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Dinâmica do Uso do Solo, Balanço hídrico e NDVI no município de Floresta-Pernambuco, Brasil

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R E S U M O

Na região semiárida do Brasil, o conhecimento das condições hidroclimáticas e das atividades humanas é decisivo para que as ações de políticas públicas sejam mais assertivas. Portanto, o objetivo deste estudo foi avaliar as mudanças no uso da terra e ocupação e sua relação com a disponibilidade de água no município de Floresta, uma região semiárida no Nordeste do Brasil. Para conduzir a investigação sobre o uso da terra, foi utilizada uma base de dados no MapBiomas, considerando os anos de 1985 a 2021. Para avaliar o vigor vegetativo, foram utilizadas imagens dos satélites Landsat 5 e 8. Para verificar os mapeamentos, foram empregadas imagens de Veículos Aéreos Não Tripulados (UAV). Essas imagens foram processadas no aplicativo ADIVA – Análise do Índice de Vegetação e Água. Para avaliar o balanço hídrico, foi utilizado o SUPer - Sistema de Unidades de Resposta Hidrológica para Pernambuco. Os resultados mostraram que as variáveis do balanço hídrico que mais se relacionam com a cobertura vegetal e o uso da terra é a biomassa e o Índice de Área Foliar (IAF), principalmente no que se refere aos dias de estresse hídrico. Essas variáveis podem ser úteis para um melhor planejamento e gerenciamento dos recursos hídricos. Conclui-se que, para alcançar a segurança hídrica e o desenvolvimento sustentável com um uso racional da água em regiões semiáridas, é importante conhecer os dias de estresse hídrico e atender às necessidades espaciais e temporais desses dias.

Palavras-chave: SUPer, ADIVA, UAV, NDVI, Corpo d'água, Landsat.

The Dynamics of Land Use, Water Balance, and NDVI in the Municipality of Floresta, Pernambuco, Brazil

A B S T R A C T

In the semi-arid region of Brazil, knowledge of hydroclimatic conditions and human activities is crucial for more effective public policy actions. Therefore, the objective of this study was to assess changes in land use and occupation and their relationship with water availability in the municipality of Floresta, a semi-arid region in Northeast Brazil. To conduct the land use investigation, a MapBiomas database was used, considering the years from 1985 to 2021. Images from Landsat 5 and 8 satellites were used to assess vegetative vigor. Unmanned Aerial Vehicle (UAV) images were employed to verify the mappings. These images were processed using the ADIVA - Vegetation and Water Index Analysis application. The SUPer - Hydrological Response Unit System for Pernambuco was used to evaluate the water balance. The results showed that the hydrological balance variables most related to vegetation cover and land use are biomass and the Leaf Area Index (LAI), especially concerning days of water stress. These variables can be useful for better water resource planning and management. It is concluded that to achieve water security and sustainable development with rational water use in semi-arid regions, it is important to know the days of water stress and address the spatial and temporal requirements of these days.

Keywords: SUPer, ADIVA, UAV, NDVI, Water, Landsat.

[1] *Esta pesquisa é parte do capítulo de dissertação da primeira autora.*

Introduction

In the Brazilian semi-arid region, as well as in other regions of the world, climate conditions have a control over landscape evolution and population distribution. Population growth can be one of the causes of the greatest impact on land use and occupation, since there is often no adequate planning. Areas under development or of economic interest are usually impacted by deforestation or changes in land use and occupation, bringing changes in water resources, and they can also compromise water security for future generations. Anthropogenic and natural factors significantly alter changes in land use. Intense explorations of agricultural and livestock areas are common in the semi-arid region of Northeastern Brazil, with the historical process of droughts and the lack of water being a constant academic-scientific, management and public policy concern (Maldonado, Carvalho, 2010), (Zanella, 2014) (Fiorese, 2021).

Assessing land use and occupation in the semi-arid region is extremely important due to the specific characteristics of this region, where the scarcity of water resources and climate conditions represent significant challenges for sustainable development. Landscape changes can be analyzed by studies, as shown by (Noronha, Freitas, Solórzano, 2022), where, by the mapping of land use and occupation, it was possible to state that the modification of space is conducted according to historical demands, society, economy and public policies. An analysis of land use and occupation in a given territory can help in a proper planning and contribute to the protection of natural resources and the reduction of land use conflicts. It is important to emphasize that data modeling can be used in the process of investigating areas, on a time scale that will determine different types of occupation and land use (Santos, Feitosa, 2022). Remote sensing helps in the development of studies that evaluate land use (Mamede, Araújo, 2021). Information on land use and occupation can be obtained by different methodologies using satellite images (Sousa, et al, 2021). The observation performed in images using remote sensing brings the possibility of systematically monitoring the growth of a population, polluting sources, deforestation and land use and occupation (Schleich, Filho, Lahm, 2023).

To perform the monitoring of different areas in the world, the Normalized Difference Vegetation Index (NDVI) has been widely used and is already well established in the scientific academic environment for this purpose. NDVI refers to the qualification and detection of plant health, using reflected light in both visible and near-infrared bands (Kumar, 2022). For the caatinga biome, which presents, as one of the main characteristics, a diversity in its plant composition, often being thorny shrubs (Sales, et al 2023) (Araújo et al., 2023), remote sensing, especially NDVI, can often be a great analysis tool to obtain temporal and spatial variations.

The biodiversity of the fauna and flora that are present in the caatinga deserves prominence, and it is important to emphasize that the plant dynamics of this biome is mainly affected by edaphoclimatic factors (Caetano et al. 2022). It is important to highlight that NDVI becomes attractive due to its ability to quickly delimit vegetation and vegetative stress, for example, which is essential in land use studies (Huang, et al 2020) and in semi-arid areas.

Vegetative stress is related to water availability in the area. Thus, NDVI represents spatially and temporally the water conditions of the place. Many of the elements of the hydrological cycle can be closely related to NDVI. In addition, this index represents and highlights the use and occupation of the soil very well. (Galvincio et al., 2022) developed a system that allows obtaining NDVI quickly and easily. In this system, it is also possible to classify the NDVI images in order to verify the areas with high vegetative vigor. In semi-arid regions, in the dry period, the plants that stand out with high vegetative vigor are usually riparian forest and irrigated areas. Thus, it is possible to quickly and easily map these two land uses, employing NDVI and satellite images of the dry period.

