ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 10, nº 2 (2024)

https://doi.org/10.21680/2447-3359.2024v10n2ID33545

Anthropic Transformation Index (ATI) applied to the Araranguá river hydrographic basin, Santa Catarina, between 1985, 2005 and 2019

Índice de Transformação Antrópica (ITA) aplicado à bacia hidrográfica do rio Araranguá, Santa Catarina, entre os anos de 1985, 2005 e 2019

José Gustavo Santos da Silva[1]; Nilzo Ivo Ladwig[2]; Álvaro José Back[3]

[1] University of the Extremo Sul Catarinense, Postgraduate Program in Environmental Sciences, Criciúma/SC, Brazil. Email: gustasantos92@gmail.com
ORCID: https://orcid.org/0000-0003-0578-8266

[2] Federal University of Santa Catarina, Postgraduate Program in Geography, Florianópolis/SC, Brazil. Email: ladwignilzo11@gmail.com
ORCID: https://orcid.org/0000-0003-3031-0192

[3] Agricultural Research and Rural Extension Company of Santa Catarina, Urussanga, SC, Brazil. Email: ajb@epagri.sc.gov.br
ORCID: https://orcid.org/0000-0002-0057-2186

Abstract: Studies of land cover and use are essential for land planning and management, especially when the aim is to represent landscape dynamics. The aim of the present study is to understand and quantify the transformations that occurred in the Araranguá River hydrographic basin in the state of Santa Catarina, Brazil, in three different periods (1985, 2005 and 2019). The methodology was done in two phases. In the first phase, a multitemporal analysis of land cover and use was carried out with the application of the regional method to thematically classify LANDSAT 5 and 8 satellite images. To process the images, the QGIS, ArcGIS 10.3 and IDRISI Selva software were used. In the second phase, the Anthropic Transformation Index (ATI) was used after the thematic classification with the aim of understanding the anthropic influence on the land being analyzed. Results indicated that, during the 35 years covered by the study, the class pastures and creeping vegetation underwent the greatest reduction in terms of total area (-532.29 km^2), while agricultural areas (of the exposed soil type) increased significantly (521.97 km^2). Other classes that presented a reduction were those of mining extraction areas (-29.15 km^2) and dunes and sands (-7.00 km^2). The ATI was classified as “average degradation” for the basin as a whole in all the years analyzed, with values varying between 3.15 in 1985, 3.52 in 2005 and 3.49 in 2019.

Keywords: Geoprocessing; Remote Sensing, Multitemporal Analysis.

Resumo: Os estudos de cobertura e uso da terra são fundamentais para o planejamento e gestão territorial, especialmente quando se busca representar a dinâmica da paisagem. Este estudo teve como objetivo compreender e quantificar as transformações ocorridas na bacia hidrográfica do Rio Araranguá, no estado de Santa Catarina, Brasil, ao longo de três períodos distintos (1985, 2005 e 2019). A metodologia utilizada consistiu em duas etapas. Na primeira etapa, foi realizada uma análise multitemporal da cobertura e uso da terra, utilizando o método de regiões para classificação temática das imagens de satélite LANDSAT 5 e 8. Para processamento das imagens, foram empregados os softwares QGIS, ArcGIS 10.3 e IDRISI Selva. Na segunda etapa, foi aplicado o Índice de Transformação Antrópica (ITA) após a classificação temática, com o objetivo de entender a influência antrópica sobre o território em análise. Os resultados indicaram que, ao longo dos 35 anos abordados pelo estudo, a classe de pastagem e vegetação rasteira foi a mais reduzida em termos de área total (-532,29 km^2), enquanto as áreas agrícolas (tipo solo exposto) cresceram significativamente (521,97 km^2). Outras classes que apresentaram redução foram as áreas de extração mineira (-29,15 km^2) e áreas de dunas e areais (-7,00 km^2). O ITA foi classificado como "degradação regular" para a bacia como um todo em todos os anos de análise, com valores variando entre 3,15 em 1985, 3,52 em 2005 e 3,49 em 2019.

Palavras-chave: Geoprocessamento; Sensoriamento Remoto; Análise Multitemporal.

Received: 08/08/2023; Accepted: 20/03/2024; Published:19/07/2024.

1. Introduction

Society's use of land has impacted its original conditions and characteristics. Humans have modified their dwelling spaces to adapt them to their needs, often without much adequate planning. This results in alterations in the natural characteristics of land cover (BEPPLER; JUSTINO, 2017). Assessing these changes in the landscape is essential for efficient land planning and management since these studies can give support to decisions related to the use and conservation of nature.

For this assessment, it is crucial to count on precise cartographic information that depicts cover dynamics and land use, as well as the transformations in the landscape of a specific territory. In the present study, the territorial unit under analysis is the Araranguá River hydrographic basin (ARHB). Hydrographic basins have stood out as units for analysis because they are water resource management units according to legislation (SCHUSSEL; NASCIMENTO NETO, 2015). Hence, they should be considered units that need to be studied in scientific research as a means to constantly improve the quality of the biotic, abiotic and social environment, which are integral parts of this geographic space. Therefore, a hydrographic basin is a territory where human activity occurs. All urban, industrial, agricultural or preservation areas are part of a hydrographic basin and hence are a relevant planning unit (PORTO; PORTO, 2008).

The methodology for analysis used in this study is based on two different phases. Initially, a multitemporal analysis of land coverage and management will be performed to understand the landscape dynamics of this basin. This type of analysis has been used in scientific studies since the 1950s and gained relevance with developments in remote sensing. The continuous gathering of satellite images of the earth's surface allows for the broad detection and analysis of changes of land cover and landscape dynamics.

During the second phase, another methodology will be applied, called the Anthropic Transformation Index (ATI). The use of this methodology is made possible with the data obtained by multitemporal analysis. This methodology was proposed by Lémechev (1982) and modified by Rodriguez (1991); it aims at understanding the anthropic pressures suffered by the territory under study, quantifying the degree of landscape modification by taking land use into consideration. The ATI is an objective tool that provides information regarding human action in a specific geographic space (Gomes & Sobrinho, 2018). Cover classification and the ATI are complementary methodologies for environmental analysis.

Therefore, the aim of this research is to analyze the changes in land cover and use of the ARHB in a multitemporal way, as well as the anthropic pressures the basin is going through with the application of the ATI.

2. Location and Characterization of study área

The territory for this study was determined as being the Araranguá River Hydrographic Basin, located in the south of the state of Santa Catarina (Figure 1). The basin's watersheds are the Mampituba River Hydrographic Basin (MRHB) to the south, the Urussanga River Hydrographic Basin (URHB) to the north, the Atlantic Ocean to the east and the cliffs of the Serra Geral to the west. The Serra Geral is the main watershed of the hydrographic network in the south of Santa Catarina, directing the basins to the east of its cliffs to the Atlantic Ocean branch. The area occupied by the basin is approximately 3,071 km² (KREBS, 2004; COMASSETO, 2008; PERH/SC, 2017).

