https://rbgeomorfologia.org.br/
ISSN 2236-5664

Revista Brasileira de Geomorfologia

v. 27, nº 3 (2026)

http://dx.doi.org/10.20502/rbg.v27i3.2791

Technical Note

São Gonçalo Channel Marginal Lagoon Plain: landscape analysis and geomorphological review

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Received: 10/02/2026; Accepted: 10/09/2026; Published: 23/11/2026

Abstract: The objective of this paper was to understand the environmental integrity of the wetlands of the São Gonçalo Channel Marginal Lagoon Plain (SGCMLP) and to conduct a geomorphological review and update of its boundaries. The SGCMLP is a geomorphological compartment that is part of the Coastal Plain of Rio Grande do Sul and comprises part of the territories of Pelotas, Rio Grande, Capão do Leão, and Arroio Grande. The first stage of the work was based on a geomorphological review and update of the SGCMLP limits, based on the original limits established by Simon; da Silva (2015) and the Geomorphological Mapping of the Plain and Coastal Lowlands of Rio Grande do Sul (Moura et al., 2023). The update was made in order to respect the scale adopted for the original boundaries (1:40,000), with an increase from 790.90 km² to 886.52 km². The assessment of wetlands was based on land cover and land use data from MapBiomas Collection 8. The data analysis identified 15 classes: 7 for cover, 7 for use, and one class called Not Observed. Finally, it was concluded that even with the decrease, the wetlands remained intact, and the main factor behind the decrease was the issue of land use and occupation.

Keywords: Wetlands, Environmental Analysis, Land Covers, Land Use and Occupation, Geomorphological Redelimitation.

Resumo: O presente estudo teve como objetivo compreender a integridade ambiental das áreas úmidas da Planície Lagunar Marginal do Canal São Gonçalo (PLMCSG) bem como realizar uma revisão geomorfológica e atualização dos limites. A PLMCSG é um compartimento geomorfológico que integra a Planície Costeira do Rio Grande do Sul e compreende parte dos territórios de Pelotas, Rio Grande, Capão do Leão e Arroio Grande. O primeiro estágio do trabalho pautou-se na revisão geomorfológica e atualização dos limites da PLMCSG, baseando-se nos limites originais estabelecidos por Simon; Da Silva (2015) e no Mapeamento Geomorfológico da Planície e Terras Baixas Costeiras do Rio Grande do Sul (Moura, 2022). A atualização foi feita de modo a respeitar a escala adotada dos limites originais (1:40.000) com aumento de 790,90 km2 para 886,52 km2. A avaliação das áreas úmidas foi feita com base nos dados de coberturas e usos da Terra da Coleção 8 do MapBiomas. A análise dos dados identificou 15 classes sendo elas: 7 de coberturas, 7 de usos e uma classe denominada Não Observado. Por fim, concluiu-se que mesmo com diminuição, as áreas úmidas permaneceram íntegras, e a diminuição teve como principal fator a questão do uso e ocupação da Terra.

Palavras-chave: Áreas Úmidas, Análise Ambiental, Coberturas, Uso e Ocupação, Re-delimitação Geomorfológica.

1. Introduction

At certain locations where water meets land, an ecosystem of vital importance can be found: wetlands (AUs). AUs represent complex geodiversity ecosystems, with relevance to global biodiversity, playing a fundamental role in water regulation and in supporting wildlife (Queiroz, 2015). Because they are highly biodiverse, AUs are among the most productive ecosystems on the planet (Mitsch; Gosselink, 1993) and form part of the evolutionary history of ancient civilizations of Earth such as the Egyptians and the Mesopotamians (Barbier et al., 1997; Hails, 1996).

Wetlands are portions of the landscape that are periodically occupied by waters arising from the overflow of rivers or lakes, rainfall, or the discharge of groundwater. This condition leads to anatomical, morphological, physiological, and ethological adaptations of the local biota, forming specific and characteristic structures within the communities present (Junk et al., 1989).

AUs are composed of hydrological, climatological, geomorphological, pedological, and biochemical factors. They constitute portions of space shaped by nature, whose function is to receive, retain, and regulate pluvial–fluvial waters (Gomes; Magalhães Júnior, 2017).

In Brazil, wetlands occur in all biomes, covering hundreds of thousands of square kilometers. They can be classified according to the area where they occur (marine, coastal, continental, and artificial areas) as mangroves, flooded grasslands, veredas, floodplains, igapós, campinarana, the Pantanal, and flood basins (Piedade et al., 2012). Piedade et al. (2012) further indicate that wetlands should receive specific treatment and that their management should be guided by laws, since their combined area exceeds 20% of the territory of Brazil.

In the state of Rio Grande do Sul, wetlands are called banhado, which comes from the word *bañado*, due to the cultural influence exerted on southern Brazil by the proximity of Spanish- and Portuguese-speaking countries such as Argentina and Uruguay (Simioni; Guaselli, 2017). The Coastal Plain of Rio Grande do Sul (PCRS) comprises one of the five major Geomorphological Domains of the state, representing a vast expanse of lowlands with an altitudinal range between 0–20 meters above sea level (Verdum et al., 2012).

The accelerated transformation and intensification of the use and occupation of land constitute the main degradation affecting Brazilian wetlands. Spatial changes to AUs in the PCRS in recent years have been occurring due to the intensification of extensive agricultural and urban uses on them, which makes the process of use and occupation the primary threat to these natural complexes (Piedade et al., 2012; Irigaray, 2015).

This study's main objective was to analyze which percentages of the wetlands belonging to the Marginal Lagoon Plain of the São Gonçalo Channel (SGCMLP) remained intact or were altered in response to the use and occupation process over nearly four decades (37 years), as well as to understand and verify the environmental integrity of the wetlands that compose it throughout the period analyzed.

To achieve these objectives, the following theoretical-methodological sequence was adopted: updating the boundaries of the SGCMLP, obtaining land cover and land-use data for 38 scenarios (1985–2022) from the MapBiomas Platform, and obtaining and analyzing the dynamics of land cover and land use in the SGCMLP.

2. Study Area

The study area is located in the extreme south of the state of Rio Grande do Sul . It is divided among the municipalities of Pelotas, Rio Grande, Capão do Leão, and Arroio Grande, totaling 886.52 km², as shown in Figure 1.

