ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 10, nº 1 (2024)

https://doi.org/10.21680/2447-3359.2024v10n1ID34886

Spatiotemporal dynamics in the land cover and land use in a river basin in southern Brazil: analysis based on remote sensing and big data

Dinâmica espaço-temporal na cobertura e uso da terra em uma bacia hidrográfica no sul do Brasil: análise baseada em sensoriamento remoto e big data

Cristiane Scussel[1]; Sylvia Christina de Lima[2]; Amanda Letícia de Meneses Mendes[3]; Marina Barros Santander[4]; Anderson Targino da Silva Ferreira[5]; Jairo José Zocche[6]; Carlos Henrique Grohmann[7]; José Alberto Quintanilha[8]

[1] University of the Extremo Sul Catarinense, Postgraduate Program in Environmental Sciences, Criciúma/SC, Brazil. Email: cris._scussel@hotmail.com
ORCID: https://orcid.org/0000-0003-0242-5566

[2] University of São Paulo, Institute of Energy and Environment, São Paulo/SP, Brazil. Email: sclima.br@gmail.com
ORCID: https://orcid.org/0000-0002-0453-9252

[3] Paulista State University Júlio de Mesquita Filho, Postgraduate Program in Environmental Sciences, Sorocaba/SP, Brazil. Email: alm.mendes@unesp.br
ORCID: https://orcid.org/0000-0003-0242-5566

[4] University of São Paulo, Department of Geography, São Paulo/SP, Brazil. Email: marinabsantander@gmail.com
ORCID: https://orcid.org/0009-0005-7007-5467

[5] Technological College of the State of São Paulo, Technology in Environment and Water Resources, Jaú/SP, Brazil. Email: andersontsferreira@gmail.com
ORCID: https://orcid.org/0000-0002-0440-6273

[6] University of Extremo Sul Catarinense, Postgraduate Program in Environmental Sciences, Criciúma/SC, Brazil. Email: jjz@unesc.net
ORCID: https://orcid.org/0000-0003-2291-3065

[7] University of São Paulo, Institute of Energy and Environment, São Paulo/SP, Brazil. Email: guano@usp.br
ORCID: https://orcid.org/0000-0001-5073-5572

[8] University of São Paulo, Institute of Energy and Environment, São Paulo/SP, Brazil. Email: jaquinta@usp.br
ORCID: https://orcid.org/0000-0003-3261-7825

Abstract: The exploitation of natural resources is of concern because economic growth results in negative impacts on environmental balance. This study analyzed the spatiotemporal changes in land cover and land use (LULC) in the Araranguá River Watershed (ARW), southern of Santa Catarina state, south Brazil, in the period of 2016-2023. Images from the Sentinel-2A satellite were used, the RGB, NIR and SWIR 1 bands were selected and the EVI2, MNDWI, NDBI indices were applied, which resulted in the selection of eight LULC classes. The orbital images were classified using programming routines in Google Earth Engine (GEE) and validation was performed by obtaining data generated by the platform. The overall accuracy was 93% for both years assessed. The Native Forest class was the most representative and increased by 1.62% in the last seven years. The Built Area class grew the most, and Pasture/Herbaceous Vegetation class decreased by 5.6%. The results revealed slight changes in the landscape, with areas with native forests being maintained and urban expansion occurring. These data can help public policy makers and decision makers to manage the basin territory with a bias towards the conservation and preservation of natural resources.

Keywords: Environmental degradation; Machine learning; Decision trees.

Resumo: A exploração dos recursos naturais é alvo de preocupação visto que o crescimento econômico interfere no equilíbrio ambiental. O estudo analisou as mudanças espaço-temporais na cobertura e uso da terra (CUT) na Bacia Hidrográfica do Rio Araranguá (BHRA), sul de Santa Catarina, Brasil, no período de 2016-2023. Foram utilizadas imagens do satélite Sentinel 2A, selecionadas as bandas RGB, NIR e SWIR 1 e, aplicados os índices EVI2, MNDWI e NDBI, o que resultou na seleção de oito classes de CUT. As imagens orbitais foram classificadas por meio de rotinas de programação no Google Earth Engine (GEE) e a validação foi realizada a partir da obtenção de dados gerados pela plataforma. Os resultados evidenciaram acurácia geral de 93% para os dois anos. A classe Floresta Nativa foi a mais representativa e aumentou cerca de 1,62% nos últimos sete anos. Área Construída foi a classe que mais cresceu e a classe Pastagem/Vegetação Herbácea teve redução de 5,6%. Os resultados revelaram mudanças tênues na paisagem, mantendo áreas com florestas nativas e incremento da expansão urbana. Esses dados podem auxiliar as políticas públicas e as tomadas de decisão no gerenciamento do território da bacia com viés para a conservação e preservação dos recursos naturais.

Palavras-chave: Degradação ambiental; Aprendizado de máquina; Árvores de decisão.

Recebido: 17/12/2023; Aceito: 07/02/202; Publicado: 08/03/2024.

1. Introduction

The exploitation of natural resources is of concern because economic growth results in negative impacts to the environmental balance. This topic is widely discussed in an attempt to establish the rational use of natural resources (CONTERATO, 2000; KREBS; ALEXANDER, 2000). Urbanization processes and agricultural activities are the main causes of changes, which are established in spaces reserved for the conservation of biodiversity (ALTIERI, 2001) such as, for example, in native forests and in riparian forests, which have a great influence on the quality of water bodies (SILVA *et al*., 2023; VOGEL; ZAWADZKI; METRI, 2009) and, consequently, enhances the negative impacts on the environment and human health.

The scenario above described coincides with the reality of the more than 3,000 km² of the area of interest in this study, the ARW, which is located in southern Santa Catarina. The European colonization of this vast territory began in the first decades of the nineteenth century (DALL'ALBA, 1997; HOBOLD, 1994), with family farming, agro-pastoral activities, urban occupation (SANTA CATARINA, 1997), logging (SCHEIBE; BUSS; FURTADO, 2010), and coal mining (CAMPOS, 2001) being the activities that mostly caused environmental degradation (KREBS, 2004). Studies such as Marcon, Zocche and Ladwig (2014) and Pereira (2023) highlighted the accelerated expansion of urban spaces towards lowland wetlands and Permanents Preservation Areas (PPA) in recent decades, thus indicating to public managers and the population the need for more attention to territorial management, since the conservation of these natural spaces is extremely necessary to guarantee the balance of ecosystems.

At the river basins, obtaining detailed and accurate information about the geographical space is necessary for planning and decision-making (ARAÚJO; MENESES; SANO, 2009). The vast majority of published studies about land cover and use mappings deal with rural areas, use LANDSAT images and classify through classical methods (MARTINS *et al*., 2023). However, geotechnologies, which include the processing of large data sets (big data) in the cloud and applications via machine learning, appear as viable alternatives for geospatial analysis. In this way, GEE becomes interesting because it is a cloud-based platform, facilitating access to high-performance computing resources for processing large amounts of data (GORELICK *et al*., 2017).

Given the past of predatory exploitation that resulted in a considerable conversion of areas covered by native forest into diversified uses in the southern region of Santa Catarina, it is essential to know how the ARW landscape is currently characterized to ensure its proper management. In this regard, the present study uses the GEE platform and Geographic Information System (GIS) to analyze the spatiotemporal changes in the land use and land cover in the Rio Araranguá Hydrographic Basin focusing on the environmental degradation caused by types of use.

