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The use of environmental indicators in the characterization and definition of wetlands in the Eastern Amazon

Wetlands play a vital role in water quality because, in addition to providing coastal stabilization, erosion control and aquifer recharge, they serve as important biological habitats, as nurseries for wildlife. The present study aimed to elaborate, based on environmental indicators, the characterization and classification of an estuarine fluvial plain in a wetland, considering a gradient of water bodies. The areas defined for the present study are in the cities of Abaetetuba and Barcarena, in Pará, which have an important and significant role for the region and the Amazon as a whole. The indicators used for characterization and classification were altimetry, rainfall, hydrography and land use and coverage, and such information was processed in a GIS environment. Additionally, the Topographic Wetness Index (TWI) was used, and the method of map reclassification was proposed to evaluate altimetry, vegetation cover and precipitation, generating product through map algebra, thus defining areas with Potential Wetland Formation. In general, in the region of the present study, low altimetric values less than or equal to 15 meters predominate, the rainfall for the annual accumulated varied between 3594 mm to 4844 mm, and land use and cover presented a configuration in which the vegetation represents 56%. Approximately 46.54% of the area has a strong potential wetland formation, which are linked to the topographic processes and the main drainages. It is possible to demonstrate that the adoption of vegetation cover, altimetry, and rainfall categories, with their respective parameters, proved to be effective for zoning wetlands in the region. It is proposed that, based on this work, methodological procedures can be applied in an expanded way in the region or in other Amazonian areas, in order to confirm or indicate the classification as an wetland, for different uses.

Keywords: Wetlands; Environmental change; Environmental monitoring.

O uso de indicadores ambientais na caracterização e definição de áreas úmidas na Amazônia Oriental

As áreas úmidas possuem um papel vital na qualidade das águas, além de proverem a estabilização costeira e controle de erosão, recarga de aquíferos, servem como importantes habitats biológicos, como berçários para a vida selvagem. O presente estudo, objetivou elaborar com base em indicadores ambientais, a caracterização e a classificação de uma planície flúvio estuarina em área úmida, considerando um gradiente de corpos hídricos. As áreas definidas para o presente estudo, ficam localizadas nos municípios de Abaetetuba e Barcarena no Pará, tendo estes um importante e significativo papel, para a região e para a Amazônia como um todo. Os indicadores usados para caracterização e classificação, foram altimetria, precipitação pluviométrica, hidrografia e uso e cobertura da terra, sendo tais informações processadas em ambiente SIG. Adicionalmente foi usado o Índice Topográfico de Áreas Úmidas (ITU), e proposto o método de reclassificação de mapas visando avaliar (altimetria, cobertura vegetal e precipitação) gerando produto através da álgebra de mapas, definindo então áreas com Potencial de Formação de Áreas Úmidas (PFAU). De forma geral a região do presente estudo predomina valores altimétricos baixos menores ou igual a 15 metros, a precipitação pluviométrica para o acumulado anual, variou entre 3594 mm a 4844 mm, o uso e cobertura da terra, apresentada configuração onde a vegetação representa 56%. Cerca de 46,54% da área possui forte Potencial de Formação de Áreas Úmidas, estando diretamente ligadas, aos processos topográficos e as principais drenagens. Sendo possível demonstrar que a adoção de categorias cobertura vegetal, altimetria e precipitação pluviométrica, com seus respectivos parâmetros, mostrou-se eficaz para o zoneamento das AU's da região. Propõe-se, que a partir desse trabalho, possam ser aplicados os procedimentos metodológicos, de forma ampliada na região ou em outras áreas amazônicas afim de confirmar ou indicar a classificação como uma AU, para diferentes usos.

Palavras-chave: Zonas úmidas; Alteração ambiental; Monitoramento ambiental.

Topic: **Tecnologia, Modelagem e Geoprocessamento**

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INTRODUCTION

Wetlands are ecosystems of interconnection between terrestrial and aquatic environments (continental or coastal, natural, or artificial), which are permanently or periodically flooded by fresh, brackish or salt water (JUNK et al., 2013; JUNK, 2013). In the Amazon, about 30% of the territory, that is, 2,000,000 km2, corresponds to wet areas. They are presented in a great diversity of environments subject to floods, which include: i) areas with permanent flooding (wet fields, paths and grove of Mauritia palms); ii) areas subject to unpredictable and short-lived flood pulses caused by rains, associated with small rivers and streams (shallows); iii) areas subject to monomodal flood pulses (floodplains, igapos and paleovárzea forests), with a full and dry phase per year; iv) areas subject to polymodal pulses (several phases of drought and flooding per year), of predictable and short-term flooding, which include estuarine environments in coastal areas or under the influence of tides (JUNK et al., 2011).

These ecosystems can by classified through different international indicators (TINER, 2016). In Brazil, it can be legally defined, as provided in the Law No. 12,651 of May 25, 2012, which describes them as a land surface that can be flooded periodically by water, and may contain vegetation adapted to flood pulses (BRASIL, 2012). There are also definitions of some researchers who have developed an initial proposal for the classification of wetlands in coastal, Amazonian and Pantanal regions (JUNK et al., 2011; JUNK et al., 2012; JUNK et al., 2013, JUNK, 2013). In addition, it is possible to use ecological classifications, such as mangroves, paths, southern wetlands, and Amazonian floodplains (QUEIROZ, 2015).

