ASSOCIAÇÃO PORTUGUESA DOS RECURSOS HÍDRICOS
APRH

Journal of Integrated Coastal Zone Management (2024) 24(1): 73-92
© 2024 APRH
ISSN 1646-8872
DOI 10.5894/rgci-n591
url: https://www.aprh.pt/rgci/rgci-n591.html

GEOENVIRONMENTAL ZONING OF THE MUNICIPALITY OF RIO GRANDE, SOUTHEAST BRAZIL

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ABSTRACT: Zoning has the function of making the development of urban and rural areas compatible, defining restrictions and adjustments to the use of the soil. A subdivision of environmental zoning is geoenvironmental zoning, which considers the landscape as a physical and conceptual tool/contribution to the planning actions. The municipality of Rio Grande (Rio Grande do Sul-South Brazil), which is situated in a lagunar area, with sectors far away from the beach, allowed different uses of the urban and rural spaces, which drastically affected the operation and organization of the landscape. Therefore, there has been a need for studies on environmental planning, being the objective of this research to present the geoenvironmental planning for Rio Grande municipality. The geoecology of landscapes will be used as a theoretical and methodological approach, as it allows the establishment of geoenvironmental units. The geoenvironmental zoning defined six areas, which are: preservation, conservation, damping, rehabilitation, improvement, and use. The geoenvironmental zoning allowed the proposition of rules to the adequate use of the environment, conciliating the characteristics of the physical environment with the needs of socioeconomic dynamics.

Keywords: Planning, Landscape, Geoenvironmental Units, Zoning.

RESUMO: *O zoneamento tem a função de compatibilizar o desenvolvimento das áreas urbanas e rurais, definindo restrições e adequações ao uso do solo. Uma subdivisão do zoneamento ambiental é o zoneamento geoambiental, que considera a paisagem como instrumento/contribuição física e conceitual para as ações de planejamento. O município de Rio Grande (RS), situado em uma área lagunar, com setores distantes da praia, permitiu usos diferenciados dos espaços urbano e rural, o que afetou drasticamente o funcionamento e a organização da paisagem. Portanto, houve a necessidade de estudos sobre planejamento ambiental, sendo o objetivo desta pesquisa apresentar o planejamento geoambiental para o município de Rio Grande. A geoecologia de paisagens será utilizada como abordagem teórica e metodológica, pois permite o estabelecimento de unidades geoambientais. O zoneamento geoambiental definiu seis áreas, sendo elas: preservação, conservação, amortecimento, reabilitação, melhoria e uso. O zoneamento geoambiental permitiu a proposição de regras para o uso adequado do meio ambiente, conciliando as características do meio físico com as necessidades da dinâmica socioeconômica.*

Palavras-chave: *Planejamento, Paisagem, Unidades Geoambientais, Zoneamento.*

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Submission: 14 APR 2024; Peer review: 7 MAY 2024; Revised: 11 OCT 2024; Accepted: 11 OCT 2024; Available on-line: 21 OCT 2024

1. INTRODUCTION

Environmental planning is based on integrating information gathered from the natural environment with information from the social-economic dynamic of places. Its objective is to keep the integrity of the elements, both natural and anthropic, with propositions aiming at adjusting the use of the land to its natural vocation. It seeks harmonic development and the maintenance of the natural characteristics of the environment aligned with sustainable development (Santos, 2004; Rodriguez *et al*., 2013).

Environmental planning establishes goals and guidelines to be reached within a temporal scenario, and zoning is one of its guiding principles. Zoning is both a methodology and a planning instrument, as it spatially organizes the area in question (Santos, 2004; Zacharias, 2010).

Zoning is the division of a certain territory into smaller areas according to their most relevant attributes and dynamics (Santos, 2004). Each delimited area is considered a homogeneous one, with similar characteristics, and highly differentiated from the other sectors. The areas are constituted as expressions of the vocations, susceptibilities, good actions, and conflicts inherent to each spatial segment. Therefore, a specific set of rules is attributed to each area, which are used to guide the land uses and the protection of nature.

Environmental zoning is one of the instruments of the Brazilian national environmental policy (Brasil, 1981) and has the function of integrating the development of urban and rural areas, defining the restrictions or the suitability of the uses of the areas. Besides, it also defines that environmental zoning has a subdivision called geoenvironmental zoning (Zacharias, 2010).

According to Oliveira (2012), geoenvironmental zoning is a territorial planning instrument strongly guided by environmental issues and seeks support from a systemic approach. It provides insight into the possibilities and limitations of the landscape and also addresses land use and the pressures caused by such uses. Benini (2009) states that geoenvironmental zoning is a prevention strategy when choosing areas, in which it is possible to carry out specific planning. The main objective is to individualize areas with similar characteristics based on a diagnosis integrated with ordered surveys for better interpretation of the results.

Sato (2008) mentions that geoenvironmental zoning allows the identification of areas whose environmental characteristics provide the individualization of zones, in which socioeconomic issues are incorporated, promoting integrated analysis.

It means, geoenvironmental zoning results from the integrated diagnosis of the landscape, which identifies its capabilities and use restrictions, where the analysis of the physical environment constitutes the basis for initial knowledge of the landscape.

Hence, the objective of this study is to perform the geoenvironmental zoning of a municipality in South Brazil (Rio Grande – RS – Brazil), using the geoecology of landscape as the theoretical-methodological approach that surveys the landscape based on a systemic approach. Such an approach dates from the end of the 19th century, when it was necessary to integrate the geographic approach (spatial) with the ecological one (functional) to analyzes landscapes, considering them as a global system (Rodriguez *et al*., 2013).

The notion of landscape is the basic concept of Landscape Geoecology, which offers an essential contribution to the knowledge of the natural base and also provides solid foundations in the elaboration of theoretical and methodological bases for planning, focusing attention on the interaction between the physical environment and the socioeconomic dynamics (Rodríguez *et al*., 2017).

The geoecology of a landscape can be used in environmental planning as it allows the systematization of the multiple elements of the landscape that is the object of the research. Crossing information, in a synthetic way, allows the identification of similarities and differences that promote the delimitation of the geoenvironmental units, the homogeneous areas of the landscape, acquired through the integration of natural and anthropic elements (Santos, 2004; Rodríguez *et al*., 2017).

There have been various studies in Brazil lately using this approach, namely Farias (2012), related with a geoecological zoning of the municipality of Novas Russas (Semi-arid - CE-Brazil); Farias (2015), who describes the use of geoecology of landscape in hydrographic basin of Palmeira River (CE-Brazil); Alencar (2018), who attests that geoenvironmental zoning of the municipality of Camocin (Costal area – CE-Brazil); Lima and Oliveira (2018), who analyzes the geoenvironmental zoning of the municipality of Caraguatatuba municipality (SP-Brazil); and Teixeira (2018), who focus on the geoecological analysis of the municipality of Tejuçuoca (CE-Brazil) as support to environmental planning.

Thus, the present study identifies the areas that present a balance between the physical environment and socioeconomic dynamic;

the areas with limitations to endure anthropic interventions; and the areas that are in an advanced stage of degradation. Therefore, as an example, it is presented the geoenvironmental zoning of the municipality of Rio Grande (RS-Brazil), situated in a lagunar area, with sectors far away from the shoreline, but with elements of coastal dynamics controlling its evolution.

2. STUDIED AREA

The municipality of Rio Grande (Figure 1) is located in the south of Rio Grande do Sul State (Brazil). It has a total area of 3,338.3 km^2 divided into five districts (Rio Grande, 2008), having more than 191,900 inhabitants (IBGE, 2022).

The origins of the municipality, in an area originally inhabited by *Tupi-Guarani* and *Chaná* indigenous nations, date from the geopolitical context of the conflicts between Portugal and Spain in the XVII and XVIII centuries, when both European nations were engaged in expanding their territory. Ever since its foundation, on 19th February 1737, by Brigadier José de Silva Paes, extensive sandy plains, severe weather, and the existence of salty areas imposed difficulties on the settlement of the Europeans. However, its strategic location on the Atlantic coast allowed the town to develop as one of the main Brazilian seaports, which was vital to promote the urban and commercial development of the area during the XIX century, attracting immigrants and investors from different countries, and fomenting the textile industry (Vieira, 1983; Queiróz, 1987; Wilwock and Tomazelli, 1995; Martins, 2007; Torres, 2008; Telles, 2011).