2. Methodology

2.1 Study area

The ARW is located in southern Santa Catarina (Figure 1). It occupies an area of approximately 3,000 km² covering the territory of 16 municipalities, of which ten (Ermo, Forquilhinha, Maracajá, Meleiro, Morro Grande, Nova Veneza, Siderópolis, Timbé do Sul, Treviso, and Turvo) are fully located in the basin, and the remaining six (Araranguá, Balneário Arroio do Silva, Balneário Rincão, Criciúma, Içara, and Jacinto Machado) are partially inserted (KREBS, 2004; COMASSETTO, 2008; PERH/SC, 2017). Considering all, the total number of inhabitants is 488.902 (IBGE, 2023).

The ARW is characterized by two different climates, with 77.8% being Cfa (humid mesothermal subtropical with hot summers) and 22.2% being Cfb (humid mesothermal subtropical with mild summers) (PERHSC, 2017). The average annual temperature ranges between 17 and 19.3 ºC, where in January the warmest averages are between 23.4 and 25.9 ºC and in July these tend to be colder, staying between 12 and 15 ºC (ALVARES *et al*., 2013). Annual rainfall ranges from 1,200 to 1,600 mm (BACK, 2020).

Southern Santa Catarina is characterized by having one of the most important river basins of the southern coast of Santa Catarina with headwaters that drain a wide area from the Serra Geral escarpments crossing an extensive coastal lowland until flowing into the Atlantic Ocean (KREBS, 2004). The ARW has approximately 15 watercourses, of which the Mãe Luzia, Manoel Alves, and Araranguá rivers stand out (KREBS, 2004). Regarding relief, the altitudes vary between 0 and 1,500 m, from the Coastal Plain to Serra Geral escarpments, ranging between flat and mountainous (SANTA CATARINA, 1998). The predominant soils are the Haplic Gleisol (28.53%), Haplic Cambisol (23.6%), and Litholic Neosol (18.92%) (PERHSC, 2017). In relation to phyto-ecological regions, most of the ARW is covered by the Dense Ombrophilous Forest (DOF) and, to a lesser extent, Coastal Vegetation (KLEIN, 1978).

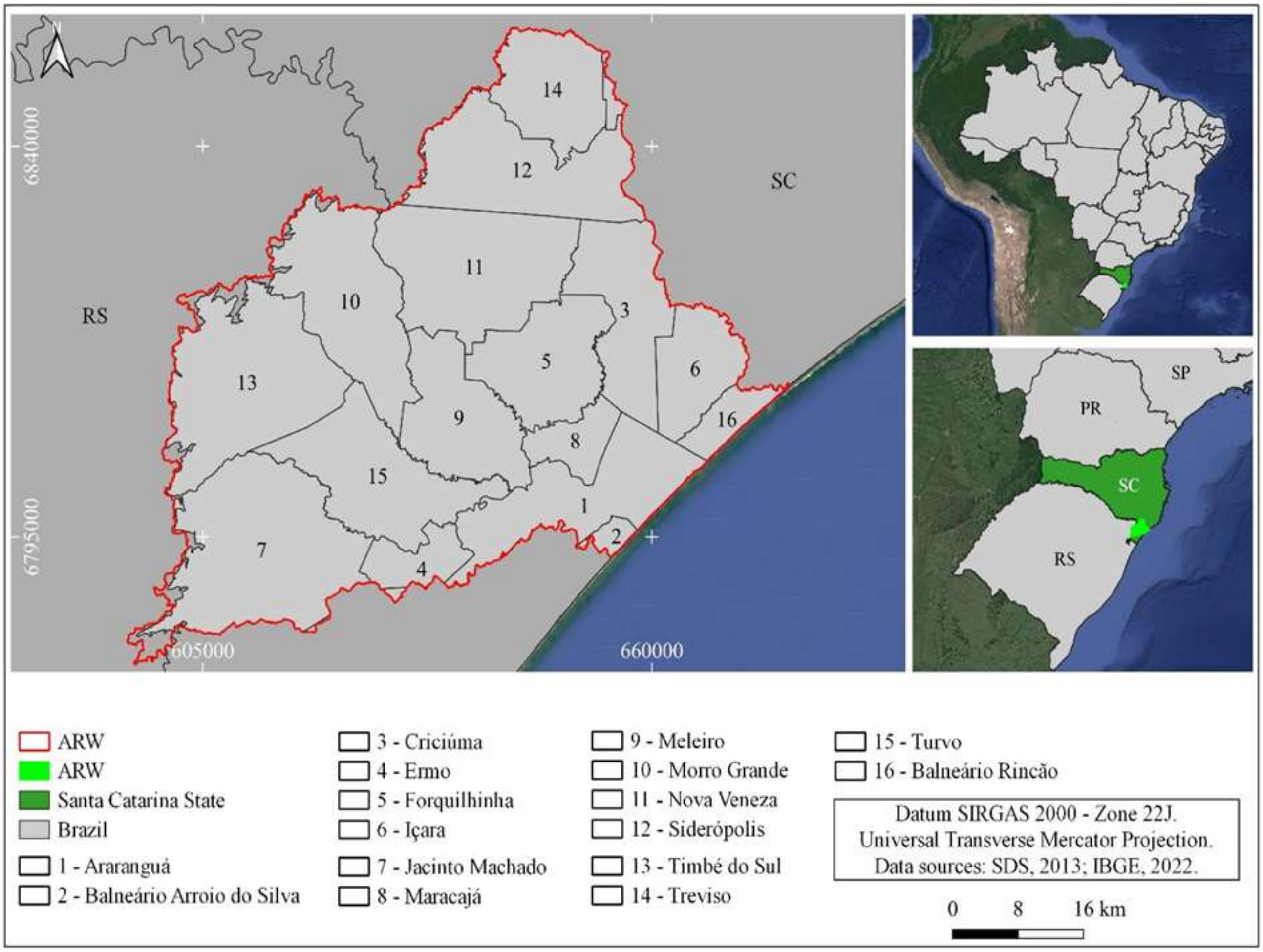


Figure 1 – Location of the ARW and municipalities comprising it, in southern Santa Catarina, Brazil.
Fonte: Authors (2023).

2.2 Image acquisition and processing

The methodological steps involved are as follows: 1) acquisition of orbital images; 2) generation of spectral indices; and 3) production and validation of thematic maps (Figure 2). The Sentinel-2 (S2) satellite is part of the European Space Agency's Copernicus programme. With a spatial resolution of up to 10 m it is able to provide multispectral images in 13 bands, ranging from visible to infrared. Its temporal resolution of 5 days renders it ideal for several applications, including short-term land-use analysis, which assists in the detection of rapid changes in landscapes, such as transformation and/or degradation (DRUSCH *et al*., 2012). Orbital images were customized through JavaScript programming routines and algorithms using the Code Editor available on the GEE cloud processing platform. Therefore, two images were selected, whose dates were derived from the median between March 1 and April 30, respectively, for the years 2016 and 2023.