The basin has three different forms of land occupation and use: the strong influence of agropastoral interests, especially irrigated rice culture; the mineral extraction of coal and other minerals; and the intensification of urbanization and the growth of the population residing throughout the basin. Hence, the anthropic load on resources is compounded with the demand for sewage and drinking water for consumption and irrigation.

Krebs (2004); Scheibe; Buss and Furtado (2010) state that the water resources in the region have been greatly harmed and estimate that 2/3 of these resources are polluted in some form and improper for use. This is not limited only to the ARHB but includes the three basins that drain the coal mining region in the south of Santa Catarina. Santos da Silva et al., (2003) point out that the environmental quality of the ARHB can be classified as having suffered impacts in its lower course, being altered in its middle course and being natural in its upper course.

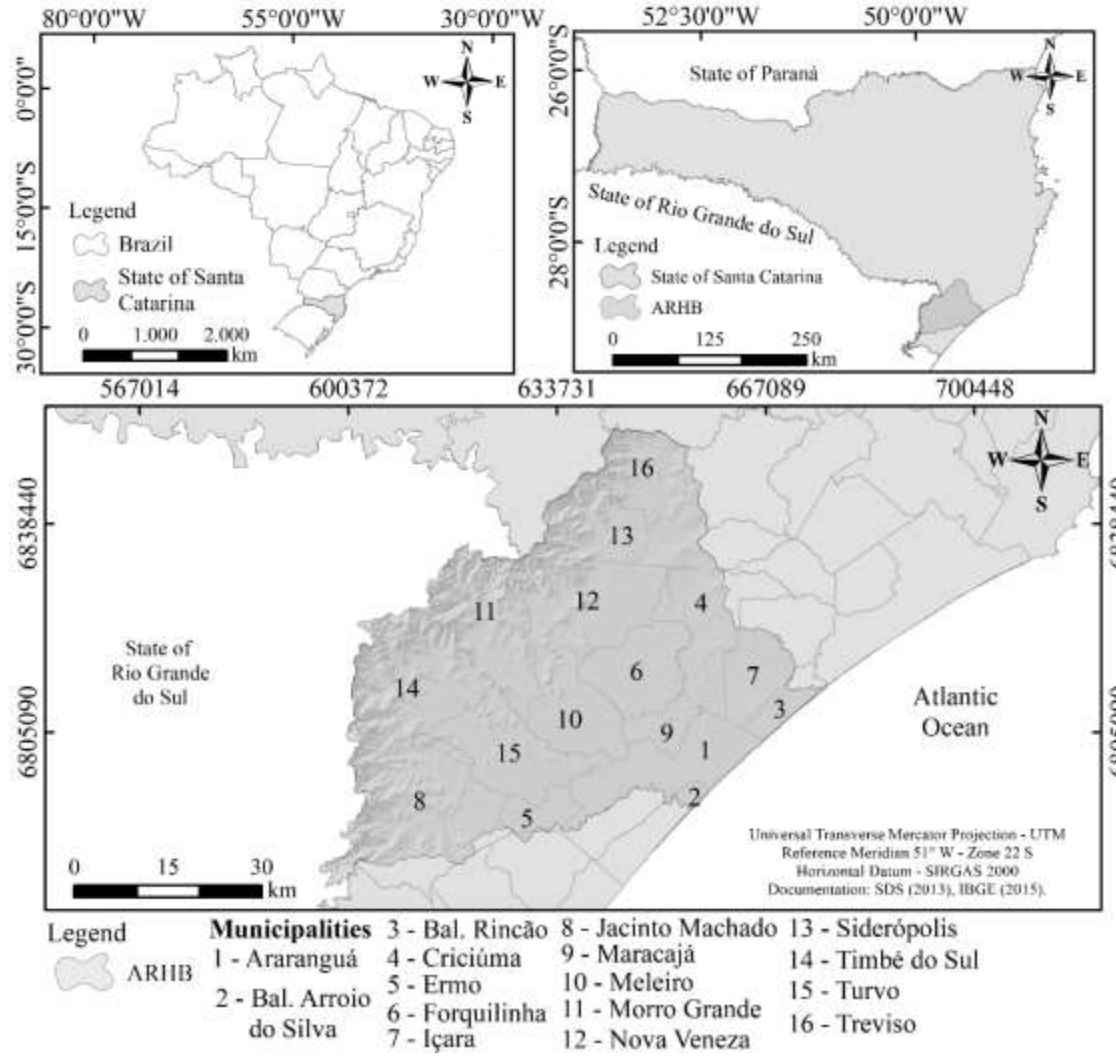

Figure 1 – Geographical localization of the Araranguá River Hydrographic Basin
Source: Authors (2024).

As for the climate, the ARHB presents two climatic types according to the Köeppen classification. Mostly, the basin presents a humid mesothermic subtropical climate (Cfa), with hot summers; while more elevated areas present a humid mesothermic temperate climate (Cfb) with mild summers (Figure 2A). Areas with the Cfa climate have an annual average temperature that varies from 17.0 to 19.3°C (Figure 2 B), and the total annual rainfall varies between 1,220 and 660 mm (Figure 2C). Areas with the Cfb climate present annual average temperatures that vary between 11.4 and 17.9°C (Figure 2 B) (ALVARES et al., 2014).

The terrain of the ARHB is distributed in altitudes between 0 and 1,500 m (Figure 3A) and occupy spaces from the Coastal Plains to the cliffs of the Serra Geral, with planes varying from slightly undulating, undulating, steeply undulating to mountainous (SANTA CATARINA, 1986). The basin's pedologic formations are seen in nine types of soils (Figure 3B). The most expressive in terms of area are the Argisoils, Cambisoils, Gelisoils, Neosoils (EMBRAPA, 2018). The ARHB is found in hydrographic region number 10 (RH 10 Extreme south of Santa Catarina) (BACK, 2014). Its waters flow into the mouth of the Atlantic and its main source is found in the Serra Geral region (Figure 3C) where average altitudes vary from 1,200 to 1,400 m (SANTA CATARINA, 1986). The main river (Araranguá) is the largest recipient, draining the volume of water that comes from the other affluents that form the basin. According to Santos da Silva et al., (2023), the large volume of water that flows from the affluents of the basin end up carrying contaminants caused by anthropic activities such as irrigated rice crops, urban-industrial waste, solid waste, acid drainage from mines and heavy metals that come from coal mining areas.

