales, distributors, and other enterprises), financial purposes (services provided by the nearby Caixa Lottery unit), transportation (boarding/waiting point for transportation to other cities), and cultural purposes (festive events).

6 CONCLUSIONS

Urban green areas, more than just a scientific topic, have a direct impact on people's quality of life. This greenery is usually present in cities' open space systems (such as public squares) and, in addition to its ecological and landscape value, it improves the thermal sensation, providing shade, ventilation, and well-being for users of the environment.

In seeking to observe and analyze the environmental aspects of greenery in public squares in the city of Alexandria, RN, through vegetation indices, specifically SAVI, and field research, no significant vegetation was found in squares, neighborhoods, or even in the surrounding urban area, except for the denser vegetation associated with the course of the Alexandria River, which cuts through part of the city.

The application of SAVI in the urban area resulted in five classes, with values ranging from -0.262 (corresponding to water) to 0.936 (dense vegetation). However, low to medium values predominate, ranging from approximately 0.100 to 0.337. This indicates that, both within the urban perimeter and in its surroundings, areas with exposed soil or low-growing vegetation, shrubs, or herbaceous plants prevail. On the SAVI map, only a few isolated green spots appear within the urban polygon.

In the survey of tree species present in the squares, the height ranges from 4 to 10 meters, with low diversity and, for the most part, small, open crowns that do not provide much shade, being more related to aesthetic than ecological function. Tree management basically involves periodic pruning and daily watering.

It would be appropriate to promote better distribution and introduction of native species, aiming at the diversification of urban afforestation. Of the 13 genera identified, only one (Licania rigida) is endemic to the Caatinga. In addition, it is recommended to plant trees with wider crowns, capable of providing shade to users. This measure is feasible, since there are no overhead wires in the quadrants of the squares and the wide streets do not compromise the circulation of larger vehicles.

Regarding uses, various functions associated with leisure, well-being, health, commerce, work, etc. were identified. However, it is more common to find people enjoying these spaces at specific times, such as in the early hours of the day (5:00 a.m. to 11:30 a.m.) and in the late afternoon and evening (after 5:00 p.m. until 11:00 p.m.). At other times, precisely because there is no tree cover to provide shade, there is no demand for these places, which could be used as rest areas during work breaks, after school, or for other social purposes.

Finally, it should be noted that this study does not exhaust the subject matter for this area of research. On the contrary, other approaches related to green spaces in the urban area of Alexandria can be applied, such as the identification of tree species in other squares and the quantitative and ecological relationship between native and exotic species, among others.

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