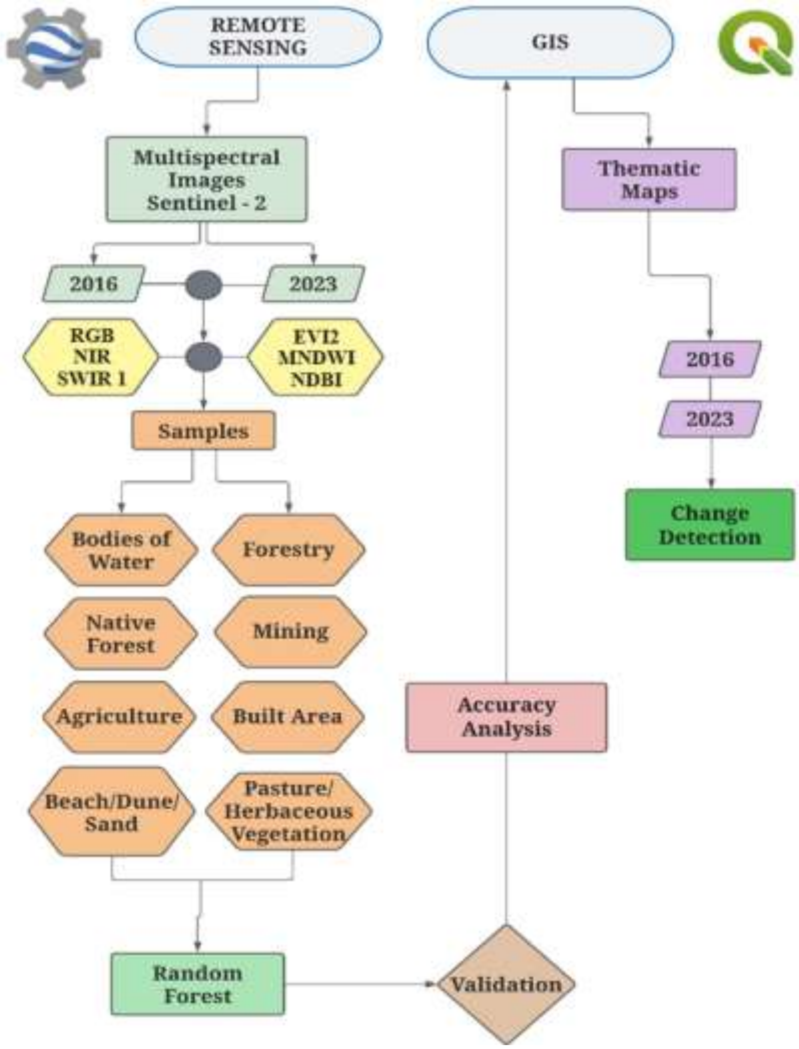


Figure 2 – Workflow chart.
Fonte: Authors (2023)

Considering the B2, B3, B4, B8, and B11 bands responsible for spectral reflectance in the Blue, Green, Red, Near Infrared and Shortwave Infrared wavelengths, the following spectral indices were used: Enhanced Vegetation Index (EVI2, Equation 1) which, from the suppression of the blue band (influenced by atmospheric effects), optimizes the sensitivity of regions with high biomass (JIANG *et al*., 2008); Modified Normalized Difference Water Index (MNDWI, Equation 2), which replaces the near-infrared band with the mid-infrared band to obtain better results in regions that have flooded areas and water bodies (XU, 2008); and Normalized Difference Built-Up Index (NDBI, Equation 3), to improve the identification of built-up areas (ZHA; GAO; NI, 2003).

$$EVI2= 2{,}5*(B8-B4)/(B8+6*B4+2{,}4*B2+1) \quad (1)$$

$$MNDWI=(B3-B11)/(B3+B11) \quad (2)$$

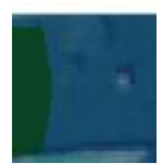
$$NDBI= (B11-B8)/(B11+ B8) \quad (3)$$

It is noteworthy that, for the images used in EVI2 a Laplacian filter was used. This emphasizes the edges around objects or features in an image to make them easier to analyze. Spatial filtering was performed through a two-dimensional rectangular matrix that detects the edges (3×3 window convolution kernel) (GONZALEZ; WOODS; EDDINS, 2009).

2.3 Image classification

For image classification, eight classes that represented the different forms of coverage and use of landscapes were generated: Bodies of Water, Native Forest, Agriculture, Built Area, Forestry, Mining, Beach/Dune/Sand, and Pasture/Herbaceous Vegetation. They were visually identified in images obtained by creating polygons randomly distributed throughout the study area using elements such as tonality/color, shape, and texture, according to Florenzano (2002) (Table 1). In addition, they were based on multispectral images from visible to infrared (B2, B3, B4, and B8), as well as spectral indices (EVI2, MNDWI, and NDBI) with spatial filtering.

Table 1 – Interpretation key.

Class	**Criterion**	**S2 Image**
Bodies of Water (BOW)	Rivers, ponds, and reservoirs with shades of blue, irregular shape, and smooth texture.	
Native forest (NF)	Dense Ombrophilous Forest and Arboreal *Restinga* with shades of dark green, irregular shape, and rough texture.	
Agriculture (AGR)	Annual crops with varying shades of green and brown, regular shape, and medium texture.	
Built Area (BA)	Civil constructions with varying shades of gray, and light red and matte green, regular shape, and rough texture.	
Forestry (FOR)	Monocultures of pine and eucalyptus with shades of dark green, regular shape, and smooth texture.	
Mining (MIN)	Extraction of coal and sand, with shades in purple, regular shape, and medium-rough texture.	
Beach, Dune, and Sand (BDS)	Sandy soils with shades of white and light beige, irregular shape, and fine texture.	

Pasture and Herbaceous Vegetation (PHV)	Fields with undergrowth, shades of light green, irregular shape, and fine texture.	

Fonte: Authors (2023)

The classification used the supervised Random Forest algorithm, with 100 trees, calibrated and validated using 70% and 30% of the training areas, respectively (FERREIRA *et al*., 2023; GORELICK *et al*., 2017). The training areas were calculated from the difference between the years 2016 and 2023 for each ARW class through Google spreadsheets. Thematic maps with the final classification derived from GEE were produced in the *QGIS* software, v. 3.16.5.

2.4 Analysis of changes

Changes in the ARW landscape were detected and analyzed from comparative visual interpretations between the 2016 and 2023 classified images within the GEE data platform. Analyses of the changes considered all forms of land use existing in the ARW. Monitoring was specific to land cover that considered areas covered by native forest, including the Restinga environment, in the coastal region, and the DOF, which extends to the Serra Geral. The quantitative data generated, as well as the thematic maps produced, were also used for comparison and change detection.

3. Results

3.1 Classification validation

For the year 2016, the vast majority of classes showed significant accuracy values, between 90 and 99%, (Table 2). The highest percentage of omission error was found in the BA class (13.18%), which had a correct-classification rate of 86.82% and was mistakenly confused with the agricultural-area class (Table 2). Beaches, dunes, and sand naturally have light colors, which led the classifier to confuse them with residences, resulting in an 88.46% accuracy in the 2023 classification. Notably, for all classes, in the two years, the accuracy in classifications exceeded 86% and the overall accuracy was 93%.

Table 2 – General accuracy of classification, by class and in percentage.