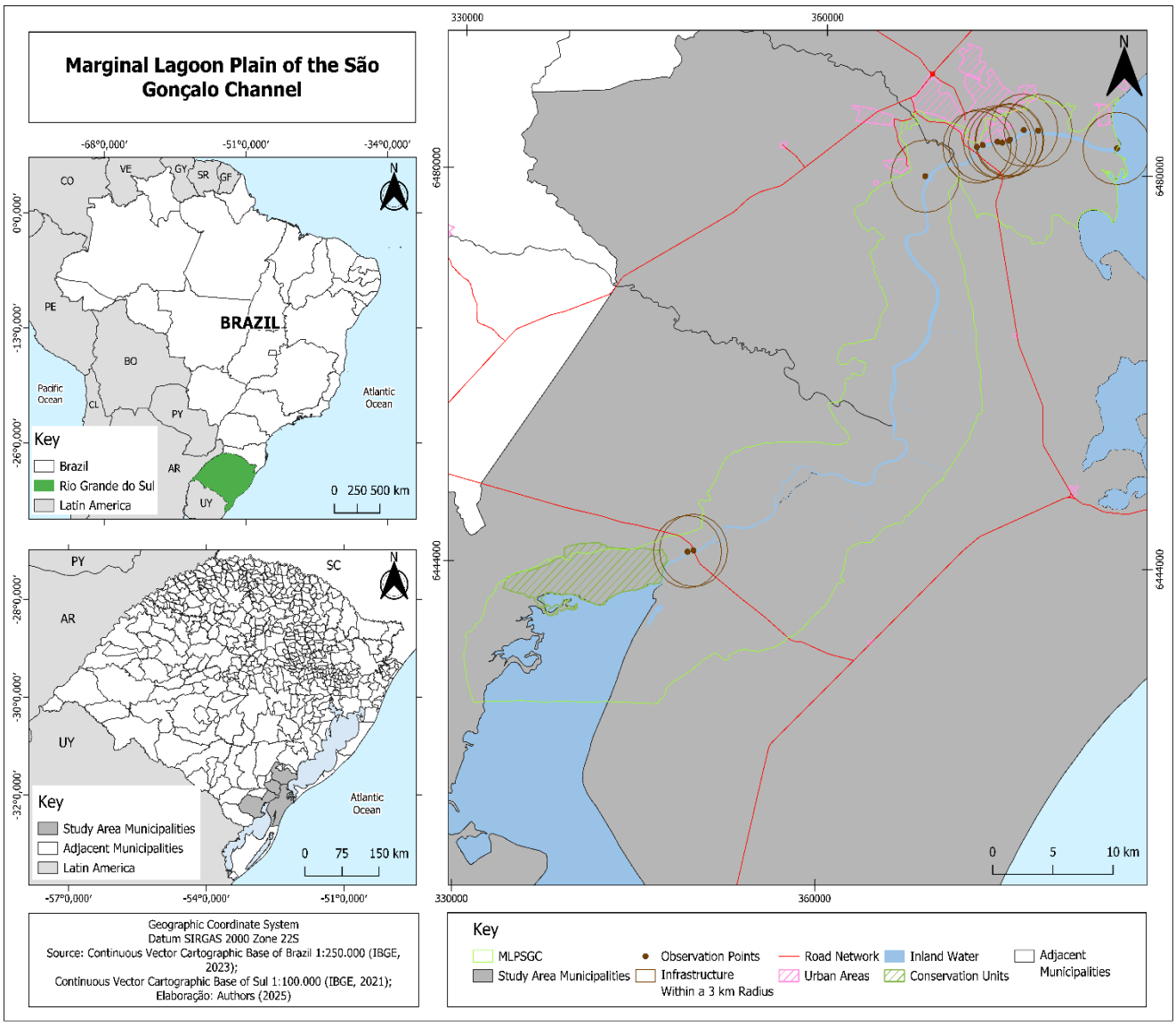


Figure 1. Location map of the study area. Source: Ferreira (2025).

The geology of the area (Figure 2), considered here within the Quaternary, has its origin linked to marine dynamics (the sea's maximum transgressive and regressive phases) and to terrestrial dynamics (fluvio-lagoonal processes), involving the deposition and accumulation of marine and alluvio-colluvial sediments (sediments derived from the higher parts of the relief, transported, accommodated, and deposited by the drainage network). These processes generated the Alluvial Fan and Lagoon Barrier Systems (Pleistocene I, II, III and Holocene IV), as indicated by Villwock and Tomazelli (1995).

The Alluvial Fan Systems are sedimentary deposits formed by rivers that descend from the uplands and lay down coarse sediments (sands, gravels) upon entering the Coastal Plain. They characterize high-energy fluvial environments typical of glacial periods (when sea level is low). Lagoon Barriers correspond to sequences of sandy barriers (shoreline ridges) parallel to the coast, associated with lagoons or protected bays behind them. They form during periods of high sea level (interglacials), When waves and alongshore currents build barriers from sands

(Villwock & Tomazelli, 1995). The sedimentary deposits that make up the study area correspond to the Pleistocene II and III Barriers and the Holocene IV Barrier. Both systems can be seen in Figure 3.