Diegues (1994) was one of the first to classify wetlands in Brazil, by producing the Brazilian Wetlands Inventory, in which he describes the importance of these ecosystems according to their ecological and socio-economic values. In this document, one finds the Mato Grosso wetland, coastal ecosystems (mangroves, ponds, lagoons, salt pans), river floodplains, continental lagoons, igarapés (streams in the Amazon), in addition to artificial ecosystems (dams, weirs, and reservoirs) (SILVA, 2016).

In the Amazon, wetlands stand out for providing environmental services that guarantee the maintenance of biodiversity and the sustenance of human communities (BARROS et al., 2014; RODRIGUEZ-ALVAREZ et al., 2019). They constitute the base of aquatic food chains, present high primary and secondary production, and have great diversity of species of plants and animals, including invertebrates and vertebrates, many of which are valuable fishing resources (JUNK et al., 2011; HU et al., 2016).

The classifications in the literature include the biological, ecological, physical, chemical, hydrogeological and/or geomorphological attributes (JUNK et al., 2014; GOMES et al., 2018). The definitions/classifications aim at the adoption of terminological uniformity, grouping in types of units relatively similar to each other, and, through that, they become instruments for mapping and delimitation (DAVIDSON et al., 2018), and, moreover, inventories, environmental planning tools, and conservation programs and/or environmental impact assessment (RICAURTE et al., 2019; HALL et al., 2019).

Wetlands are not easily legally defined, as they present different physical and biological conditions, varying dimensions, and their origin may even be associated with anthropic influences (BATZER et al., 2014).

The complexity in the conceptual definition often results in unclear, somewhat restricted, or generic, and/or even contradictory definitions (GOMES et al., 2017). The terminologies used, such as swamp, marsh, swamp, mangrove, among others, demonstrate how challenging it is to find an accurate classification of wetlands (ZEDLER et al., 2005), and to guarantee that the examples of wetlands provided will correspond to the definition.

In this diverse scenario, it is difficult to develop a classification acceptable to all scientists and wetland specialists, whether at an international, national, or regional level (GOMES et al., 2018). However, it is a consensus that wetlands in systems are configured in two trends, one in the horizontal direction, and the other in the vertical direction, named hierarchical (JUNK et al., 2013). Horizontal classifications divide habitats into a series of classes or types, such as meanders, peat bogs, mangroves etc. (JUNK et al., 2011; CUNHA et al., 2015). Hierarchical classifications separate the types of wetlands at different levels. The first ones have more general vegetation and hydrology characteristics, while the subsequent levels use more specific aspects between the marine, estuarine, fluvial, lake and palustrial environments (CRONK et al., 2016; GOMES et al., 2018). The hierarchical approach is the most widespread, as it tends to facilitate regional, national and/or international comparisons between similar systems and allows to identify the individual types of wetlands in the landscape in more detail (TINER, 2016).

Recently, hydro-geomorphological indicators have been used and legitimated in the classification of wetlands because, besides determinant in their formation, they include the diversity of morphological charts of the landscape that condition different types of wetlands (GOMES et al., 2018). Thus, it viable to understand its hydrological functioning and maintenance processes, as well as its interactions with adjacent terrestrial and/or aquatic geomorphological systems, and its various environmental functions (TOOTH et al., 2014; OLLIS et al., 2014; OLLIS et al., 2015; SEMENIUK et al., 2016).

In this sense, the present study aimed to elaborate the classification of an estuarine fluvial plain in a wetland applied to the Amazon region, based on environmental indicators. The behavior of the plain is topographically and climatologically characterized, as well as its use and occupation, in addition to the application of a new wetland's zoning method, through map algebra. We must emphasize that there is no presentation of this classification or description in the literature for the region studied, which demonstrates the need for systematization and evaluation of this knowledge, especially in those subject to anthropic pressures.

METHODOLOGY

Study area

The areas defined for the present study are located in the region known as Baixo Tocantins, formed by 11 cities in Pará (Abaetetuba, Acará, Baião, Barcarena, Cametá, Igarapé Miri, Limoeiro do Aruju, Mocajuba, Moju, Oeiras do Pará, Thailand). It is a region of ancient colonization that dates to the 17th century (DIAS et al., 2011). The occupation of the region began in 1635, with the foundation of Cametá, located to the left of the Tocantins River. The region currently houses the largest port in the state, the Vila do Conde port, used to transport bauxite, aluminum ingots, oils, fuels, and wood etc. (TOBIAS et al., 2016; GONÇALVES et al., 2019).

Two locations of the present study, Abaetetuba and Barcarena, of all above mentioned cities, have important and significant economic-financial (SÁ, 2019; BORGES et al., 2019), sociocultural and migratory (SANTOS et al., 2011; DIAS et al., 2016; FARIAS et al., 2016; MACHADO et al., 2019) and ecological-environmental roles (ROCHA et al., 2011; BOULHOSA et al., 2009; VIANA et al., 2012; SANTOS, 2019) in the region and in the Amazon as a whole.