At the beginning of the XX century fishing industries became important due to the biological diversity of the Patos Lagoon (which lasted until the 1980s) and, later, in the 1970s, the town received oil refining and fertilizing industries. In the XXI century, the town witnessed the emergence of naval industries and offshore, with the construction and/or repair of ships and oil and gas platforms, however, such investments have been stagnated lately (Martins, 2007; Carvalho, 2011; Torres, 2011).

The municipality of Rio Grande is located on a coastal plain, a recent geological formation characterized by the accumulation of thick sedimentary packages due to sea-level oscillations. These events culminated in an area of sedimentation, formed by extensive sandy ridges and a complex hydrographic system comprised of the Atlantic Ocean, Patos Lagoon, Mirin Lagoon, and São Gonçalo Channel, a natural channel that communicates between the waters of Lagoa Mirim and Patos Lagoon (Delaney, 1962; Wilvock and Tomazelli, 1995).

The local climates considered humid subtropical (Krusche *et al*, 2002) whose main characteristics are regular rainfall distribution along the year and moderate temperatures, without abrupt transitions (Castelão and Möller Jr, 2003; Rossato, 2011).

Climate and geological conditions, associated with a plain topography without great elevations, have allowed a constant water table supply, allowing the existence of shallow water depths and wetlands. The low energy of the geographic relay allows a longer period of water runoff and its consequent infiltration (Rio Grande, 2013b).

The conjugation between the aspects of the climate (well-distributed rainfall and moderate temperatures) and the geological ones (sandy permeable deposits) determined a peculiar vegetation formation that allows the development of small to medium-sized cover (Vieira, 1983). The vegetal cover is comprised predominantly of herbaceous grass, which is characterized by thick underbrush vegetation that covers the soil entirely (Bonilha, 2013), and tree species of heterogeneous aspect, known as Restinga forest (coastal plain forests), are also found in this area. Physiognomy of the Restinga forest shows variations due to the peculiar conditions of origin, as they migrate from different coastal areas (Tagliani, 2002; Scherer *et al*., 2005).

Various aspects regarding climate, hydrography, biogeography, geology and geomorphology condition the different pedogenetic processes of the soil and determine the type of soil found in this area (Bastos *et al*, 2005), predominantly of sandy texture, with exception for the areas near to the Patos Lagoon and São Gonçalo Channel, where the soil is hydromorphic (Klant *et al*., 1985; Cunha *et al*., 1996).

3. METHODOLOGY

The methodology used in this study was based on the one proposed by Rodriguez *et al*. (2017) regarding the Geoecology of Landscape and it is comprised of 5 stages: organization, inventory, analysis, diagnosis and propositions.

In the organization stage, a bibliographic review was conducted and the scale of the work was established (1:250.000). The inventory stage was used to evaluate the physical environment related to geology (IBGE, 2017a), geomorphology (IBGE, 2017b), pedology (IBGE, 2017c), vegetation (IBGE, 2017d), climate and hydrography. Despite the importance of climatic and hydrographic conditions in the configuration of the landscape of the study

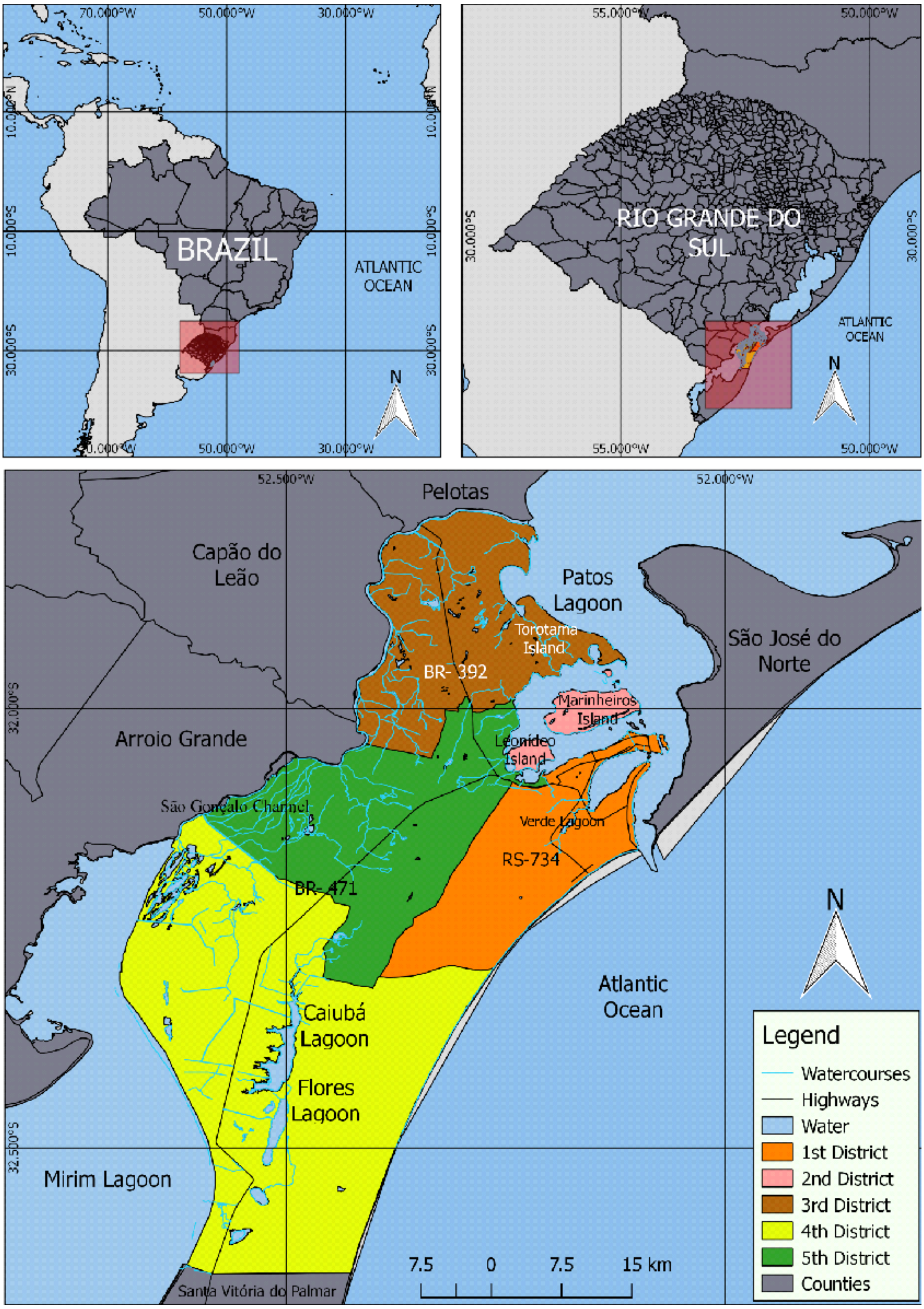

Figure 1. Location of the municipality of Rio Grande (RS-Brazil) and its district division. (Bonilha, 2019; Modified by Bonilha, GO)

area, as modelling agents, it is not possible to characterize homogeneous zones using these quantities, considering that they are vector quantities, such as winds. Thus, priority is given to the physical-natural aspects in which there is the availability of cartographic products, whose aspects become more latent in the research in question. It was also carried out the socioeconomic characterization of the area using land cover and land uses maps (Bonilha, 2019) that were elaborated with Landsat images dated from 11/05/1990, 04/05/2005 and 10/12/2015.

The treatment and interpretation of data obtained by the inventory was done in the stage of the analysis when the geoenvironmental units (Figure 2) were identified. As the recent landscape is conditioned by various natural and anthropic elements over time (Rodriguez *et al*., 2017), geoenvironmental units of the studied area represent the areas of the territory where there is a greater interaction between the natural elements (geology, geomorphology, soil, vegetation and the anthropic ones (land uses) allowing their spatial delimitation. It is important to highlight that the geomorphological criteria were preponderant.