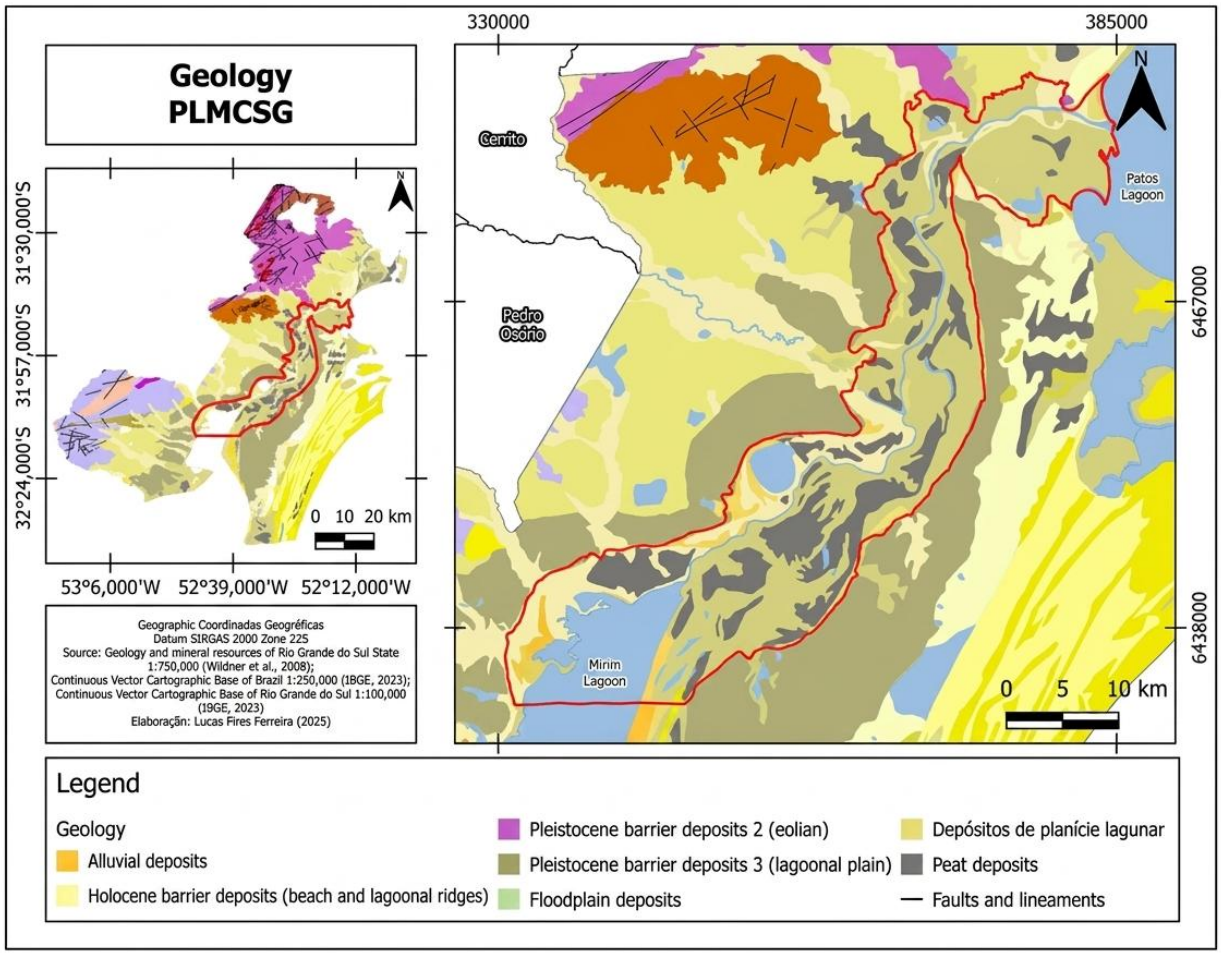


Figure 2. Geology of the study area. Source: Ferreira (2025).

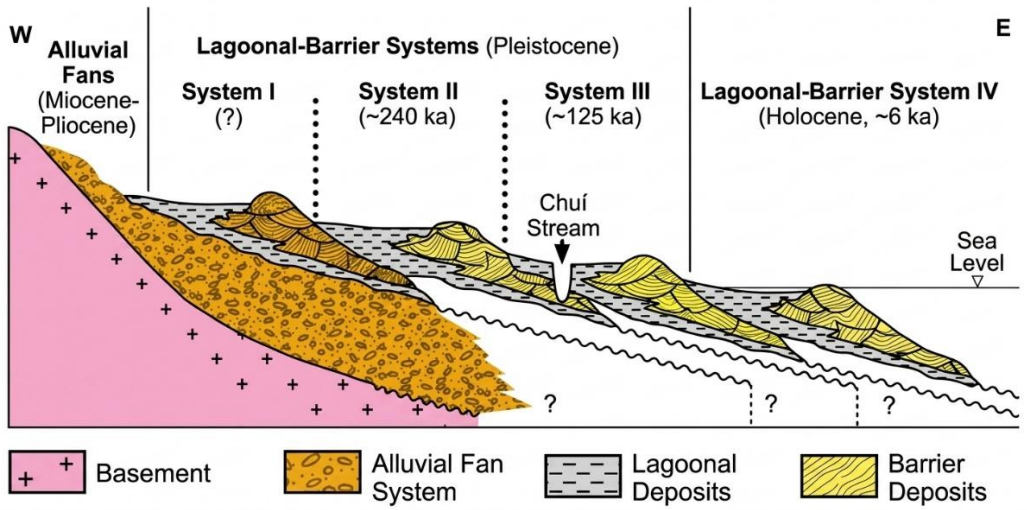


Figure 3. Schematic of the Alluvial Fan Systems and the Laguna Barriers. Source: Tomazelli; Villwock (2005).

The geomorphological context corresponds to the Rio Grande do Sul Coastal Plain Morpho-Structural Unit (Wildner et al., 2008). For the study area (Figure 4), the following Geomorphological Units are present: Lagoon Plain (formed by the Patos/Mirim lagoon dynamics) and Alluvial-Colluvial Plains. They show different depositional landforms across their various subdivisions. The relief ispredominantly flat, of sedimentary origin, with very little altitudinal variation, extending from the marine coast to the interior (the contact zone with the Basement Morpho-Structural Unit in Complex Styles).