Thus, the estuarine fluvial plain is located partially in the city of Barcarena, which belongs to the metropolitan region of Belém, limited to the south with the cities of Moju and Abaetetuba, to the north with the Guajará Bay and the City of Belém, to the west with Marajó Bay and to the east with Guajará Bay and the city of Acará (SOUZA et al., 2005). It is also partially located in the City of Abaetetuba, which belongs to the mesoregion of the Northeast of Pará and the micro-region of Cametá, limited to the south with the cities of Iguarapé Miri and Moju, to the north with the Pará River, and the City of Barcarena, to the west with the cities Iguarapé Miri, Limoeiro do Ajuru and Muaná, and to the east with the City of Moju (Figure 1-A).

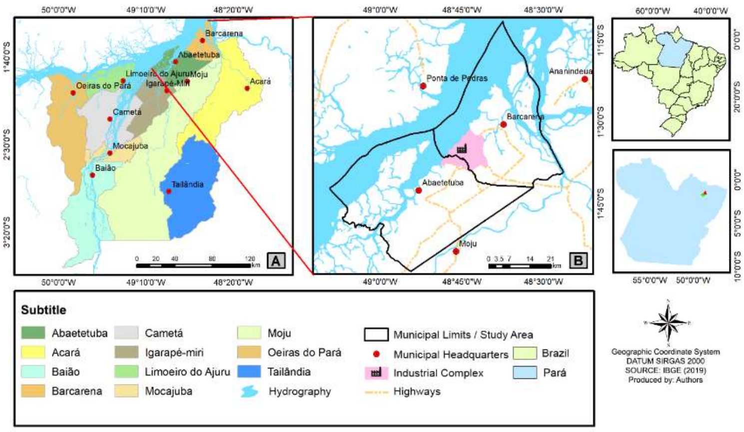

Figure 1: Location of the Baixo Tocantins region (A); Study area location (B)
Source: Authors

Abaetetuba and Barcarena are large cities in the State of Pará, whose population estimate was 157,698 and 124,680 inhabitants, respectively, in 2019. These cities have territorial areas of around 1,610,108 and 1,310,588 square kilometers. They are located to southwest of the City of Belém, with an approximate distance of 90 km in relation to the downtown of the capital and are part of the hydrographic basin of the Pará River (Figure 1-B).

Some furos (river channels) separate the continental portion from the island portion of the city. The area is an estuarine region with great influence of fresh water, classified as an estuary of fluvial tide; Small streams (igarapés) are influenced by the tides. Besides, there are, on the banks of the Pará river, several estuarine beaches, i.e., exposed sand strips during low tide (MARTINS et al., 2011).

Physiographic aspects

The climate of this region is hot and humid, type Af (Koppen classification), with an average annual temperature of 26 ° C. The lower average air temperatures occur in February and the higher occur in October; the average annual rainfall is between 2,300 and 2,800 mm. The rainiest quarter corresponds to the months of February, March, and April; the least rainy are August, September, and October. The relative humidity of the air varies between 84.1 and 86.0% (MORAES et al., 2005).

The Marajó Bay is the main body of waterin Barcarena (PA), which, together with other water resources (the wide mouth of the Amazon River between Amapá and Marajó Island; the Breves Strait, to west of that island; the long stretches of Bocas Bay; and to the east-northeast, the Pará River, the Lower Tocantins River and the Marajó Bay) (BORDALO et al., 2012), form the "Golfão Marajoara". In addition to these, there are furos that separate the continental portion from the island, as well as important rivers for the region, such as Barcarena and Moju (BORDALO et al., 2017). Among the studied drainages, the Furo do Arrozal, and the rivers Murucupi, Abaeté, Arapiranga, Arienga and Dendê are in the Barcarena area (ALMEIDA et al., 2006).

According to Almeida et al. (2006), there are five hydrogeological systems in the area corresponding to Abaetetuba and Barcarena, formed by aquicludes, aquitards and aquifers belonging to the stratigraphic units Pirabas, Barreiras and Quaternary Coverage. These systems are called Aluviões, Pós-Barreiras, Barreiras, Pirabas Superior and Pirabas Inferior, with a predominance of the Barreiras group in these areas and other regions of Pará, but, in the vicinity of the main surface water bodies, the predominant systems are the Aluviões.

The geological structure of the city is represented by lithologies from the Quaternary and Tertiary Periods (SANTOS, 2003), with sediments from the Barreiras formation, mainly in the continental portion and Quaternary on the banks of rivers, constituting the island portion of the cities. As for the relief, there are areas of floodplains, terraces and trays, which constitute the Lower Plateau of the Amazon, Lower Amazon (ALMEIDA, 2005; BOULHOSA et al., 2007).

The soils of the continental portion differ from those found on Barcarena and Abaetetuba. The dystrophic Yellow Latosol medium texture, the indiscriminate, dystrophic Hydraulic and Concrete Lateritic Podzol predominate in the continental portion, while the indiscriminate hydromorphic, eutrophic and dystrophic soils, indiscriminate texture, and gley hydromorphic soils, such as low humic gley and alluvial soil and eutrophic and dystrophic, indiscriminate texture, predominate on the islands (SANTOS et al., 2003).

The vegetation surrounding Barcarena is represented by the following units: riparian and lowland forests, occurring in stretches under the influence of floods, bordering the great rivers and islands of the city. Planting areas for species in subsistence agriculture and areas of forest regeneration with different stages of secondary forest development can be observed due to the action of deforestation, responsible for replacing the primitive vegetation cover of dense forest (AMARAL et al., 2002).