Regarding the compatibility between the land uses (urban area, agriculture, livestock, rice cultivation and forestry) and the physical characteristics of the coastal plain, the land use was considered as:

- Compatible when its use has not spoiled nor affected the physical characteristics of the geoenvironmental unit;
- Incompatible when its use has spoiled and negatively affected the physical characteristics of the geoenvironmental unit.

Regarding the environmental legislation, the uses of the land were considered as:

- Adequate: when the land use has not violated the environmental legislation;
- Inadequate: when the land use has violated the environmental legislation.

The objective of identifying geoenvironmental units is to allow the understanding of the structure and the behavior of the landscape (Rodriguez *et al*., 2017). In the diagnosis stage, geoenvironmental units were evaluated according to the fulfilment of their geoecological functions, and their capacity to ensure the conservation of the structure and the functioning of the system through the exchange of matter and energy (Rodriguez *et al*., 2017). Therefore, the functional approach used here allowed the classification of the function of each geoenvironmental unit into three categories:

- Emitting areas: the ones that ensure the flow of matter and energy to the other areas, being positioned in higher altimetry levels;
- Transmitting areas: the ones that ensure the flow of matter and energy to lower altimetry levels;
- Accumulating areas: the ones that accumulate the flow of matter and energy and are situated in lower altimetry levels.

The identification of the functional role of each unit allowed the determination of their geoecological status (Figure 3), which is the result of the integration of physical and socioeconomic characteristics in each geoenvironmental unit, considering the changes in the structure and functioning of the landscape (Rodriguez *et al*., 2017).

It is important to highlight that the starting point to define the geoecological state is based on a landscape of reference, which are the earliest images available from the area under study. Thus, the modification on of the structure of the landscape was characterized by changes in the relief and the removal of native vegetation, as in the field structural changes are more perceptible in these elements.

The way the landscape has functioned in the studied area has been influenced by the rainfall, as it intensifies energy flows and matter transportation. Changes in watercourses and drainage patterns have modified how the landscape works, as drainage processes have acted to shape the landscape of the studied area (Vieira, 1983).

The classification done categorizes the geoecologcal stages as (Roodriguez *et al*, 2017):

- Stable: when the original structure is in a good state of conservation or presents few changes. There are no major problems affecting the way the landscape works. The anthropic influence is small and the land use is limited to the areas where the conservation of the natural elements is assured.
- Unstable: when there are considerable changes and partial loss of the original structure as a result of anthropic interference. However, the changes are reversible and it is possible to keep the landscape working. The uses of the land exceeded the capacity for renewal of the natural elements.
- Critical: when there are general, irreversible modifications and total loss of the original structure, being the functioning of the modified landscape. Those are areas where the land use does not allow the self-regulation of the natural elements.

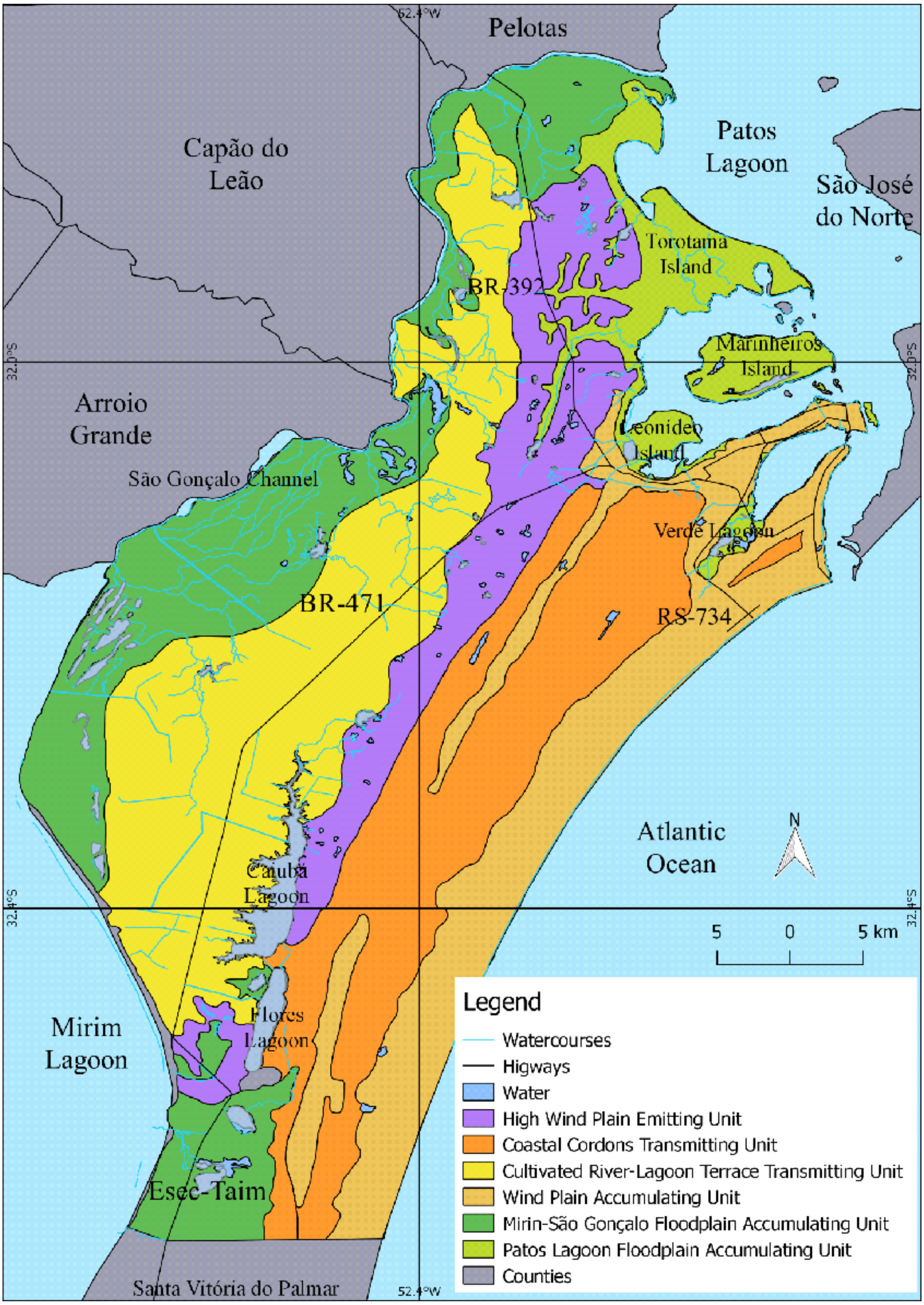

Figure 2. Geoenvironmental Units of Rio Grande (RS-Brazil) Municipality. (Bonilha, 2019; Bonilha, 2023).

