

THE POTENTIAL FOR URBAN EXPANSION OF THE COASTAL PLAIN OF THE STATE OF PIAUÍ

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ABSTRACT

The objective of this study was to evaluate the areas of the Coastal Plain of the State of Piauí that have a vocation for urbanization, using geoprocessing techniques, and the tools and databases of the geographical information systems (GIS), as a way of subsidizing environmental planning of this area of study. The area is located in the northern portion of the coast and in the north northeast of Brazil, with a coastline of 66 km. This covers four municipalities: Ilha Grande de Santa Isabel, Parnaíba, Luís Correia and Cajueiro da Praia. The methodology used in the study was the overlap of maps using map algebra by the additive multicriteria method. In order to obtain the final product (Map of potential urban expansion), geology, geomorphology, flood risk, and erosion risk were initially defined as factors/variables, where weights were assigned for each variable inserted in the modeling process and grades were assigned to the mapping units of each theme. Thus, through the mapping of Expansion Potential it was possible to identify 5 classes, being them: Good (38.00%); Regular (17.86%); Marginal (7.29%); Not recommended (31.27%) and Special (5.58%). Thereby, the coastal plain of the state of Piauí presents many areas with potential for urban expansion and, therefore, has a high potential for urban growth, however, construction on lands that present low or no potential must be avoided.

Keywords: Geoprocessing. Urban expansion. Multicriteria analysis. Coastal zone.

O POTENCIAL DE EXPANSÃO URBANA DA PLANÍCIE COSTEIRA DO ESTADO DO PIAUÍ

RESUMO

O objetivo deste estudo foi avaliar as áreas da Planície Costeira do Estado do Piauí com vocação para a urbanização, utilizando técnicas de geoprocessamento e ferramentas e bases de dados de Sistemas de Informações Geográficas (SIG), como forma de subsidiar o planejamento ambiental da área de estudo. A área estudada está localizada na porção norte do litoral do Estado do Piauí, no Nordeste do Brasil, com aproximadamente 66 km de extensão costeira. Abrange quatro municípios: Ilha Grande, Parnaíba, Luís Correia e Cajueiro da Praia. A metodologia empregada consistiu na sobreposição de mapas por meio de álgebra de mapas, utilizando o método multicritério aditivo. Para a obtenção do produto final (Mapa do Potencial de Expansão Urbana), foram inicialmente definidos como fatores/variáveis a geologia, a geomorfologia, o risco de inundação e o risco de erosão. Em seguida, foram atribuídos pesos a cada variável inserida no processo de modelagem e notas às unidades de mapeamento de cada tema. A partir do mapeamento do Potencial de Expansão Urbana, foi possível identificar cinco classes de aptidão: Boa (38,00%), Regular (17,86%), Marginal (7,29%), Não recomendada (31,27%) e Especial (5,58%). Dessa forma, a Planície Costeira do Estado do Piauí apresenta extensas áreas com potencial para expansão urbana e, consequentemente, elevada aptidão ao crescimento urbano. Entretanto, deve-se evitar a implantação de empreendimentos em terrenos que apresentem baixo potencial ou que sejam classificados como inadequados para ocupação urbana.

Palavras-chave: Geoprocessamento. Expansão urbana. Análise multicritério. Zona costeira.

POTENCIAL DE EXPANSIÓN URBANA DE LA PLANICIE COSTERA DEL ESTADO DE PIAUÍ

RESUMEN

El objetivo de este estudio fue evaluar las áreas de la Planicie Costera del Estado de Piauí con vocación para la urbanización, utilizando técnicas de geoprocusamiento y herramientas y bases de datos de Sistemas de Información Geográfica (SIG), con el fin de apoyar la planificación ambiental del área de estudio. El área estudiada se localiza en la porción norte de la costa del Estado de Piauí, en el noreste de Brasil, con aproximadamente 66 km de extensión costera. Comprende cuatro municipios: Ilha Grande, Parnaíba, Luís Correia y Cajueiro da Praia. La metodología empleada consistió en la superposición de mapas mediante álgebra de mapas, utilizando el método multicriterio aditivo. Para la obtención del producto final (Mapa del Potencial de Expansión Urbana), se definieron inicialmente como factores/variables la geología, la geomorfología, el riesgo de inundación y el riesgo de erosión. Posteriormente, se asignaron pesos a cada variable incorporada al proceso de modelización y valores a las unidades de cartografía de cada temática. A partir del mapeo del Potencial de Expansión Urbana fue posible identificar cinco clases de aptitud: Buena (38,00 %), Regular (17,86 %), Marginal (7,29 %), No recomendada (31,27 %) y Especial (5,58 %). De este modo, la Planicie Costera del Estado de Piauí presenta extensas áreas con potencial para la expansión urbana y, en consecuencia, una elevada aptitud para el crecimiento urbano. Sin embargo, debe evitarse la implantación de emprendimientos en terrenos que presenten bajo potencial o que sean clasificados como inadecuados para la ocupación urbana.