In Abaetetuba, the original vegetation is Hylean Forest, which is currently practically nonexistent and replaced by patches of secondary forests and agricultural areas. The broadleaf ombrophilous species and palm trees (such as açai) constitute the vegetation of the lowland areas, in addition to species of fungi (SOUZA et al., 2005).

Economic activities in the region

As an important part of supporting economic activities in the region, the Vila do Conde port was inaugurated in October 1985, as a result of the economic cooperation agreements signed between Brazil and Japan, in which the Brazilian government assumed responsibility for the implementation of the port, road and urban infrastructure, for the flow of the aluminum produced in the industrial complex of Albras/Alunorte (CDP, 2010) (Figure 1-B).

Due to the dynamics, there are also operations of the multinational industries linked to some activities, such as the mineral transformation of kaolin, and of bauxite into aluminum, as well as the export of oilseeds (soybeans, corn and palm oil), logistics and fuels (SANTOS, 2015). Also noteworthy is the presence of private (ports of Terfron-Bunge) and public (Vila do Conde) outlets, respectively, the Terfron-Bunge and the Vila do Conde ports. Highlights are the exports of soy production - from the south and southeast of Pará, and the Brazilian Midwest- the sale of solid fuels (petcoke and mineral coal), and the export of live cattle to Venezuela and Lebanon (SANTOS et al., 2015).

Other activities consist in logistics, services, metallurgy, and projects, such as the forecast for the implantation of a fertilizer industry, the French multinational Timac Agro Brasil, in a licensing process by the state agency. Besides, infrastructure works to expand the Brazilian export logistics corridor, such as the Federal Government's planning to expand the Vila do Conde port and implement the North-South railroad, stretch Açailândia-Barcarena (SOUSA, 2015).

Information Base and Methods Applied in the Characterization and Zoning of Wetlands

As highlighted, wetlands are not easily defined due to their varied dimensions and diverse influences (BATZER et al., 2014), which results in a complex development of an acceptable classification by different researchers (GOMES et al., 2018). In this sense, the present study gives some classification proposals through parameters of different indicators. We aim to carry out a process of environmental characterization of the area, considering what the literature recommends as essential for the formation of wetland and its dimensioning, using adapted criteria from Akumu et al. (2018) for this purpose.

Thus, the selected variable was the altimetry, obtained through SRTM (Shuttle Radar Topography Mission) images made available by the TOPODATA Project (Geomorphometric Brazilian Database), based on Valeriano et al. (2011). The latter was used in the generation of the slope chart and in the identification of altimetric classes in the region, according to procedures described in Cronemberger (2009).

The rainfall data comes from microwave sensors in the infra-red channel on-board polar and geostationary satellites used in the CMORPH technique (CPC MORPHing technique) (JOYCE et al., 2004). This technique for estimating precipitation by sensing is based on an association of information from various sensors on-board stationary and geostationary satellites, which use high spatial resolution data (8km x 8km) and short temporal resolution (30 minutes) in its analysis (SANTOS et al., 2019). These were processed and interpolated in geoprocessing software, using the “nearest-neighbor” interpolator. It was chosen due to the grid layout of the data, which makes it favorable; the series used was from 1998 to 2016.

The other data used to complete the classification proposal were: hydrography (vector base of the National Water Agency [ANA], consisting of the distribution of the drainage network and the delimitation of the hydrographic basins according to the Otto Basins system, scale 1: 250,000) ; geology (CPRM vector base [2008], scale 1: 1,000,000); geomorphology (IBGE vector database [2003], scale 1: 250,000); soils (IBGE vector base [2003], scale 1: 250,000); land use (IBGE vector base [2017], scale 1: 250,000); and logistical aspects (municipal headquarters, roads and administrative limits, vector base of the Brazilian Institute of Geography and Statistics [IBGE] and the Geographic Information System of the State of Pará - GEOPARÁ).

Additionally, the Topographic Wetness Index (TWI), described in Conrad et al. (2015) and Capoane et al. (2017), which defines the areas with the greatest contribution of runoff; the drainage network and slope were the defining elements. The processing was adopted in SAGA-GIS (QGIS module). The basis is the Digital Elevation Model (DEM), that is processed for the detection of the areas of contribution of a drainage network and of greater direct contribution of the surface runoff in the terrain.

Ruhoff et al. (2011) attribute to the ITU the following formulation: $ITU = \ln(\alpha/tang\beta)$; α is the area of specific contribution based on the flow direction (with reference to the land surface) and β is the slope of the surface; thus, the areas of saturated soils typically found in geomorphologically converging segments are defined. The authors describe the specific area of contribution, as related to the concept of accumulated flow, and take into account the complexities of the slope shape; thus, the curvature of the slopes in the plane and in the profile effectively determine the hydro-sedimentological behavior of erosive processes. In the SAGA-GIS system (QGIS module), the flow direction of each pixel (smallest sample of an image) is performed wetlandtomatically, based on the level difference between them, weighted by the distance.

The data used for the development of the land use chart come from the IBGE and the satellite image from the satellite Sentinel – 2, available in the the USGS (United States Geological Survey). The satellite image acquired from the USGS underwent a supervised classification treatment in a geoprocessing software. The classification resulted in a True-color image with RGB composition (red, green, blue), created from bands 4, 3, 2. Thus, four classes (vegetation, exposed soil, agriculture and field and urban core) were obtained, which were exposed for visualization of land use in the region of Abaetetuba and Barcarena.