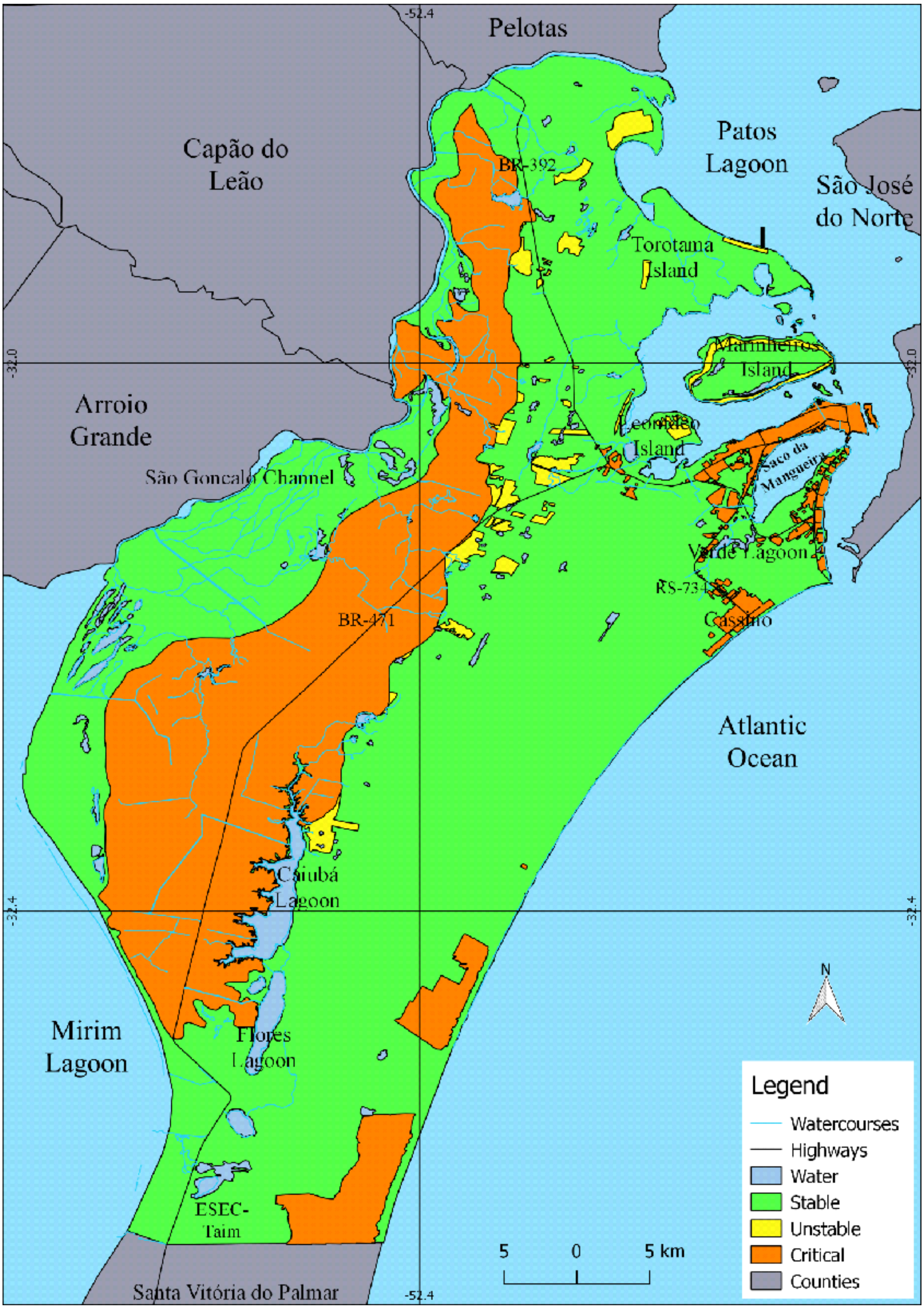

Figure 3. Geoecologica state. (Elaborated by Bonilha, 2023).

The classification of the geoecological states along with the identification of the compatibility and adequacy of the uses were considered to classify the current landscape (Figure 4), according to the geoecological degradation levels caused by the anthropic intervention. Rodriguez *et al*. (2017) classifies the landscape as

- Optimized: when the original structure is preserved, under regular protective measures, and the landscape does not present geoecological degradation.
- Compensate: when the original structure is preserved and the land uses are controlled or happen in small areas. The landscape may present some degree of geoecological degradation; however, it can be easily reverted
- Depleted: when the original structure was modified and its functions badly affected. The landscape reaches a degree of geological degradation that is difficult to revert, however possible.
- Modified: when the original structure was so modified that the functions were eliminated. The land is intensively used and the landscape presents a degree of irreversible geological degradation.

Finally, in the proposition stage, the geoenvironmental-zoning map (Figure 5), the main objective of the planning, is presented. The careful evaluation of the geoecological state and the classification of the current landscape allowed identify the areas that need urgent mitigating measures to ease the imbalance generated in the self-regulatory mechanisms of the landscape, and define preventive and/or corrective measures to guarantee the fulfilment of the functions of each geoenvironmental unit of the landscape.

The areas were identified by colours, following the principle of the intensity of the phenomenon. The areas that need simple measures are marked in light cool colours and the areas where urgent measures are required are in dark warm colours (Sato *et al*., 2015). Data collected from the diagnosis stage and the field trip were used to propose the necessary actions for each area.

The nomenclature of the areas was proposed based on the studies of Oliveira e Souza (2012) and Braz *et al*. (2015). Six categories were elected: preservation, conservation, prevention, use, regeneration and improvement. Some actions were recommended for delimited and defined areas (Table 1), which should be carried out by the local government and population of Rio Grande (RS-Brazil) municipality.

4. RESULTS

The geoenvironmental zoning of Rio Grande (RS-Brazil) municipality (Figure 5) aims to establish guidelines that will allow efficient maintenance of matter and energy flows in the area studied. Such actions will contribute to keeping the balance between the geoecological functions of the landscape and the current uses of the landscape.

The areas defined have the objective of guiding the land uses, considering the legal aspects and physical characteristics of the environment, or indicating the most adequate kind of land used for each area on the map. Six areas were defined: Preservation Area, Conservation Area, Prevention Area, Use Area, Regeneration Area, and Improvement Area.

Table 1. Type of action recommended for the categories of the geoenvironmental zoning (Oliveira and Souza, 2012; Bonilha, 2023).

CATEGORY	ACTIONS
Preservation	Prohibition
Conservation	Restriction and/or Limitation
Prevention	Prevention and/or Restraint
Use	Control and/or Improvement
Regeneration	Recovering
Improvement	Repair

4.1 Preservation Area

The main function of the preservation area is the protection of the natural conditions due to their high relevance to environmental dynamics, as they are essential to the structural and functional integrity of the landscape (Oliveira and Souza, 2012). Therefore, it is necessary to keep these areas protected from anthropic interventions to avoid possible environmental problems; excepting those actions aimed at conservation (Braz *et al*., 2015). The actions aim at keeping the geoecological state stable (Figure 3) and the landscape optimized or balanced (Figure 5).

The following geoenvironmental units comprise the preservation area: Mirin-São Gonçalo Floodplain Accumulating Unit, Patos Lagoon Floodplain Accumulating Unit and Coastal Cordons Transmitting Unit (Figure 2).

The preservation area of the Mirin-São Gonçalo Floodplain Accumulating Unit is characterized by wide surfaces that were originated from lagoon accumulation processes, permanent or periodically flooded, which lithology is composed of unconsolidated alluvial deposits originating from coastal lagoons silting up (RADAMBRASIL, 1986; IBGE, 2003). Lagoa Mirim and São Gonçalo Channel are subjected to periodical floods, which allow the accumulation of organic matter that gave origin to lowland soils, organic soils and gley soils (Embrapa, 2006), and a large extension of areas constantly wet.