Peixoto, Araújo, Neto, (2023), explain that changes in a given area are directly related to environmental conditions and forms both in the past and in the present, and, according to the authors, environmental studies are extremely important to understand the dynamics of a given location. According to (Santiago 2023), the pressure on natural resources is more evident in drought regions, such as the northeastern sertão, whose morphoclimatic characteristics are fragile and a high susceptibility to anthropic actions is observed.

According to (Daneshi et al 2021), water security is a key policy objective for sustainable development, which is under pressure as a result of land use and climate change, especially in (semi)arid areas. Land use change alters surface runoff and affects hydrological processes and water consumption across the basin, while climate change modifies precipitation and temperature patterns and, consequently, evapotranspiration and water supply. It is important to emphasize that water is a precious commodity all over the planet. Brazil has several regions that are experiencing serious problems of scarcity of natural resources. The São Francisco River basin is an important basin in Brazil. It has a large territorial extension and has supplied different demands in Brazil, such as electricity generation, irrigated agriculture, public and human supply, tourism, navigation, among others. It has also supplied the need for water from other semi-arid regions in the Northeast of Brazil, such as the case of the Project for the Integration of the Waters of the São Francisco River-PISF. The latter has been of great importance for water security and the pursuit of compliance with the Sustainable Development Goals-SDGs in Brazil. Water supply and water security are among the most important life support functions of our planetary ecosystem, strongly connected to local and regional social and economic conditions (Liquete et al., 2011, Lang et al., 2017, Lang et al., 2018, Daneshi et al 2021, Luz, Galvincio, 2022).

Water replenishment is a key component in the processes of aquatic and terrestrial ecosystems that produce water-related ecosystem services, contributing to the availability of water for different consumptive and non-consumptive uses (Vigerstol and Aukema, 2011), local and regional (Legesse et al., 2003,) However, it is important to assess the impacts of these changes in land use and occupation and water availability in these areas. The big question is: what are the real benefits of water availability in the region with the arrival of water from the São Francisco River?

Given the above, the aim of this study was to evaluate changes in land use and occupation and their relationship with water availability in a semi-arid region of Northeastern Brazil.

Material and methods

This research was conducted in the municipality of Floresta, which belongs to the hinterland of Pernambuco (Figure 1). The municipality has a territorial area of 3,604.948 km^2, and its population is estimated in 30,144 people, with a demographic density of 8.36 inhabitants per km^2, according to data from the Brazilian Institute of Geography and Statics (IBGE), 2022 census on land use and occupation. It is an area of many conflicts related to water availability.

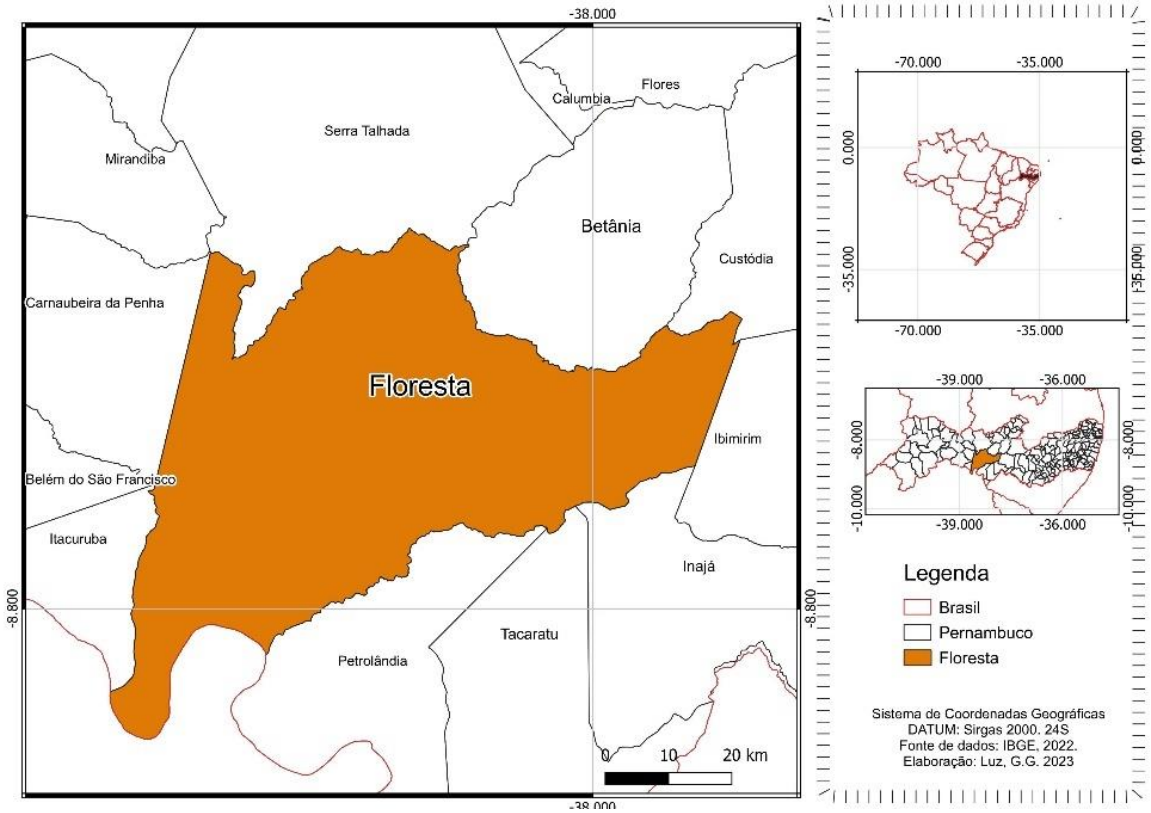

Figura 1. Localização do município de Floresta-PE.