Class	**Producer accuracy (%)**		**User accuracy (%)**	
	2016	**2023**	**2016**	**2023**
Bodies of water (BOW)	98.15	98.15	99.32	98.65
Native forest (NF)	92.45	90.82	91.34	92.64
Agriculture (AGR)	86.36	87.88	91.10	89.69
Built Area (BA)	85.99	83.84	86.82	91.06
Forestry (FOR)	90.07	91.05	90.69	89.91
Mining (MIN)	97.96	98.68	94.43	96.15
Beach/Dune/Sand (BDS)	98.99	97.68	93.33	88.46
Pasture/Herbaceous Vegetation (PHV)	94.50	95.90	96.05	95.30
Overall Accuracy		**93%**		

Fonte: Authors (2023)

3.2 Classification of land coverage and use

The landscape of the ARW is characterized by a spatially heterogeneous mosaic and is marked by the influence of anthropogenic activities, which together occupy more than 60% of the territory. The native vegetation coverage, represented mainly by the DOF, is associated with the use agricultural and is strongly concentrated on the slopes of the

Serra Geral. The pioneer formations of the Restinga lie within the area of marine influence. Figure 3 shows maps with the results of the land coverage and use classifications for the years 2016 and 2023.

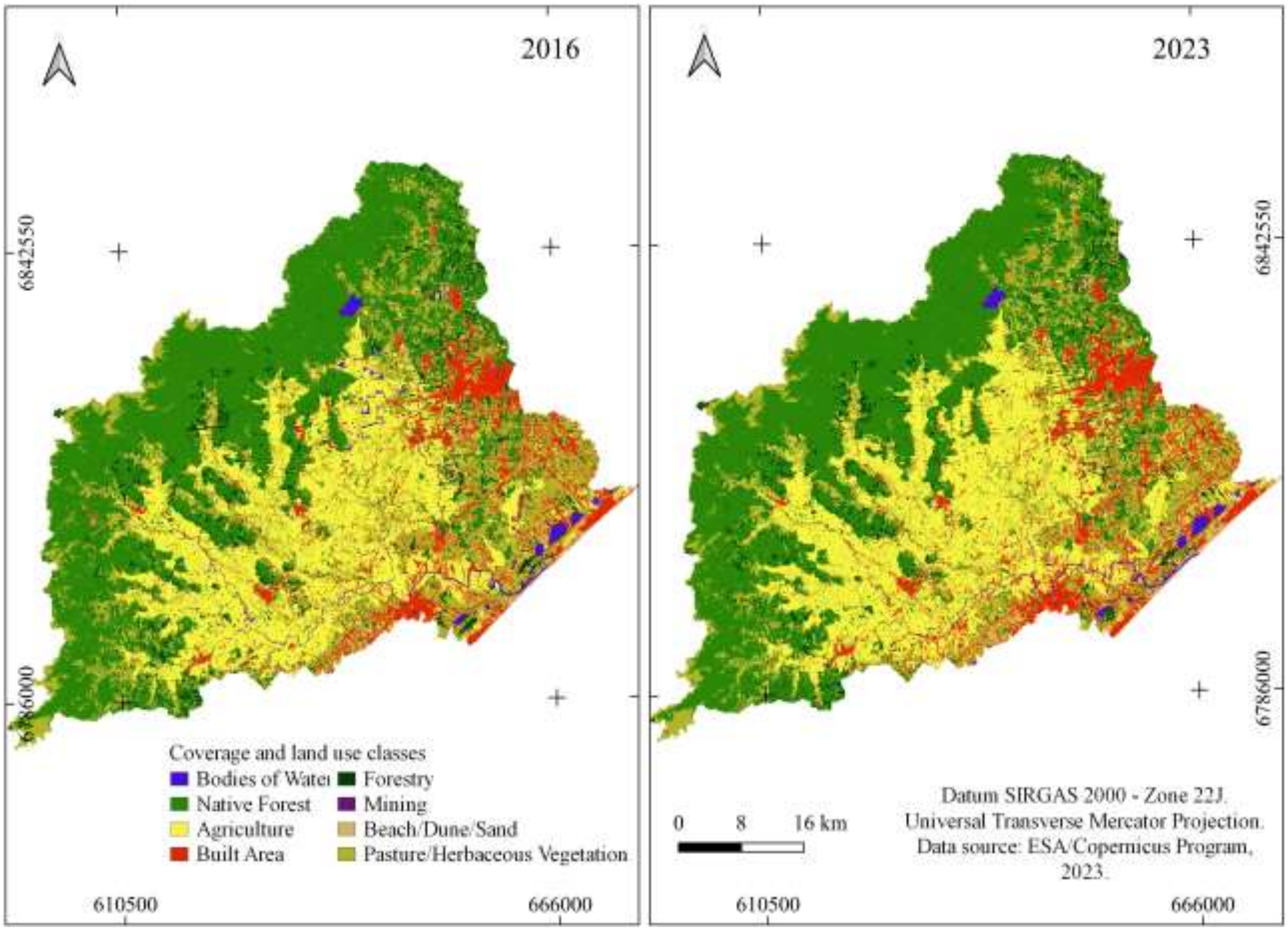


Figure 3 – Maps of ARW land coverage and use in the years 2016 and 2023.
Fonte: Authors (2023)

The area of the NF class was the most representative in the mapping in both years, followed by the AGR class. The first accounted for 34.45% in 2016 and 36.13% in 2023, with an area increase of 1.68% in the last seven years (Table 3). Most of the space that characterizes it is concentrated at higher altitudes because this physical condition hinders the advancement of the different forms of use in the landscape. The subtle increase in the areas of native forest also indicates the inapplicability of environmental legislation regarding the preservation of water bodies that, because of rice farming, cause the planting of irrigated rice to remain within the limits of water PPAs, occupying space that should be riparian forest (Figure 4). It is noteworthy that, owing to the reduced range of forest along the watercourses/rivers, the algorithm was unable to classify it as NF. Regarding areas destined for agricultural planting, the great extension of area destined to be a single form of occupation that has been maintained for more than a century was noted.

Table 3 – Area data and percentages of ARW land coverage and use classes.

Class	**2016**		**2023**		**Change (%)**
	Area (km²)	**Area (%)**	**Area (km²)**	**Area (%)**	
Bodies of water (BOW)	66.04	2.16	52.14	1.70	-0.46
Native forest (NF)	1,055.18	34.45	1,110.00	36.13	1.68

Agriculture (AGR)	762.52	24.89	814.46	26.51	1.62
Built Area (BA)	260.45	8.50	343.00	11.16	2.66
Forestry (FOR)	253.02	8.26	216.17	7.04	-1.22
Mining (MIN)	15.95	0.52	27.00	0.88	0.36
Beach/Dune/Sand (BDS)	22.95	0.75	52.93	1.72	0.97
Pasture/Herbaceous Vegetation (PHV)	627.19	20.47	456.55	14.86	-5.61
Totals	**3,063.30**	**100**	**3,072.25**	**100**	

Fonte: Authors (2023)

The other classes show percentages of territorial occupation lower than those listed above, where coal and sand mining areas obtained the lowest percentage in the two years. Considering the advances of human activities in recent years, the class that obtained the largest increase in the landscape of the basin since 2016 was BA, with a gain of 82.55 km².