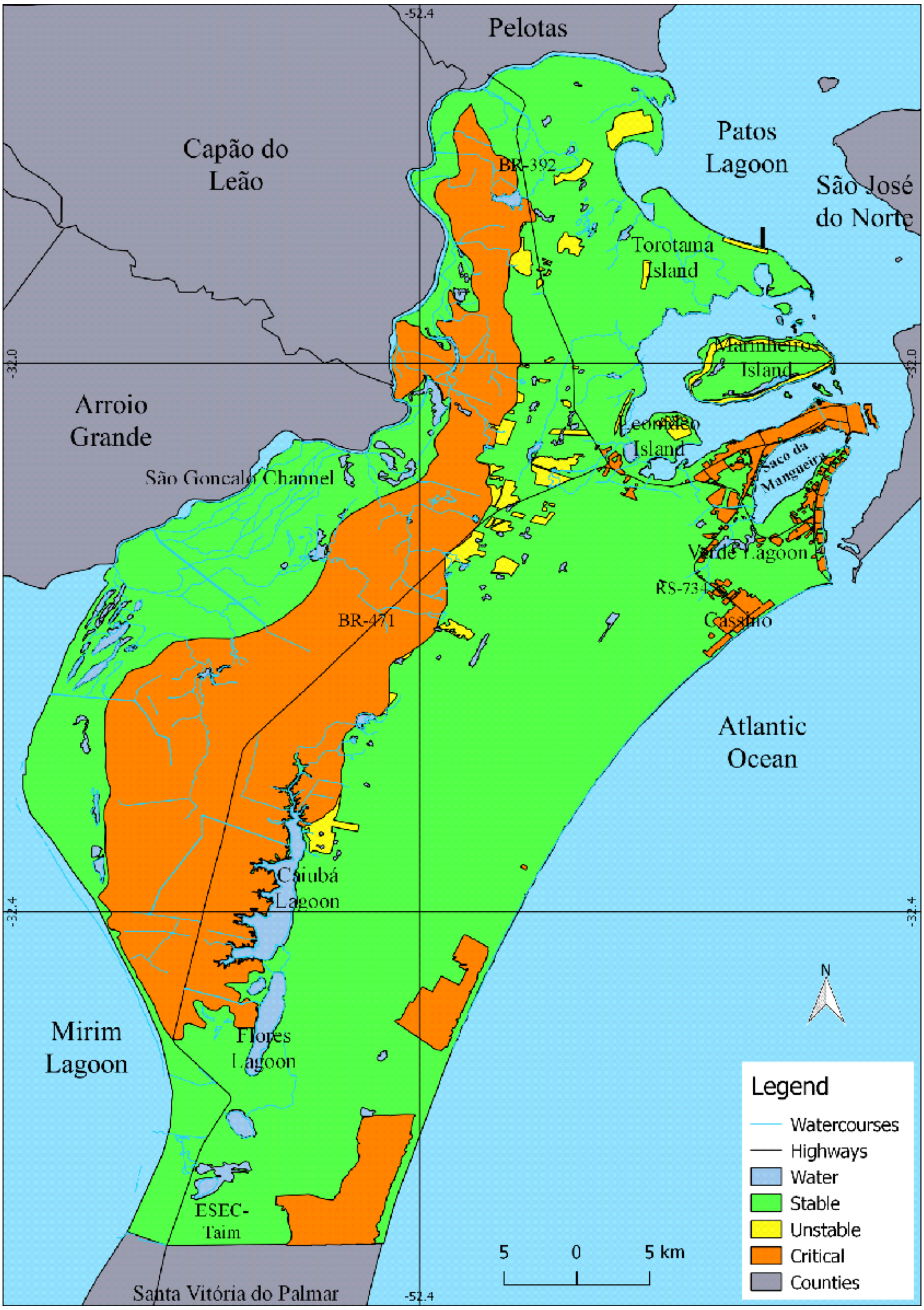

Figure 4. Current Landscape. (Elaborated by Bonilha, 2023).

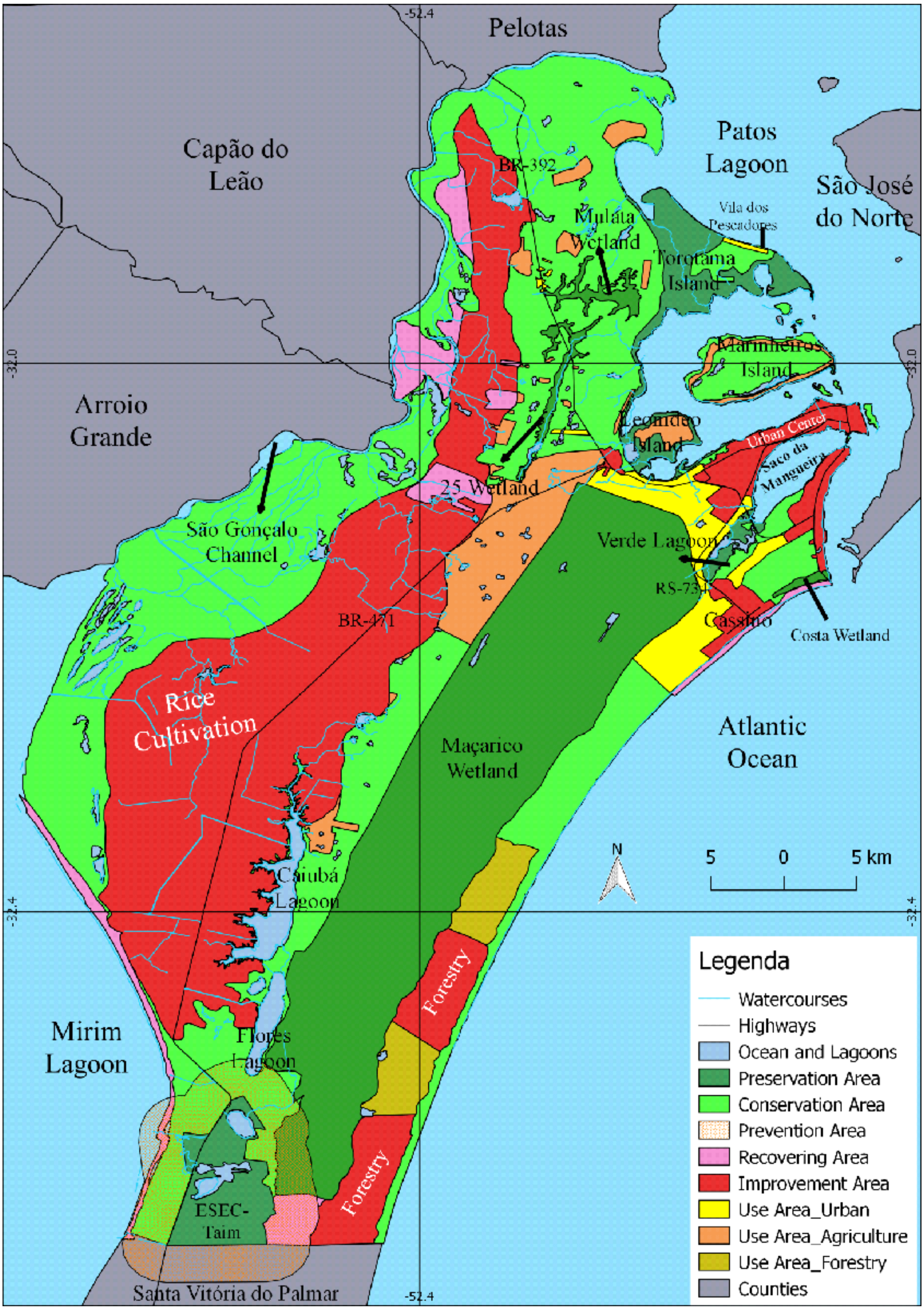

Figure 5. Geoenvironmental Zoning of Rio Grande (RS-Brazil) municipality. (Bonilha, 2019; Bonilha, 2023).

Taim Ecological Park (Figure 6) is an example of such wetlands, being characterized as vital to the maintenance of hydrological regulation. The land use in this geoenvironmental unit is restricted to livestock due to the soil conditions and frequent flooding. However, our proposition is for this activity to be forbidden in the area of ESEC-Taim, as the ecologic park is protected by a law that forbids anthropic interventions in this area (Brasil, 2000).

The conservation zone where Patos Lagoon Floodplain Accumulating Unit (Figure 2) is located is an area originated by fluvial and lagoon accumulating processes that are subject to periodical flooding. Unconsolidated alluvial deposits originated from coastal lagoons silting up compose the lithology of the area (IBGE, 2003). Planosoils are predominant in this area, however organic soils and plinth soils may also be found. As for their proximity to the estuary, the planosoils may present high concentrations of sodium and high natural fertility (Embrapa, 2006). The land use in this area is associated with rural activities, livestock and agriculture.

Salt marshes are frequent in this geoenvironmental unit, as they are herbaceous grasses (Figure 6) that bear periodic flooding, salinity variation, and low temperatures, both air and water (Schaeffer-Novelli, 2000; Marangoni and Costa, 2010). Salt marshes are considered areas of permanent conservation - APP (Brasil, 2000; Rio Grande, 2008), and they have the function of mitigating erosive processes caused by the water flow of the Patos Lagoon (Schaeffer-Novelli, 2000; Marangoni and Costa, 2010). Therefore, the salt marshes should continue to be categorized as an area of permanent conservation and protected from anthropic interventions, being the livestock activity removed from this area.