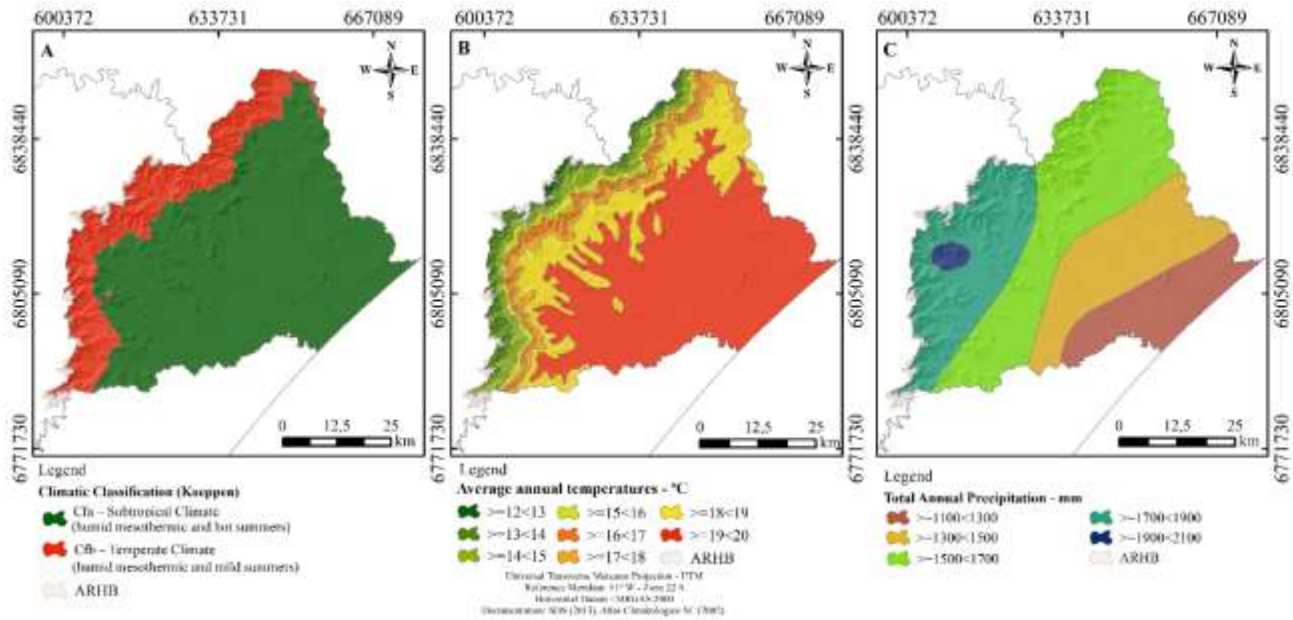

Figure 2 – Distribution of climatic types Cfa and Cfb (A), annual average temperatures (B) and annual total rainfall (C) of the Araranguá River Hydrographic Basin, south of Santa Catarina, Brazil.
Source: Authors(2024).

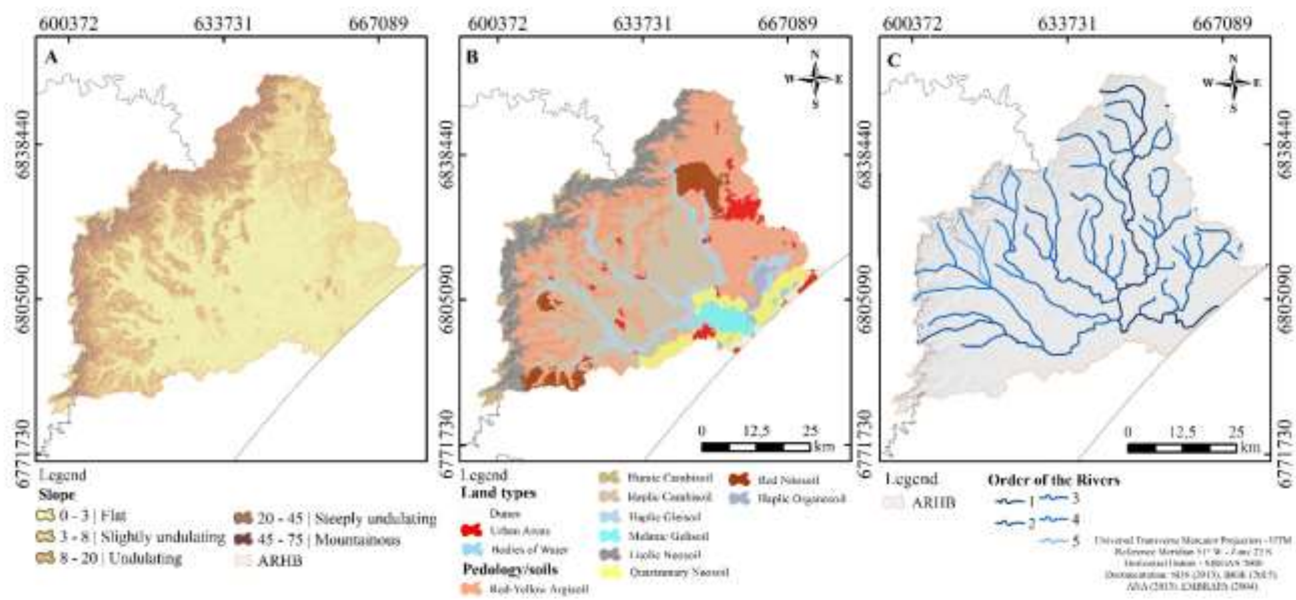

Figure 3 – Slope (A), pedologic formations (B) and hydrography (C) of the ARHB, south of Santa Catarina, Brazil.
Source: Authors(2024).

3. Methodology

3.1 Digital processing of images

The synthesis of the digital processing of images can be seen in Figure 4.

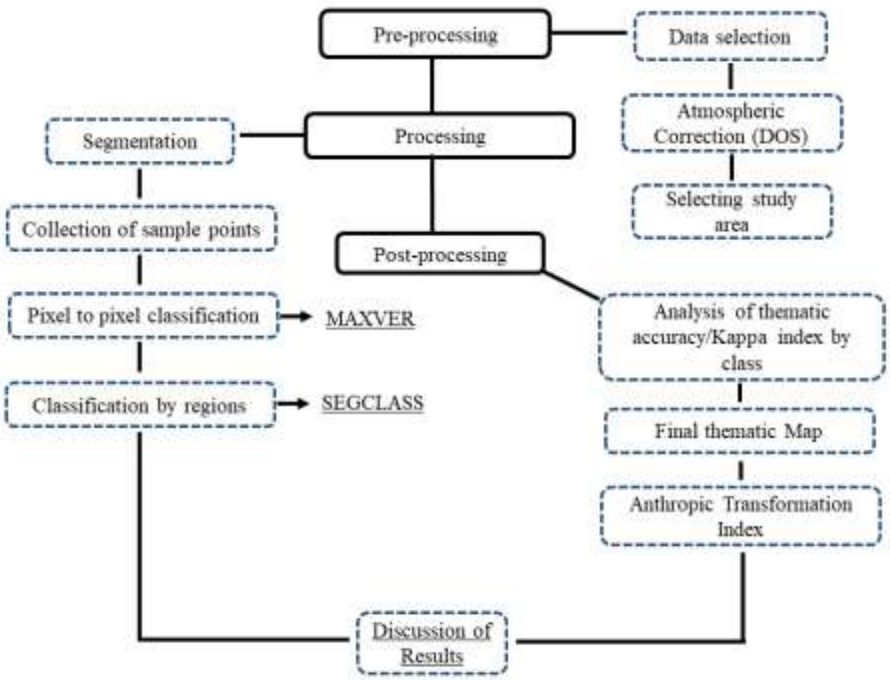

Figure 4 – Flowchart of digital processing of images.
Source: Authors (2024).