Palabras clave: Geoprocusamiento. Expansión urbana. Análisis multicriterio. Zona costera.

POTENTIEL D'EXPANSION URBAINE DE LA PLAINE CÔTIÈRE DE L'ÉTAT DU PIAUÍ

RÉSUMÉ

L'objectif de cette étude était d'évaluer les zones de la Plaine Côtière de l'État du Piauí présentant une vocation à l'urbanisation, en utilisant des techniques de géotraitement ainsi que des outils et des bases de données des Systèmes d'Information Géographique (SIG), afin de soutenir la planification environnementale de la zone étudiée. La zone d'étude est située dans la partie nord du littoral de l'État du Piauí, dans le nord-est du Brésil, avec un linéaire côtier d'environ 66 km. Elle comprend quatre municipalités : Ilha Grande, Parnaíba, Luís Correia et Cajueiro da Praia. La méthodologie employée reposait sur la superposition de cartes au moyen de l'algèbre cartographique, en utilisant la méthode multicritère additive. Pour l'élaboration du produit final (Carte du Potentiel d'Expansion Urbaine), la géologie, la géomorphologie, le risque d'inondation et le risque d'érosion ont d'abord été définis comme facteurs ou variables. Des pondérations ont ensuite été attribuées à chaque variable intégrée au processus de modélisation, ainsi que des notes aux unités cartographiques de chaque thème. La cartographie du Potentiel d'Expansion Urbaine a permis d'identifier cinq classes d'aptitude : Bonne (38,00 %), Moyenne (17,86 %), Marginale (7,29 %), Non recommandée (31,27 %) et Spéciale (5,58 %). Ainsi, la Plaine Côtière de l'État du Piauí présente de vastes zones favorables à l'expansion urbaine et, par conséquent, un potentiel élevé de croissance urbaine. Toutefois, il convient d'éviter l'implantation d'aménagements sur des terrains présentant un faible potentiel ou classés comme inadaptés à l'occupation urbaine.

Mots-clés: Géotraitement. Expansion urbaine. Analyse multicritère. Zone côtière.

INTRODUCTION

The process of urbanization, known by Oliveira and Moraes (2014) as the process responsible for the transformation of a rural area into an urban area, characterized by an increase in the population and changes in its structure, has enabled man to constantly create new environments that result from increasingly more complex interactions between various social groups and nature.

Accelerated urban growth has been disorganized in the vast majority of Brazilian cities, especially when it comes to the coastal zone. This disorganized and irregular urban expansion has caused serious problems, as highlighted by Nascimento et al., (2009) such as the occupation of areas of environmental protection, the occupation of areas subject to floods, the occupation of areas with marked slopes and areas with high susceptibility to erosive processes. Consequently, chaotic cities emerge with problems of different natures, associated with the

inadequate occupation of the physical environment or the disorderly spatial organization of urban activities, which has been increasing in recent years.

The deep spatial relationship between the coastal zone and human activities drives us to a thought increasingly more focused on the full understanding of the opportunities and fragilities of this environment, as well as the action and the role of all social actors involved in the spatial processes and of management of this space of socio-environmental conflicts and exchanges.

In order to do so, the minimization of urban problems, resulting from the disorganized growth of these cities, is associated with the need for adequate land occupation planning. The study of environmental characteristics, physical, social and economic of the urban territory generates the necessary knowledge for decision-making, in the orientation of the physical expansion of cities, in order to ensure a rational occupation of spaces, prevention of environmental impacts and prevention of conflicts (NASCIMENTO et al., 2009).

Thus, faced with such human pressure experienced mainly in coastal areas, it is evident the need for knowledge and understanding of the possibilities and limitations of these fragile environments, in the face of urban expansion and the need to verify and understand if the lands of the coastal zone have a vocation for building or not.