Obtaining data

First, data on land use and occupation provided by MapBiomas class 07, available at https://brasil.mapbiomas.org/download, were used. The mapping produced by them is dynamic and updated every time there is an improvement in the algorithm. MapBiomas is a Brazilian collaborative network formed by Non-Governmental Organizations (NGOs), Universities and technology-based companies (startups), which provides information about land use in the Brazilian territory, predicting the conservation of natural resources and assisting in the combat to climate change. The choice of the data series obtained from MapBiomas was years per interval. From this perspective, the years used in MapBiomas were 1985, 1990, 1995, 2000, 2005, 2015 and 2021, obtained on 06/20/2023 on the website, with 2021 being the most recent year available in the MapBiomas data source.

According to data from images acquired by the satellites Landsat 5 and 8, on the website: https://earthexplorer.usgs.gov/, the cloud coverage parameter was selected for images with up to 30% of cloud coverage. The following dates were selected according to the lowest cloud coverage available on 11/24/1987, 08/22/1988, 09/19/1998, 11/06/1998, 01/02/2014, 10/15/2019, 02/22/2021, 09/02/2021, 02/12/2023, 07/14/2023.

Landsat 5 and 8 satellite images were used to calculate NDVI. It is important to emphasize that in the two selection criteria for both processes, the study aimed at analyzing the possible changes related to the insertion of the Integration Project of the São Francisco River with Hydrographic Basins of the Northeastern Northeast (PISF) in the municipality of Floresta.

Two flights obtained with drones were used for the local validation of land use and occupation. The flights were performed on 09/27/2022 and 09/28/2022, in a stretch of the eastern axis of PISF that is located in the municipality of Floresta. The false color composites of the landsat and drone images are shown in Figure 2.

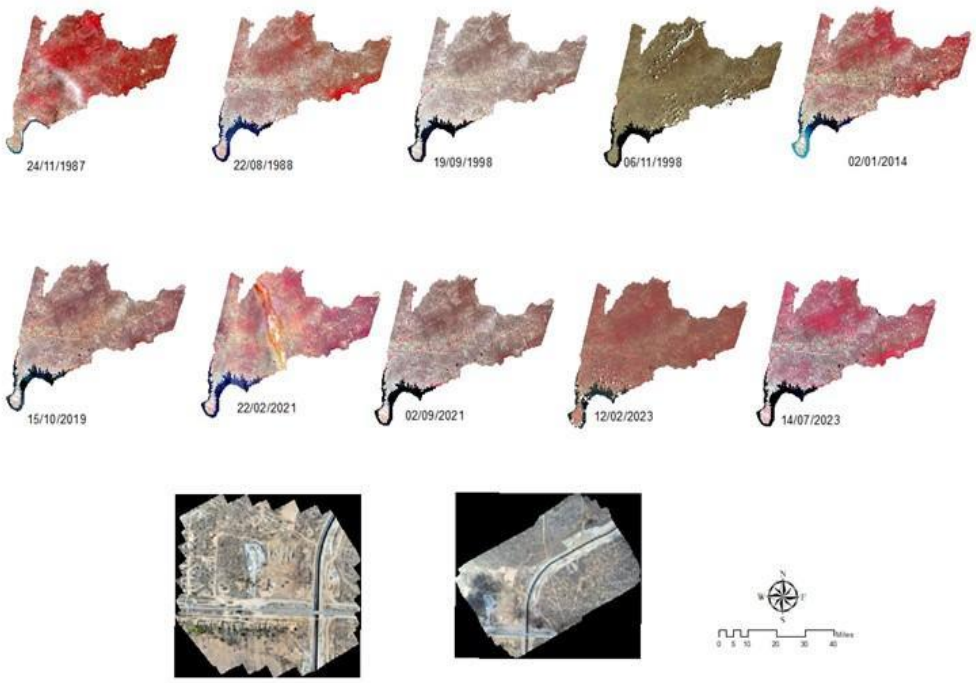

Figura 2- False color composite of landsat 5 and 8 and drone images.

Processing Steps

For the MapBiomes data, the following classes were selected: Forest formation, savannah formation, grassland formation, pasture, mosaic of uses, urban areas, other non-vegetated areas, mining, river, lake, ocean, other temporary crops, other perennial crops. The area in km^2 regarding the years of the study was quantified. After tabulating the classes, the differences between the most recent year and the previous years were calculated.

Performance of the Normalized Difference Vegetation Index (NDVI)

Landsat 5 and 8 images were processed using the Water Vegetation Index Analysis (ADIVA) software. ADIVA quickly and accurately estimates vegetation and water indices, evaluates the physical conditions of the vegetation, evaluates the water conditions of the vegetation, in addition to assessing vegetation vigor. It is available at: https://sites.ufpe.br/sergeo/wp-content/uploads/sites/125/2022/03/ADIVA-lancamento_versao-final.pdf. After processing, for performing the NDVI, the images were classified from 0-5, and for the validation of the results, orthomosaics of drone images were used.

Annual and monthly water balance of the studied area

To obtain the annual and monthly water balance, the System of Hydrological Response Units for Pernambuco, https://super.hawqs.tamu.edu/, was used. This system uses the SWAT-Soil Water Assessment Tools model to assess water balance. This system can be used to assess the quality and quantity of water in a watershed. The data that are within the SUPer systems and used in this study were calibrated by Farias et al., (2023). The data series available in SUPer is from 1961-2021.

In the variables of water balance, Precipitation, SW-soil water, W_STRS - Number of days under water stress, TEM_STRS - Number of days under temperature stress, biomass and LAI statistics

of similarities with Euclidean squared distance and Ward's grouping method were applied. The aim was to evaluate the similarities between water balance variables and vegetation cover and, consequently, soil use and occupation.

Results and discussion

In this study, the greatest loss occurred in the savannah formation, Table 1. Another striking result was the mosaic of use that had the greatest growth. This result shows the loss of natural vegetation and the increasing number of different uses/mosaics of uses/mix of uses. From the identification of the increase of different uses in the area, it is possible to state that the management and planning of the area has become increasingly challenging. Figure 3 shows the spatial and temporal variation of land use and occupation in the municipality of Floresta for each analyzed year. Even with significant losses, the savannah formation continues to be prominent in the municipality. Nonetheless, it has been replaced especially by mosaics of uses.

