ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 11, nº 1 (2025)

https://doi.org/10.21680/2447-3359.2025v11n1ID37540

Geoprocessing applied to the evaluation of Permanent Preservation Areas of springs located in the area of influence of the Suape Port Complex

Geoprocessamento aplicado à avaliação de Áreas de Preservação Permanente de nascentes inseridas na área de influência do Complexo Portuário de Suape

Fabrynne Mendes de Oliveira[1]; Rosângela Gomes Tavares[2]; Valmir Cristiano Marques de Arruda[3]; Júlio da Silva Corrêa de Oliveira Andrade[4]; Daniel Pereira de Morais[5]; Alex Souza Moraes[6]

[1] Federal Rural University of Pernambuco, Graduate Program in Environmental Engineering, Caruaru - PE, Brazil. Email: fabrynnemendes@gmail.com
ORCID: https://orcid.org/0000-0001-9944-5189
[2] Federal Rural University of Pernambuco, Department of Rural Technology, Recife - PE, Brazil. Email: rosangela.gomestavares@ufrpe.br
ORCID: https://orcid.org/0000-0001-8400-3759
[3] Federal Rural University of Pernambuco, Department of Rural Technology, Recife - PE, Brazil. Email: valmir.arruda@ufrpe.br
ORCID: https://orcid.org/0000-0002-8054-2576
[4] Federal Rural University of Pernambuco, Department of Rural Technology, Recife - PE, Brazil. Email: julio.andrade@ufrpe.br
ORCID: https://orcid.org/0009-0009-5549-2480
[5] Federal Rural University of Pernambuco, Department of Rural Technology, Recife - PE, Brazil. Email: daniel2018morais@gmail.com
ORCID: https://orcid.org/0000-0002-7615-6920
[6] Federal Rural University of Pernambuco, Department of Chemistry, Recife - PE, Brazil. Email: alex.moraes@ufrpe.br
ORCID: https://orcid.org/0000-0002-4324-8271

Abstract: Springs are water bodies that are essential for the ecological balance of river basins, which are ideal units for use in environmental studies. Therefore, sought to evaluate the springs and their Permanent Preservation Areas, including the microbacteria of Riacho Algodoais, in the area of influence of the Port of Suape, using geotechnologies, such as the Mapbiomas program. The methodology consists of creating thematic maps and collecting quantitative data, analyzing from 2002 to 2022 variations in land use and occupation and contour dynamics that can influence the flow of water in the soil, such as the transport of materials and a possible distribution of contamination in the area. In the selected period, an increase was observed in the Urbanized Area class (+ 77.17%), as well as in Forest Formation (+ 53.51%). However, there was a reduction in the River, Lake and Ocean (-59.55%), which includes the water bodies in the research area. The study showed similarity with related publications, demonstrating that geotechnologies are effective tools for environmental monitoring, with an accurate approach to vegetation cover and contributing to the implementation of appropriate measures. Furthermore, they are essential in preventing and mitigating problems resulting from adverse environmental impacts caused by the interaction between human activities and the environment.

Keywords: Remote sensing; Forest Code; Environmental monitoring.

Resumo: As nascentes são corpos hídricos fundamentais para o equilíbrio ecológico das bacias hidrográficas, que são unidades ideais para utilização em estudos ambientais. Em virtude disto, buscou-se avaliar as nascentes e suas Áreas de Preservação Permanente, inclusas na microbacia do riacho Algodoais, da área de influência do Porto de Suape, por meio de geotecnologias, como o programa Mapbiomas. A metodologia consistiu em elaborar mapas temáticos e levantar dados quantitativos, analisando de 2002 a 2022 variações de uso e ocupação do solo e dinâmicas de curvas de nível que podem influenciar no fluxo da água no solo, com o transporte de materiais e uma possível disseminação de contaminação na área. No período selecionado, observou-se aumento da classe Área Urbanizada (+ 77,17%), como também de Formação Florestal (+ 53,51%). Contudo, houve redução de Rio, Lago e Oceano (-59,55%), que contempla os corpos hídricos na área da pesquisa. O estudo apresentou similaridade com publicações relacionadas, mostrando que as geotecnologias são eficientes ferramentas de monitoramento ambiental, com abordagem precisa da cobertura vegetal e contribuindo para implementação de medidas apropriadas. Além disso, são fundamentais na prevenção e mitigação de problemas decorrentes dos impactos ambientais adversos da interação entre atividades humanas e meio ambiente.

Palavras-chave: Sensoriamento remoto; Código florestal; Monitoramento ambiental.

Received: 04/09/2024; Accepted: 17/01/2025; Published: 04/03/2025.

1. Introduction

Watersheds can be used as a study area because, in addition to being hydrological units, they are also biophysical and socio-political units, with key contributions to the definition of food, social, habitat and economic services, i.e. life-supporting attributes (Taye e Moges, 2020).

Springs are essential for the formation and maintenance of watercourses in basins (Martins *et al*., 2020). The riparian forest near the springs acts as a means of preserving the diversity of the environment and as a “sponge” for absorbing rainwater and recharging the water table (Freire *et al*., 2022).

In this way, these established forest systems are fundamental for reducing siltation and environmental degradation, as well as being a natural means of processing and transforming environmental diversity. Monitoring the strips along the banks of water bodies is essential, as it is a safety support for the balance of the ecosystem and its intrinsic relationships, and is associated with the management and conservation of natural resources (Castro; Castro; Souza, 2013)

The Brazilian Forestry Code establishes the delimitation of Permanent Preservation Areas (APP), among other criteria, as to the areas surrounding springs and perennial waterholes, regardless of their topographical situation, within a minimum radius of 50 (fifty) meters. Corroborating this, the aforementioned legislation defines a spring as “a natural outcropping of the water table that is perennial and gives rise to a watercourse” and a waterhole as “a natural outcropping of the water table, even if intermittent” (Brasil, 2012).

The work made by Alvarenga *et al.* (2012) highlighted the importance of conducting studies that characterize the areas where springs contribute, as these are areas of extreme influence and environmental importance, as they are the cradles of watercourses and, primarily, of all available water supply.

In 2014, the Suape Springs Program of the Governador Eraldo Gueiros - Suape Port Industrial Complex (CIPS) was published, with the aim of learning about the location and environmental conditions of the springs located in the Ecological Preservation Zone (ZPEc). The Suape Springs project (2018) identified around 70 springs distributed throughout the area of influence of the Algodoais Creek watershed, in the aforementioned municipality and in the neighboring municipality of Cabo de Santo Agostinho.

Technological advances related to the analysis of cartographic documents and images obtained by remote sensing have been a fundamental tool for studying land use and land cover (Francisco *et al*., 2020). In the case of river basins, use and cover can be modified by anthropogenic activities, resulting in alterations to the physiographic attributes of the natural environment (Vale; Costa; Pimentel, 2021).

The automatic classification of the images obtained makes it possible to create different types of indices according to different needs. One example is Normalized Difference Vegetation Index (NDVI), which is used to study anthropized areas to check the biomass of vegetation cover (Moreira, 2012).

The use of geoprocessing, remote sensing and geographic information system techniques associated with the Annual Mapping of Land Use and Land Cover in Brazil Project - MapBiomas, performs cloud processing and automated classification for development and operation on the Google Earth Engine platform, generating a historical series of annual maps of land use and land cover in Brazil (Mapbiomas, 2021).

According to the scientific reference publication, Souza *et al.* (2020), the MapBiomas classification scheme is a hierarchical system with a combination of land use and occupation classes compatible with the classification systems of the Food and Agriculture Organization (FAO) and the Brazilian Institute of Geography and Statistics (IBGE).

The aim of this study is to evaluate, using geoprocessing and digital image processing techniques, the spatio-temporal evolution of land use and occupation in the territory adjacent to the APPs of springs located in this area of influence of the Port of Suape, Pernambuco. In the discussions, based on numerical data and interactive maps, it is proposed to verify possible causes for changes in the environmental quality of these sensitive water bodies in the region.

2. Methodology

2.1 Description of the study area

The SUAPE Industrial Port Complex (CIPS) is located in the Pernambuco municipality of Ipojuca, about 40 km from the capital Recife. In this area, intense economic activities are carried out, port activities for the export and import of products at national and international level, in addition, there are communities living in the place, as it is a strategic region.