The elements considered in the integrated analysis that defined a specific zoning for the study region were the topographic factors, the distribution of rainfall and the land cover. Assuming the characteristics of the estuarine environment, the study started from the conceptual proposition that, in the delimitation of wetlands, hybrid ecosystems, such as the combination between terrestrial and humid, continental or coastal, environments must be considered vulnerable to the occurrence of periodic or permanent floods (NAG et al., 2019). For this reason, the specific criteria that conditioned this analysis were: a)Greater potential wetland formation: altimetry less than 15 meters, presence of vegetation cover and greater concentration of rainfall; b) Less potential wetland formation: altimetry greater than 15 meters, absence of vegetation cover and/or predominance of land use forms and less concentration of rainfall.

The use of integrated processing, through map algebra, in a specific geoprocessing software, allowed the generation of the potential wetland formation (PWF) chart (Figure 4-B). It is noteworthy that the effect of the tides and the variation in the level of the drainage network were not included in the analysis. The main reason is the absence of fluviometric measuring points that would allow a joint assessment of the effect of the tides.

RESULTS AND DISCUSSION

Assessment of potential wetland formation (PWF)

In the assessment of altimetry of the study area, it is observed that the topographic falls predominate, marking the valleys of the main water courses and the island regions (Figure 2-A). The main topographical divisions are in the northeast, bordering the Moju River.

The distribution of the drainage network is marked by a set of channels that drain towards the Guajará Bay and the Pará River; they are all influenced by the tides and already show changes due to the growth of of urban, rural and industrial areas, especially over the water source areas. The main tributaries of the region are: Murucupi River, Barcarena River, Guajará da Serra River, Itaporanga River, Bacuri River, Arienga River, Arapiranga de Beja River, Guajará River, Jarumã River, Abaeté River and Itacuruçá River (Figure 2-B).

Wetland

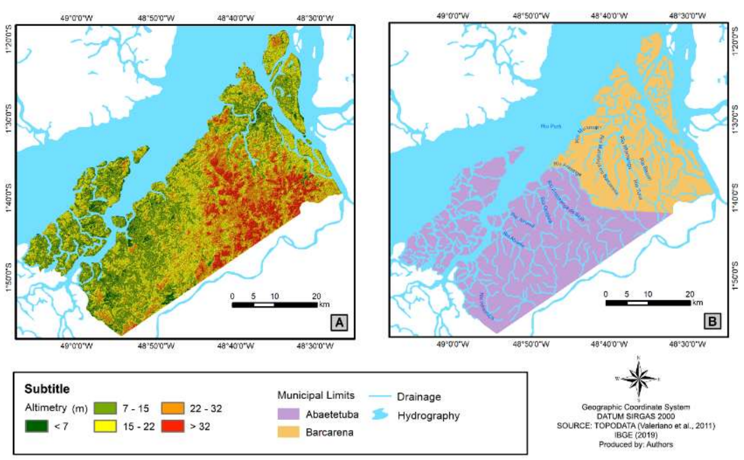

Figure 2: Altimetry and relief of the study area, Abaetetuba and Barcarena (A); Distribution of the drainage network (B).

It is noteworthy that, for the identification of regions with potential wetland formation, the presence of tidal flat environments (lower altimetric levels), where surface runoff is reduced, is important because it favors the accumulation of water, contributing to a greater amount of humidity in the wetlands (RUBBO, 2004) or in floodplains (ALMEIDA et al., 2004; GUASSELLI et al., 2020).

The areas shown in figure 2-B have significant importance for the region, due to the maintenance of water resources and because they shelter rivers and streams (CRUZ et al., 2020) in addition to river beaches (BOULHOSA et al., 2007; OLIVEIRA, 2012). The latter, in turn, are strongly influenced by the action of the tide from the estuary (RIBEIRO et al., 2007), which enables the formation of tidal floodplain zones, working as natural regulators of the flow and pulse of daily flooding (ALMEIDA et al., 2004). In addition to the altimetric elements, tidal flow, soil and vegetation, the humid Amazonian environment also has rainfall as a driving force for replenishment and limnological influence (VALE et al., 2014).

The presence of rain is essential to maintain these environments, since the contribution of rainfall and tides becomes the most significant with the reduction of the volume of water from the sources. For Fisch et al. (1998), the equatorial Climate Zones present a high rate of daily rainfall motivated by the Intertropical Convergence Zone (ITCZITCZ) and other currents of atmospheric disturbance of intertropical origin, such as Tropical Instability Waves (TIWs) (AMANAJAS et al., 2012; QUEIROZ, 2018) or West Waves (WW) (NIMER, 1989), which tend to influence strongly the rains in the Amazon (SALATI, 2001; NOBRE et al., 2007).

The values recorded for the region between the years 1998 to 2016 reflect the statements above; considering annual precipitation values, the values went from 3594 mm to 4844 mm, minimum and maximum, respectively. It shows that, in the region, rainfall is intense throughout the year and its distribution is homogeneous (Figure 3-A). This spatial-temporal variability over the years in the region, in addition to the other typically Amazonian characteristics, contributes to the high rate of evapotranspiration (VIEIRA et al., 2020), which allows the identification of two distinct rainfall regimes: a rainy one, in the months of February, March and April, with high rainfall, directly influenced by the seasonal migration of the ITCZ (MOURA et al., 2012) in the southern direction; and a less rainy, in the months of September, October and November (FISCH et al., 1998; BASTOS et al., 2002; AMANAJÁS et al., 2012).