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Table 1. Variation in land use and land cover and changes in use (km^2), in the period of 1985-2021.

Classes	1985	1990	1995	2000	2005	2015	2021	Alteration (km^2)
Forest Formation	5.600	6.859	7.897	6.757	3.417	5.834	6.395	0.795
Savannah Formation	2590.040	2431.625	2663.074	2325.635	2240.584	2465.856	2205.955	-384.08
Grassland	27.520	7.327	7.274	7.888	8,453	15,183	15,766	-11,754
Pasture	207,146	306,295	242,044	219,033	236,956	419,246	188,587	-18,558
Mosaic of Uses	766,185	692,601	814,959	892,080	943,901	846,016	1010,390	244,205
Urban Area	1,904	2,251	2,375	2,494	2,883	3,415	4,439	2,536
Other non-Vegetated Areas	8,776	27,542	37,042	22,597	27,944	43,742	55,434	46,657
Mining	0,074	0,117	0,132	0,132	0,132	0,132	10,133	10.059
River, Lake and Ocean	31.888	174.541	174.364	172.452	182.150	145.843	158.483	126.596
Other Temporary Crops					0.005	0.397	0.097	0.097
Other Perennial Crops	0.318	0.010	0.005	0.094	0.552	3.723	3.485	3.166

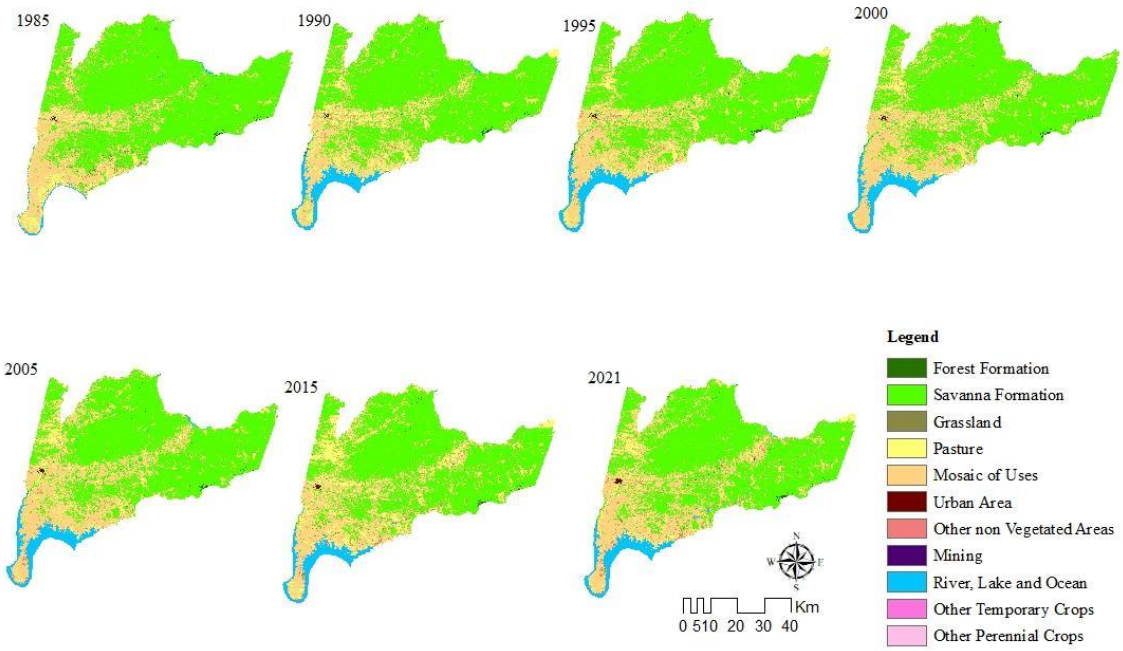

Figure 3. Land use.

According to a publication by MapBiomas (2022), the Caatinga Biome had an average of 38.03% of deforestation events per day. According to the Brazilian Institute of Geography and Statistics (IBGE), the municipality of Floresta had a population increase of 2.93% in 2022 compared to the 2010 census. According to the water and sanitation institute, data from 2020, about 68.2% of the population lives in urban areas and only 31.08% of the municipality lives in rural areas. Population growth is one of the reasons for the increase in urban areas in semi-arid municipalities.

After evaluating the use and occupation of the soil in the MapBiomas database, the NDVI from 1987 to 2023 was evaluated (Figure 4). The variation in vegetative vigor in the area under study is noticeable. It is known that the spatial and temporal distribution of vegetative vigor in a semi-arid region is primarily related to water availability, which is an initial consequence of precipitation. It is possible to highlight a greater vegetative vigor in 2014, 2021 and 2023. We can also highlight a greater water stress of the vegetation in 1998, 2019 and 2021. It is known that these last years were years of El Nino (Galvinê and Souza 2002), (Barbosa Junior and Galvincio 2009), (Tiburcio et al., 2023).

To highlight the relationship with water availability, the water balances of these years were presented for comparison with the vegetative vigor and the changes in soil use and occupation. We still highlight a small area that was flown over with drones to validate the NDVI and land use and land cover mapping (Figure 4). Human-induced land use changes on short-time scales have significant impacts on water production, especially in China, because of the rapid social economic development (Lang et al., 2018). This problem can occur in the area under study, since with PISF the area has become of economic interest and is in a rapid development process.