In terms of its physical characterization, CIPS is located in the Pernambuco Coastal Physiographic Zone, with a warm humid climate, according to the Köppen climate classification system. The complex is located in the southern sector of the

Pernambuco Basin, which is part of the classification of the Brazilian Marginal Basins, which are sedimentary basins along the continental margin, with a base of igneous rocks of Precambrian age and Cretaceous volcano-sedimentary sequence (Cabo Formation and volcanics of the Ipojuca Suite) and Quaternary sediments (CIPS, 2011).

In addition to these physical aspects, this area is located in a humid zone, with good soil development, which favors the occurrence of groundwater due to the direct infiltration of rain. The water is recharged in the outcrops of the aquifers and discharged into the rivers and the sea (CIPS, 2011).

The Port of Suape is a set of infrastructures and industries for development, production and commercial transportation, a benchmark in the state of Pernambuco for its economic potential. The port is located in the Ipojuca river basin. In this basin, among the other constituent micro-basins, is the Algodoais creek, which falls within Suape's area of influence and is responsible for supplying water for consumption, agriculture and industry. This watershed stands out for its abundance of springs.

According to the CIPS Master Plan, the territorial area of CIPS is divided into two Macrozones: Economic Development Macrozone - MADE and Environmental and Sociocultural Protection Macrozone - MAAS, the latter containing the Ecological Preservation Zone - ZPEC, which "comprises the areas with diverse environmental characteristics that surround the productive zones of CIPS, destined for protection for ecological preservation purposes, as well as for the promotion of future environmental compensation within the scope of CIPS" (Pernambuco, 2022).

Four points of interest were selected for sampling (figure 1), representing watercourses contributed to by these springs, which are included in the Algodoais creek micro-basin, within Suape's area of influence.

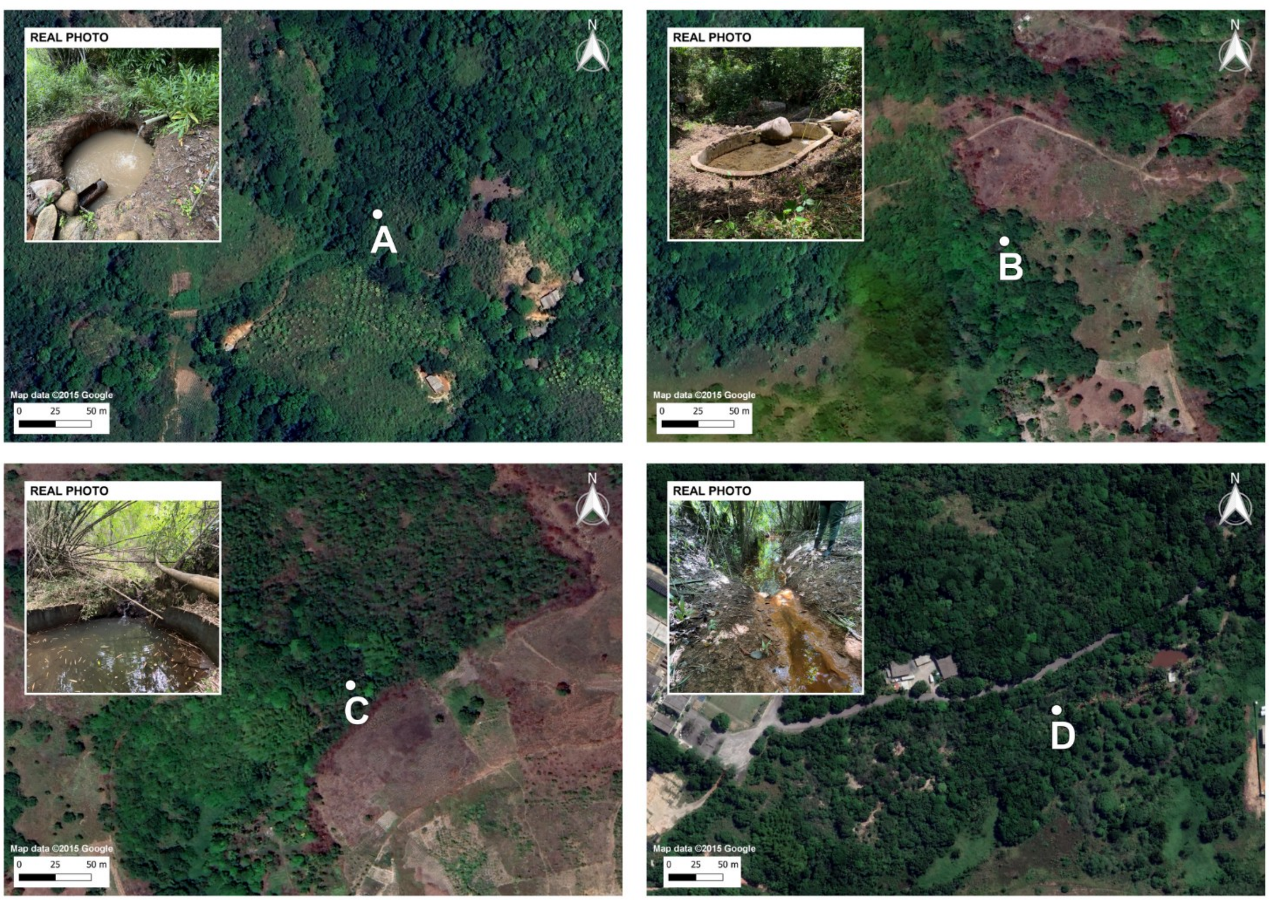

Figure 1 – Location and real photos of the study sites.
Source: Authors (2024) and Google Satélite (2015), made by software QGIS 3.10.14.

2.2 Data collection and processing

The four points chosen (Table 1) were georeferenced on site using a Garmin Etrex Vista HCx GPS, attached to Google Earth Pro and extracted into files compatible with the free QGIS software (.kml). From this vector data, the coordinates were reprojected to the Coordinate Reference System (CRS) EPSG:31985 - SIRGAS 2000 / UTM zone 25 S. With the points adjusted using the Buffer tool, the APPs were demarcated within 50 meters of each water body, as determined by the Forest Code (Brasil, 2012).

Table 1 – Sampling location.

Point of Study	**Longitude**	**Latitude**
A	35º 2' 22.569" O	8º 19' 47.038" S
B	35º 1' 21.036" O	8º 19' 52.300" S
C	35º 1' 11.882" O	8º 19' 51.272" S
D	35º 0' 43.727" O	8º 22' 7.612" S

Source: Authors (2024).

To analyze land use and occupation, MapBiomas Collection 8 was used, which includes maps and annual data for Brazil from 1985 to 2022. The files for the years 2022, 2018, 2014, 2010, 2006 and 2002 were extracted in order to check soil variation over time at a four-yearly frequency. The files were downloaded in the original SRC EPSG:4326 - WGS 84 and then reprojected into the SRC EPSG:31985 - SIRGAS 2000 / UTM zone 25 S.

A polygon was created containing the 4 points of interest, which fall within the area of influence of the Organized Port of Suape, according to the polygon that comprises the port facilities and the port protection and access infrastructure (Brasil, 2022), illustrated in figure 2.