The images were obtained from the Earth Explorer site image bank of the *United States Geological Survey* (USGS) derived from the Landsat 5 and 8 earth imaging system. The general characteristics of the images can be seen in Table 1. The 2019 images were chosen because there were no images found in 2020 without cloud coverage during the period aimed for.

Sensor	Date of image acquisition	Orbit/point	Spatial Resolution	Radiometric Resolution	Temporal Resolution	Bands used
Landsat 5 - TM	7/9/1985	220/80	30 m	8 bits	16 days	1(B)2(G) 3(R)4(IR)
Landsat 5 - TM	5/29/2005	220/80	30 m	8 bits	16 days	1(B)2(G)3(R)4(IR)
Landsat 8 - OLI	6/5/2019	220/80	30 m	16 bits	16 days	2(B)3(G) 4(R)5(IR)

Table 1 – Characteristics of the Landsat images used.
Source:Earth Explore/USGS

The pre-processing phase began with the definition of images and bands. After defining bands and the dates of images, the phase for distinguishing thematic classes began. Eight classes were defined by means of the photointerpretation key technique. This phase consists of differentiating the elements of the landscape that will be classified through visual interpretation (JENSEN, 2009). These are: urban texture, agricultural area (exposed soil type), pastures and creeping vegetation, tree/bush vegetation, areas of mineral extraction, bodies of water, dunes and sands, and shade. The names of classes was based on a program called *CORINE land Cover* (*Co-ordination of Information on the Environment*) created in 1985 by the European Committee. After selection, the bands were imported to the QGIS 3.14.0 “pi” software where they were registered, reprojected to the Datum SIRGAS 2000 and corrected atmospherically with the DOS (*Dark Object Subtraction*) method.

For image classification, the region methodology classification was used, following the recommendations of Mastella and Vieira (2018). In this methodology the image is segmented or divided into regions, a process which consists of grouping pixels with similar characteristics (BRITES et al., 2012). The procedure used the segmentation tool and was based on bands 1/2/3/4 for the TM sensor and bands 2/3/4/5 for the OLI sensor. A similarity index equal to 1 and a 3x3 scan were used.

After image segmentation, the SegTrain tool was used, in which the segments generated are crossed with an image in false color composition to carry out the training sample collection in the segments and generate a signature folder for each class where an ID (identifier) and the respective class name is attributed.

With the determination of the signature folder, the process of classifying images pixel by pixel begins, using the Maximum Likelihood Method (MAXVER). The last phase used the image classified pixel by pixel as the basis for a reclassification in segments (classification by regions) using the SEGCLASS tool (MASTELLA; VIEIRA, 2018) this type of classification is seen as supervised.

The mapping validation was conditioned to the Kappa coefficient and global accuracy. These indices evaluate the total accuracy of mapping. Landis and Koch (1977) developed the intervals of the Kappa index connected to the quality level of the thematic mapping, varying from 0 to 1. The results obtained by the Kappa index can be seen in Table 2 below.

Year	Kappa	Global Accuracy	Mapping Quality
1985	0,8933	0,9067	Excellent
2005	0,8819	0,8967	Excellent
2019	0,8933	0,9067	Excellent

Table 2 – Kappa Values and Global Accuracy.
Source: Authors (2024).

3.2 ATI Calculation

Após a classificação After classification and final mapping of land cover and use, the second phase of the study begins. This consists of applying the ATI calculation in which land use classes are entered. The ATI calculation was performed following directions carried out in the studies by Mateo Rodriguez (1991). The aim is to provide information regarding the anthropic pressure of each class that was mapped. Therefore, without previously classifying land cover and use, the ATI cannot be applied.

The studies developed by Mateo Rodriguez (1991) propose the following equation for ATI calculations:

$$ATI = \sum (\%USExWEIGHT)/100 \qquad \text{Eq.}$$

Where:

USE: refers to the area in percentage values of the class of land cover and use;

WEIGHT: is the weight given to the different types of cover and use as to the degree of anthropic alterations.

The weights attributed to the different types of land cover and use in relation to the degree of anthropic alteration were established after consulting specialists in the field. This involved the knowledge of eight researchers with different backgrounds (Biology, Engineering and Geography) to help define weights. The results of this consultation can be seen in Table 3. We would like to point out that the class “Shade” did not receive an anthropic weight due to the lack of knowledge regarding what can be found in the shaded region.

Classes	Weights	Classification
Urban texture	7,78	Very degraded
Agricultural Areas (exposed soil type)	6,11	Degraded
Pastures and creeping vegetation	4,67	Average Degradation
Tree/bush vegetation	1,22	Low degradation
Areas of mineral extraction	8,67	Very degraded
Water mass	1,67	Low degradation
Dunes and sands	2,50	Low degradation
Shade	0	No attribution

Table 03 – Weights attributed and degradation classification of classes.
Source: Authors (2024).

The ATI classification method is based on the studies by Cruz (1984), Gouveia; Galvanin; and Neves (2013) who classified the ATI as low degradation (0 – 2.5), average degradation (2.5 – 5), degraded (5 – 7.5) and very degraded (7.5 – 10).

3. Results and discussion

In Figure 5, we can observe the mapping of land cover and use for 1985, 2005 and 2019 of the ARHB. Table 4 demonstrates the results of class measurement for each year. The main results of the multitemporal analysis show the expansion of areas for agriculture, with a growth of 521.3 km² (139.07%) during the period analyzed. These areas expanded to the detriment of areas for pasture and creeping vegetation which were suppressed in terms of area in -532.29 km² (-48.7%). Another class analyzed that has expanded were urban areas, with a growth rate of 79.24 km² (192%) during this period. Another important result to point out is the decrease in mining and dune areas, which lost -29.15 km² (-85.52%) and -7 km² (-46.89%) during the period, respectively.