It is also important to evaluate that the periods of greater and lesser humidity throughout the months of the year, considering evapotranspiration in the region, are extremely important factors In this context, the months of June, July and December are considered as transition between the two periods mentioned above.

Nobre et al. (2007) point out that precipitation in the Amazon can also be modulated by variations in the strength of the South American and by ZCIT shifts. Other modulations, which can induce precipitation, are changes in sea surface temperatures (TSM) of the Atlantic and Pacific oceans, which affect the transport of moisture towards the Amazon, partially controlling the discharge of rivers and their tributaries (MARENGO et al., 2016; BERTASSOLI JUNIOR et al., 2019). As a result, precipitation in the region will be the result of a series of interactions, of different phenomena and atmospheric systems, acting on different spatial and temporal scales (SANTOS et al., 2017).

The results found in the present study are similar to other surveys that punctuated and characterized the environment as having intense and frequent rainfall dynamics (ARAÚJO, 2012). A study by Souza et al. (2017) recorded average annual rainfall between 2,500 and 4,000 mm, which indicates that the region has great variability of environments, in which the changes in climatic patterns of precipitation and temperature occur in short periods of time and short distances (ALMEIDA et al., 2018).

It is also noteworthy, according to Zubieta et al. (2019), that high temperatures in the region favor rain, especially between December and May. For Amorim et al. (2013), the climate is an important environmental condition, which presents cyclical, unexpected and harmful changes, but regions that present water seasonality, except for the extreme south of the country, result in a rainy and a dry season, well defined in the annual cycle , favoring the maintenance and classification of wetlands (CUNHA et al., 2015).

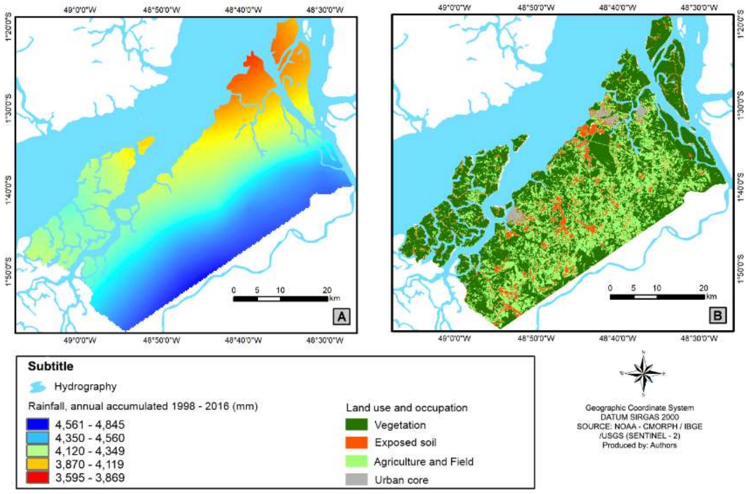

Figure 3: Rainfall in the study area, Abaetetuba and Barcarena (A); Land use and occupation chart (B).

This classification is not based only on the climatological characteristics, since the precipitation in the region is not distributed homogeneously throughout the year, but with different patterns between the time of less rain and more rain. Another important element that allows the classification of the wetland type is the vegetation cover, in which more evident patterns in regions of low latitudes, close to the equator, result in a tropical rainforest vegetation, in this case, the Amazon, classified as dense ombrophilous forest (CUNHA et al., 2015).

Based on the assumption that coverage becomes a crucial element for the viability and classification of wetland's, the use and occupation of land was then analyzed in order to understand the local dynamics in Abaetetuba and Barcarena, since there are different, intense and complex human occupation processes in the region (NASCIMENTO et al., 2015; HAZEU et al., 2019; NASCIMENTO et al., 2020). It is worth mentioning that this tool is indicated for phytogeographic mapping, territorial planning, and environmental restoration (SANTOS, 2019).

The land use and cover chart (figure 3-B) shows the following distribution: vegetation (56%), agriculture and field (33%), exposed soil (10%), urban areas (2%). The vegetation cover of the region consists mainly of two plant types: dense ombrophilous forest (typical of tropical environments) and alluvial forest with vegetation of flooded areas (AMARAL et al., 2002). However, currently its floristic covering is mainly characterized by secondary forests (DENICH, 1986; PIRATOBA, 2013). Souza et al. (2005) emphasize that the predominant vegetation in the studied region are secondary forests (capoeiras) in different successional stages. Due to the deforestation of the region, the primitive natural forest was almost completely replaced for the planting of subsistence agricultural species,

Therefore, the percentage characterized as agricultural area and fields, added to the exposed soil, is directly linked to the modified environments, either by the occupation of the industrial pole, or by the use of land with buildings and/or plantations of different cultures in the area (RIBEIRO et al., 2003), which may increase the probability of erosion (BORGES, 2009; CUNHA, 2019), and, consequently, make the area more environmentally vulnerable (RIBEIRO et al., 2007; SANTOS et al., 2018), as a result of the restructuring of the space, changing its landscapes and socio-spatial relationships (TRINDADE JUNIOR, 2010).