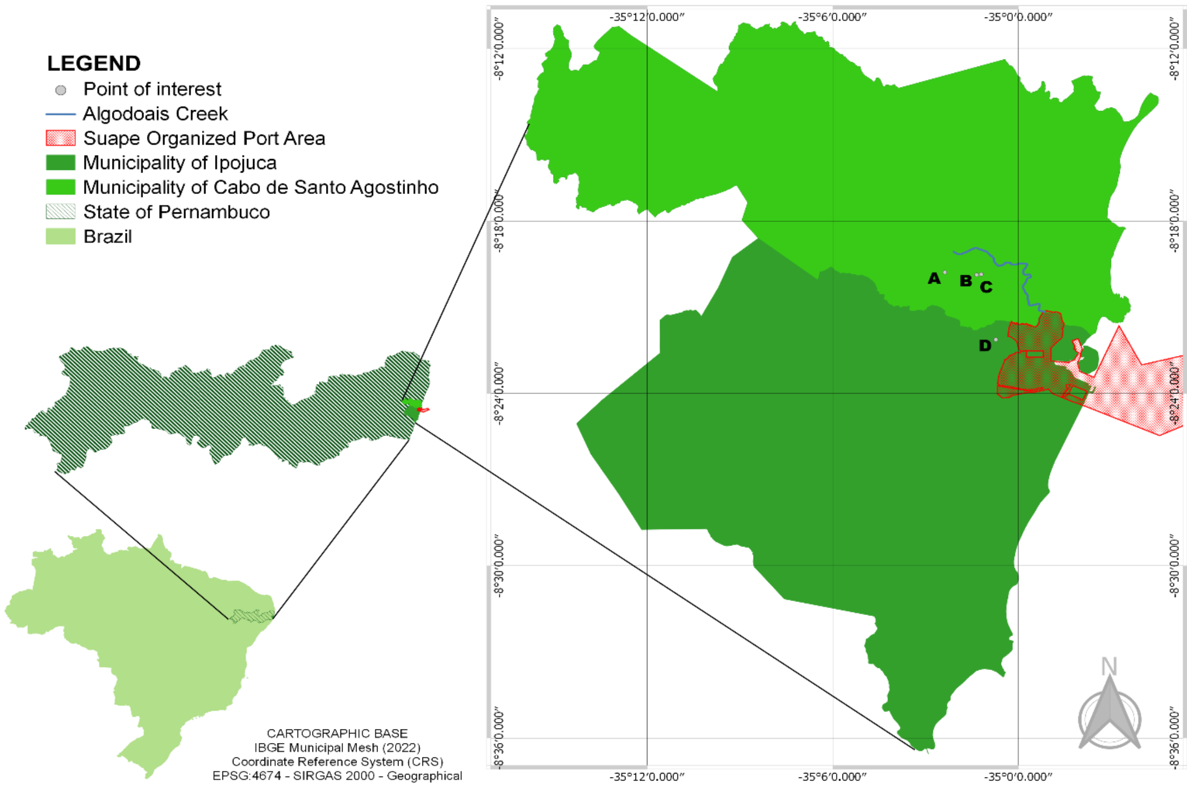

Figure 2 – Location map of the area of interest.
Source: Authors (2024), made by software QGIS 3.10.14.

All the reprojected images were cropped according to the mask layer of the polygon created. The images were processed according to the land cover and land use classification system for MapBiomas in Brazil, obtaining the classes listed in table 2.

Table 2 – Land use and occupation classes from the Mapbiomas Project.

MAPBIOMAS CLASSES - COLLECTION 8		
Rocky Outcrop	Cotton	Hypersaline Tidal Flat
Aquaculture	Urban Area	Rice
Coffee	Wetland	Sugar cane
Citrus	Palm Oil	Floodable Forest
Grassland	Forest Formation	Savanna Formation
Mangrove	Mining	Mosaic of Uses
Other non Vegetated Areas	Other non Forest Formations	Other Perennial Crops
Other Temporary Crops	Pasture	Beach, Dune and Sand Spot
Wooded Sandbank Vegetation	Herbaceous Sandbank Vegetation	River, Lake and Ocean
Forest Plantation	Soybean	-

Source: Souza et al. (2020).

The shapefile layer of the watercourses was obtained from the Metadata platform of the National Water Resources Information System (SNIRH), using hydrographic contribution areas from the Ottocoded Hydrographic Base (BHO) used by the National Water and Basic Sanitation Agency (ANA) in water resources management from the Brazilian Systematic Mapping.

The contour lines layer was developed with the aid of the QGIS add-on called Open Topography, which can provide the Digital Elevation Model (DEM) for determining the topographic differentiation profiles. The Copernicus Global DSM 30m DEM was used to download the spatial image of the previously defined polygon. In QGIS itself, the image was converted to shapefile format with an equidistance of 10 meters between curves, in order to analyze the variations in relief in the study area.

The Mapbiomas images were obtained in matrix format and the pixels were converted to shapefile in order to read the attributes. In QGIS, the tools “pixel to polygon”, “geoprocessing to vector” and finally the creation of the attributes table were used, creating a column to calculate the area in square kilometers (km²) of each soil class included in the area of interest. This information was calculated for all the study years and then processed using Microsoft Excel software.

Once all the graphs and maps had been drawn up, the results obtained were discussed in the light of relevant and current scientific publications, as well as legislation and technical documents, which were collected by searching digital platforms (Scholar Google) and scientific journals (Periódicos Capes - remote access via institutional CaFe).

3. Results and discussion

The survey of environmental aspects combined with remote sensing data and geoprocessing techniques enabled a series of discussions to be held about the area of interest in this study. The first aspect discussed is the drainage pattern and runoff regime. Surface runoff refers to the movement of water over the soil surface when the intensity of precipitation exceeds the infiltration capacity of the soil (Pinto *et al*., 2011).

Silva *et al*. (2019) assess that recharge areas can play a satisfactory hydrological role when they take into account the presence of infiltration areas. Using geographic tools and analyzing contour lines, the aim is to find these areas of infiltration or contribution of the points of interest to the watershed in which they are located. A more advanced study, using hydrological modeling, can assess the effect on the generation of surface runoff (Silva, 2023). To analyze this environmental variable, the maps in Figures 3, 4 and 5 were created, outlining the possible surface runoff of rainwater according to the differences in level of the relief around the points of interest.

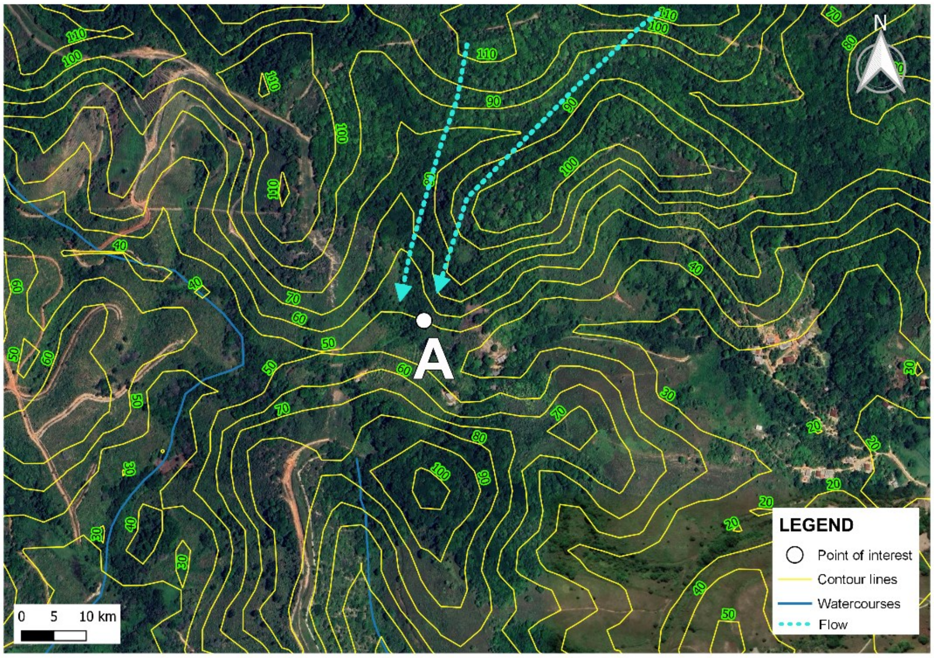

Figure 3 – Contour lines of the point of interest A.
Source: Authors, made by QGIS v. 3.10.14 and data from DEM Copernicus Global DSM 30m.