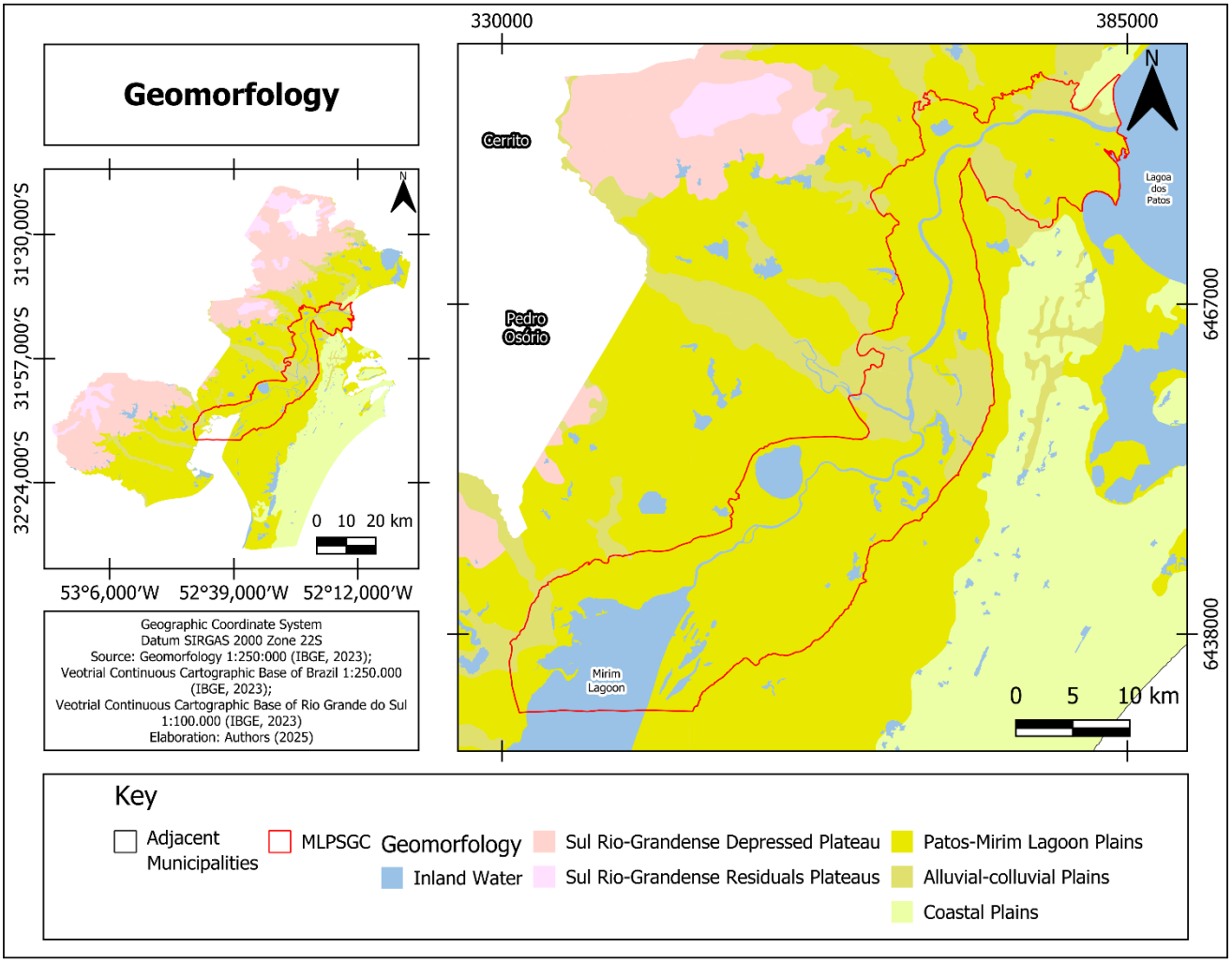


Figure 4. Geomorphology of the study area. Source: Ferreira (2025).

It has a Köppen climate classification of Cfa. The letter C indicates the climatic group (temperate), F indicates the climate type (no dry season), and A indicates the climatic subtype (hot summer). It is characterized by hot, humid summers, with mean monthly temperatures above 22°C, and mild winters, with temperatures between 0°C and 18°C. Precipitation is distributed throughout the year, with no clearly defined dry season, and it is more intense during summer. Humidity is relatively high year-round, especially in summer. Seasons are defined more by changes in temperature than by rainfall amounts (Kuinchtner & Buriol, 2001).

The SGCMLP is located in the Mirim/São Gonçalo Hydrographic Basin (MSGHB), a binational basin (covering parts of Brazil and Uruguay). The MSGHB is an endorheic basin, meaning it does not drain water and sediments directly to the sea, but instead discharges into Lagoa dos Patos. It has a dendritic drainage pattern, so called because its landscape configuration resembles the branching of trees, where the main channel corresponds to the trunk and

the tributaries to the irregular branches. Within the basin, the São Gonçalo Channel is the main water body. It connects the largest coastal lagoons in the country, giving rise to one of the world's largest lagoon complexes: the Patos–Mirim Lagoon Complex. It is 76.6 km long, has an average width of 250 m, and a maximum depth of 15 m (Figueiredo et al., 2023).

For the spatial extent, hydromorphic soil types predominate, such as Gleissols, Organosols, and Planosols—soils that retain water because they have an impermeable B horizon (due to the presence of mineral clays). They are also rich in organic matter, which supports the cultivation of irrigated rice (Figure 13). In some portions of the plain, Ultisols (Argissols) and Spodosols also occur.

The predominant presence of hydromorphic soils is linked to the geological–geomorphological morphogenesis of the area (a sedimentation environment characterized by intense circulation of water from rainfall and fluvial sources, along with the outcropping of groundwater on the surface).

The study area lies within the Pampa biome, a biome restricted to Rio Grande do Sul; however, its largest extent occurs over Uruguayan territory. In that country, it occupies 176,496 km², corresponding to 63% of the state's territory and 2.07% of the national territory. Within it, there are mountain ranges, vast stretches of plains, hills, hillocks, and coxilhas (small, smooth, rounded hills typical of the southern grasslands). Regarding vegetation, native grasslands predominate, but there are also riparian forests, hillside forests, shrub formations, wet meadows (butiazais), wetlands (banhados), and rocky outcrops.

Land use and occupation were obtained from the MapBiomas platform (Collection 8). Within the study extent, seven land-use classes were identified: Silviculture, Mosaic of Uses, Rice, Soybean, Other Temporary Crops, Urban Area, and Other Non-Vegetated Areas.

3. Materials and Methods

The bibliographic review involved a systematic process of searching, selecting, and analyzing materials. The first step consisted of defining the themes and keywords, in which the core concepts were identified and the keywords used in the search for references were established. Next, references were searched by consulting sources such as books, scientific articles, dissertations, theses, technical reports, and official documents. Databases such as SciELO, Google Scholar, and CAPES were essential tools for this search. The concepts used for the searches carried out in this theoretical stage were: landscape, GIS, land cover and land use, Geoecology and Landscape Ecology, and wetlands.

The cartographic review complemented the bibliographic review by providing a spatial basis for the study. It involved the collection and analysis of data (in shapefile, raster, KML, and XML formats), maps, and satellite imagery. The first step consisted of defining the study area, the Marginal Lagoon Plain of the São Gonçalo Channel (PLMCSG), previously delimited by Simon and Silva (2015). Still at this stage, it was defined which databases and repositories (public and private, national and international) would be used: IBGE and the MAPBIOMAS Platform.

The land cover and land-use data were obtained from the MAPBIOMAS Platform using the Google Earth Engine tool. The boundaries of the PLMCSG were analyzed during the bibliographic and cartographic review process and were obtained from the author via email. The political-administrative data were obtained from the online geosciences repository of IBGE.

All geoprocessing techniques were applied in a GIS environment using the open-source software QGIS V3.34.11. All data were reprocessed by adopting the same spatial reference system: the SIRGAS 2000 Coordinate Reference System (SRC), Zone 22 South, and the Universal Transverse Mercator (UTM) projection.

This stage covered the entire process of obtaining and processing land cover and land-use data, as well as analyzing their dynamics. Until the beginning of this study, the MapBiomas Platform made data available for the

time period 1985–2022; therefore, it was decided to analyze the entire period provided. These data are part of Collection 8, the eighth set of land cover and use datasets made available. It is worth noting that Collection 8 has an overall accuracy of 85.8%, meaning that the platform's virtual representation of the real world has an accuracy of 85.8%. This accuracy is proven, verified, and attested by the platform itself.

A total of 38 land cover and land-use scenarios were obtained from the MapBiomas platform (1985–2022) using the Google Earth Engine tool. After being downloaded, the raw data underwent a processing step consisting of clipping and mosaicking the datasets to fit the study area boundaries, along with reprojection to the appropriate datum.

The analysis of land cover and land use indicated points where the boundary should be revised (area inclusions and exclusions). Therefore, the first procedure focused on readjusting the delimitation for the geomorphological compartment. For this purpose, the current boundary defined by Simon and da Silva (2015) was used together with the Geomorphological Mapping of the Coastal Plains and Lowlands of Rio Grande do Sul (Moura, 2022), along with a false-color band composition (enhancement of the blue band) using the spectral bands of the Landsat 9 satellite from late August 2023 (a date when maximum rainfall exceeded normal levels—an occurrence in which the entire floodplain saturates and is replenished by exceptionally high waters from the main channel).