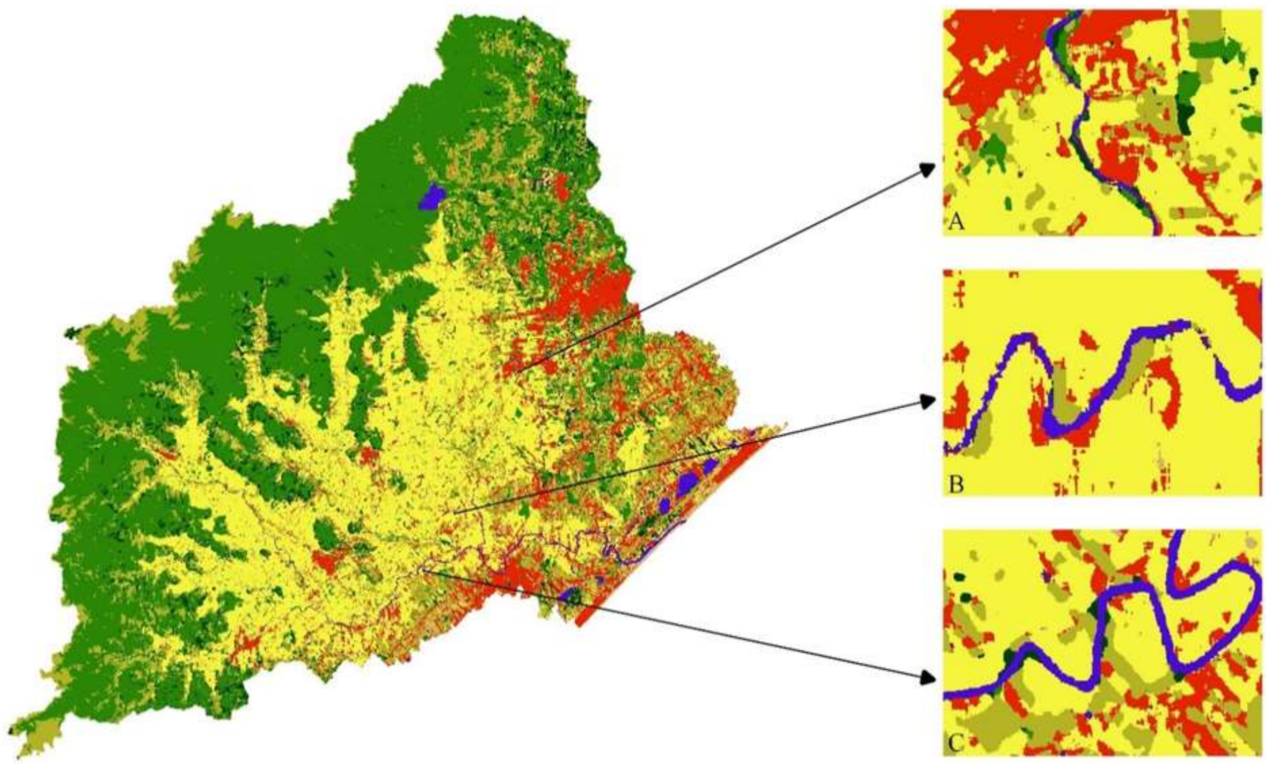


Figure 4 – Land coverage and use in water Permanent Preservation Areas (PPAs) in the year 2023. (A) Mãe Luzia River, (B) Manoel Alves River, and (C) Araranguá River.
Fonte: Authors (2023)

Another form of land use that increased was the AGR, occupying 1/4 of the total area of the basin, and it has advanced by 51.94 km² in the last seven years. Currently, it is considered the second most representative class, thus showing the traditional influence of agriculture on the spatiotemporal dynamics of the landscape. The smallest increases occurred in the MIN and BDS classes, with less than 1% each. Some forms of land use have had the areas converted to other anthropic activities. The PHV class, which reduced its area by about 170.64 km², stands out. Many areas of pasture/herbaceous vegetation have been replaced by urban sprawl, agricultural rice, and soybean crops planting, increasingly consolidating grain production in the region.

The results of the survey also revealed a drop in the areas that were intended for FOR. This class suffered a decrease of 36.85 km² in 2023 mainly because some areas have been abandoned, facilitating the successional process of native vegetation and even increasing NF areas, especially in places of higher altitudes. The areas occupied by BOW suffered a loss equivalent to 14.26km² in the last seven years.

Thus, the changes in the landscape of the basin (Figure 6) were more significant for the pasture areas, where from (a) to (c), it was observed that over the seven years the urban expansion (installation of allotments) occurred towards the PHV area; from (b) to (d), an increase of native forests towards pasture areas was noted. Substitution of areas destined for forestry to forested areas was also observed (Figure 6).

Regarding MIN class, the values have remained stable over the last seven years. This comprises areas of mineral extraction such as coal, sand, and clay extraction, which have negatively impacted the environment in the last century. Based on the data shown above, it can be inferred that the forms of land use that currently exist have undergone minor significant changes in the landscape of the basin.