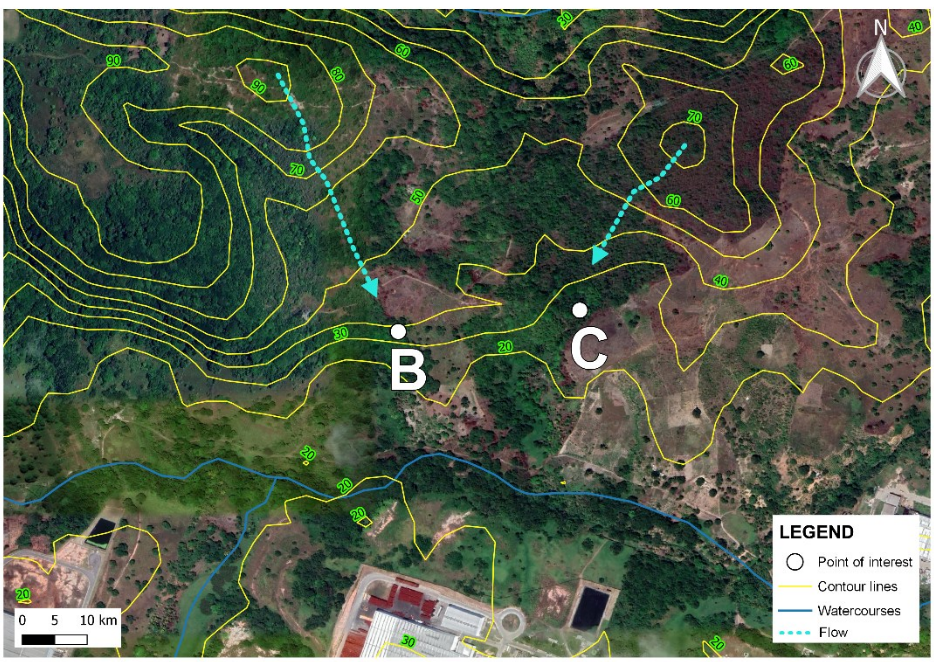

Figure 4 – Contour lines of points of interest B and C.
Source: Authors, made by QGIS v. 3.10.14 and data from DEM Copernicus Global DSM 30m.

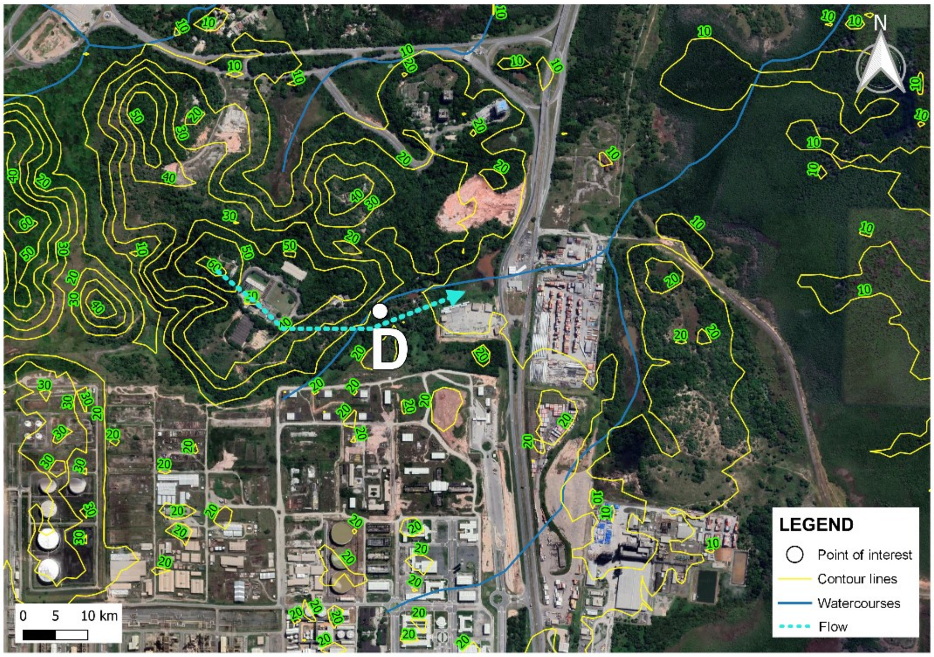

Figure 5 – Contour lines of the point of interest D.
Source: Authors, made by QGIS v. 3.10.14 and data from DEM Copernicus Global DSM 30m.

The flow of water in the soil can favor the transport of materials and, due to the differences in level and soil characteristics, can carry and spread pollutants. In this way, the soil can be contaminated at a certain point and this pollution can spread throughout the underground aquifer, reaching water bodies, resulting in effects - harmful to human health (Silva, Borges e Vasconcelos, 2020).

Given the location of the springs under study, the dynamics of the adjacent slopes should be considered in order to understand whether direct surface runoff is greater than the processes of infiltration and groundwater recharge, which could reduce the flow over time (Oliveira *et al*., 2014; Menezes, 2007). As can be seen in Figures 3, 4 and 5, the points of interest do not refer specifically to the place where the water outcrops, but it is an area that receives contributions from the watercourse of these springs and is susceptible to water exploitation due to the development, natural or otherwise, of an area of water accumulation.

In this context, it is important to differentiate between the hydrogenetic zones that make up the areas of the springs, be they: catchment, transmission and outcrop zones (Cortines, 2008). These zones are created by dividing a stable micro-basin according to the primary functions of the water cycle, with homogeneous and well-structured soils, infiltration and water storage will be according to the particularities such as capture/recharge, transmission/erosion and outcropping/moisture reinforcement (Valcarcel, 2003).

This is how begin to evaluate the elements that can cause these instabilities, which make it difficult to balance the natural processes of these bodies of water. In watersheds with preserved vegetation, there is a supply of water with good distribution throughout the year and of better quality, due to the fact that the hydrological cycle occurs naturally and without anthropogenic interference (Tucci, 2001). Differences in land use and land cover have a direct influence on a region's hydrological response to rainfall events (Silva, 2023). Thus, studying these advances helps to prospect for changes in the recharge of water bodies, whether underground or surface.

For the analysis of land use and occupation, the temporal observation of the distribution of classes allowed the identification of different activities present in the study area. Figures 6, 7, 8, 9, 10 and 11 illustrate the four-year variations in land characterization, highlighting the classes mapped by Collection 8 of the Mapbiomas project.

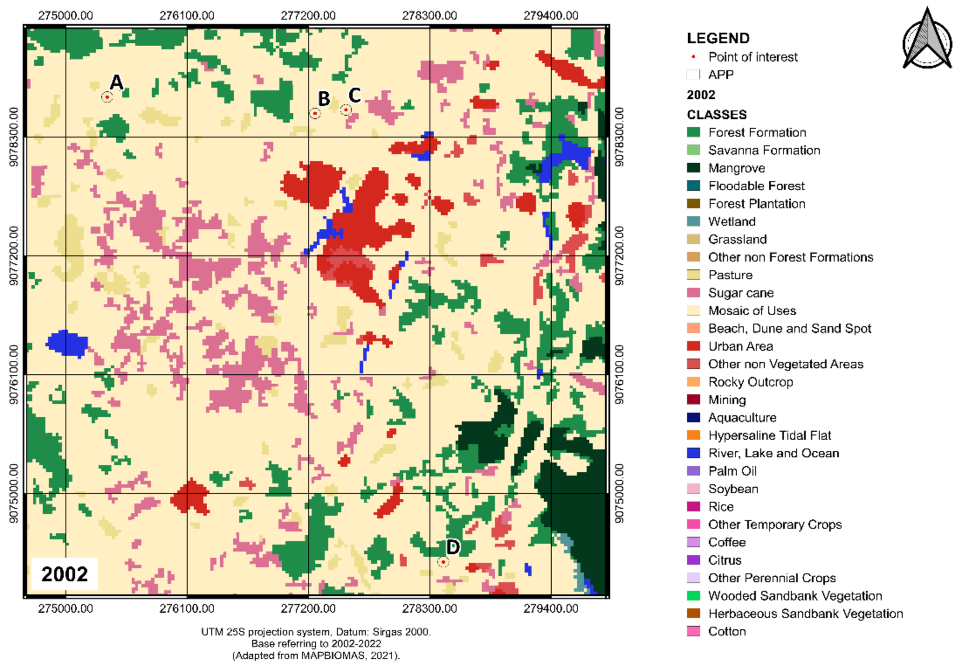

Figure 6 – Image classification of the area in 2002.
Source: Authors, made by QGIS v. 3.10.14 and data from Mapbiomas Collection 8.