The geomorphological mapping of the PLMCSG carried out by Simon and da Silva (2015) was based on stereoscopic interpretation of aerial photographs at a scale of 1:40,000 from 1953, a factor considered responsible for the inconsistencies observed. With the decision to change the study area boundaries, theoretical-methodological frameworks and data supporting this new stage were sought in the literature. Table 2 shows the data used in this stage.

The redefinition of the boundaries for the geomorphological compartment was based on the overlap of the boundary defined by Simon; da Silva (2015) with a satellite image and verification/validation of the Geomorphological Mapping of the Coastal Lowlands and Plains of Rio Grande do Sul (Moura, 2022). The boundaries were adjusted using manual digitizing techniques within a GIS environment.

Once the boundaries were established, the cartographic database was organized by obtaining land cover and land use data from the MAPBIOMAS platform (2023) for the period 1985–2022, from the first year of recording to the last set, collection 8. The raster files were downloaded through the Google Earth Engine platform. For the entire period between 1985 and 2022, 38 scenarios were obtained. For each scenario, the data were clipped to the defined boundary. For a better cartographic representation of the obtained data, it was determined that presenting the results by decades would be the most appropriate approach, since this period allowed for a better analysis of the data, given the variability of land covers and uses.

The preparation of the products (maps, tables, and graphs) was the final methodological stage. It was mostly decided to work with spatial data at a scale of 1:250,000 in order to ensure a good level of detail and avoid inconsistencies. Table 3 shows the data used in this stage.

4. Results

For the re-delimitation process, the scale adopted by Simon; da Silva (2015), 1:40,000, was respected. The original boundaries recorded an area of 790.90 km²; after the changes, including the inclusion and exclusion of areas, the boundary area became 886.52 km². There was an area difference (expansion) of 95.62 km², which represents an approximate increase of 12.1%. The re-delimitation proposal identified four critical points of change, in addition to some smoothing procedures applied along the entire boundary.

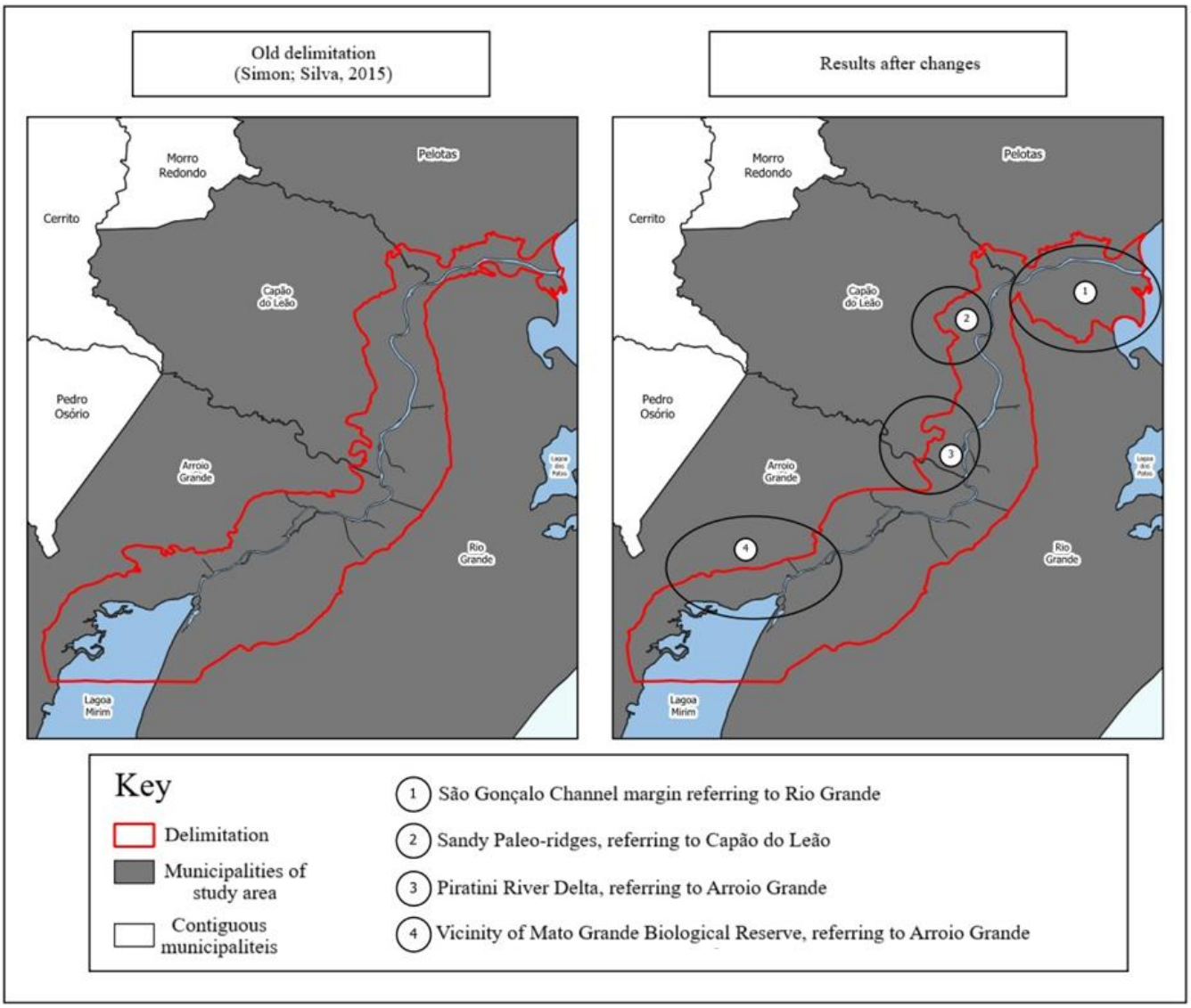


Figure 5. Comparison of the delineation of the PLMCSG. Source: Ferreira (2025).

As mentioned above, the analysis of the dynamics of land cover and land use was conducted by decades, since this approach allows for a clearer and more objective identification and analysis of spatiotemporal variability, as well as the exposure of the dynamics of land cover and land use. As a result of this land cover and land use dynamic, five scenarios were obtained: 1985, 1995, 2005, 2015, and 2022. It is important to note that all 38 scenarios from the 1985–2022 time frame were analyzed; in particular, the presentation of the dynamics by decades proved to be more effective and accurate.