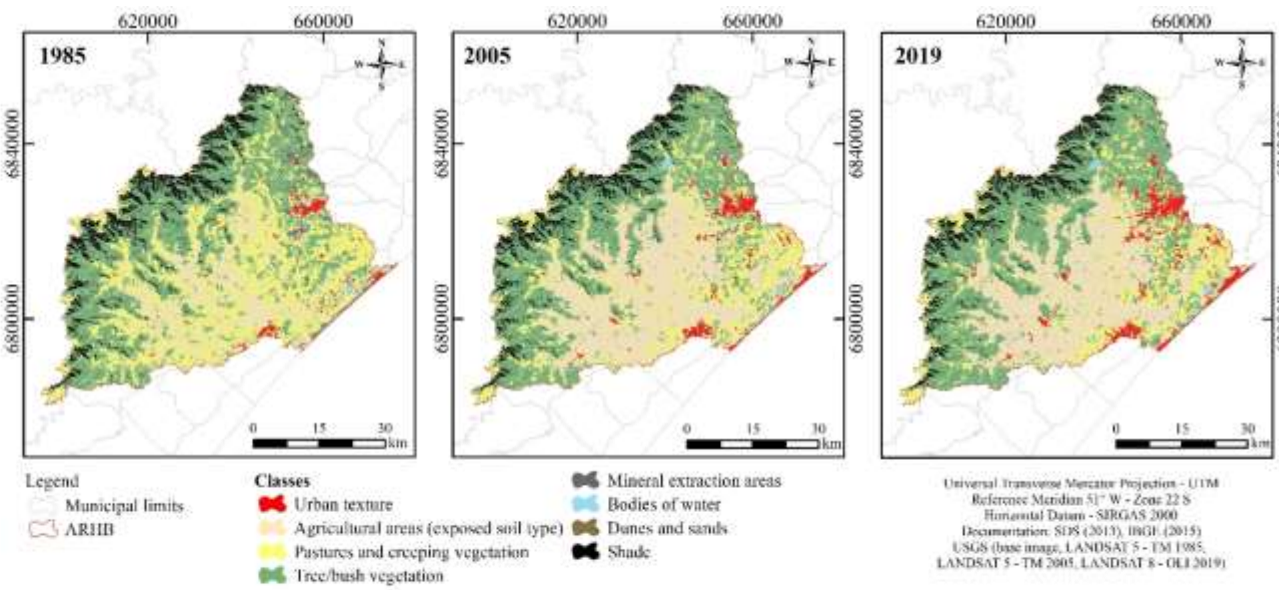

Figure 5 – Land cover and use maps.
Source: Authors (2024).

Class	Area (Km²) 1985	Area (%) 1985	Area (Km²) 2005	Area (%) 2005	Area (Km²) 2019	Area (%) 2019
Urban texture	41,31	1,35	79,88	2,60	120,55	3,93
Agricultural Areas (exposed soil type)	375,33	12,22	897,16	29,21	897,30	29,22
Pastures and creeping e vegetation	1115,91	36,33	670,25	21,82	583,62	19,00
Tree/bush vegetation	1212,14	39,47	1154,10	37,58	1221,24	39,76
Mineral extraction areas	34,11	1,11	13,27	0,43	4,94	0,16
Bodies of water	16,54	0,54	20,64	0,67	20,82	0,68
Dunes and sands	14,93	0,49	8,78	0,29	7,93	0,26
Shade	260,93	8,50	227,12	7,40	214,79	6,99
Total	3071,19	100	3071,20	100	3071,20	100

Table 4 – Measurement of classes of land use and cover of the ARHB.
Source: Authors (2024).

In Figure 6, we can observe the ATI mapping results for the three periods studied. Table 5 shows the results obtained for the ATI which, in general, was classified as “average degradation” for the ARHB in all the years analyzed, varying from 3.15 in 1985, 3.52 in 2005, and 3.49 in 2019. Individual results are discussed below along with the measurement of each class.

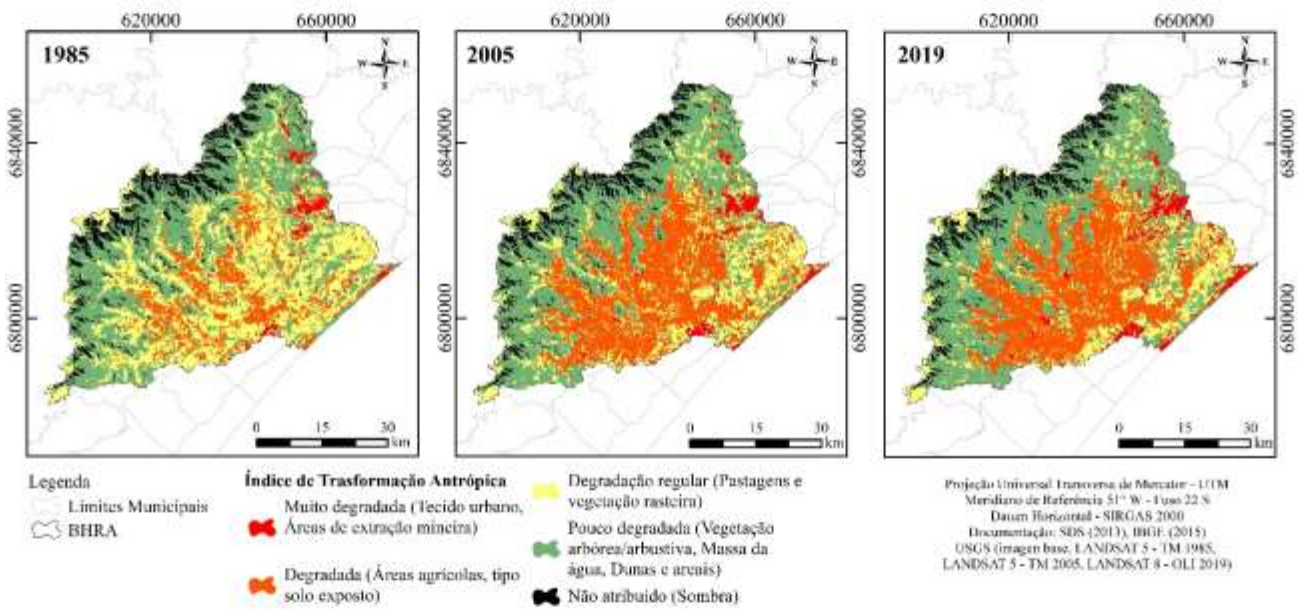

Figure 6 – ATI mapping for the ARHB.
Source: Authors (2024).

	Area (%)				ATI Results		
Class	**1985**	**2005**	**2019**	**ATI weight**	**1985**	**2005**	**2019**
Urban texture	1,35	2,60	3,93	7,78	0,10	0,20	0,31
Agricultural Areas (exposed soil type)	12,22	29,21	29,22	6,11	0,75	1,78	1,79
Pastures and creeping e vegetation	36,33	21,82	19,00	4,67	1,70	1,02	0,89
Tree/bush vegetation	39,47	37,58	39,76	1,22	0,48	0,46	0,49
Mineral extraction areas	1,11	0,43	0,16	8,67	0,10	0,04	0,01
Bodies of water	0,54	0,67	0,68	1,67	0,01	0,01	0,01
Dunes and sands	0,49	0,29	0,26	2,5	0,01	0,01	0,01
Shade	8,50	7,40	6,99	0,00	0,00	0,00	0,00
Total	100	100	100	-	3,15	3,52	3,49

Tabela 5 – ATI results.
Source: Authors (2024).

The first class of cover and use analyzed in the thematic mapping refers to “Urban texture” which includes areas with the buildings, highways and properties that make up a city. This class represented, in 1985, an area of 41.31 km², expanding to 79.88 km² in 2005 and, continuing the tendency towards growth, 120.55 km² in 2019. The total increase in area between 1985 and 2019 was 79.24 km². The class Urban Texture presented the second highest ATI weight (7.78) proposed by the evaluators - classified as degraded - which demonstrates the anthropic pressure this unit of analysis has undergone.