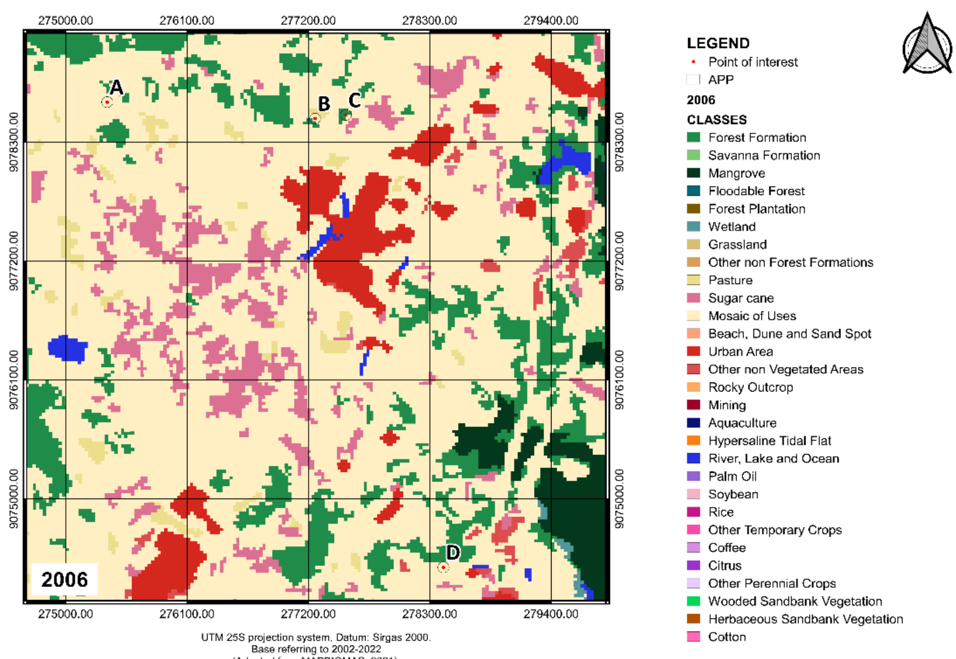

Figure 7 – Image classification of the area in 2006.
Source: Authors, made by QGIS v. 3.10.14 and data from Mapbiomas Collection 8.

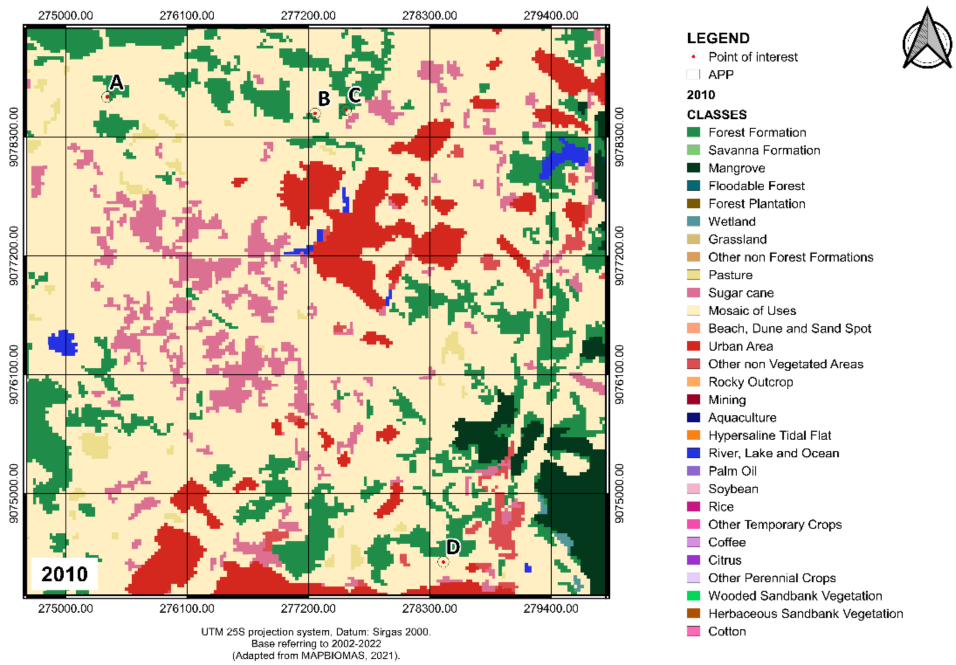

Figure 8 – Image classification of the area in 2010.
Source: Authors, made by QGIS v. 3.10.14 and data from Mapbiomas Collection 8.

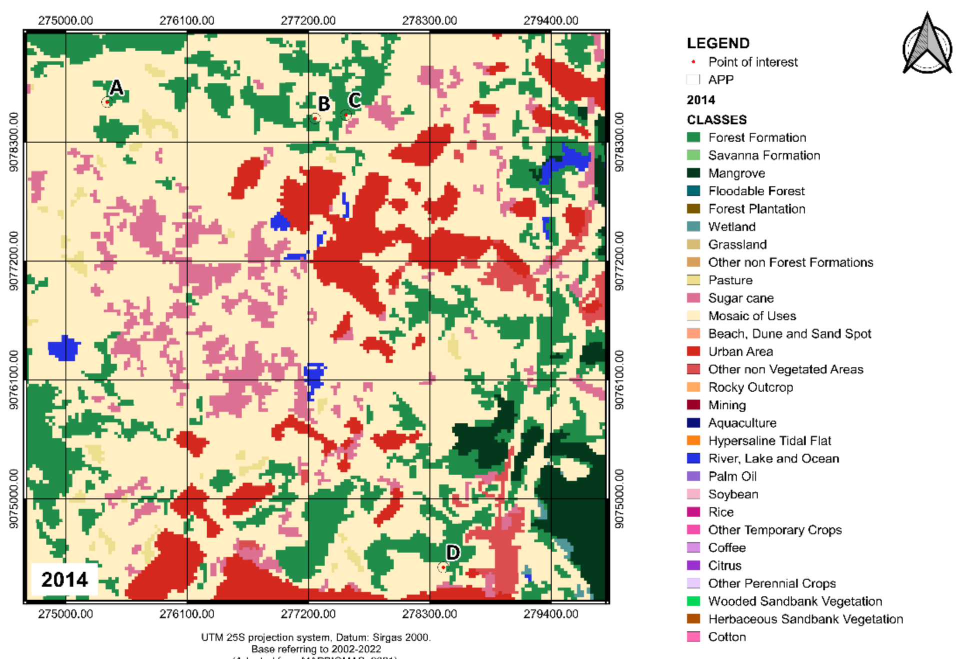

Figure 9 – Image classification of the area in 2014.
Source: Authors, made by QGIS v. 3.10.14 and data from Mapbiomas Collection 8.

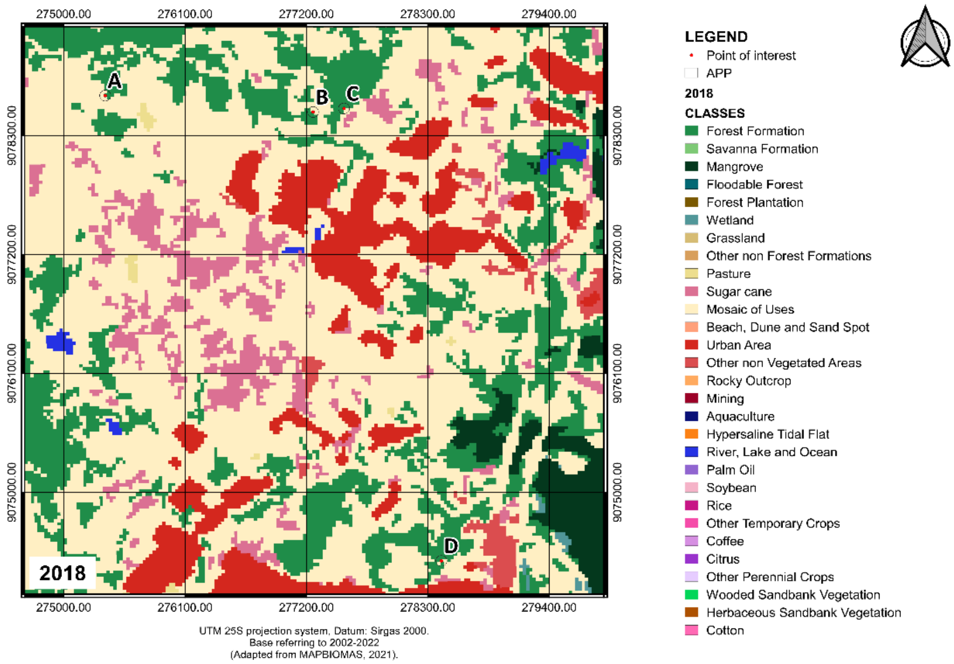

Figure 10 – Image classification of the area in 2018.
Source: Authors, made by QGIS v. 3.10.14 and data from Mapbiomas Collection 8.