For the analyzed period (1985–2022), it was found that, among the land covers and uses in the study area, the natural covers of the Pampa biome prevail (mostly wet areas, due to the locality), along with anthropogenic uses (urban area, rice fields, and other temporary crops). Not only in the five land cover and land use scenarios for the SGCMLP, but across the entire analyzed time frame (37 years, 38 scenarios), the same 15 classes were identified according to the MapBiomas classification; the only variations were related to the area measurements of these classes.

Fifteen classes were identified for the study area: seven land cover classes (Forest Formation, Arboreal Restinga, Flooded Field and Marsh Area, Grassland Formation, Herbaceous Restinga, Beach, Dune and Sand, and River, Lake, and Ocean), seven land use classes (Silviculture, Mosaic of Uses, Rice, Soybean, Other Temporary

Crops, Urban Area, and Other Non-Vegetated Areas), and one class in which the pixels collected by the satellite could not be classified (Unobserved). The figure below presents the map of land cover and land use for the entire period 1985–2022. Figure 6 and Table 1 respectively show the land cover and land use map and the table with area values and area percentages for each analyzed land cover/land use class:

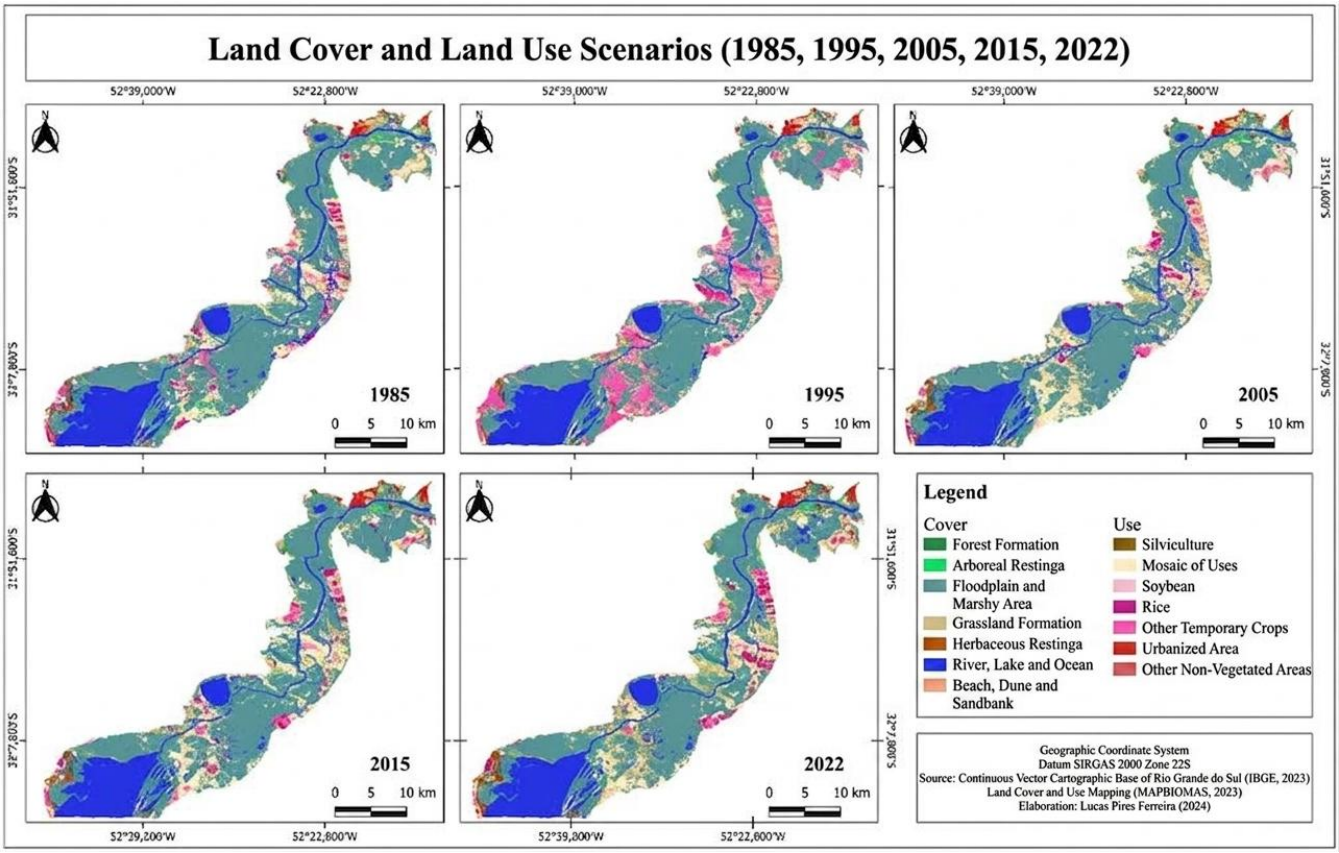


Figure 6. Land cover and land use scenarios in the SGCMLP. Source: Ferreira (2025).

Table 1. Area and percentage of land cover and land use in the SGCMLP. Source: Ferreira (2025).

ID	CLASS	AREA										
		1985		1995		2005		2015		2022		INCREASE OR DECREASE (%)
		km²	%	km²	%	km²	%	km²	%	km²	%	
1. FOREST												
3	FOREST FORMATTION	0,76	0,09%	0,75	0,09%	0,99	0,11%	0,98	0,11%	1,01	0,12%	32,89
49	ARBOREAL RESTINGA	13,75	1,59%	10,69	1,23%	11,35	1,31%	12,97	1,50%	13,39	1,55%	2,61
2. NON-FOREST NATURAL FORMATION												
11	FLOODED FIELD AND ÁREA PANTANOSA	446,28	51,50%	413,52	47,72%	421,81	48,66%	443,30	51,16%	411,36	47,47%	7,82
12	GRASSLAND FORMATION	61,90	7,14%	44,59	5,15%	78,57	9,07%	58,33	6,73%	101,61	11,73%	64,15
50	HERBACEOUS RESTINGA	5,67	0,65%	4,94	0,57%	7,92	0,91%	7,17	0,83%	10,16	1,17%	79,18
3. AGRICULTURE AND LIVESTOCK												
9	SILVICULTURE	0,12	0,01%	0,57	0,07%	0,71	0,03%	0,82	0,09%	0,84	0,10%	600
21	MOSAIC OF USES	116,10	13,40%	86,45	9,98%	137,44	15,86%	128,77	14,86%	114,46	13,21%	1,41
39	SOY	1,63	0,19%	26,24	3,03%	1,56	0,18%	0,76	0,09%	0,86	0,10%	47,23
40	RRROZ	7,94	0,92%	5,00	0,58%	11,71	1,35%	21,59	2,49%	25,03	2,89%	215,23
41	OUTRAS LAVOURAS TEMPORÁRIAS	41,45	4,78%	108,37	12,51%	16,42	1,39%	17,54	2,02%	12,56	1,45%	69,99
4. NON-VEGETATED AREA												
23	BEACH, DUNE AND SANDY	0,20	0,02%	0,29	0,03%	0,29	0,03%	0,32	0,04%	0,33	0,04%	65
24	ÁREA URBANIZADA	6,74	0,78%	7,96	0,92%	9,29	1,07%	10,57	1,22%	11,40	1,32%	69,13
25	OUTRAS ÁREAS NÃO VEGETADAS	3,54	0,41%	1,59	0,18%	1,74	0,20%	1,89	0,22%	1,66	0,19%	53,1
5. WATER BODIES												
33	RIVER, LAKE AND OCEAN	160,44	18,51%	155,55	17,95%	166,72	19,24%	161,51	18,64%	161,85	18,68%	0,87
6. NOT OBSERVED												
27	NOT OBSERVED	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