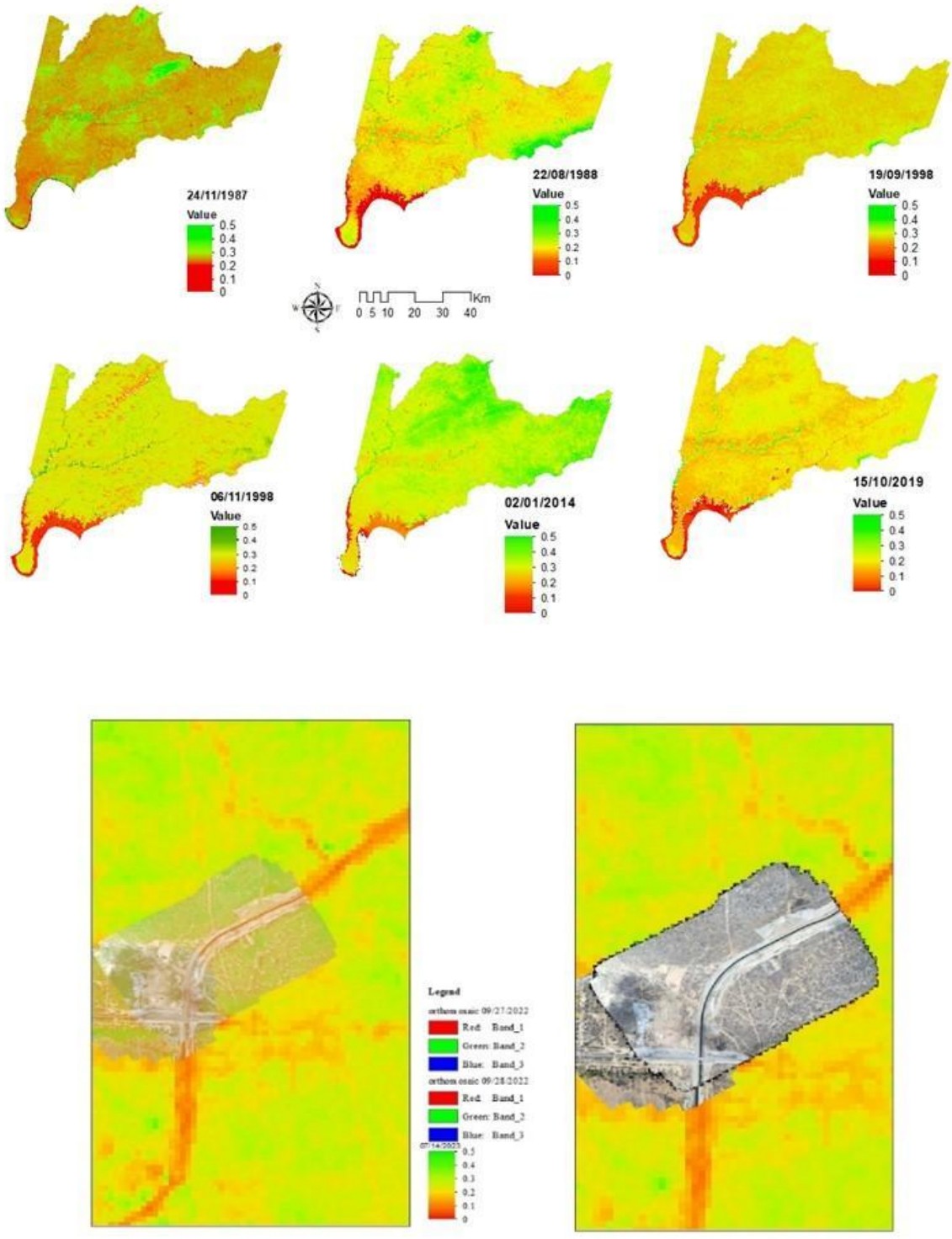

Figure 4. NDVI spatial and temporal variation, UVA image in NDVI overlap and validation.

In order to evaluate these alterations and their impacts on water resources, annual and monthly water balances were evaluated for each year of the studied period.

Annual and monthly water availability for the years under study

Among the analyzed years, 1998 stands out with a great water scarcity, presenting a total annual precipitation of only 182mm and a high potential evapotranspiration of 2133mm. Even though 2019 is a year when El Nino occurred, the water balance is not as impactful.

Regarding the year 2014, where there was a greater vegetative vigor, water balance did not present the highest precipitation, but the value of lateral runoff is significant. Therefore, for a better planning of a watershed in the semi-arid region, it is important to evaluate the flow variables below the surface.

When evaluating soil moisture, it is possible to notice that the decade from 1990 to 2000 had little water available in the soil (Figure 5). This directly reflects on vegetation cover (Figure 4) and the variation in land use and occupation (Figure 2), reflecting on a greater loss of savannah formation. In 1987, when the soil was more saturated (Figure 5), vegetative vigor was clearer (Figure 4). It is important to highlight that the return flow decreased from 2005 to 2019. This return flow has a contribution from plants through their roots by percolation. The decrease in vegetation cover may be affecting this return flow. This variable is of paramount importance in semi-arid regions, where the use of family farming is very present with the use of this water resource. That is, public policies are needed aiming at replacing this natural resource and providing water security for the use of family farming. Similarly to this study, (Vigerstol and Aukema, 2011) used the SWAT tool, and concluded that this tool provides more details on the hydrological cycle and that it is often necessary for decision making.