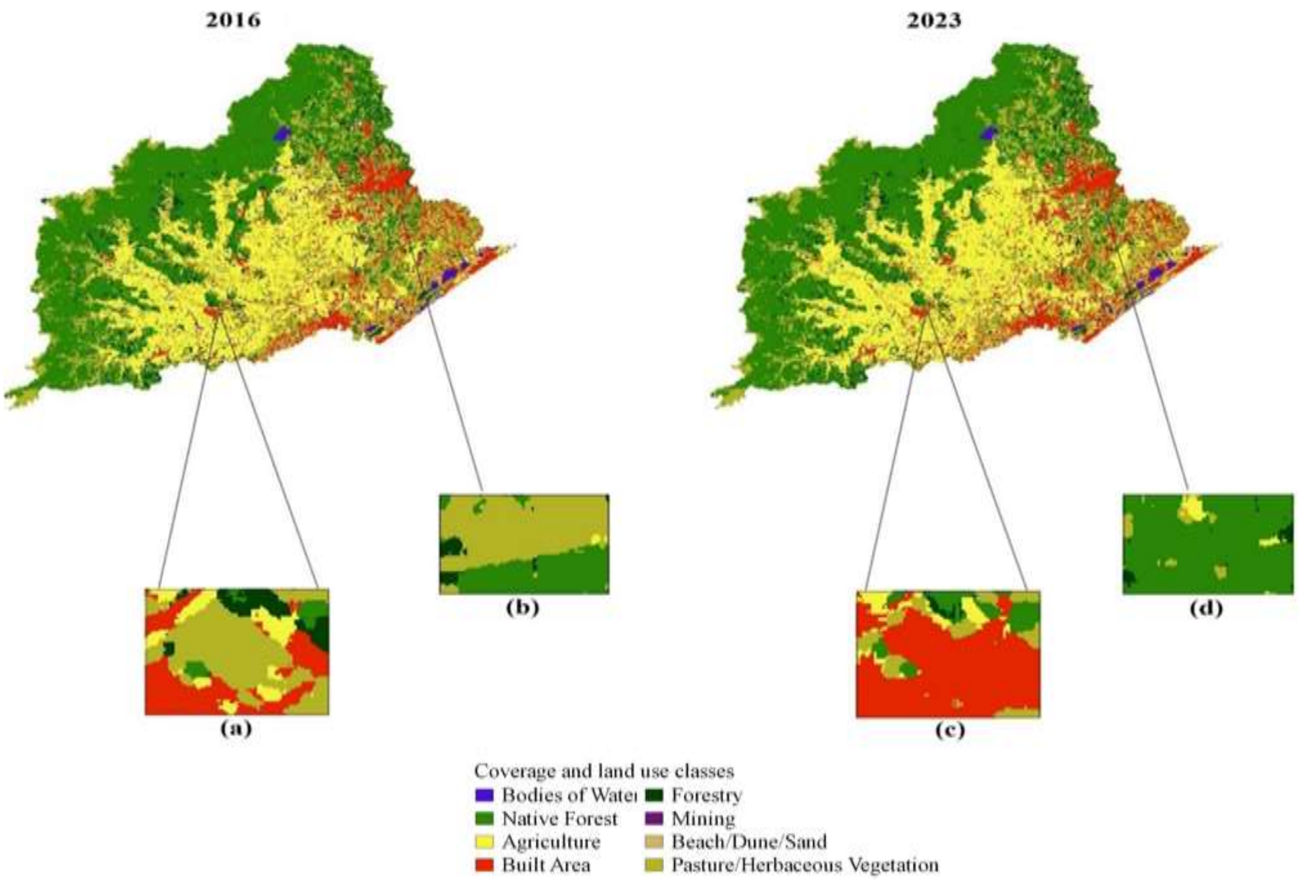


Figure 6 – Detections of changes in the Araranguá River Watershed land coverage and use. Increase of the Built Area class from (a) to (c) and of the Native Forest class from (b) to (d), in addition to the decrease of the Pasture or Herbaceous Vegetation class in (c) and (d).
Fonte: Authors (2023)

4. Discussion

The error matrix and accuracies associated with the Consumer, Producer, and Overall Accuracy should be the core elements of an evaluation of the accuracy of a classification (STEHMAN; FOODY, 2019). The similarity between the linear forms of civil constructions and rectangular geometry resulting from agricultural crops may have been a driver for some areas of the BA class being assigned to agricultural areas and vice versa. Moreover, this result can be attributed to the spectral similarity obtained by certain targets, where the classifier found it difficult to properly distinguish urban constructions from agricultural areas in a fallow state for certain crops such as beans, corn, and tobacco, an event that occurred in the region within the analyzed period.

Even so, the results indicate that the method based on decision trees effectively associated the pixels with the training samples in all classes, qualifying the classifications for the two years. The data generated validate other studies that used the Random Forest algorithm, where it provided high levels of accuracy when integrated with GEE (CARVALHO; FILHO; SANTOS, 2021; KOUASSI *et al*., 2023; ROSA, 2018).

The current scenario in ARW is the result of the European colonization process that occurred through the free labor of settlers from the installation of small properties (FERREIRA, 2020). Post-war state incentives (1945-1970) for coal production in the northwest portion of the basin (LADWIG; SILVA, OLIVEIRA, 2023) and, later, the National Program for the Rational Use of Irrigated Floodplains (PROVÁRZEAS) as an incentive to agricultural production accentuated environmental impacts. These public policies have had a remarkable impact on the modifications of the geographical space in the basin (SILVA, 2021).

The environmental problems caused by coal mining since the beginning of the last century have also manifested themselves in the contamination of soil, water and biota due to the amount of pollutants present in the activity's waste (PEDROSO-FIDELIS *et al*., 2020; ZOCCHE *et al*., 2010; ZOCCHE *et al*., 2023). Recent studies infer that the Rio Bonito and Leques alluvial aquifers, in the Santa Catarina coal region, still remain contaminated with high levels of pollutants due to coal mining (BELLETTINI, 2019).

Rice cultivation has caused major changes in the landscape, such as the removal of native forest on the banks of rivers, the leveling of land to obtain rectangular and homogeneous fields and the waterproofing of the soil, modifying the natural flow of water, and large quantities of chemical products with negative effects on aquifer recharge (COMASSETTO, 2008; PRESA, 2011; ROSSO, 2007). Hadlich (1997) and Gaidzinski (2001) stated that water returned to rivers compromises the quality of surface and groundwater. Currently, the largest irrigated rice cultivation areas are located in the municipalities that are part of the ARW, such as Meleiro (70.5%), Ermo (66.4%), Forquilhinha (59.9%), Turvo (59.5%) , New Venice (34.1%) and Maracajá (30.5%) (VIBRANS *et al*., 2021). It draws attention the fact that the activity still persists in the same way as in the past, benefiting from the natural resources existing in the landscape.

In the same trajectory and resulting from the two primary activities already highlighted comes urban expansion. Both the city of Criciúma and Araranguá act as regional poles of two associations of municipalities, the Association of Municipalities of the Coal Region (Associação de Municípios da Região Carbonífera - AMREC) and the Association of Municipalities of the Extreme South of Santa Catarina (Associação de Municípios do Extremo Sul Catarinense - AMESC). While the coal industry and agriculture promoted changes in the middle and upper third of the ARW, urban expansion in recent decades has occurred in several areas of the ARW, with a slight concentration in locations closer to the Atlantic Ocean and, therefore, linked to the lower middle third of the basin. Ladwig, Silva and Oliveira (2023) highlighted the intensification of urbanization and population growth leveraging the anthropogenic burden on natural resources.

Comparing the 2010 census with the last one carried out in 2022, among the municipalities of ARW, Criciúma, Araranguá, Forquilhinha and Balneário Arroio do Silva were the ones that increased the most in the number of inhabitants (IBGE, 2023). The population increase in the municipalities of Araranguá and Criciúma in recent years is justified by the fact that they are considered hub cities of two micro-regions. Forquilhinha also stood out for the development of agribusiness, and Balneário Arroio do Silva for housing people from other regions who retire and choose to acquire second home properties. Studies carried out in the coastal region of Southern Santa Catarina showed geometric population growth in recent decades (PEREIRA, 2023), being more significant towards lagoon complexes and permanent preservation areas (MARCON; ZOCCHE; LADWIG, 2017), leading to an increase in the load of pollutants in water bodies and damage to ecosystem services.

Regarding the conversion of pasture areas, Ladwig, Silva and Oliveira (2023) stated that these areas are dynamic and consequently different pressures are exerted on these spaces. In the case of the ARW, agriculture and fishing are not as representative as agriculture only in advancing in these areas (LADWIG; SILVA, OLIVEIRA, 2023). The losses of the FOR class that occurred for the NF class are convenient, as these help in biological conservation since forestry positively influences the structural connectivity of the landscape, especially when it shows a reduction of forest remnants (SCUSSEL *et al*., 2020). Regarding land cover in the ARW, the results of the present study are similar to those reported by Vibrans *et al*. (2021), where in 2017 ARW's forest coverage was approximately 30%.

Although there is a larger area designated for vegetation cover in the ARW, it is concentrated in specific locations. A small portion is part of Conservation Units such as the Aguaí State Biological Reserve to the north and the Serra Geral National Park to the south. A large part of the Atlantic Forest remnants still existing in the basin (especially those located on mountain slopes) are outside protected areas (SILVA, 2021). For Scheibe, Buss and Furtado (2010), the preservation of the forest in escarpment areas is relevant, not only for the rich biodiversity, but also for the protection against erosion processes and the regularization of rivers, whose sources are concentrated on the slopes and run through short paths.

Changes in the native forest coverage of the Atlantic Forest biome and its spatial distribution increased forest isolation in 36.4% of the landscapes (ROSA *et al*., 2021). Vibrans *et al*. (2013) inferred that, due to the process of logging that has occurred since the beginning of colonization, the forest coverage of the Atlantic Slope of Santa Catarina has undergone simplification in its structure. This scenario may be observed in the basin plain, where the remnants of native forest are few and very fragmented.