The social and functional fragmentation of the urban space, resulting from its different uses, is reflected in the environmental problems that offer different risks to the population that inhabits and/or circulates that area (BIRKMANN, 2006). The identified risks in the urban restructuring process can be social, technological or natural; the latter can be strongly enhanced by the first two risks (SILVA, 2019), influencing the degree of vulnerability and socio-environmental commitment (SILVA, 2017).

In this context, the vulnerability can indicate the propensity for negative impacts, from dangerous to disastrous, mainly due to the socioeconomic profiles of the affected populations, whose living conditions make them more vulnerable (TELES, 2020). This statement was made by Costa et al. (2016), who analyzed urban growth and floodplain occupation in small towns in the Amazon. In these places, floodplain occupations tend to have a precarious or absent network of urban structure, with irregular electricity, no basic sanitation services, and risky housing. These issues are linked to several urban problems which threaten the ecological environment and economically disadvantaged populations, pushing them into areas of risk and generating situations of environmental inequity (ESTEVES, 2011).

In the region, other studies have assessed the degree of vulnerability with different tools. We highlight Santos et al. (2017), who assessed the General Vulnerability Index (GVI), which consists of three other indexes: the Socioeconomic Vulnerability Index (SeVI), the Epidemiological Vulnerability Index (EVI) and the Climate Vulnerability Index (CVI); the region was characterized as of medium vulnerability, which reinforces the previous statements. Rodrigues et al. (2020) used environmental vulnerability charts to categorize their damage degree, finding values that made it possible to be classified as moderately vulnerable to the vulnerable, considering the slope, rainfall and land use indicators.

Therefore, to understand how the region behaves in the face of these changes caused by the process of human occupation and urban transformation, it is necessary to define more precisely which areas are characterized as wetland, aiming at the environmental management process. This is due to the fact that the delimitation of the region and the influence of the seasonal variation of the waters may spatially define the most vulnerable zone to the effects and extreme events in the region (FERREIRA et al., 2020) and also the level of environmental risk.

As previously mentioned, a study by Rodrigues et al. (2020), registered values that show a worrying scenario, since the region in general is vulnerable due to the changes that occurred over the years. Markedly, in the last three decades, the intensification of local forest fragmentation, mainly at the margins of the city's furos and rivers, contributed to their silting up (SEABRA, 2019), in addition to the massive process of alteration in the use and occupation of the soil, evidenced in the region (FURTADO et al., 2020). Therefore, it is necessary to delimit local wetlands, using descriptive tools such as the Topographic Wetness Index, in order to assist the process of conservation (MALTCHIK et al., 2010) and preservation (BITTENCOURT et al., 2018).

Figure 4-A represents the list of factors: altimetry - slope - drainage network, in the form of the

Topographic Wetness Index (TWI), which shows that the smallest gradient represents the positive relationship for the topography x water accumulation zones relationship. Thus, it demonstrates that the classification as wetland applies to the whole region, since the concentration of drainage channels indicates a higher probability of occurrence of water accumulation zones according to topographic factors. According to Guasselli et al. (2020) the Topographic Wetness Index (TWI) can assist in the identification of areas with possible presence of hydromorphic soils (MALONE et al., 2018). These soils are especially relevant for identifying wetlands because: (1) they integrate temporary and permanent soil saturation over a long time scale and result from the general functioning of the wetlands; (2) they leave traces that provide indicators of existing wetlands (ROSOLEN et al., 2008; PIEDADE et al., 2013; JUNK, 2014; GUASSELLI et al., 2020).

In the region, depositional systems are intricately linked to the floodplain formation process. Barcarena presents low topographic levels, especially in the islands, which are partly subject to flooding (PRADO et al., 2007); in the continental portion, the levels become a little higher, especially in the headquarters, whose altitude is 14 meters. It can be divided into five altimetric planes, according to the regional standard, namely: low floodplain, constant flooding (0-3 m), high floodplain, periodically flooding (3-5m), stumps (5-12m), cliffs of the Pará River (12-15m) and dry lands (10-14m) (ALBRAS, 1984).

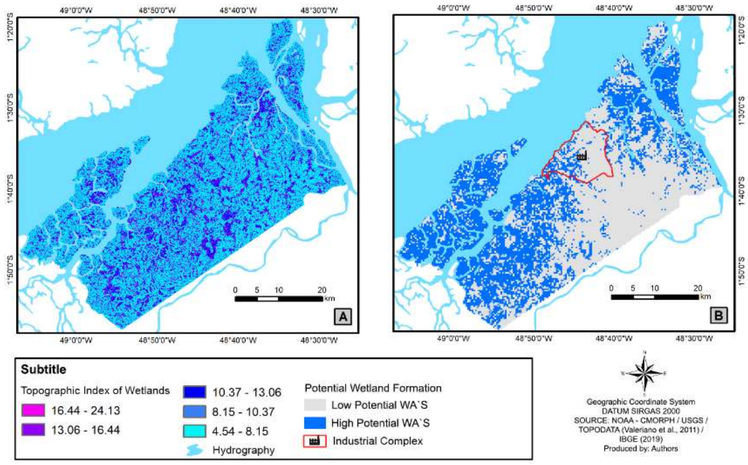

Figure 4: Topographic Index of Wetlands (A); Result of the potential wetland formation for the region of Barcarena and Abaetetuba (B).