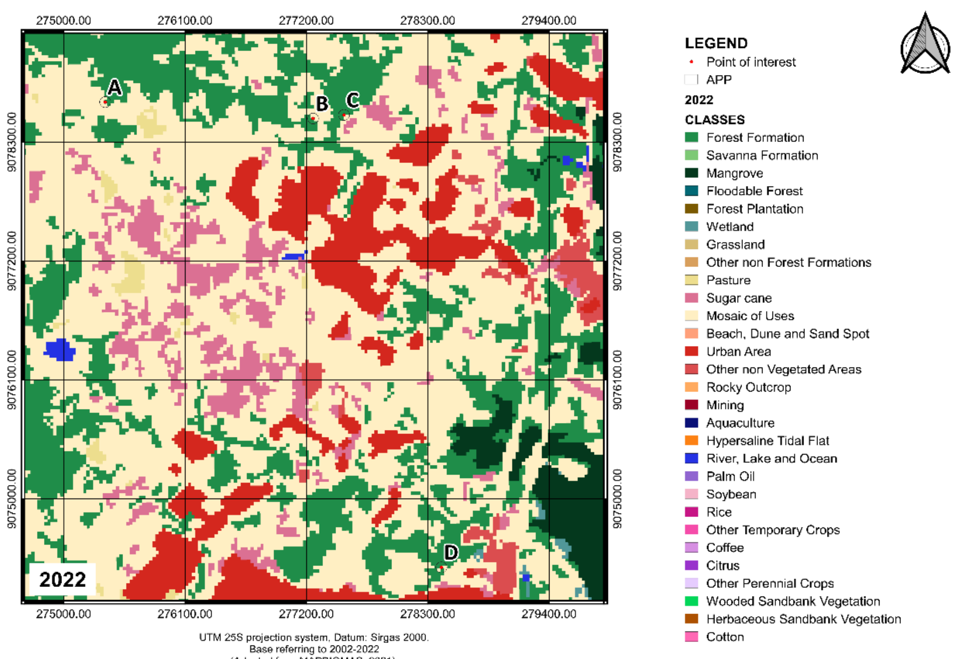

Figure 11 – Image classification of the area in 2022.
Source: Authors, made by QGIS v. 3.10.14 and data from Mapbiomas Collection 8.

The four points of interest were located in areas that, at first, were not preserved. Over the course of the study period, the progress made in preserving the APPs under study is remarkable. This can be seen in the enactment of the New

Brazilian Forest Code, Federal Law No. 12.651/2012, which was the first legal instrument to define the extent of the region around springs and waterholes to be preserved.

Despite this, points of anthropogenic pressure can extend beyond the defined radius, thus highlighting the need to monitor not just a pre-determined area, but an entire territory of direct and indirect influence. CONAMA Resolution No. 303/2002 establishes that the APP is, in addition to the minimum radius of fifty meters, the area located in such a way as to protect, in each case, the contributing watershed. In this way, even though the regions adjacent to springs and waterholes are analyzed, it is important to observe the entire area of contribution that directly influences the flow of the basin.

As can be seen visually, the study area is partially urbanized in all the years analyzed, a fact that has intensified especially in recent years. In order to quantitatively understand the behavior of the temporal evolution of the classification of occupations, the data of the main 9 classes were collected, identifying the values in area (km²) per class and the difference between the first and last year of analysis, contained in table 3.

Table 3 – Spatio-temporal evolution of land use and classification in the study area.

CLASS	**AREA (km²)**						**DIFFERENCE 2022 - 2002 (%)**
	2002	**2006**	**2010**	**2014**	**2018**	**2022**	
Mosaic of Uses	25,2900	24,3945	21,3498	19,8603	19,1394	17,7642	- 29,76%
Forest Formation	3,8268	4,3605	5,2542	5,9895	7,2171	8,2314	+ 53,51%
Sugar cane	2,8494	2,8719	2,5560	2,5227	2,4003	2,4039	- 15,63%
Urban Area	1,2366	1,9305	4,5081	5,1210	5,3649	5,4162	+ 77,17%
Mangrove	1,5021	1,5255	1,5111	1,5498	1,5219	1,5444	+ 2,74%
Pasture	0,9540	0,6588	0,6165	0,4869	0,0837	0,2736	- 71,32%
River, Lake and Ocean	0,4383	0,3870	0,2826	0,3240	0,2322	0,1773	- 59,55%
Other non Vegetated Areas	0,3456	0,3186	0,3915	0,5886	0,4689	0,6030	+ 42,69%
Wetland	0,0792	0,0747	0,0522	0,0792	0,0936	0,1080	+ 26,67%

Source: Authors, made by Excel v. 2016 and data from Mapbiomas Collection 8.

According to the quantitative data, the predominant class in the area of interest in all the years is called “Mosaic of uses” and, according to the Mapbiomas Project legend (Souza *et al*., 2020), it is defined as “areas of agricultural use where it was not possible to distinguish between pasture and agriculture”. Among these, pasture is an activity that generates clear impacts through trampling and soil compaction by the flow of animals, causing incomplete plant development, exposure and soil erosion (Santo *et al*., 2020).

Although they make up the class discussed above, pasture have a class of their own and this was the second largest decrease in the study area. Even with the reduction, this activity cannot be reversed in any way, but must go through the process of recovering the degraded area, with the aim of changing the degraded site to a form of land use with environmental stability (Brasil, 1989).

In the diagnosis of the APPs studied, there is evidence of environmental degradation in terms of the removal of native vegetation, proximity to inhabited areas and roads, proximity to pasture areas and agriculture. Agricultural activities, mainly monoculture (which also includes other classes, such as sugar cane), use chemical fertilizers in the soil, causing water contamination and making human consumption impossible (Santos and Cavalcanti, 2022).

The class that encompasses urbanized areas, “with a significant density of buildings and roads, including areas free of buildings and infrastructure”, was the one that grew the most in percentage terms during the period studied. It is inferred that this is, among other reasons, due to the growing expansion of economic and industrial activities in this region, with the Suape Port Complex being an important driver of Pernambuco's economy (Ribeiro *et al*., 2013).

Currently, roads and highways have been built in this area, particularly near point D, according to satellite images (figures 1 and 5). Rezende and Coelho (2015) highlight negative environmental impacts arising from their construction and operation, such as intensification of erosion processes, alteration of watercourses, deposition of waste materials, suppression of native vegetation, alteration of habitats, among others.

With regard to surface water resources, the “River, Lake and Ocean” class includes water bodies such as rivers, lakes, dams, reservoirs and others. It is important to mention a significant reduction in its area with each year studied, resulting in 59.55% less area in the 20 years of analysis. Corroborating this, Amorim *et al.* (2023) studying coastal erosion in the municipality of Ipojuca - PE, also found a significant decrease in the area occupied by water bodies between the years 1985 and 2019, the time interval covered by the research. However, more than observing quantitative changes, it is important to pay attention to monitoring the quality of surface water, since it is exposed to various natural and anthropogenic aspects that can compromise its availability and multiple uses.

On the other hand, the “Forest Formation” class showed an increase of more than 50% in area, demonstrating the efficiency of preservation actions in the study area. Federal Law No. 14.653/2023 regulates the intervention and implementation of facilities necessary for the recovery and protection of springs. In the state of Pernambuco, where the study site is located, Ordinary Law No. 17,947 was enacted in 2022, with the aim of encouraging the implementation of Programs for the Preservation of Springs and Conservation of Riparian Forests on the banks of streams and rivers by the municipalities of Pernambuco.