It is possible to argue that much of the environmental degradation in the analyzed area is a consequence of predatory exploitation that occurred in the past and, in some cases, still occurs, negatively impacting the environment. In essence, it is worth mentioning urban expansion, agriculture and coal mining as the current main agents of environmental degradation in ARW. Understanding the agents that modify space is necessary and indispensable for the planning and environmental management of the territory (RODRIGUES; MEDEIROS, 2022). On the other hand, direct participatory democracy still has flaws given the population's low concern about environmental issues (HAMMES et al., 2022).

5. Final considerations

The classification methods adopted made it possible to identify the main changes in the ARW landscape resulting from human activities. The methodology applied to classify land cover and use using open and freely available data in GEE proved to be sufficiently robust to detect changes over seven years, especially in areas with dense and herbaceous native forest vegetation. The validation and accuracy of the classifications, as well as the maps generated from the use of pixel-based decision trees, showed efficiency and met the objectives of the present study.

The changes detected today are succinct, as the most relevant changes in landscape dynamics were observed in past decades, where environmental issues were not observed. This condition signals the acceptance of scientific research by managers who take it as a logical subsidy in decision-making, as well as the process of adapting to environmental legislation, where through environmental agencies it is possible to put into practice the conservation and preservation of natural resources. The results obtained here can be useful to public policy formulators and decision makers with regard to environmental planning of the territory, aiming at sustainable development.

Acknowledgments

The authors wish to thank the State Fund for Support to the Maintenance and Development of Higher Education (Fundo Estadual de Apoio à Manutenção e ao Desenvolvimento da Educação Superior - FUMDES) of Santa Catarina, the Coordination for the Improvement of Higher Education Personnel - Brazil (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES) - Financing Code 001, and the Graduate Program in Environmental Science (Programa de Pós-Graduação em Ciência Ambiental - PROCAM). José Alberto Quintanilha and Carlos Henrique Grohmann are CNPq productivity fellows (procs. 305188/2020-8 and 311209/2021-1).

References

Altieri, M. A. *Agroecologia*: a dinâmica produtiva da agricultura sustentável. 3. ed. Porto Alegre: Ed. Da Universidade FRGS, 2001.

Alvares, C.A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. L. M.; Sparovek, G. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, [S.L.], v. 22, n. 6, p. 711-728, 2013. http://dx.doi.org/10.1127/0941-2948/2013/0507

Araújo, M. C. F; Meneses, P. R.; Sano, E. E. Sistema e classificação de uso e cobertura da terra com base na análise de imagens de satélite. *Revista Brasileira De Cartografia*, v. 59 (2), 2009. https://doi.org/10.14393/rbcv59n2-44902

Back, A. J. *Informações climáticas e hidrológicas dos municípios catarinenses (com programa HidroClimaSC)*. Florianópolis: Epagri, 2020.

BELLETTINI, A. S. *Avaliação da contaminação proveniente da mineração de carvão nas águas subterrâneas na Bacia Hidrográfica do rio Araranguá – SC*, 2009. 65f. Dissertação (Mestrado em Ciências). Programa de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre-RS, 2009. http://hdl.handle.net/10183/224067

Brasil. *Decreto nº 86.146, de 23 de junho de 1981*. Dispõe sobre a criação do Programa Nacional para Aproveitamento de Várzeas Irrigáveis - PROVÁRZEAS NACIONAL. Brasília, DF: Presidência da República, 1981. Disponível em: https://legislacao.presidencia.gov.br/atos/?tipo=DEC&numero=86146&ano=1981&ato=c15UzaU90MrRVTed1. Acesso em: 15 ago. 2023.

Campos, S. N. *Uma biografia com um pouco de história do carvão catarinense*. Florianópolis: Insular, 263 p., 2001.

Carvalho, W. S; Filho, F. J. C. M.; Santos, T. L. Uso e cobertura do solo utilizando a Plataforma Google Earth Engine (GEE): Estudo de caso em uma Unidade de Conservação. *Brazilian Journal of Development*, v. 7 (2), 15280 – 15300, 2021. https://doi.org/10.34117/bjdv7n2-243

COMASSETTO, V. *Água, meio ambiente e desenvolvimento na bacia do Araranguá (SC)*, 2008. 339f. Tese (Doutorado em Geografia). Programa de Pós-Graduação em Geografia, Universidade Federal de Santa Catarina, Florianópolis-SC, 2008. http://repositorio.ufsc.br/xmlui/handle/123456789/91353

Conterato, M. A. *Estudo da ação antrópica sobre o meio ambiente em área de produção familiar na Bacia Hidrográfica do rio Ibicuí/RS* - uma aplicação do zoneamento na perspectiva do desenvolvimento ambiental Boletim Gaúcho de Geografia, v. 26, 226 – 231, 2000.

Dall'Alba, J. A. *História do grande Araranguá, SC*. Gráfica Orion Editora, 519 p., 1997.

ESA - European Space Agency. *Sentinel-2 user handbook*. 1.ed. Darmstadt: ESA, 64 p., 2015.

Drusch, M. *et al*. Sentinel-2: ESA's optical high-resolution mission for GMES operational services. *Remote sensing of Environment*, 120, 25-36, 2012.

Ferreira, L. M. S. Estrutura fundiária e concentração da propriedade da terra na colônia de imigrantes Dona Francisca (Joinville), Santa Catarina, 1850-1920. *Estudos Econômicos* (São Paulo), v. 50 (3), p. 485 – 512, 2020. https://doi.org/10.1590/0101-41615034lmsf

Ferreira, A. T. S. *et al*. Coastal Dynamics Analysis Based on Orbital Remote Sensing Big Data and Multivariate Statistical Models. *Coasts*, 3 (3), 160-174, 2023. https://doi.org/10.3390/coasts3030010

Florenzano, T. G. *Imagens de satélite para estudos ambientais*. São Paulo: Oficina de Textos, 97 p., 2002.

Gonzalez, R. C.; Woods, R. E.; Eddins, S. L. *Digital Image Processing Using MATLAB®*. Pearson Education Inc., 2009.

Gorelick, N. *et al*. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, v. 202, p. 18 – 27, 2017.

Hammes, H. F. *et al*. Impressions of public opinion on environmental licensing and popular participation in decisions regarding the design and implementation of public management practices. *Brazilian Journal of Environmental Sciences*, v. 57 (4), p. 555 – 569, 2022.

Hobold, P. *A história de Araranguá*: reminiscências desde os primórdios até o ano de 1930. Porto Alegre: Palmarinca, 255 p., 1994.

IBGE. Instituto Brasileiro de Geografia e Estatística. *Censo populacional de 2022*. Disponível em: https://cidades.ibge.gov.b Acesso em: 15 ago. 2023.

Jiang, Z. *et al*. Development of a two-band enhanced vegetation index without a blue band. *Remote sensing of Environment*, v. 112 (10), 3833-3845, 2008.

Klein, R. M. *Mapa fitogeográfico do Estado de Santa Catarina*. Itajaí: Herbário Barbosa Rodrigues, 1978.