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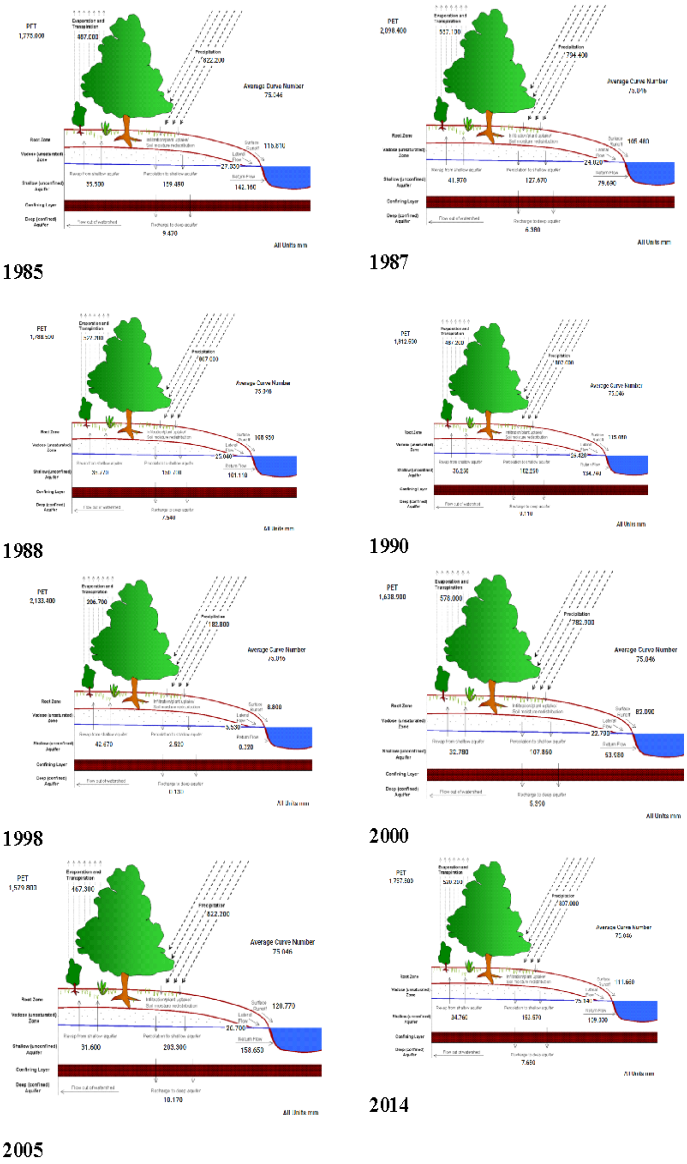

Figure 5- Annual water balance in the area under study.

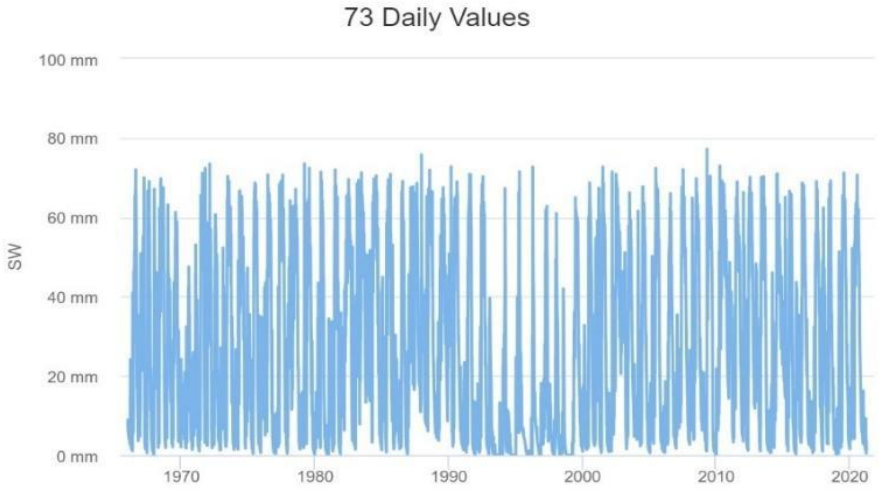

Figure 6- Soil Water-SW- current.

Assessing which water balance variables are most similar to vegetation cover and land use and occupation, it was possible to highlight that biomass and LAI are more similar to the days of water stress (Figure 7). That is, the variables related to vegetation cover are more closely related to the number of days of water stress. This information may lead us to believe that climate change in the area can greatly impact vegetation cover by the increase in the number of days under water stress. This means it is not only the amount of water available, but also the temporal distribution that has a great impact on the dynamics of the vegetation cover in the area. It is important to highlight that days under water stress are more intense and longer (Figure 8).

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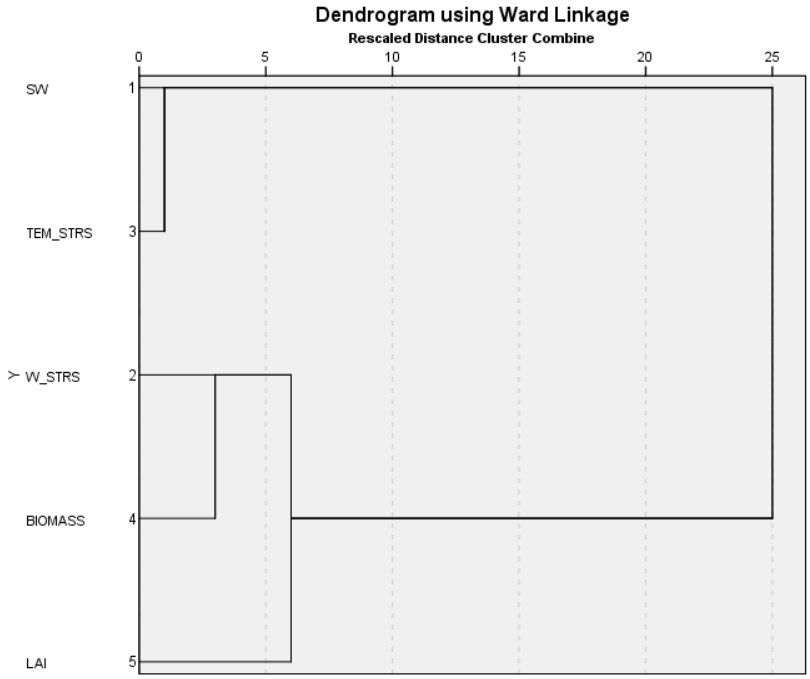

Figure 7. Dendrogram. SW-Soil Water, Precip-precipitation, W_STRS - Number of days under water stress, TEM_STRS - Number of days under temperature stress, biomass and LAI- Leaf Area Index.