The expansion of the class Urban Texture can be observed in the basin’s territory in four axes: to the north of the basin, in the Araranguá region, on the coast and the in hinterland towns. In the northern portion of the basin, in the region of the towns of Criciúma, Içara and Forquilhinha, urbanization developed more rapidly due to the discovery of coal and the resulting income of people to work in this sector. Criciúma became the most important town in the basin, with commercial prominence since the beginning of the 1900s. With the passing years, the town would capture several areas of interest.

The towns located in the northern part of the hydrographic basin presented a faster paced urbanization from the 20th century onwards when compared to the towns in the southern portion, which maintained more rural characteristics. The urban growth of the northern region can be attributed to the impulse brought on by the commercial activities that began at the beginning of the 20th century, especially in the mining sector. Later, ceramic, metal-mechanic, agro-industrial and textile factories contributed to urbanization. The establishment of these companies in the towns of the northern portion of the basin became an agent of production and change in the morphology of the urban space, with state support for installation and activities (SILVA, 2012).

According to Manenti (2019), who worked with predictions of change in land cover and use in the region of the AMREC (which includes a part of the towns north of the basin), for 2040, the tendency shows the likelihood that conurbation, which has already began in Criciúma and Içara, will expand between Criciúma and neighboring towns such as Nova Veneza, Forquilhinha, Morro da Fumaça and Cocal do Sul, affected by road and commercial connections.

Another activity that puts pressure on the water resources of the basin is agriculture. This is the second class analyzed and is called “Agricultural Areas (exposed soil type)”, which includes the areas of temporary cultures of dry and/or irrigated land.

These areas stand out in the landscape and are represented by regular, well-defined shapes found in almost the entire territorial extension of the basin. It can be found irregularly in the territory, with portions going from the cliffs of the Serra Geral to the coast. In this class are included areas of exposed soil that do not necessarily present any kind of crop, but that have a similar spectral response.

The class that mostly converted from being agricultural was pasture and creeping vegetation, especially if it was located in the flatter areas of the basin. The ATI classification for this class was “degraded” (6.11). This is connected to the expansion of agricultural areas in the basin, especially to the culture of irrigated rice from the 1980s onwards.

The system of irrigated crop or floodplain cultures is typically found near water resources, generally in river plains, that are a part of the sedimentation zones of hydrographic basins. The type of seeding used is pre-germinated, in which seeding is done in the water. This type of crop is found in flood prone areas which are suitable for this culture due to water depth requirements during part of production (COLOMBO, 2017).

Back; Deschamps and Santos (2016) comment that although this system presents advantages, it also requires a longer continuous irrigation period, hence demonstrating disadvantages in terms of a higher water consumption and the probability of the contamination of water resources. Floodplain crops are predominant in the south of Santa Catrina, especially in the ARHB area, since it has flood plains that are favorable to the establishment of this culture.

The agricultural production in the basin is a strain on water resources in the use of pesticides in the production of irrigated rice crops. This use has increased in the past three decades along with the expansion of the planted area and the planting systems. The use of pesticides in the basin raises concern for the contamination of water, surface and subterranean resources (BACK; DESCHAMPS; SANTOS, 2016).

The third class analyzed is called Pastures and creeping vegetation. This appears in the landscape intermittently throughout the territory and is characterized by open field areas. This class presented an area of 1,115.91 km² in 1985, with a significant decrease in 2005, to 670.25 km², and 583.62 km² in 2019. It received an ATI classification of 4.67 (average degradation) by evaluators and presented the largest reduction in the period analyzed, with a total loss of 532.29 km².

According to Santos et al. (2020), pasture areas have presented an increase in the last decades in Brazil. Consequently, areas for agriculture grew in tandem, taking up the areas used for pastures. This fact is present in the dynamics of the basin landscape in which, historically, first the conversion of forest areas into pastures occurs and, subsequently, the conversion of artificial pastures into agricultural fields takes place.

The fourth class analyzed was called "Tree/Bush Vegetation and is seen continuously on the Serra Geral cliffs, where it is predominant, and in more spaced out plots distributed in the basin in steeper areas. It is important to point out that this class of cover and use encompasses the forest formations that are in process of succession (secondary forests), as well as those areas used for commercial plants (pine, eucalyptus, among other species). This occurs due to the limitations of spatial and radiometric resolution of the images used in digital processing.

This class presented an area of 1,212.14 km² in 1985, decreasing to 1,154.10 km² in 2005, and increasing to 1,221.24 km² in 2019. The ATI classification for this class was "low degradation" (1.22), which occurs, among other reasons, due to the regeneration this class presented during the period under study.

Although the above class showed regeneration during this period, it is important to point out that the quality of this vegetation needs to be further analyzed, along with monitoring, which should be broad and constant. The issue of monitoring the quality of vegetation in the area is significant since, after the 1980s, according to Marcondes (2016), there was a large expansion of forestry, especially with *Pinus* spp. which took up the areas of natural pastures and, subsequently, the expansion also of *Eucalyptus* spp. in pasture lands.

It is historically recognized that there has been a suppression of tree/bush vegetation in favor of the fifth class analyzed, called "areas of mineral extraction". This class is included in the landscape as areas of open cast coal extraction. There are other types of mining in the study area such as clay, sandstone, sand, basalt, among others, although the most significant in terms of environmental impact and residual consequences for the landscape is coal extraction.

This class presented an area of 34.11 km² in 1985. In 2005, there was a decrease in the mapped areas to 13.27 km²; this tendency continued in 2019 with an area of 4,94 km². This class received the highest ATI value among the classes analyzed with 8.67 (very degraded).

The ARHB is found in a commercially prominent area, which is the coal mining area of southern Brazil. In Santa Catarina, coal mining goes back to the end of the 19th century; in the mid-1980s the lack of defined policies for the sector led to the decrease in coal production in the basin's coalfield. Coal mining activities are mentioned as being mainly responsible for environmental degradation, especially of the water sources in the southern region of Santa Catarina (Alexandre, 2000).

Another problem caused by mining is acid draining of the mine (ADM) which contributes to contaminating three hydrographic basins covered by the coal mining region. Besides pits, another mechanism that generates ADM are subterranean galleries, spoil tips, decantation basins and other refuse.

The sixth class analyzed is called "Bodies of water", which includes areas of the basin that present liquid bodies, whether artificial or natural. This class is found on the coast, with the predominance of the lagoon complex of the towns of Balneário Rincão and Araranguá. It is also intermittent, as in the dams and reservoir of the São Bento River in Siderópolis.

The variation in area for this class went from 16.54 km² in 1985 to 20.64 km² in 2005, with a small increase to 20.82 km² in 2019. The ATI for this class was evaluated as presenting "low degradation" (1.67).

The basin presents a lagoon complex on the coastline formed by three main lagoons: Mãe Luzia Lagoon, Esteves Lagoon and Faxinal Lagoon. This complex is formed by transgressions and regressions of the sea level during the quaternary period in a system called lagoon-barrier (HORN-FILHO, 2003). The coastal lagoons in the studied area have been undergoing anthropic pressure in the last few years, mainly through urbanization, as mentioned above. This class has increased both in area and density of occupation around these lagoons.