Considering that several methods that help identify areas with a propensity for building can assist the government not only in the determination of areas used improperly but also in the mapping of irregular buildings, several pieces of research were developed aiming at better land use for these areas, such as the studies made by Araujo and Kux (2005); Araujo and Freire (2007); Marques et al., (2011); Nascimento et al., (2009), among others.

The geographical information systems (GIS) have been used in urban planning as an important tool in space management, due to the great power of automation and analysis of spatial data. These systems allow us to carry out a multicriteria analysis that, according to Jannuzi et al. (2009), is a qualitative-quantitative technique situated in the middle of the *continuum* separating approaches that are purely exploratory and little structured to decision-making from the strictly structured quantitative models aimed at the optimization of objective functions, subject to a set of constraints.

In view of this perspective, the objective of this research was to evaluate the areas of the Coastal Plain of the State of PiauÍ that have a vocation for urbanization, using geoprocessing techniques, and the tools and databases of the geographical information systems (GIS), as a way of subsidizing environmental planning of this area of study.

MATERIALS AND METHODS

Location of the study area

The coastal plain of the state of PiauÍ is located in the north of the state's coast and in the north northeast of Brazil, which goes from the Bay of Canaries to the border with Ceará, at the mouth of the Ubatuba and Timonha rivers (CEPRO FOUNDATION, 1990; BAPTISTA, 2004). This is an area that deserves attention due to the importance that these environments represent considering their natural potential and, above all landscape that they carry with them.

The spatial area of the study area covers the municipality of Ilha Grande and partially the coastal municipalities of Cajueiro da Praia, Luís Correia and Parnaíba (Figure 1) and is also part of the Parnaíba Delta Environmental Protection Area (APA). The area is limited by the coordinates UTM 9668000/182000 W and 9668000/250000 and corresponds to the continental boundaries of the topographic maps SUDENE/DSG (1972) (SA 24 Y-A-IV) Parnaíba map and (SA 24 Y-A-V) Bitupitá map, both on the scale of 1:100,000.

Figure 1 - Location Map of the Coastal Plain of the State of Piauí



Source: Prepared by the Authors, 2017

Physical characteristics of the study area

The geological structure on which the Coastal Plain of the State of Piauí is based is the Maranhão-Piauí basin. The basin has a substrate represented by solid Archean, sisbrasilianos cratons and brasiliano orogenic belts. According to the most recent geological mapping carried out by Sousa (2015) on a scale of 1:100,000, the study area presents nine geological units, namely: Non-vegetated aeolian deposits; Floodplain alluvial deposit; Marine-fluvial deposit; The Barreiras Group; Vegetated aeolian deposits; Fluviolacustrine deposits; Paleodunes and Marine and aeolian beach deposits. The geomorphological units that make up the coastal plain of the state of Piauí include the following: aggradation reliefs and degradation reliefs. Also according to Sousa (2015) in a more detailed work on the mapping of the geomorphological units of the coastal plain of Piauí, the area presents ten (10) geomorphological units namely: Sand cord, aeolian plain, active dunes, stable dunes, paleodunes, fluvial-marine plain, marine terrace, plain and fluvial-terrace, lacustrine plain and coastal plain.

According to the classification of soils conducted by Cabral and Valladares (2015) and Lima et al. (2016), the following soil classes were found in the coastal plain of the state of Piauí: Yellow Argisol, Quartzarenic Neosol, Fluvic Cambisol, Fluvic Neosol, Haplic Planosol, Humiluvic Spodosol, and Haplic Vertisol. Also in their mapping were discovered some representative soils in the mangrove areas such as Salic Gleysol, and Thymorphic Gleysol.

The coastal plain of Piauí is influenced by several oceanic, atmospheric and continental agents, which is why it is particularly sensitive to climate change. According to Cavalcanti (1996) the coastal plain of the state of Piauí state has high levels of rainfall, and for that reason

it is considered a privileged area, although throughout the year the occurrence of rainfall is very irregular, therefore dividing the year into two distinct periods: the rainy season, which begins in December and lasts until April or May and the dry period, which corresponds to the months from June to November. Among the main systems responsible for the rainy season on the coast of Piauí, we can highlight: the Intertropical Convergence Zone (ITCZ), its influence is reflected in intense and relatively regular rains, mainly in the months of March and April, when there are the highest rates of rainfall, the instability lines (LI) and the MCCs (Mesoscale Convective Complexes)

Methodological procedures

For the mapping of areas with a vocation for urbanization of the coastal plain of Piauí, the main objective of this research, an additive multicriteria method (weighted average) and the boolean logic were adopted.