There are also wet areas in the Patos Lagoon Floodplain Accumulating Unit (Figure 2) that require attention, which are "Banhados do 25 and Mulata" (wetlands) and Verde Lagoon Environmental Protection Unit (Figure 5). The late one is a conservation unit (Brasil, 2000) recognised by the municipal law (Rio Grande RS-Brazil) 6.084/2005, which has the objective of protecting the natural resources and biodiversity and performing educational and research activities (Rio Grande, 2005).

Verde Lagoon Environmental Protection Unit (EPU), which has been considered as an area of sustainable use, should be considered as a Permanent Protection Unit (PPU). Such change in category has been suggested in an attempt to prevent the urban expansion that has been observed in this area and its implications, such as the disposal of illegal waste.

"Wetlands of the 25 and Mulata" (Figure 5) should be classified as PPU due to their systemic functions as hydrological regulators and refuge for biodiversity, as both areas shelter animal and vegetal species.

The area of preservation comprised by the Coastal Cordons Transmitting Unit (Figure 2) is an area of marine terrace slightly declined towards the Atlantic Ocean (IBGE, 2003). The area is characterized by a series of beaded bundles, with crests and pits, parallel to the shoreline (Godolphin, 1976). Lithology is composed of thin sand deposits, rich in organic matter (RADAMBRASIL, 1986), however, the spodosol present in the unit should not be used for agriculture (Embrapa, 2006).

Native vegetation composed of herbaceous grasses and paleoxerophytes is still preserved (Tagliani and Vicens, 2003), and the land is used mainly for livestock. Coastal cords (Figure 6) are comprised of a large area of wetlands used as shelter and reproduction areas for many species. Therefore, in 2014 Maçarico Wetland Biological Reservation was created (Sema, 2017).

It is understood that Maçarico Wetland Biological Reservation should be categorized as a PPU, as it is located on coastal cordons that should be preserved, as they are part of the geological formation of the coastal plain (Brasil, 2012), and livestock should also be removed from these areas. Furthermore, the coastal cordons connect the Mirim Lagoon (through Taim Wetland) to the Patos Lagoon (through Verde Lagoon and da Costa Wetland) establishing a balanced system. Da Costa Wetland (Figure 5) shelters numerous species of birds and it is closely related to the coastal cordons, being relevant to the flow of matter and energy, and in the hydrological regulation. Therefore, it should be categorized as PPU.

The suggestions for the waterways, based on municipal, state and federal legislation (Rio Grande do Sul, 2000; Rio Grande, 2008; Brasil, 2012) take into consideration the water oscillation in periods of flood and drought. It is proposed a propose a range of 200 m for São Gonçalo Channel, aiming at protecting riparian vegetation and possible erosion events; 100 m for Caiubá and Flores Lagoons, aiming at the restraint of rice cultivation; and, at least 30 m for the other waterways in an attempt to restrain urban expansion.

4.2 Conservation Area

The conservation area has the function of keeping the natural characteristics, being different from the preservation area as its function is the restriction (or limitation), and not the prohibition. The land can be used within limitations that will guarantee the

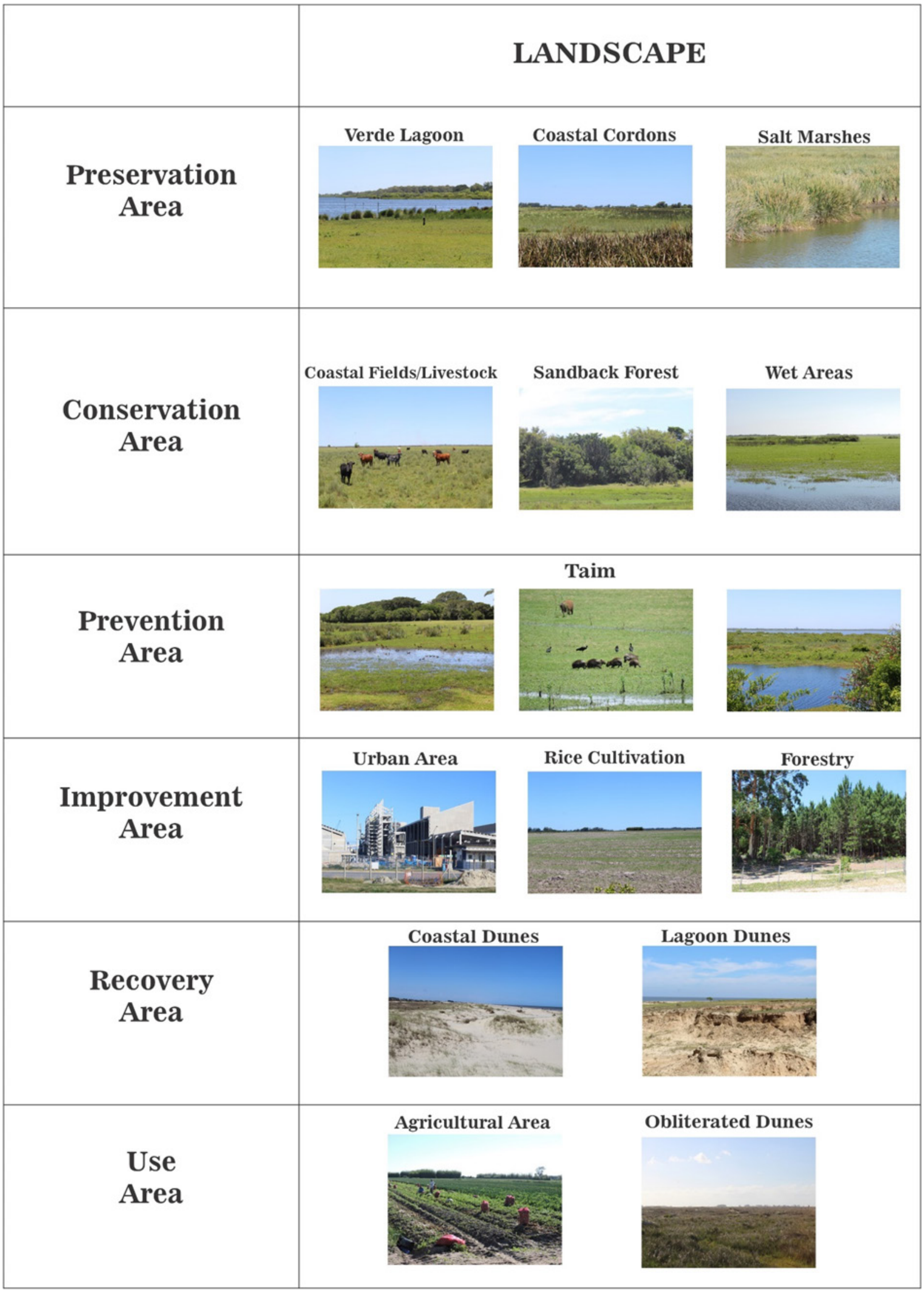

Figure 6. Characteristic landscape of the defined areas. (Bonilha, 2023).

integrity of the physical environment, conciliating the uses of the land with the characteristics of the landscape, and respecting its capacity (Oliveira and Souza, 2012; Claudino-Sales and Peulvast, 2002). The functions of this area should be kept as they are (Braz *et al*., 2015), as long as the geoecological state is stable (Figure 3), and the landscape optimized or balanced (Figure 4).

The conservation area is composed of the following geoenvironmental units: High Wind Plain Emitting Unit, Wind Plain Accumulating Unit, Mirim São Gonçalo Flood Plain Accumulating Unit, Patos Lagoon Flood Plain Accumulating Unit (Figure 2).