In addition to the use of TWI, which proved to be efficient in indicating the region as wetland, the present study proposes to complement the analyzes carried out up to now, aiming at the use of other tools that might confirm the classification of the region in the formation of wetlands. Figure 4-B shows the proposal generated for the Abaetetuba and Barcarena region, based on the integrated processing between the categories of rainfall, altimetry, and vegetation cover. The main favorable conditions for the presence of potentially floodable areas were admitted, giventhe extension of the existing vegetation cover (Figure 5).

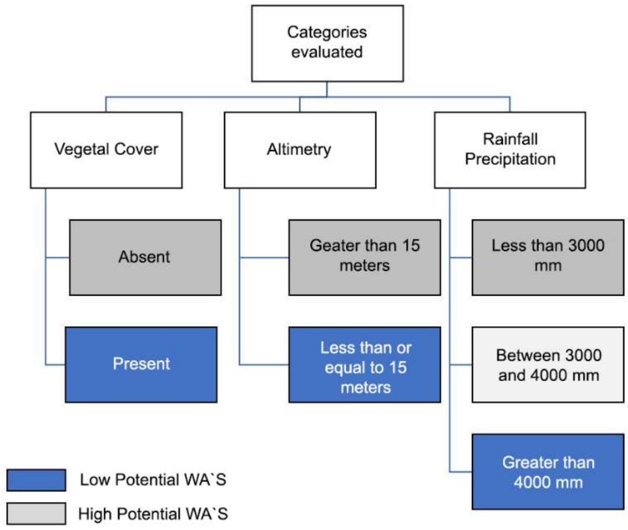

Figure 5: Limits adopted in the analysis.

Such proposal, among others, has the purpose of classifying the Amazon estuarine fluvial region as wetlands, since the existing definitions are varied, and, for the most part, confusing and complex (CUNHA et al., 2015; JUNK et al., 2015). One of the most accepted is the proposal by the Ramsar Convention in 1971 (BOWMAN, 1995), reorganized by Scott et al. (1995). However, Guasselli et al. (2020) asserts that this reorganization is very wide, so the adoption of regional and local definitions is necessary.

Figure 4-B illustrates the result obtained, indicating that approximately 46.54% of the region effectively represents wetland coverage areas. In the area with the greatest potential wetland formation, there are certain delimitations that favor and challenge the formation of such areas, respectively, in the region of Barcarena and Abaetetuba. We demonstrated that areas with lower topographic altitude values because they are lower and close to the drains, are more likely to have wetlands. We also corroborate that such places have an almost unchanged state of preservation of riparian forest (Figure 3-B), increasing the potential for formation.

The regions that had the greatest potential for formation are also known in the literature as fluvial-marine floodplains, since they are under the influence of the tide pulse of the Pará River, an environment classified as an estuary, that has the influence of a hydrographic complex formed by the rivers Araguaia, Tocantins, Capim, Acará, Moju, Guamá, Anapu, Jacundá, Pacajás, and Araticum (RIBEIRO et al., 2004).

In contrast, areas with less potential wetland formation should not be less important or disregarded, since the reverse occurs in the topographic sense, and land use and occupation can cause different environmental problems. It is noteworthy that these areas are described as exposed, and potentially environmentally vulnerable (RODRIGUES et al., 2020; FURTADO et al. 2020). Similar scenarios of vulnerability and/or pressure on wetlands, exceptionally, are common in other regions of the planet, as in Uganda (MUWANGA et al., 2006) Kenya (MWAMBURI, 2009), China (LI et al., 2010), India (CHANDRASEKARAN et al., 2015) and Australia (GELL et al., 2019).

In this perspective and regarding the region, wetlands are extremely important from different points of view, considered one of the most relevant ecosystems in the world in environmental terms (HAVRIL et al., 2018; MEGONIGAL et al., 2019), and should be protected, preserved and monitored (JUNK, 2013; JUNK et al., 2014) using, among other, bioindicator elements (PINTO et al., 2020). This classification proposal will be extremely important for the region, since the existence of the Industrial Port Complex (IPC) and with the current 94 companies (CRUZ et al., 20200) that directly influence wetlands , and the predictability of new companies, in addition to the implementation of anExport Processing Zone (EPZ), that will occupy a total area of 925.7197 hectares, which in the medium and long term, may compromise the environment, with adverse impacts for the area (NASCIMENTO et al., 2020).

CONCLUSIONS

On the basis of the analyzes presented in this study, we state that the tools and the methodology adopted proved to be effective for the characterization of wetlands in the Amazon and the measurement of environmental impacts suffered by them, which proves its environmental importance. We could also assess that further studies are needed to demonstrate its physical, chemical, and social importance for the preservation and monitoring process. The adoption of the vegetation cover, altimetry, and rainfall categories, with their respective parameters, proved to be effective for zoning wetlands in the region. Regarding the categories, through the assessment of vegetation cover and the land use and occupation map, it was possible to conclude that their presence is potentially related to the existence of riparian forest. As for the altimetry, we found that lower areas (> 15m altitude), tend to be conducive to the formation of wetlands because they are saturated areas. Precipitation, on the other hand, proved to be an intrinsic factor, due to its frequency and homogeneous coverage in the region.

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