Another fact regarding this class is the increase in area in 4.1 km², from 16.54 km² in 1985 to 20.64 km² in 2005. The increase is due to the construction of the São Bento River dam in the town of Siderópolis. The dam was built for many purposes, among water supply for humans, water supply for agriculture (irrigation) and flood control (COLONETTI et al., 2009).

The next to last class that was mapped is called dunes and sands, concentrated more on the basin's coast, occupying areas between the towns of Balneário Rincão, Balneário Arroio do Silva and Araranguá. The areas for this class changed from 14.54 km² in 1985 to 8.78 km² in 2005 and, following the tendency, to 7.93 km² in 2019.

The area of dunes is part of the coastal system which, according to Portz *et al.* (2014), is a strip for interfacing and integrating phenomena between dry land and the sea. Furthermore, according to the authors, dunes are a part of this system. In most of the sandy beaches, these are formed by large volumes of sediment with different shapes, sizes and directions (PORTZ et al., 2014).

The dune areas are considered Permanent Preservation Areas (PPA) and a part of the new forestry code which includes them in the *restinga* (sandbank) areas in their totality as PPA areas (BRAZIL, 2012). According to Portz et al. (2014), they are a part of legally protected territorial spaces, environmentally fragile and vulnerable.

The dune areas of the hydrographic basin are undergoing a process of suppression and alteration due to the encroachment of urbanization in the direction of the coast, to unplanned touristic and local practices, as well as foresting with exotic species (CRISTIANO, 2018). Other types of degradation can be listed, such as trampling, the use of vehicles and garbage disposal.

According to Cristiano (2018), frontal dunes are a barrier that protect against undertows. The author also states that without phenomena such as undertows, the function of dunes is easily forgotten and they are seen as an undesired nuisance by residents who live in areas near dunes, mainly when there is the wind transportation of these dunes toward their homes.

In Figure 7 we can see the advance of dunes transported by the wind in the direction of the urban texture. Undoubtedly, the advance of dunes is a problem for residents; however, irregular occupations are the main cause and source of these annoyances as a result by their advancement.

Figura 7 – Wind transportation of dunes in the direction of houses.
Source: Authors (2024). Legend: images A and B (portal Sulinfoco, 2013, Town of Bal. Rincão); images C and D (Author, 2021, town of Bal. Rincão).

The last class considered in the analysis was "Shade" which presented a variation in area between the dates studied. However, in general, this area cannot be considered part of the research since we do not know what is really to be found in the shaded forms. These are found mostly in the basin's steepest areas, generally on the slopes of the Serra Geral, and vary according to the angle and inclination of the sun and the quantity of energy reflected.

4. Final Considerations

The use of orbital images and digital image processing techniques used in this study enabled the utilization of a multitemporal analysis methodology of land cover and use to map out and describe changes in the landscape of the ARHB in a period of 35 years. This methodology also gave support to the calculation of the anthropic changes in the basin.

The results show that changes in land coverage and use in the ARHB territory were significant, especially in terms of the growth of the urban texture and, consequently, the increase in the population residing in the basin. This has accelerated environmental degradation due to excessive urbanization with no control or planning.

Another highlight in the changes of land cover and use were the conversions of lands for pasture and creeping vegetation into lands occupied by extensive agricultural areas, especially those for irrigated rice crops, that lead to pressures on the water resources of the basin.

It is clear there has been an increase in the anthropic pressure in the different covers and uses presented here since it is observed that the ATI shows an increase in the period under study and in general. It is important to point out that a periodic update of this data is needed, which is possible with the orbital images that are available with no cost for this purpose, as well as software that produce this information.

Acknowledgements

The authors would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and the Agência Nacional de Águas e Saneamento Básico (ANA) for funding the research and also the Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina (FAPESC) for the doctoral scholarship (CP48/2021) currently awarded to the first author. The authors would like to thank the reviewers of the Northeast Geosciences Journal for their contributions to improving the article.

References

ALEXANDRE, N.Z. *Análise Integrada da Qualidade das Águas da Bacia do Rio Araranguá (SC).* 2000. 297 f. Dissertação (Mestrado) - Curso de Mestrado em Geografia, Geociências, Universidade Federal de Santa Catarina, Florianópolis, 2000.

ALVARES, C.A. *et al*. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, [S.L.], v. 22, n. 6, p. 711-728, 1 dez. 2013. Schweizerbart. http://dx.doi.org/10.1127/0941-2948/2013/0507

BACK, Á.J; DESCHAMPS, F.C; SANTOS, M.G.S. Ocorrência de agrotóxicos em águas usadas com irrigação de arroz no sul de Santa Catarina. *Revista Brasileira de Ciências Ambientais* (online), [s.l.], n. 39, p.47-58, mar. 2016. http://dx.doi.org/10.5327/z2176-9478201611014.

BACK, Á. J. *Bacias Hidrográficas: Classificação e caracterização física (com o programa HidroBacias para cálculos).* Epagri. 2014.

BEPPLER, M; JUSTINO, G. Avaliação espaço temporal da Cobertura Vegetal da bacia hidrográfica do rio Miriri (PB). In: SOUSA, R. F; FALCÃO, E. C (Org.). *Geoprocessamento Aplicado: Contexto Multidisciplinar*. João Pessoa: IFPB, 2017. Cap. 3. p. 55-75.

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, 24 jun. 1981. v. 4, Seção 1, p. 11781-11781

BRASIL. *Lei n. 12.651, de 25 de maio de 2012*. Dispõe sobre a proteção da vegetação nativa; 2012. Diário Oficial da União, Brasília, DF, Ano CXLIX, n. 102, 28 maio 2012. Seção 1, p.1. Disponível em > http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm Acesso em 07 maio de 2021.

BRITES, R.S; BIAS, E.S; Rosa, A.N.C. Classificação Pixel a Pixel de Imagens. In: MENESES, Paulo Roberto; ALMEIDA, Tati de. *Introdução ao Processamento de Imagens de Sensoriameto Remoto.* Brasília: UnB, 2012. Cap. 12. p. 191-208.

COLOMBO, T.C. *Análise dos indicadores de sustentabilidade na produção de arroz irrigado no sul de Santa Catarina.* 2017. 111 p. Dissertação (Mestrado) - Universidade do Extremo Sul Catarinense, Programa de Pós-Graduação em Desenvolvimento Socioeconômico, Criciúma, 2017

COLONETTI, S; CITADINI-ZANETTE, V; MARTINS, R; SANTOS, R; ROCHA, E; JARENKOW, J.A. Florística e estrutura fitossociológica em floresta ombrófila densa submontana na barragem do rio São Bento, Siderópolis, Estado de Santa Catarina. *Acta Scientiarum*. Biological Sciences, [S.L.], v. 31, n. 4, p. 397-405, 20 ago. 2009. Universidade Estadual de Maringa. http://dx.doi.org/10.4025/actascibiolsci.v31i4.3345.