Alves (2016) pointed out that the CIPS activities were responsible for causing various negative socio-environmental impacts in the territory, including those related to the suppression of vegetation that alters fauna and flora, the degradation of ecosystems, fishing resources and alteration of the quality of the environment, with loss of biodiversity.

According to the study conducted by Jones *et al.* (2018), approximately one third (32.8% or around 6 million km²) of terrestrial protected areas around the world face intense anthropogenic pressure, suffering degradation due to the presence of roads, pastures or urbanization. The researchers stress the urgency of making efforts to allow an objective assessment of human pressure and housing conditions in these areas. In addition, they emphasize the importance of implementing better management practices in the regions surrounding these protected areas.

Vasconcelos, Lima and Paranhos Filho (2022) stated that the use of Mapbiomas expands the possibilities for environmental studies in Brazil. This consideration can be attested to through the various discussions raised through this study, which reinforces the demand for this monitoring in various areas, however, in particular in the territory of influence of the Port of Suape, given the socio-environmental conflicts related to environmental degradation already intensified in this region (Alves *et al*., 2021).

4. Final considerations

The use of digital image processing, geoprocessing and remote sensing is proving to be an efficient tool for monitoring APPs, especially around springs, which are water bodies that are sensitive to significant environmental changes and play an important role in ecological balance.

The analysis of the temporal evolution of land use and occupation in the area of this study indicates that anthropic activities tend not to consider the hydrogenetic zones that make up the areas of the springs, nor the waterholes and outcropping points themselves, where unbridled exploitation of the resource generally occurs without even knowing the environmental aspects that may be compromising water quality.

The diagnosis of these areas and zones, through the application of geotechnological tools, allows a precise approach to vegetation cover and thus contributes to the implementation of appropriate measures to prevent and mitigate current and future problems caused by adverse environmental impacts related to the interaction between human activities and the environment.

Acknowledgements

This work was carried out with the support of the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - Funding Code 001.

References

ALVARENGA, L. A.; MARTINS, M. P. P.; CUARTAS, L. A.; PENTEADO, V. A.; ANDRADE, A. Estudo da qualidade e quantidade da água em microbacia, afluente do rio Paraíba do Sul – São Paulo, após ações de preservação ambiental.

Rev. Ambiente e Água - An Interdisciplinary Journal Of Applied Science, v. 7, n. 3, p. 228-240, 31 dez. 2012. Instituto de Pesquisas Ambientais em Bacias Hidrograficas (IPABHi). http://dx.doi.org/10.4136/ambiagua.987.

ALVES, M. J. C. F.; ALVES, S. G.; CAVALCANTI, A. M. C.; SANTOS, C. P. S.; OBANDO, G. N.; GURGEL, I. G. D.; SANTOS, M. O. S. Mapeamento de conflitos socioambientais no território de Suape, Pernambuco/Brasil. *Revista Mutirõ. Folhetim de Geografias Agrárias do Sul*, [S.L.], v. 2, n. 2, p. 176, 30 dez. 2021. Universidade Federal de Pernambuco. http://dx.doi.org/10.51359/2675-3472.2021.252448.

ALVES, S. G. *Injustiças Socioambientais e Interferências na Saúde de Populações Localizadas na Área do Complexo Industrial Portuário de Suape*. 2016. 138 p. Dissertação (Mestrado em Desenvolvimento e Meio Ambiente). Universidade Federal de Pernambuco, Recife, PE, 2016. Disponível em: https://repositorio.ufpe.br/handle/123456789/17683. Acesso em: 27 ago. 2024.

AMORIM, E. S.; SAMPAIO, G. M.; LAFAYETTE, K. P. V.; SILVA, S. R. Aplicação do sistema Betonbloc, como alternativa de contenção da erosão costeira no município de Ipojuca/PE. *Revista de Geociências do Nordeste*, [S.L.], v. 9, n. 1, p. 44-58, 19 maio 2023. Universidade Federal do Rio Grande do Norte - UFRN. http://dx.doi.org/10.21680/2447-3359.2023v9n1id31283.

ANA. Agência Nacional de Águas e Saneamento Básico. *Manual de Usos Consuntivos da Água no Brasil*. Brasília, DF: ANA, 2019. Disponível em: http://snirh.gov.br/usos-da-agua/. Acesso em: 25 jul. 2024.

BRASIL. *Decreto Federal Nº 97.632, de 10 de abril de 1989*. Dispõe sobre a regulamentação do Artigo 2°, inciso VIII, da Lei n° 6.938, de 31 de agosto de 1981, e dá outras providências. Diário Oficial da União, Brasília, DF, 12 abril 1989.

BRASIL. *Lei Nº 12.651, de 25 de maio de 2012*. Institui o novo código florestal brasileiro. Diário Oficial da União, Brasília, DF, Ano CXLIX, n. 102, 28 maio 2012. Seção 1, p.1.

BRASIL. *Lei Nº 14.653, de 23 de agosto de 2023*. Altera as Leis nºs 12.651, de 25 de maio de 2012, e 14.119, de 13 de janeiro de 2021, para disciplinar a intervenção e a implantação de instalações necessárias à recuperação e à proteção de nascentes. Diário Oficial da União, Brasília, DF, Ano CLXIII , n. 162, 24 ago 2023. Seção 1, p.7.

BRASIL. *Portaria Nº 21, de 28 de abril de 2022*. Define a área do Porto Organizado de Suape – Complexo Industrial Portuário Governador Eraldo Gueiros, no Estado de Pernambuco. Diário Oficial da União, Brasília, DF, n. 80, 29 abril 2022. Seção 1, p. 524.

CASTRO, M. N.; CASTRO, R. M.; SOUZA, P. C. A importância da mata ciliar no contexto da conservação do solo. *Revista Eletrônica de Educação da Faculdade Araguaia*, [S.L.], v. 4, n. 4, p. 230-541, 01 ago. 2013. Disponível em: https://sipe.uniaraguaia.edu.br/index.php/REVISTAUNIARAGUAIA/article/view/172/156. Acesso em: 27 de junho de 2024.

CIPS. Complexo Industrial Portuário de Suape. *Estudo Ambiental Complementar (EAC) ao Estudo de Impacto Ambiental e Relatório de Impacto Ambiental (EIA- RIMA) do Projeto de Ampliação e Modernização do Porto de Suape*. FADE. Recife, PE: CIPS, 2011.

CIPS. Complexo Industrial Portuário de Suape. *Programa Nascentes de Suape*: conhecimento, conservação e educação ambiental. Ipojuca, 2014. 50 p.

CIPS. Complexo Industrial Portuário de Suape. *Relatório do diagnóstico ambiental das nascentes da microbacia do riacho algodoais inseridas na Zona de Preservação Ecológica (ZPEc) de Suape identificadas em 2016, 2017 e 2018*, Parte III. Ipojuca, 2018. 50 p.

CONAMA. Conselho Nacional do Meio Ambiente. *Resolução Nº 303 de 20 de março de 2002*. Dispõe sobre a proteção das áreas de preservação permanente. Brasília, DF: CONAMA, 2002.

CORTINES, E. *Funcionamento hidrológico de nascentes em microbacias instáveis, Barra de Guaratiba* - RJ. 2008. 87 p. Dissertação (Mestrado em Ciências Ambientais e Florestais). Instituto de Florestas, Universidade Federal Rural do

Rio de Janeiro, Seropédica, RJ, 2008. Disponível em: https://rima.ufrrj.br/jspui/handle/20.500.14407/11171. Acesso em: 23 ago. 2024.

FRANCISCO, C. N.; RUIZ, P. R. S.; ALMEIDA, C. M.; GRUBER, N. C.; ANJOS, C. S. Análise do impacto da correção atmosférica no cálculo do Índice de Vegetação Por Diferença Normalizada a partir de Imagem Landsat 8/OLI. *Revista Brasileira de Geografia Física*, [S.L.], v. 13, n. 1, p. 076-086, 29 fev. 2020. http://dx.doi.org/10.26848/rbgf.v13.1.p076-086.