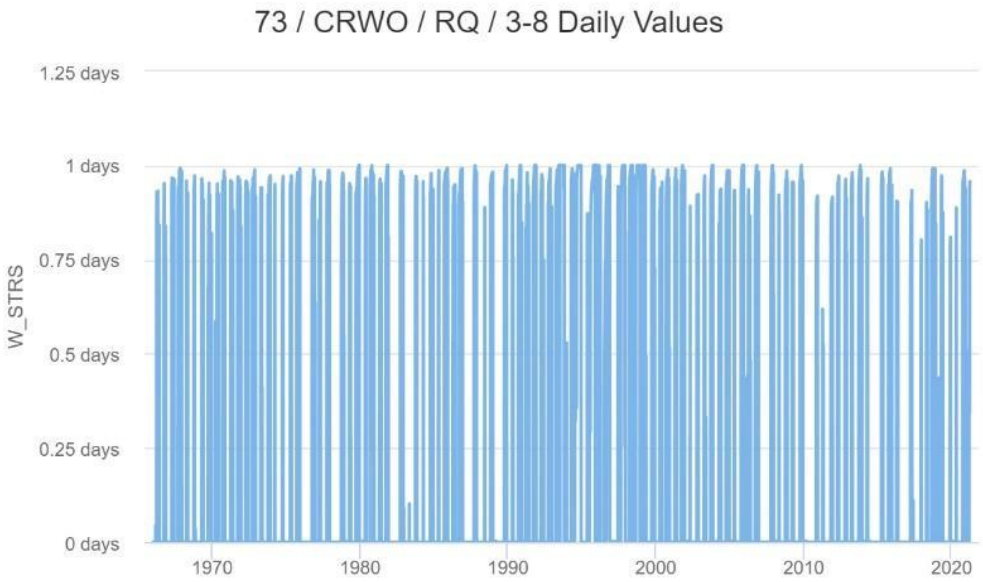

Figure 8- W_STRS - Number of days under water stress-current.

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PISF- São Francisco Integration Project

Public water security policies have been adopted in the studied area. PISF, which in this area is also called the east channel of the São Francisco Transposition, runs from Floresta, in the state of Pernambuco, to Monteiro, in the state of Paraiba. The municipality of Floresta obtained an increase of 126,596 km^2 of water, that is, there was an increase in water availability in this region. Nevertheless, for this water availability to be effective, the spatial and temporal distribution of this water needs to be efficient, overcoming the problem of increasing the number of days under water stress. The reservoir Barra do Juá is a reservoir in the municipality under study and is currently the only one to be contemplated with the waters of the São Francisco River Integration Project with the Northern Northeast Hydrographic Basins (PISF), (APAC, 2023). The main purpose of this reservoir is to supply water for irrigation in the region. In 2021, the Ministry of Regional Development (MDR) released water from the Muquém Reservoir to the Juá Dam, both in the municipality of Floresta, in Pernambuco. The waters of the East Axis of the São Francisco River Integration Project benefit around 800 properties in the system Barra do Juá-Riacho do Navio Reservoir. https://www.gov.br/pt-br/noticias/transito-e-transportes/2021/07/liberadas-aguas-do-reservatorio-do-muquem-para-a-barra-do-jua-em-pernambuco

The release of water will occur gradually – up to 3m³/s – for approximately 90 days, to minimize losses in transit. The maneuver will also allow Riacho do Navio, marked by drought for years, to flow water again. This is also another completed stage of the São Francisco River Integration Project, which is at more than 97% operational progress in the North and East axes.

On the East Axis, more than 57 municipalities – 21 in Pernambuco and 36 in Paraiba – have been receiving water from the São Francisco River since 2017. Operation, even in pre-operation, prevented the Paraiba city of Campina Grande from collapsing in water at the time due to the worst drought ever recorded in the last 100 years.

The water from 'Velho Chico' has traveled the 217 kilometers of channels and other engineering structures, which has lead it from Floresta (PE) to the bed of the Paraiba River, in Monteiro (PB). The section comprises six pumping stations, five aqueducts, a tunnel, a pipeline and 12 reservoirs.

It is worth noting that PISF is expected to meet the water demands of the semi-arid population (Cunha, SobraL, Melo, 2023). This initiative aims at providing water for human consumption and future agricultural use. Between 2012 and 2017, the Northeast experienced a period of drought, which accelerated the completion of the East Axis of PISF, so that the cities that compose the axis would not have a possible collapse in the supply system (Pereira, Miranda, 2023). It is possible to observe in figure 2 an increase in the water body in the municipality. The year 1985 was the period with the lowest flow of these bodies.

Conclusion

It is concluded that, for a greater water security in semi-arid regions, it is important that public policies on water availability pay attention to the number of days with water stress and be able to meet this temporal and spatial need. The loss of savannah formation in the semi-arid region is a complex and multifaceted process, resulting from the interaction between natural and human factors. In addition, sustainable soil management practices, conservation of water resources and protection of biodiversity are extremely important for the preservation of vegetation. This problem can occur in the area under study, since with PISF, the area is of economic interest and is in a fast development process.

Nonetheless, it is important to emphasize that the success of temporary crops in the semi-arid region depends on a combination of factors, including the adequate choice of crops and the use of appropriate technologies. In addition, it is essential that farmers have access to updated information and guidance, so they can have better results in their crops. It is essential to conduct studies and constant monitoring to validate the effects of water transfer and ensure the sustainability and efficient use of water resources in the semi-arid region.

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References

APAC- Agência Pernambucana de Águas e Climas, Conselho Gestor- Barra do Juá, 2023,

Araújo, E., Mamede, G. L. 2021. Validation of soil uses around reservoirs in the semi-arid through image classification. Revista Caatinga, 34, 670-681.

Bai, J., Huang, L., Gao, H., Zhang, G. (2017). Wetland biogeochemistry and ecological risk assessment. Physics and Chemistry of the Earth, 97, 1-2.

Caetano, R., Silva, T. B., de Castro, D. R., & Benfica, N. S. 2022. Uso de índices espectrais na caracterização da cobertura vegetal em região de Caatinga do Semiárido Baiano. Revista de Geociências do Nordeste,8, 28-43.

Cunha, C. R. M., Sobral, M. D. C. M., & de Souza Melo, M. G. 2023. Avanços e desafios do gerenciamento integrado dos recursos hídricos no modelo de gestão no eixo leste do projeto de Integração do Rio São Francisco com bacias hidrográficas do nordeste setentrional (PISF). Revista Foco,16, e1118-e1118.