Kouassi, C. J. A. *et al*. Google Earth Engine for Landsat image processing and assessing LULC classification in southwestern Côte D'ivoire. *Geodesy and Cartography*, v. 49 (1), p. 37 – 50, 2023. https://doi.org/10.3846/gac.2023.16805

Krebs, A. S. J. *Contribuição ao conhecimento dos recursos hídricos subterrâneos da bacia hidrográfica do rio Araranguá, SC*, 2004. 375f. Tese (Doutorado em Geografia). Centro de Filosofia e Ciências Humanas, Universidade Federal de Santa Catarina, Florianópolis-SC, 2004. http://repositorio.ufsc.br/xmlui/handle/123456789/87645

Krebs, A. S. J.; Alexandre, N. Z. Recursos hídricos da bacia hidrográfica do rio Araranguá - SC: disponibilidade e conflitos. *Águas Subterrâneas* (São Paulo, Brazil), 2000.

Ladwig, N. I.; Silva, J. G. S.; Oliveira, A. J. M. *Alteração Antrópica nas Bacias Hidrográficas do Rio Araranguá e Urussanga*. São Carlos: Pedro & João Editores, 2023, 200 p. DOI: 10.51795/9786526507117

Marcon, L., Zocche, J., & Ladwig, N. O crescimento e espalhamento urbano da cidade de Araranguá, estado de Santa Catarina, de 1957 a 2010 e as consequências ambientais. *Revista Brasileira de Ciências Ambientais* (Online), v. 43, 32 – 48, 2017. https://doi.org/10.5327/Z2176-947820170078

Martins S. F.S. *et al*. Processamento Digital de Imagens para Mapeamento de Uso e Cobertura da Terra: Uma Revisão de Literatura. *Rev. Geociênc. Nordeste*, Caicó, v.9, n.2, (Jul-Dez) p.131-143, 2023.

Pedroso-Fidelis, G.S. *et al*. Pulmonary oxidative stress in wild bats exposed to coal dust: a model to evaluate the impact of coal mining on health. *Ecotoxicology and Environmental Safety*, v. 191, p. 110211, 2020. https://doi.org/10.1016/j.ecoenv.2020.110211

Pereira, J. R. *Sustentabilidade socioambiental das lagoas costeiras no sul do estado de Santa Catarina*, 2023. 153f. Tese (Doutorado em Ciências Ambientais). Programa de Pós-Graduação em Ciências Ambientais, Universidade do Extremo Sul Catarinense, Criciúma-SC, 2023.

PERHSC. Plano estadual de recursos hídricos de Santa Catarina. *Caracterização geral das regiões hidrográficas de Santa Catarina*. RH10 – Extremo Sul Catarinense, 2017.

Presa, J. B. "*O arroz no espigão e o milho no banhado*": programa Provárzeas – O desenvolvimento de uma política pública e o cultivo do arroz em municípios da bacia do rio Araranguá, 2011. 195f. Dissertação (Mestrado em História). Programa de Pós-Graduação em História, Universidade Federal de Santa Catarina, Florianópolis-SC, 2011. http://repositorio.ufsc.br/xmlui/handle/123456789/95384

Rodrigues, J. P. B; Medeiros, W. D. A. Uso e ocupação do solo no município de Mossoró/RN (1998-2018). *Rev. Geociênc. Nordeste*, Caicó, v.8, n.2, (Jul-Dez) p.1-12, 2022.

Rosa, M. R. *et al.* Hidden destruction of older forests threatens Brazil's Atlantic Forest and challenges restoration programs. *Science advances*, v. 7 (4), p. 1 – 8, 2021.

Rosa, M. R. Classificação do padrão de ocupação urbana de São Paulo utilizando aprendizagem de máquina e Sentinel 2. *Revista do Departamento de Geografia*, 15 – 21, 2018.

Rosso, J. C. *Avaliação do Consumo de Água em Lavoura de Arroz Irrigado no Sistema Pré-Germinado nas Condições Climáticas do Sul*. 2007, 64f. Dissertação (Mestrado em Ciências Ambientais). Programa de Pós-Graduação em Ciências Ambientais, Universidade do Extremo Sul Catarinense, Criciúma-SC, 2007.

Santa Catarina. *Lei n. 10.949, de 09 de novembro de 1998*. Dispõe sobre a caracterização do Estado em 10 (dez) Regiões Hidrográficas. Florianópolis, SC, 1998. Disponível em: https://www.aguas.sc.gov.br/jsmallfib_top/DHRI/Legislacao/Lei-Estadual-10949-1998.pdf. Acesso em: 23 ago. 2023.

Scheibe, L. F. (Org.); Buss, M. D.; Furtado, S. M. A. Atlas Ambiental Bacia do Rio Araranguá: Santa Catarina - Brasil. Florianópolis: Ed. UFSC: Cidade futura, 2010, 64 p.

Scussel, C. *et al*. Fragmentação florestal em área de Mata Atlântica no sul do Brasil: uma análise baseada em métricas da paisagem. *Geografia, Ensino & Pesquisa*. vol. 24 (45), 2020. https://doi.org/10.5902/2236499443836

Silva, J. G. S. *Cobertura e uso da terra na Bacia Hidrográfica do rio Araranguá, Santa Catarina, Brasil*, 2021. 164f. Dissertação (Mestrado em Ciências Ambientais). Programa de Pós-Graduação em Ciências Ambientais, Universidade do Extremo Sul Catarinense, Criciúma-SC, 2021. http://repositorio.unesc.net/handle/1/9103

Silva, J. G. S. *et al*. Aplicação de protocolo de avaliação rápida da integridade ambiental na Bacia Hidrográfica do Rio Araranguá, SC. *Boletim Paulista de Geografia*, v. 109 (1), p. 147 – 171, 2023.

Stehman, S. V.; Foody, G. M. Key issues in rigorous accuracy assessment of land cover products. *Remote Sensing of Environment*, v. 231, 111199, 2019. https://doi.org/10.1016/j.rse.2019.05.018

Vibrans, A. C. *et al*. *Inventário Florístico Florestal de Santa Catarina*: Floresta Ombrófila Densa. Blumenau: Edifurb, 2013.

Vibrans, A. C. *et al*. MonitoraSC: um novo mapa de cobertura florestal e uso da terra do estado de Santa Catarina. *Agropecuária Catarinense*, v. 34 (2), p. 42-48, 2021.

Vogel, H. F.; Zawadzki, C. H.; Metri, R. Florestas ripárias: importância e principais ameaças. *SaBios-Revista de Saúde e Biologia*, v. 4 (1), 2009. https://revista2.grupointegrado.br/revista/index.php/sabios/article/view/143

Xu, H. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *Int J Remote Sens*, 27:3025–3033, 2006.

Zha, Y.; Gao, J.; & Ni, S. Use of normalized differene built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing*, v. 24 (3), p. 583 – 594, 2003.

Zocche, J.J. *et al*. Heavy metals and DNA damage in blood cells of insectivores bats in coal mining areas of Catarinense coal basin, *Brazil. Environ. Res*. v. 110, 684–691, 2010. https://doi.org/10.1016/j.envres.2010.06.003

Zocche, J.J. *et al*. Technosols in coal mining areas: Viability of combined use of agroindustry waste and synthetic gypsum in the restoration of areas degraded. *Cleaner Engineering and Technology*, v. 13, p. 100618, 2023. https://doi.org/10.1016/j.clet.2023.100618