COMASSETTO, V. *Água, Meio Ambiente e Desenvolvimento Na Bacia DoO Araranguá (SC)***.** 2008. 339 f. Tese (Doutorado) - Curso de Programa de Pós-graduação em Geografia, Departamento de Geociências, Universidade Federal de Santa Catarina, Florianópolis, 2008.

CRISTIANO, S.C. *Interfaces entre a Geoconservação e a gestão costeira no município de Araranguá (Santa Catarina, Brasil).* 2018. 252 f. Tese (Doutorado) - Curso de Programa de Pós-Graduação em Geociências, Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2018.

CRUZ, C.B.M, TEIXEIRA, A.J; BARROS, R.S; ARGENTO, Mauro, S.F; MENEZES, P.M.L. Carga antrópica da bacia hidrográfica da Baía de Guanabara. In: Simpósio Brasileiro De Sensoriamento Remoto, Santos. *Anais*... Santos: 1998. p.99-109.

EMBRAPA, E. B. d. P. A. (2018). *Sistema brasileiro de classificação de solos.* (5ª ed.). Embrapa.

GOMES SOBRINHO, J. M. (2018). *Índice de transformação antrópica (ita) como suporte para análise da degradação da paisagem no município Jardim de Piranhas-RN*. Trabalho de Conclusão de Curso (Curso de Bacharelado em Geografia). Universidade Federal do Rio Grande do Norte.

GOUVEIA, R.G.L; GALVANIN, E.A.S; NEVES, S.M.A.S. Aplicação do índice de transformação antrópica na análise multitemporal da bacia do córrego do Bezerro Vermelho em Tangará da Serra-MT. *Revista Árvore*, [s.l.], v. 37, n. 6, p.1045-1054, dez. 2013. FapUNIFESP (SciELO). http://dx.doi.org/10.1590/s0100-67622013000600006

HORN FILHO, N.O. Setorização da província costeira de Santa Catarina em base aos aspectos geológicos, geomorfológicos e geográficos. *Geosul*, 2003. 18(35):71-98

JENSEN, J.R. *Sensoriamento Remoto do Ambiente: Uma perspectiva em Recursos Terrestres*. 2. ed. São José dos Campos: Parêntese, 2009. 598 p.

KREBS, A.S.J. *Contribuição ao conhecimento dos recursos hídricos subterrâneos da Bacia Hidrográfica do Rio Araranguá, SC***.** 2004. 375 f. Tese (Doutorado) - Doutorado em Geografia, Universidade Federal de Santa Catarina, Florianópolis, 2004.

LANDIS, R.J; KOCH, G.G. The measurement of observer agreement for categorical data. *Biometrics***,** v.33, n.1, p. 159-174, 1977.

LÉMECHEV, T. On hydrological heterogeneity catchment morphology and catchment response. *Journal of Hydrology*. v.100, p. 357- 375. 1982.

MANENTI, V.D. (2019). *Modelagem Do Uso Da Terra E Planejamento Territorial Da Região Carbonífera Do Sul De Santa Catarina, brasil*. 2019. 113 f. Dissertação (Mestrado) - Curso de Ciências Ambientais, Programa de Pós-Graduação em Ciências Ambientais, Universidade do Extremo Sul Catarinense, Criciúma., 2019.

MARCONDES, T. A agropecuária em Santa Catarina: cenário atual e principais tendências. *Revista NECAT*, ano 5, nº 9, p. 8-38, jan-jun de 2016.

MASTELLA, A.F; VIEIRA, C.A. Acurácia temática para classificação de imagens utilizando abordagens por pixel e por objetos. *Revista Brasileira de Cartografia*, [s.l.], v. 70, n. 5, p.1618-1643, 31 dez. 2018. http://dx.doi.org/10.14393/rbcv70n5-44559.

MATEO, J.R. *Geoecologia de los Paisajes*. Universidad Central de Caracas. Monografia. 1991

PERH/SC: *Plano Estadual de Recursos Hídricos de Santa Catarina*. Secretaria de Estado do Desenvolvimento Econômico Sustentável (SDS). Plano Estadual de Recursos Hídricos. RH 10. 2017. Disponível em: http://www.aguas.sc.gov.br

PORTO, M. F. A., & PORTO, R. L. L. (2008). Gestão de bacias hidrográficas. *Estudos Avançados*, *22*(63), 43–60. https://doi.org/10.1590/s0103-40142008000200004

PORTZ, L; ROCKETT, G, C; FRANCHINI, R.A.L; MANZOLLI, R.P; GRUBER, N.L.S. Gestão de dunas costeiras: o uso de sistema de informações geográficas (sig) na implantação de planos de gestão no *litoral do rio grande do Sul, brasil. Revista de Gestão Costeira Integrada***,** [S.L.], v. 14, n. 3, p. 517-534, set. 2014. Associação Portuguesa dos Recursos Hidricos (APRH). http://dx.doi.org/10.5894/rgci445.

SANTA CATARINA. *Atlas de Santa Catarina*. (Gabinete de planejamento e coordenação geral. subchefia de estatística, geografia e informática). Aerofoto Cruzeiro. 1986.

SANTA CATARINA. *Lei nº. 10.949, de 09 de novembro de 1998, dispõe sobre a caracterização do Estado em 10 (dez) Regiões Hidrográficas.* Disponível em: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.aguas.sc.gov.br/jsmallfib_top/DHRI/Legislacao/Lei-Estadual-10949-1998.pdf.

SANTOS da SILVA, J. G., Scussel, C., Varela, E. P., Nicoladelli, T. B., Luz, C. d., Pires, D. A., Milanez, P. R., Olivo, E. F., Zocche, J. J. Aplicação de Protocolo de Avaliação Rápida da Integridade Ambiental na Bacia Hidrográfica do Rio Araranguá, SC. *Boletim Paulista de Geografia*, *109*(1), 147–171. 2023. https://doi.org/10.54446/bpg.v109i1.2974

SANTOS, L.D; SCHLINDWEIN, S.L; FANTINI, A.C; HENKES, J.A; BELDERRAIN, M.C.N. DINÂMICA DO DESMATAMENTO DA MATA ATLÂNTICA: causas e consequências. *Revista Gestão & Sustentabilidade Ambiental*, [S.L.], v. 9, n. 3, p. 378, 30 set. 2020. Universidade do Sul de Santa Catarina - UNISUL. http://dx.doi.org/10.19177/rgsa.v9e32020378-402.

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.

SCHUSSEL, Z., & NASCIMENTO NETO, P. Gestão Por Bacias Hidrográficas: Do Debate Teórico à Gestão Municipal. *Ambiente & Sociedade*, *18*(3), 137–152. 2015 https://doi.org/10.1590/1809-4422asoc838v1832015

SILVA, M.J.A. *A produção do espaço urbano de Criciúma – SC e seus agentes de transformação***.** 2012. 165 f. Dissertação (Mestrado em Geografia) – Curso de Mestrado em Geografia, Pontifícia Universidade Católica de São Paulo. Puc-sc, São Paulo, 2012.

.