Luz, G. G., Galvincio, J. D. 2022. Balanço hídrico superficial da bacia hidrográfica do riacho Milagres-PE, utilizando o SUPer. Revista Brasileira de Geografia Física, 15, 1094-1107.

Daneshi, A., Brouwer, R., Najafinejad, A., Panahi, M., Zarandian, A., & Maghsood, F. F. 2021. Modelling the impacts of climate and land use change on water security in a semi-arid forested watershed using InVEST. Journal of Hydrology, 593, 125621.

Araújo Filho, J. C., Correa, M. M., Paiva, A. Q., Costa, O. V., Valladares, G. S., Ribeiro, M. R., & Schaefer, C. E. 2023. Semi-arid Soils of the Caatinga Biome of Northeastern Brazil. In The Soils of Brazil (pp. 175-193). Cham: Springer International Publishing.

Medeiros Pereira, M. C., amp; de Sousa Miranda, R A intensificação das desigualdades sociais como consequência da crise do abastecimento

de água no semiárido nordestino. ENAPUR. 1-18. 2023.

Santana Peixôto, M. C., de Araújo, J. P. R., Neto, M. C. P. 2023. Sistemas ambientais, vulnerabilidade e uso e ocupação no município de Assú/RN. Geografia (Londrina), 32, 31-48.

Sousa, M. D. C., Veloso, G. V., Gomes, L. C., Fernandes-Filho, E. I., de Oliveira, T. S. 2021. Spatio-temporal dynamics of land use changes of an intense anthropized basin in the Brazilian semi-arid region. Remote Sensing Applications: Society and Environment, 24, 100646. disponível em: https://www.apac.pe.gov.br/133-barra-do-jua/156-barra-do-jua-

Santos, Sávio Barbosa; Feitosa, Ailton. 2022. Caracterização da dinâmica no uso e ocupação do solo diante das adversidades do clima no município de Palmeira dos Índios/AL.Revista Brasileira de Geografia Física 15, 1053-1062.

Fiorese, C. H. U. 2021. Land use and occupation in the Fundaça Stream subbasin, Espírito Santo, Brazil. Revista Agrogeoambiental, 13, 82-96.

Galvíncio, J. D., Souza, F. A. S. 2002. Relação entre o fenômeno El Niño e os totais mensais precipitados na bacia hidrográfica do rio São Francisco. RBRH-Revista Brasileira de Recursos Hídricos, 7, 113-119.

Galvincio, J., de Miranda, R. Q., De Moura, M. S. B., Montenegro, S. M. G. 2022. ADIVA-Análise de Índice de Vegetação e Água. Revista Brasileira de Geografia Física 15, 1654-1659.

Huang, S., Tang, L., Hupy, J. P., Wang, Y., Shao, G. 2021. A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. Journal of Forestry Research 32, 1-6.

IAS- Instituto Águas e Saneamento. Retrieved J (accessed uly 23, 2023), fromhttps://www.aguaesaneamento.org.br/municipios-e-saneamento/pe/floresta.

IBGE, Instituto Brasileiro de Geografia e Estática, portal cidade, censo 2022. (accessed 29 july 023).

Júnior, E. V. B., Galvincio, J. D. 2009. Análise Climatológica da Quadra Chuvosa do Município de Belém de São Francisco–PE, para o Período de 1962 A 2009. Revista Brasileira de Geografia Física, 2, 31-42.

Kumar, B. P., Babu, K. R., Anusha, B. N., & Rajasekhar, M. 2022. Geo-environmental monitoring and assessment of land degradation and desertification in the semi-arid regions using Landsat 8 OLI/TIRS, LST, and NDVI approach. Environmental Challenges, 8, 100578.

Lang, Y., Song, W., Zhang, Y. 2017. Responses of the water-yield ecosystem service to climate and land use change in Sancha River Basin, China. Physics and Chemistry of the Earth, Parts A/B/C, 101, 102-111.

Legesse, D., Vallet-Coulomb, C., Gasse, F. 2003. Hydrological response of a catchment to climate and land use changes in Tropical Africa: case study South Central Ethiopia. Journal of hydrology 275(1-2), 67-85.

Liquete, C., Maes, J., La Notte, A., Bidoglio, G. 2011. Securing water as a resource for society: an ecosystem services perspective. Ecohydrology & Hydrobiology 11, 247-259.

Maldonado, F. D., Santos, J. D., De Carvalho, V. C. 2002. Land use dynamics in the semi-arid region of Brazil (Quixaba, PE): characterization by principal component analysis (PCA). International Journal of Remote Sensing 23, 5005-5013.

MapBiomas. 2022. Relatório Anual do Desmatamento no Brasil 2021 –p.49. 2022. Disponível em: http://alerta.mapbiomas.org. (accessed july 2023)

Noronha, F., Freitas, M. M. D., Solórzano, A. 2022. Os Novos Ecossistemas do "Sertão Carioca": Transformação da Paisagem e História de Uso da Terra na Bacia do Rio Piabas (1968-2018), Rio de Janeiro. Sociedade & Natureza, 34.

Sales, F. D. C. V., de Oliveira Figueiredo, E. L., de Medeiros, N. C. G., da Silva Sousa, S. M., de Morais, G. V., de Medeiros Araújo, L. 2023. Caracterização arbórea na caatinga pelo método de parcela fixa e ponto quadrante. Boletim Paulista de Geografia, 109, 172-187.

Santiago, C. M. C., da Silva, E. V., Soares, L. S. 2023. Capacidade de suporte dos sistemas ambientais da bacia hidrográfica do Rio São Nicolau (BHSN)-Piauí. Geografia, 48, 1-24.

Schleich, A. P., da Rocha Filho, J. B., & Lahm, R. A. 2022. Aplicações do Sensoriamento Remoto em Estudos AmbientaiS. Educação Ambiental em Ação, 20(78).

Vigerstol, K. L., Aukema, J. E. 2011. A comparison of tools for modeling freshwater ecosystem services. Journal of environmental management, 92, 2403-2409.

Zanella, M. E. 2014. Considerações sobre o clima e os recursos hídricos do semiárido nordestino. Caderno Prudentino de Geografia 1, 126-142.