The multi-criteria evaluation was chosen for this type of environmental analysis because it consists of a set of techniques to assist a decision maker agent to make decisions regarding a complex problem, evaluating and choosing alternatives to solve it according to different criteria and points of view.

In the case of the proposed study, due the fact that this method has a high decision-making power in the environmental assessments for areas with a potential for urbanization, necessary to obtain useful conclusions to support the decision regarding the environmental control of a given area, it was sought to use this method by analyzing the areas with the greatest potential for building in coastal environments, but specifically on the coast of Piauí.

Similar methodologies using spatial data modeling for urban constructions were also used by several authors, such as Crespo et al. (2010); Moreira (2002), Silva (2005), Costa and Alves (2006); Samizava et al. (2008); Kux and Araújo (2008); Nascimento et al., (2009); Costa et al., (2011); Marques et al., (2011); among others.

Aiming at generating a scenario with the indication of vocation, restrictions or inadequacies for the urban occupation in the coastal plain of the state of Piauí, the methodology proposed for the study was subdivided into the following stages:

- (a) factor/variable definition;
- (b) standardization of the criteria (weights and grades) for the numerical range from 0 to 1;
- and
- (c) cross-checking of factors.

In order to obtain the final product (map of potential urban expansion), geology, geomorphology, flood risk, and erosion risk were initially defined as factors/variables, where weights were assigned for each variable inserted in the modeling process (Table 1).

It is worth noting that the dune advance variable was only crossed at the end of the evaluation between the four variables, using the Boolean logic, considered as a buffer solution, since it was not considered as a criterion of weight in the process of urban expansion and rather as an area of "attention" due to its advancement and, therefore, did not enter the sum of the weights.

Table 1 - Weights assigned to the variables used in the mapping of the urban expansion potential of the coastal plain of the state of Piauí

VARIABLE	WEIGHT / URBAN EXPANSION POTENTIAL (PEU)
<i>Geology</i>	0,30
<i>Geomorphology</i>	0,25
<i>Flood Risk</i>	0,25
<i>Risk of erosion</i>	0,20
SUM	1

Source: Prepared by the Authors, 2017

Knowing that the recognition of substrate conditions is of fundamental importance for the realization of a building project, since this variable consists of important pieces of information in the characterization of the natural potentialities and constraints of the study area to the demands arising from the occupation by man, it is important to emphasize geology as the variable that has the greatest influence on the decision of areas suitable for buildings and which, therefore, deserved to have the greatest weight (30%), since the characteristics related to the geological units are directly related to the capacity of support for the most of the engineering works, which demonstrates their high participation power in the identification of areas that have potential or not for urbanization.

Regarding geomorphology, the weight was attributed considering that this variable represents the landscape picture, showing the morphological reality, that is, the aspect of the relief that is a spatial indicator for urban allocations. This variable received 25% of the weight attributed to the indicator of urban expansion potential. Flood and erosion risks are factors that demonstrate the various restrictions that there are within coastal areas. This factor assisted in the identification of areas prone to flooding, in other words, areas with low and high flood risk and areas that are most vulnerable and less vulnerable to erosion, thus highlighting a significant influence on the decision of areas with a vocation for edification.

Thus, from the survey and analysis of the factors were also assigned grades for each variable, which aided in the process of evaluation of the areas that presented the best vocation for urbanization. These grades were rescheduled in intervals of 0 to 1, where each unit of the variables was weighted according to their importance in favor of urban occupation. For this, the units/classes present in each factor/variable were carefully compared and judged according to the relative importance among them in front of the urban occupation, where they received varied grades (Tables 2, 3, 4 and 5).