The High Wind Plain Emitting Unit is characterized as a slightly waved plain, formed by Pleistocene-aged wind deposits, from different origins, which are impregnated by iron oxides (RADAMBRASIL, 1986; IBGE, 2003). Therefore, clay accumulation gives origin to well-developed soils, argisols; and soils developed under restricted water percolation, plintosols, which present iron segregation (Embrapa, 2006).

The area of the Wind Plain Accumulating Unit (Figure 2) is comprised of plain areas of sandy deposits reshaped by the wind, being mainly formed by obliterated dunes (IBGE, 2003), which is a type of dune pre-fixed by Psammophilus vegetation (Tagliani and Vicens, 2003). The lithology in this area is composed of Holocene quartz sand wind deposits (RADAMBRASIL, 1986). The soil is poorly developed, neosols, due to the low intensity of pedogenetic processes, or other formation factors. Neosols have a sandy texture, are susceptible to erosion, and are poor in nutrients; however, they do not present resistance to the growth of roots (Embrapa, 2006).

In both geoenvironmental units Eolic Plain and High Eolian Plain, native vegetation is represented by coastal fields, which according to Bonilha (2013) is a grassy-herbaceous vegetation characterized by thick creeping species that cover the entire soil and sandbank forests, represented by tree species originated from other environments that migrated to coastal areas. They have physiognomy variations due to the different conditions of the environment where they come from (Tagliani, 2002; Scherer *et al*., 2005).

Coastal fields (Figure 6) are largely used for livestock and should be used in an extensive way to avoid the risks of geoecological degradation. The way this land has been used has not posed a risk to the landscape.

Regarding the sandbank forests (Figure 6), the exploitation of native vegetation is legislated by Law No 11.248 (Brasil, 2006) Decree No 5.975 (Brasil, 2006b). The conservation of the vegetation in these areas is important as the vegetation interferes with the drainage maintenance and in the stability of the sandy substrate, protecting the soil from the wind which is a relevant agent in the modification of the landscape (Scherer *et al*., 2005). The native vegetation is also relevant to be used as shelter for a variety of native and/or migratory species.

The conservation area is also comprised of the wide wet areas of the Mirim São Gonçalo Flood Plain Accumulating Unit (Figure 2), which are used mainly for livestock due to their characteristics. Livestock can continue in the area if it is done extensively. Wetlands should be conserved as they guarantee the survival of adjacent areas, working as "natural sponges", supplying water in times of drought, and retaining water in floods (Simon, 2007). The way livestock activity has been conducted does not seem to pose a risk to the landscape in these areas.

Finally, the Patos Lagoon Flood Plain Accumulating Unit (Figure 2) is considered a tourist area due to its characteristics such as visiting areas and as visiting and leisure areas. Public authorities should supervise these areas as, according to Michelin (2006), most tourists have no idea of the impact of their acts on the environment. They believe they do not need to follow the rules and exploit the environment without worrying about the consequences of their actions. Tourists throw away used packaging, food, bottles and other kinds of waste, causing an accumulation of garbage that generates not only pollution but also a negative visual impact on the environment.

4.3 Prevention Area

The prevention area has the function of minimizing or even avoiding the negative environmental impacts produced by urban and rural activities that may affect the natural elements within a conservation unit. Therefore, anthropic activities are regulated in the prevention area in an attempt to keep the maintenance of the geoecological processes (Ganem, 2015).

ESEC-Taim (Figure 6) should have its prevention area, within an area of coverage with a radius of 3 km (Conama, 2010), and the elaboration of a management plan, as ESEC-Taim does not have an official one.

ESEC-Taim was created in 1986 by the decree No 92.963, aiming at the preservation of its fauna and flora. It should also protect the area that is used for resting, nesting and resting by migratory species, mainly birds. This area is also used as a shelter for migratory species, reproduction and/or habitat area for endemic species (Backes, 2012; Burger, 2000). The problems spotted in this area are the ones related to livestock, which is migrating into ESEC-Taim, poaching and the fact that many species are run over on the road that crosses this area (BR-471). The activities in the prevention area should aim at conserving the vegetation, the hydric resources and the species, both in transit and inhabitants of the ESEC-Taim.

4.4. Improvement Area

The improvement area has the objective of diminishing the environmental impact (Conama, 1986) caused by the uses of the land, as anthropic interventions have resulted in irreversible changes, giving the landscape a different dynamic. The suggestions given for this area aim at adjusting the uses of the land to allow the landscape to find its functional flow (Braz *et al.*, 2015). Here, it is not proposed changes in the use of the land, as the geoecological state of the areas is critical (Figure 3), and the current landscape has been altered (Figure 5), being the natural conditions of the area unlikely to be restored.

In the area under study, the improvement area has the following geoenvironmental units: Cultivated River-Lagoon Terrace Transmitting Unit and Wind Plain Accumulating Unit.

In the area of the Cultivated River-Lagoon Terrace Transmitting Unit (Figure 2), the improvement area is comprised of lagoon and river-lagoon terraces. These are flat areas slightly sloped towards the lagoon plain that was sculpted by changes in the flow conditions and water blade, or even by erosive processes (IBGE, 2003).

Lithology is comprised of quartz sand lagoon deposits (RADAMBRASIL, 1986), with gleysols, a type of soil originating in sloped areas under the influence of groundwater outcrop, where the water is either internally stagnant or the saturation is achieved by lateral flow, and in both circumstances, the water in the soil can emerge into the surface (Embrapa, 2006). Native vegetation can only be found on the side of the road (BR-471) (Figure 1), as the whole environment was changed by the activity of rice cultivation.

Inside this geoenvironmental unit, where rice cultivation (Figure 6) is consolidated, the water for irrigation comes from São Gonçalo Channel and Mirim, Caiubá e *das* Flores Lagoons (Figures 6). As the water returns later for these water bodies and waterways, the authorities should control the use of fertilizers and pesticides, as they cause eutrophication processes.

In the surroundings of Caiubá and *das* Flores Lagoons (Figure 5), after the recommended range of 100 m (PPU) and within the limits among Mirim-São Gonçalo Flood Plain, Cultivated Lagoon terrace, and High Wind Plain Geoenvironmental Units (Figure 2) the cultivation of organic rice is proposed. Such cultivation uses a process that does not harm the natural resources, helping plant fertilization by replacing nutrients in the soil instead of using artificial fertilizers. Therefore, there will be an offer of free toxic substances in food that are obtained from balanced and fertile systems (Mattos and Martins, 2009).

In the Wind Plain Accumulating Unit (Figure 2), the improvement area was consolidated into an urbanized area used for swine farming. The improvements in the urban areas (Figure 6) should focus on the improvement of matter and energy flow, and housing conditions, being sanitation the main action required. The propositions for the swine farming area aim at managing the use of the water resources and avoiding the dispersion of exotic species.

Rio Grande municipality has a flat relief, which means that rainwater takes a long time to runoff (Rio Grande, 2013). Such a situation requires the use of drain pumps in the urban draining system, which should be regularly revised and, in the future, this system should be replaced by a more efficient one, as in extreme situations flooding has been observed in these areas.

Furthermore, soil sealing should also be present, as it influences the infiltration of the water in the soil (Guerra and Cunha, 2005). It is here proposed the opening of spaces for urban afforestation (Figure 5) and paving the streets using *Uni Stein* blocks instead of asphalt.

Finally, the other land use consolidated in this geoenvironmental unit is Forestry activity that uses *pinus* and *eucalyptus* as the main species (Treflor, 2010), whose main characteristic is the high intake of water in the early stages of plant development (Tagliani, 2000). The forestry area is located on an area of obliterated dunes, where water table recharge is difficult, and the vegetation can retain the rainfall at the treetops, where the water is lost into the atmosphere by evapotranspiration (Guerra and Cunha, 2005).

There is not enough space among the trees in the production area (Bonilha, 2019). Therefore, the opening of corridors will allow rainfall to reach the soil. Here, it is still recommended We still recommend further studies to be conducted regarding the growth and direction of the roots towards wetter areas (coastal cordons or ESEC-Taim). Corridors of *eucalyptus* should be used as windbreaks (Ziller and Galvão, 2002) to prevent the dispersion of the seeds of *pinus*[4].