5. Discussion

5.1. Change in the delimitation of the SGCMLP

Point 1 of change in the SGCMLP boundary was named the São Gonçalo Channel Margin, referring to Rio Grande. This was the main and most significant change point made along the entire boundary. It was also the location on the boundary that gave rise to the hypothesis of delimitation change, which occurred during the analysis of the dynamics of land cover and land use.

The MapBiomas platform classifies the entire area as Flooded Field and Marsh Area—in this case, natural vegetated cover of wet areas where rushes (juncos) and aquatic macrophytes are typically recorded.

At this point, the inclusion of area and smoothing of the boundary were carried out based on all available materials: land cover and land use mapping (MapBiomas, 2023), the base delimitation (Simon; da Silva, 2015), the mapping of the lowlands of RS (Moura et al., 2023), the false-color composite (USGS, 2023), and the relief's altimetry.

Point 2 of change in the SGCMLP boundary was named Sandy Paleoridges, referring to Capão do Leão. These sandy paleoridges are paleoforms identified in the study area by Simon; da Silva (2015). Paleoridges are the only paleoforms that can be observed in the landscape. The others—such as paleobays and paleopoints—have been filled in (colmated) within the extent of the fluvio-lacustrine plain at different stages of the colmation process (Simon; da Silva, 2015). These paleoforms are under the influence of rainfall dynamics, which promotes the leveling (arrasamento) of the paleofeatures' prominences (ridges and valleys).

They result from morphogenesis and morphodynamics not only of marine origin but also of lagoonal origin, meaning they developed under direct influence at a time in the geological history when the São Gonçalo Channel (CSG), together with Lagoa dos Patos and Lagoa Mirim, still formed an extensive lagoonal body of water. It is a portion of the relief that was shaped by lagoon dynamics (when the colmation process had not yet occurred or was still at an early stage) (Silva; Simon, 2015).

The paleoridges were already within the limit proposed by Simon; da Silva (2015). Therefore, only adjustments and boundary smoothing were carried out so that the limit follows the paleofeatures as they appear in the landscape. These small changes were made using the same materials as in the previous point, particularly the relief altimetry.

Point 3 of change in the SGCMLP boundary was named the Piratini River Delta. This was an area where the review and proposal of boundary changes had to be carried out with great care, since it encompasses two different geomorphological compartments: the lagoon plain and the alluvio-colluvial plain. In this case, it can be said that this deltaic area has lagoon morphogenesis and alluvio-colluvial morphodynamics. Today, it is directly under alluvio-colluvial influence, but in the not-so-distant geological past it was under lagoon influence.

Alluvio-colluvial plains are flat or gently undulating landforms formed by the deposition of sediments transported by fluvial processes (alluvium) and by hillslope processes (colluvium). These geomorphological features are common in lowlands and river valleys, where relief energy decreases, allowing the accumulation of eroded materials (Christofoletti, 1980).

Deltaic formations are landforms that occur at the mouths of rivers, where sediments transported by the river are deposited when the river meets a larger body of water—such as an ocean, sea, lake, or lagoon. They result from complex processes involving erosion, transport, sedimentation, and compaction, which reflect the interaction between fluvial and marine or lacustrine forces (Christofoletti, 1980).

Thus, as with the previous point, the adjustment at this point used the same materials as in the previous one, based on relief altimetry, so that the newly proposed delimitation respected both geomorphological compartments present in the area.

The fourth and final point of change in the SGCMLP boundary was named Proximities of the Mato Grande Biological Reserve (ReBio) Mato Grande. To carry out the adjustment at this point, it was not necessary to apply the same level of theoretical-methodological rigor as implemented in points 2 and 3. Here, near the ReBio Mato Grande, the differential material used was the land cover and land use mapping. The change consisted of excluding an area corresponding to the MapBiomas class “Other Temporary Crops.” Relief altimetry was used as support for refining the shape of this portion of the delimitation.

5.2. Land cover and land use dynamics

Between 1985 and 2022, natural coverages increased by 1.26%, compared with the percentage decrease in land uses. The land cover classes Forest Formation, Grassland Formation, Herbaceous Restinga, Beach, Dune and Areal, and River, Lake, and Ocean were the ones that showed increases (respectively 32.89%, 64.15%, 79.18%, 65%, and 0.87%). In contrast, the Arboreal Restinga and Floodplain Field and Swamp Area cover classes were the ones that experienced decreases (respectively 2.61% and 7.82%).

Among the land-use classes, Silviculture, Rice, and Urban Area recorded increases (respectively 600%, 215.23%, and 69.13%), whereas the land-use classes Mosaic of Uses, Soybean, and Other Temporary Crops recorded decreases (1.41%, 47.23%, 69.69%, and 53.1%). These changes can be seen in Table 1 and Figure 6, which respectively show the changes in area (km²) and percentage (%) of land covers and uses, as well as the cartographic representation of the space-time dynamics (decades) of Land Cover and Land Use between 1985 and 2022 in the SGCMLP.

The 1.26% increase in total land cover, at first, appears to be of little significance in the land’s spatiotemporal dynamics, since within the study period no cover/use shows a notable increase in area compared with the decrease of another one. The land-use classes Silviculture and Rice recorded the greatest increases among all categories (600% and 215.23%, respectively). An analysis of the increase in their areas (0.72 km² and 17.09 km², respectively)

indicates that, at first, this rise does not draw much attention, because there is no significant decrease in natural covers. The land-use classes Silviculture and Rice were again the ones with the largest increases among all categories (600% and 215.23%, respectively). The main factor behind the reduction of wetland areas is the intensification of land use and occupation, specifically the increase in the Rice class at the expense of the decline in the areas of the Floodplain Field and Swamp Area class—space portions that are favorable for irrigated rice because they are naturally seasonally flooded areas with hydromorphic soils.

Any and all changes in land use in wetlands should be viewed as a critical potential, since in Brazil wetlands are no longer covered by the Permanent Preservation Areas (APPs) and their status of full/protective safeguarding has been removed. What today appears to be minor changes in terms of area quantity may become a driver of major environmental change if the importance of Wetlands (AUs) is not recognized.