Table 2 - Notes attributed to each class of geology units

GEOLOGY (units)	NOTES/PEU (0 a 1)	NOTE vs. WEIGHT (0 a 1)
<i>Non-vegetated wind farm</i>	Out of Analysis	Out of Analysis
<i>Flood plain alluvial deposit</i>	0.3	0.09
<i>Marine Fluvial Reservoir</i>	Out of Analysis	Out of Analysis
<i>Group Barreiras</i>	1	0.3
<i>Vegetable wind farm</i>	0.5	0.15
<i>Fluvial-lacustrine reservoir</i>	Out of Analysis	Out of Analysis
<i>Beach deposits</i>	0.1	0.03
<i>Paleodunas</i>	0.5	0.15
<i>Depleted wind energy</i>	0.5	0.15
<i>River channels</i>	Out of Analysis	Out of Analysis

Source: Prepared by the Authors, 2017

From this proposition it is noteworthy that, the units: Beach deposits and flood plain alluvial deposit, considering that they have a very high and high degree of vulnerability as highlighted by Sousa (2015) in his work, received the lowest grades, indicating a low potential for expansion. The units identified as out of analysis are not recommended for urban expansion.

Table 3 - Notes attributed to each class of geomorphological units

GEOMORFOLOGY (Units)	NOTES/PEU (0 a 1)	NOTE vs. WEIGHT (0 a 1)
<i>Beaches</i>	Out of Analysis	Out of Analysis
<i>Sandy cord</i>	0.1	0.025
<i>Wind plain</i>	0.5	0.125
<i>Mobile dunes</i>	Out of Analysis	Out of Analysis
<i>Stabilized dunes</i>	0.3	0.075
<i>Paleodunas</i>	0.5	0.125
<i>Fluvial-Navy Plain</i>	Out of Analysis	Out of Analysis
<i>Sea Terrace</i>	Out of Analysis	Out of Analysis
<i>Plain and river terrace</i>	0.3	0.075
<i>Lake plain</i>	Out of Analysis	Out of Analysis
<i>Coastal board</i>	1	0.25
<i>River channels</i>	Out of Analysis	Out of Analysis

Source: Prepared by the Authors, 2017.

Table 4 - Notes attributed to each class of erosion risk units

RISK OF EROSION (%)	NOTES/PEU (0 a 1)	NOTE vs. WEIGHT (0 a 1)
<i>Very low</i>	1	0.2
<i>Low</i>	1	0.2
<i>Moderate</i>	0.7	0.14
<i>High</i>	0.3	0.06
<i>Very high</i>	Out of Analysis	Out of Analysis

Source: Prepared by the Authors, 2017.

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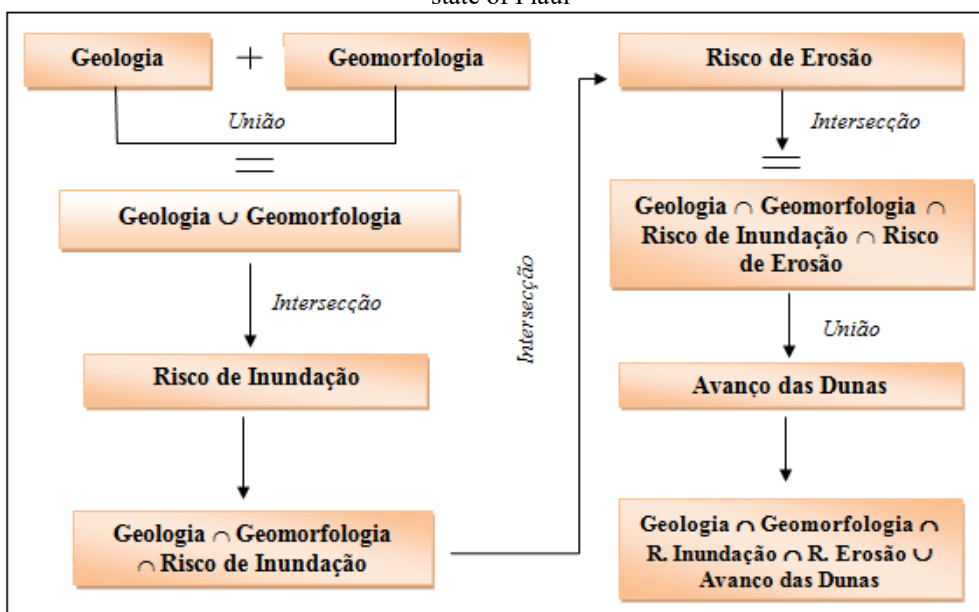
Table 5 - Notes attributed to each class of flood risk units

FLOOD RISK (%)	NOTES/PEU (0 a 1)	NOTE vs. WEIGHT (0 a 1)
<i>Very low</i>	1	0.25
<i>Low</i>	1	0.25
<i>Moderate</i>	0.5	0.125
<i>High</i>	Out of Analysis	Out of Analysis
<i>Most High</i>	Out of Analysis	Out of Analysis

Source: Prepared by the Authors, 2017.