4.5 Recovering Area

The main function of the recovering area is to recover the structure and function of the landscape (Oliveira and Souza, 2012). The propositions for this area aim at a great change in the way the land has been used, so the physical environment can have its environmental functions restored. However, due to anthropic changes, the restoration of this area is not possible; therefore, recovery measures are closer to the reality of the place (Braz *et al*., 2015).

The following geoenvironmental units comprise the recovering area: Cultivated River-Lagoon Terrace Transmitting Unit, Coastal Cordons Transmitting Unit, Mirim São Gonçalo Flood Plain Accumulating Unit and Wind Plain Accumulating Unit (Figure 2).

In the recovering area of the Cultivated River-Lagoon Terrace Transmitting Unit (Figure 2), we can observe forestry on lagoon terraces (IBGE, 2003), and rice cultivation on the river-lagoon terraces (IBGE, 2003) that reach São Gonçalo Channel bank (Bonilha, 2019).

It would be advisable to remove forestry activity from the lagoon terraces, as forestry should not be located in these areas due to the geomorphological relevance of these features to local and regional hydrological regulation (Tagliani, 2000). Furthermore, the area defined for rice cultivation should be reduced over the river-lagoon terraces, being the lagoon terrace the limit to its activity, as it would avoid economic losses related to the floods in this area (Rio Grande, 2013).

In the recovering area in the Coastal Cordons Transmitting Unit (Figure 2), the area of forestry has advanced into the prevention area of ESEC-Taim (Bonilha, 2019). Such activity should be removed from this area, as it is very difficult to control the pine dispersion, and in the prevention area, the intention is to control anthropic activities. Furthermore, forestry should also be avoided over coastal cordons (Tagliani, 2000).

The recovering area within the Wind Plain Accumulating Unit (Figure 2) is comprised of the coastal dunes (Figure 6). These features, due to their proximity to urban areas, have suffered the interference of anthropic actions that have compromised their natural dynamic and their migratory process. The actions have tried to stop the advance of the dunes over adjacent houses, and wood barriers, and the dunes have had their dynamic affected by access to the beach (Nema, 2008).

Periodic supervision by the authorities and cleaning actions in these areas should be performed due to the great amount of waste disposal. Signs with alerts regarding the relevance of the dunes, and how to protect them should be distributed along the main accesses to the beach.

Coastal dunes, despite their beauty, have the role of protecting adjacent areas, such as fields, wetlands and urban areas, from the effect of the high tides. The dunes also serve as a barrier against the penetration of salty water into the water table due to the pressure of the freshwater they retain (Nema, 2008). It is important to develop a project that would adequate the traffic of vehicles on Cassino Beach (RS-Brazil).

In the area of Mirim São Gonçalo Flood Plain Accumulating Unit, there are lagoon dunes (Figure 6) near Mirim Lagoon, a tourist area known as “Capilha”. Anthropic interventions in this area range from the illegal disposal of waste to livestock in Mirim Lagoon. Periodic actions for cleaning this area and control over the touristic activities should be monitored by the government in an attempt to avoid the degradation of the landscape. Livestock should also be removed from inside Mirim Lagoon.

4.6 Use area

The main function of the use area is the improvement of the land uses, aiming at using the available resources more efficiently, and having as a reference the basic levels of environmental sustainability (Oliveira and Souza, 2012). Improving the way the land has been used is the main proposition for the use area, as the area is geologically unstable (Figure 3) and the landscape depleted (Figure 4) due to the space occupation of the area. The measures aim to guide the urban, agricultural and forestry expansion. The following geoenvironmental units comprise the use area: High Wind Plain Emitting Unit, Wind Plain Accumulating Unit, Patos Lagoon Flood Plain Accumulating Unit.

In the agricultural areas (Figure 6) in the High Wind Plain Emitting Unit, agriculture and forestry should be managed with the addition of organic matter to help in soil cohesion. Furthermore, there is an area recommended to be used for agriculture expansion (Figure 5), as a way of avoiding the expansion of this activity into preservation areas.

In the agricultural areas in Patos Lagoon Flood Plain Accumulating Unit, the propositions aim at a more efficient and coherent use of the land with the dynamics of the physical environment, as these areas are essential to provide food sold in street markets in the town of Rio Grande (RS-Brazil). Therefore, a better use of irrigation water and the use of natural pest control should be encouraged in these areas.

In addition to encouraging family agriculture and organic cultivation, the method of drip irrigation should also be encouraged, as it is a more efficient and beneficial method than the sprinkling traditional one, taking the water to the plant at the right moment. Drip irrigation may also be associated with the use of fertilizers through the irrigation system, as the fertilizers are applied closer to the roots and the doses can be fractioned, which improves their efficiency (Deus and Bakonyi, 2012).

Pest control can be approached with neem oil instead of traditional pesticides. Neem oil is a natural compost that repels insects and pests, it does not exterminate them, has low toxicity for natural predators and pollinators, and degrades fast in the environment (Deus and Bakonyi, 2012).

The urban expansion should be stimulated in the areas of the Wind Plain Accumulating Unit, which has already been taking place towards Cassino Beach RS-Brazil (along RS-734 road), and Pelotas RS-Brazil (along BR-392 road) in an attempt to keep them away from the preservation areas. According to Martins (2007) the urban expansion that was driven by the industrial sector, has now been driven by the expansion of the real estate sector by the sale of plots of land.

The expansion of forestry should be considered along the coast over obliterated dunes (Figure 6). Northeast is the predominant wind direction in this area (Gomez *et al*., 1987) and a great amount of sand from the dunes is transported and deposited near the area of forestry, forming a barrier. Forestry would have a "beneficial" effect, which is the maintenance of the landscape. If the trees are taken from the area, environmental dynamics could be changed, which could affect the landscape by clogging the wetlands, lagoons and coastal cordons. Therefore, forestry could be developed along the coast over the obliterated dunes as a way of protecting and keeping the landscape.

5. FINAL CONSIDERATIONS

Geoenvironmental zoning in the municipality of Rio Grande (RS-Brazil), done using Geoecology of Landscape, a theoretic-methodological proposition that investigates the landscape based on a systemic approach, has proved to be satisfactory, as single characterization, analysis and delimitation of geoenvironmental units system was established. The analysis of the geoenvironmental units has allowed understanding of the flows of matter and energy. Evaluating the land uses and the pressure over the landscape, it was possible to define the geoecological states and the classification of the actual landscape, and then propose the necessary actions that characterize the zoning.

The land uses in the municipality of Rio Grande have been in expansion and it means a disarticulation between natural and anthropic elements. Results showed that the irrational land use has resulted in significant changes in the landscape, directly affecting its functioning, as Rio Grande municipality has been sensitive to the use and occupation processes. Furthermore, the land has been the main influencer of the landscape dynamic, as it causes an imbalance in the natural systems, interfering in the matter and energy flows due to its capacity to modify the characteristics of the physical environment.

Aiming at reaching a balance in the relation of the natural and socioeconomic elements, the environmental dynamics should be understood, elaborating norms and guidelines that consider this dynamic to the proposition of actions that have the objective of conciliating the proper anthropic intervention with the physical environment. In this perspective, the proposed zoning has not only aimed at the restrictions or interruptions of the use of the land but also that such uses should take into consideration the environmental conditions. It is important to highlight that restricting or ceasing the current uses of the land would demand a complete change in the social-historical-cultural patterns, as the current uses of the land are related to the survival of the population.

The geoenvironmental zoning proposed in this study, beyond offering historical, environmental and legislative knowledge regarding the natural elements, has also evaluated the capacity of use of the land taking into consideration the changes in the landscape structure and functioning. Due to its systemic character, the geoenvironmental zoning was used to recognize the limitations and possibilities of the area under study, proposing actions to mitigate punctual problems, and to guide the conciliation between the physical environment and socioeconomic dynamic. Therefore, the cartographic products generated may help the managers to make decisions aimed at the social and environmental development of Rio Grande municipality, which is situated in an important lagunar area of South America continent, what makes it a very singular region and landscape.

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