Figure 7 shows precipitation conditions and the monthly mean temperature for all municipalities where the study area is located. It is possible to observe that the rainfall regime remained uniform, with an average annual precipitation of 1,360 mm. When cross-referencing the land cover and land-use dynamics data (Table 1) with the climatological normals (Figure 7), specifically we can infer that the increases and decreases in land cover and use classes do not have a climatological influence. However, even though the Floodplain Field and Swamp Area class experienced a regression in its total area during the analyzed period, the persistence of rainfall mitigated this negative effect by helping maintain (water recharge) this portion of wetland areas and cushioning its reconfiguration.

According to Ferreira (2025), the main driver of the decrease in wetland areas is the intensification of land use and occupation, specifically with the increase in the Rice class at the expense of the reduction in the Floodplain Field and Swamp Area class—areas that are favorable for irrigated rice because they are naturally seasonally flooded and have hydromorphic soils. By contrast, the increase in the Grassland Formation class cannot be viewed as a recovery of a natural land cover, since native grasslands in the Pampa biome act as vectors for the expansion of agricultural frontiers in the state of Rio Grande do Sul (Ferreira, 2025).

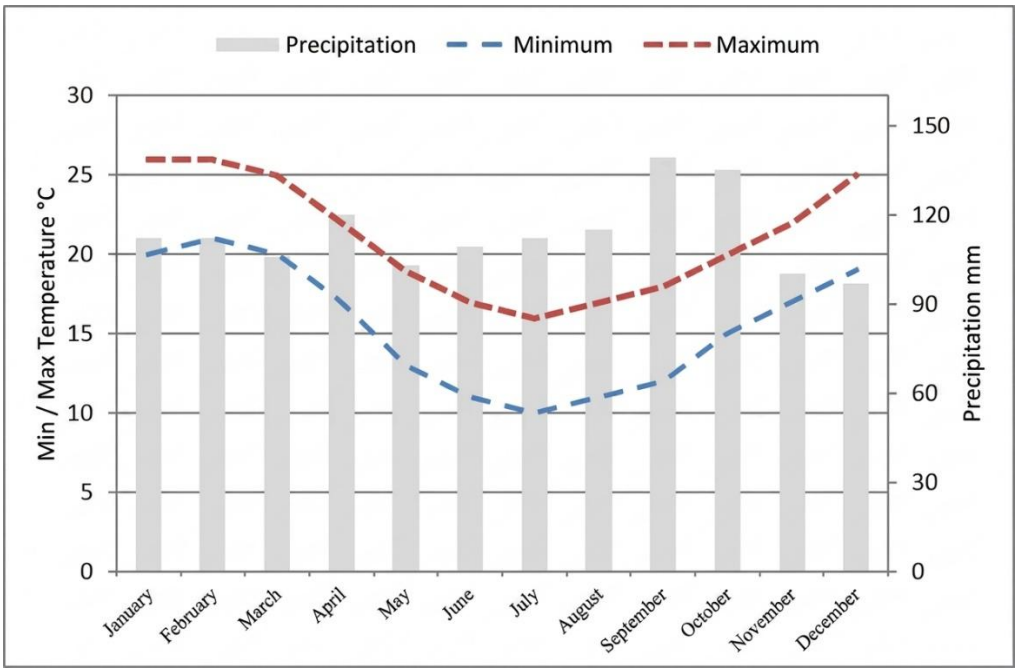


Figure 7. Mean temperature and precipitation in the study area (1995–2025). Source: Ferreira (2025).

6. Conclusions

Updating the limits for the geomorphological compartment implies updating the geomorphological mapping and bibliography for the research area, which represents an important environmental sector of Rio Grande do Sul. One of the next steps in this work is the preparation of documents and technical reports aimed at municipal public authorities, where the study area is located, with the goal of guiding a sustainable management and handling plan for portions of wetland areas, given their geo-bioecological importance and the current climate conditions and public concern in Rio Grande do Sul, which has been facing extreme precipitation events, followed by flooding that causes material losses and loss of life. For this reason, it is important that public authorities (at the municipal, state, and federal levels) review the process of city expansion and the occupation of certain areas. It is crucial that the Sustainable Development paradigm guides the formulation of public policies focused on managing and organizing space.

The analysis of the quantification of area measures for the SGCMLP limits and for the land cover and land-use data revealed an incompatibility of 19.96 km² between them, which respectively recorded 886.56 km² and 866.56 km². This incompatibility was mainly driven by the "Not observed" data class, with secondary causes related to the data type and the technique used to calculate the area of each dataset.

It was found that, in the study area, the analysis of the dynamics of land cover and land use over the 1985–2022 period indicated that, although it experienced a slight decrease, the Floodplain Field and Swamp Area class still has the largest area and percentage values when compared with other land cover and land use classes. Within the spatial extent, the Grassland Formation land cover class showed the most significant increase in area, rising from 61.90 km² in 1985 to 101.61 km² in 2022. This increase cannot be seen as a recovery of a natural cover, since Grassland Formation areas are vectors for the expansion of agricultural frontiers in the state of Rio Grande do Sul. The 600% percentage increase in the Silviculture class appears negligible, since the area increased only from 0.12 km² to 0.72 km².

It was determined that AUs (wetland areas) decreased by 8.09% throughout the analyzed period. Given the 37-year time span, this represents a small but not negligible reduction. It was concluded that this decrease was caused by the expansion of agricultural uses (rice paddies expanding over the AUs) and the edge effect, which occurred more intensely and concentrated in the central portions of the study area.

Changes in legislation may have enabled the conversion of a few wetland portions to support rice cultivation. Although small, this increase should raise alerts regarding the protection of wetlands in the SGCMLP, since the legislation no longer ensures their full protection and the agricultural sector could continue expanding its crops unchecked.

Thus, it was possible to confirm that, despite the decrease and the confirmed land use and occupation process (which took place more intensively over the Pampa's natural grassland areas [Grassland Formation]), the environmental integrity of the wetlands occurring within the study area (SGCMLP) was only slightly affected by anthropogenic pressures and also by natural processes during the 1985–2022 period.

It is important to highlight the environmental relevance that this area has shown during the successive extreme events occurring since 2022. The fact that this area managed to keep most of its natural cover preserved over time allowed it to withstand all runoff originating from the Mirim/São Gonçalo System (BHMSG). This is one of the key areas of the state of Rio Grande do Sul in buffering the impacts of climate change currently underway, and therefore it requires protection.

Finally, this study highlights the need for new research focused on wetlands—not only for this portion of the state, but for the entire coastal plain of Rio Grande do Sul, and also for the whole Brazilian territory—aimed at protecting, preserving, and conserving Brazil's wetlands.

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