After the weights and grades were established for each variable, for the process of evaluating the potential for urban expansion, the factors were combined (crossed), as shown in the flowchart (Figure 2).

Figure 2 - Processing flowchart used to generate the map of potential urban expansion in the coastal plain of the state of Piauí



Source: Prepared by the Authors, 2017

Initially, a union between two variables (geology vs. geomorphology) was performed as a way to join/group the various elements that encompass these two variables into a single

shapefile. Subsequently, an intersect, an intersection of these results with two other variables, in this case, the risk of flooding and the risk of erosion.

As a result, through the overlap of the elements present in each of these variables, a predictive model of these four situations was obtained for the study area. Then this model was crossed through Boolean logic with the shapefile of the advance of the dunes.

Thus, considering the migration of sediments and direction of the winds, this variable helped to demonstrate the areas that may suffer as the dunes progress. For this purpose, it was used a shapefile of the dune advance for the year 2015, a 500m buffer was performed, which indicated a prediction of advancement in approximately 30 years, taking into account the average annual advance of 18 meters.

Through this predictive model that included the overlapping of the four variables, a sum of all the grades and weights crossed was conducted in the different variables that are part of the analysis of the expansion potential of the Coastal Plain of the State of Piauí, thus joining the values of many different columns of the attribute table in a single column.

With this, the map of occupation potential was generated obtaining, as a result, the map with the areas favorable and the non-favorable to the occupation of the coastal plain state of Piauí. Then, these data were reworked in GIS to make the analysis of each class found.

This mapping, besides indicating the areas suitable for urbanization, could help in better territorial planning of the coastal zone that already suffers from the natural activity.

RESULTS AND DISCUSSION

Analysis of the Urban Expansion Potential in the Coastal Plain of the State of Piauí

It is necessary to plan the integration of infrastructure and superstructure of the area to be built in its surroundings, so as to enable the city to be built continuously as a whole and not as an aggregate formed by isolated settlements in inappropriate areas and without ordering (CASTRO and MELLO, 2012). For this end, it is essential to collect data and information regarding the physical environment as a way to ensure a harmonious implementation of the allotment, in such a way that a rational and economic project can be achieved.

Based on this premise, an attempt was made to evaluate the behavior and suitability of the lands for the purpose of urban expansion of the coast of Piauí, based on the information contained in the survey of the physical aspects of such lands.

Thus, based on the environmental assessment carried out on the characterization of the study area, it was observed that the photointerpretative criteria used (geology, geomorphology, flood risks, erosion risks and dune advance) allowed the inference of the factors analyzed in the characterization of the areas with potential and vocation for building in the coastal plain of the state of Piauí, establishing a quantitative and qualitative relationship between the classes of the factors analyzed.

Based on the environmental evaluations carried out, it was possible to generate a map of the potential for urban expansion of the coastal plain of the state of Piauí, presenting five classes, with degrees of vocation ranging from (< 0.40 to 1) and also areas out of analysis, as shown in the map (figure 3) and the (table 6). Thus, the closer to one, the greater the potential/vocation for edification, which will vary in degrees according to the characteristics and restrictions of each area.

Similar results were also found in the works of Calijuri and Lorentz (2003); Torres and Alves (2007); Nascimento et al. (2009); Xavier and Bastos (2010); Queiroz (2018) among others, highlighting the areas qualified for building and those that are not.

Table 6 - Area of urban expansion potential classes in the coastal plain of the state of Piauí in kilometers and percentage

CLASSES	ÁREA		GRAU
	km ²	(%)	
Good	332.60	38	< 0.40
Regular	156.32	17.86	0.40 – 0.75
Marginal	63.78	7.29	0.75 – 1
Not recommended	273.56	31.27	Fora de análise
Special	48.82	5.58	–
TOTAL	875.08	100	

Source: Prepared by the Authors, 2017

As can be seen from the map (Figure 3), the lands classified as "Good expressive potential" for urban expansion on the coastal plain of the state of Piauí correspond to the classes that comprise the largest study area, that is, a total of 875,08 km² corresponding to the areas of the coastal plain of state 332,60km² of the area (38%) refers to the class that presents greater vocation for buildings.