FREIRE, G. S.; FERREIRA, R. A.; OLIVEIRA, E. V. S.; OLIVEIRA, M. I. U. Caracterização Florística de Áreas de Nascentes na Sub-Bacia Hidrográfica do Rio Piauitinga, Sergipe, Brasil. *Revista Brasileira de Geografia Física*, [S.L.], v. 15, n. 1, p. 123-139, 23 mar. 2022. http://dx.doi.org/10.26848/rbgf.v15.1.p125-141.

JONES, K. R., VENTER, O., FULLER, R. A., ALLAN, J. R., MAXWELL, S. L., NEGRET, P. J., & WATSON, J. E. (2018). One-third of global protected land is under intense human pressure. *Science*, v. 360, n. 6390, p. 788-791, 2018.

MAPBIOMAS. *Projeto MapBiomas*. Coleção 2022 da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil 2021. Disponível em: https://mapbiomas.org/visao-geral-da-metodologia. Acesso em: 27 de junho de 2024.

MARTINS, A. M.; FILGUEIRA, H. J. A.; AZEVEDO FILHO, A. C.; SILVA, T. C.; SILVA JÚNIOR, M. H. Análise de não homogeneidades de séries de vazão de captações de nascentes na bacia hidrográfica do rio Gramame, PB, Brasil. *Revista Brasileira de Geografia Física*, [S.L.], v. 13, n. 6, p. 2896-2907, 14 dez. 2020. http://dx.doi.org/10.26848/rbgf.v13.6.p2896-2907.

MENEZES, M. D. *Levantamento de solos em bacias hidrográficas como apoio para avaliação do uso da terra e da potencialidade de recarga dos aquíferos*. 2007. 107 p. Dissertação (Mestrado em Ciência do Solo) – Universidade Federal de Lavras, Lavras, 2007.

MOREIRA, M. A. *Fundamentos do sensoriamento remoto e metodologias de aplicação*. 4 ed. Viçosa/MG: UFV, 2012. 422 p.

OLIVEIRA, A. S.; SILVA, A. M.; MELLO, C. R.; ALVES, G. J. Stream flow regime of springs in the Mantiqueira Mountain Range region, Minas Gerais State. *Cerne*, [S.L.], v. 20, n. 3, p. 343-349, set. 2014. FapUNIFESP (SciELO). http://dx.doi.org/10.1590/01047760201420031268.

PERNAMBUCO. *Decreto Nº 54.185, de 20 de dezembro de 2022*. Institui o Plano Diretor – SUAPE 2035 e dispõe sobre o ordenamento do uso e ocupação do solo do Complexo Industrial Portuário de Suape – CIPS. Diário Oficial do Estado, Recife, PE: 21 dez. 2022.

PERNAMBUCO. *Lei Ordinária Nº 17.947, de 9 de novembro de 2022*. Dispõe sobre a Política Florestal do Estado de Pernambuco e dá outras providências, a fim de incentivar a implantação de Programas de Preservação de Nascentes e Conservação de Matas Ciliares nas margens de riachos e rios pelos municípios pernambucanos. Diário Oficial do Estado, Recife, PE: 10 nov. 2022.

PINTO, N. L. S.; HOLTZ, A. C. T.; MARTINS, J. A.; GOMIDE, F. L. S. *Hidrologia Básica*. 13ª reimpressão da 1ª. ed. São Paulo: Edgard Blucher Ltda., 2011.

REZENDE, E.N.; COELHO, H.A. Impactos Ambientais Decorrentes da Construção de Estradas e suas Consequências na Responsabilidade Civil. *Revista do Mestrado em Direito da Universidade Católica de Brasília*: Escola de Direito, [S.L.], v. 9, n. 2, p. 155-180, 30 dez. 2015. Universidade Catolica de Brasilia. http://dx.doi.org/10.18840/1980-8860/rvmd.v9n2p155-180.

SANTO, C. L.; SILVA, C. C. P.; ALMEIDA, J.; LIMA, M. J. A.; MOURÃO, F. V. Avaliação ambiental da área de preservação permanente das nascentes e corpo hídrico impactados pela atividade pecuária rotativa. *Brazilian Journal of Development*, v. 6, n. 5, p. 25385-25390, 2020.

SANTOS, G. R.; CAVALCANTI, L. C. S. O uso e cobertura da terra em áreas de nascentes e rios, município de Correntes, Pernambuco. *Geografia*, [S.L.], v. 47, n. 1, p. 1-19, 18 dez. 2022. UNESP - Universidade Estadual Paulista. http://dx.doi.org/10.5016/geografia.v47i1.16736.

SILVA, E. P.; SANTOS, R. L.; AMARAL, A. K. N.; RAMOS, H. F.; SANTOS, L. P. S.; SOUZA, P. C. Uso do solo e caracterização morfométrica como subsídios para análise das áreas de alagamento e da qualidade da água nas microbacias do Macambira e Cascavel, Goiânia-GO. *Ciência E Natura*, 41, e59, 2019. https://doi.org/10.5902/2179460X38425.

SILVA, N. B. D.; BORGES, I.; VASCONCELOS, V. V. Análise do impacto potencial de áreas com contaminação de solos sobre cursos d'água e poços no município de São Paulo. *Águas Subterrâneas*, [S.L.], v. 34, n. 3, p. 250-263, 8 set. 2020. Lepidus Tecnologia. http://dx.doi.org/10.14295/ras.v34i3.29753.

SILVA, P. V. S. *Avaliação do Avanço da Urbanização de Maceió-AL e os Efeitos na Hidrologia Urbana de Bairros que Margeiam a Laguna Mundaú*. 2023. 44 f. TCC (Graduação) - Curso de Engenharia Ambiental e Sanitária, Universidade Federal de Alagoas, Maceió, 2023. Disponível em: http://www.repositorio.ufal.br/jspui/handle/123456789/13142. Acesso em: 14 ago. 2024.

SIMÕES, R. F.; RIBEIRO, L. C. S.; LOPES, T. H. C. R.; MOREIRA, T. M. Suape: novo polo de crescimento? *Novos Cadernos NAEA*, v. 16, n. 1, p. 1-12, 18 set. 2013. http://dx.doi.org/10.5801/ncn.v16i1.1198.

SOUZA, C. M.; SHIMBO, J. Z.; ROSA, M. R.; PARENTE, L. L.; ALENCAR, A. A.; RUDORFF, B. F. T.; HASENACK, H.; MATSUMOTO, M.; FERREIRA, L. G.; SOUZA-FILHO, P. W. M. Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. *Remote Sensing*, [S.L.], v. 12, n. 17, p. 2735, 25 ago. 2020. MDPI AG. http://dx.doi.org/10.3390/rs12172735.

TAYE, T.; MOGES, A. Hydrological Responses of Watershed to Historical and Future Land Use Land Cover Change Dynamics of Nashe Watershed, Ethiopia. *Cogent food & Agriculture*, London, v. 7, n. 1, p. 1-23, Dec. 2020. https://doi.org/10.1080/23311932.2020.1863596.

TUCCI, C.E.M. *Hidrologia*: ciência e aplicação. 2.ed. Porto Alegre: Ed Universidade.

VALCARCEL, R. "Meio ambiente". In: *Plano diretor de desenvolvimento sustentável, Armação dos Búzios – RJ*, Perfil do município – texto para discussão. Armação dos Búzios: Prefeitura Municipal de Armação dos Búzios, Secretaria de Pl Urbanismo, 2003.

VALE, J. R. B.; COSTA, L. S.; PIMENTEL, M. L. S. Análise da morfometria e do uso e cobertura da terra da bacia hidrográficado rio Mocajuba, zona costeira Amazônica. *Geosul*, Florianópolis, v. 36, n. 78, p. 537-557, jan./abr. 2021. https://doi.org/10.5007/2177-5230.2021.e72705.

VASCONCELOS, B. R.; LIMA, M. T. V.; PARANHOS FILHO, A. C. Detecção de mudanças no uso e ocupação do solo no estado do Amazonas baseada nas classificações do Projeto Mapbiomas. *Geofronter*, v. 10, p.1-21, e7773, 23 jan. 2024. Universidade Estadual de Mato Grosso do Sul. http://dx.doi.org/10.61389/geofronter.v10.7773.