This class is associated with the Tertiary Deposits of the Barreiras Formation areas (Figure 4), which stand out as areas with a good vocation for urbanization, considering that they have deep soils, deep water table, good support capacity and sediments appropriate to civil construction.

Figure 4- Representative image of the Barreiras Group in the coastal plain of the State of Piauí



Source: Source: Frota, 2017

In the coastal plain of the state of Piauí, these lands are represented by the highest areas corresponding to the coastal tablelands and are located more in the interior of the continent like coalescing detrital ramps diving toward the Atlantic Ocean. It is, therefore, a class that is put in places with a physical capacity favorable to the construction of new allotments. Most of the

city of Parnaíba is located in this class, presenting a good vocation, because they are overlaid on the coastal tablelands that are flat areas.

Taking into account geomorphology as a factor that contributes to the identification of the expansion potential in the class that corresponds to the "Good urban expansion potential", the coastal tablelands presented about 95.34% of their area with a propitious vocation for the construction, in geology this unit presented 94.69% of its area with good potential. In relation to the factors of flood risk and risk of erosion, the good potential class comprises the very low-risk areas, which shows that these lands do not present restrictions, that is, they present a good vocation for urbanization, as can be observed in the tables 7, 8, 9 and 10.

The so-called "Regular expansion potential" class corresponds to 156.32 km² of the study area, which represents 17.36% of the total area. This class is mainly associated with the geomorphological units: paleodunes (where 78.20% of these areas present potential for regular urbanization), stable dunes (75.70%), the plain unit and river terraces (47.02%) and the aeolian plain with a regular potential of 72.63%.

This class presents a significant potential for expansion considering that the stable dunes and paleodunes are areas that already have a certain consolidation, because they are older and, due to this, present a significant amount of iron in their composition, which gives them a yellowish-red coloration and greater sustainability.

It is worth mentioning that some of the lands of this class of regular urban expansion potential are areas that present certain limitations, such as the geomorphological units: plain and fluvial terraces, and aeolian plain, because in the coastal plain of the state of Piauí, the plain and fluvial terrace unit corresponds to the areas that are located near the rivers Parnaíba and Igarçu, therefore, this one is subject to periodic floods, possessing a risk of flooding varying of moderate to high.

Table 7 - Relation of the area of the urban expansion potential with the geomorphological units present in the coastal plain of the state of Piauí

GEOMORFOLOGY	ÁREA DO POTENCIAL DE EXPANSÃO URBANA				
	GOOD (%)	REGULAR (%)	MARGINAL (%)	NOT RECOMMENDED (%)	SPECIAL (%)
<i>Beaches</i>	-----	-----	-----	100	-----
<i>Sandy cord</i>	-----	-----	92.44	1.25	6.31
<i>Wind plain</i>	-----	72.67	0.16	14.77	12.40
<i>Mobile dunes</i>	-----	-----	-----	84.52	15.45
<i>Stabilized dunes</i>	-----	75.70	-----	0.32	23.98
<i>Paleodunas</i>	-----	78.20	-----	0.06	21.74
<i>Flúvio-Marinha Plain</i>	-----	-----	-----	96.35	3.65
<i>Sea Terrace</i>	-----	-----	-----	100	-----
<i>Plain and river terrace</i>	-----	47.02	40.94	10.35	1.69
<i>Lake Plain</i>	-----	-----	-----	93.36	6.64
<i>Coastal board</i>	95.34	0.03	-----	0.43	4.20
<i>River channels</i>	-----	-----	-----	98.66	1.34

Source: Prepared by the Authors, 2017

Table 8 - Relation of the area of the urban expansion potential with the geological units present in the coastal plain of the state of Piauí

GEOLOGY	URBAN EXPANSION POTENTIAL AREA				
	GOOD (%)	REGULAR (%)	MARGINAL (%)	NOT RECOMMENDED (%)	SPECIAL (%)
<i>Non-vegetated wind farm</i>	-----	-----	-----	85.02	14.98
<i>Flood plain alluvial deposit</i>	-----	47.03	40.93	10.35	1.69
<i>Marine Fluorite Deposit</i>	-----	-----	-----	98.02	1.98
<i>Group Barreiras</i>	94.69	-----	-----	0.28	5.03
<i>Vegetable wind farm</i>	-----	75.70	-----	0.33	23.97
<i>Fluvial-lacustrine reservoir</i>	-----	-----	-----	93.43	6.57
<i>Beach deposits</i>	-----	-----	89.46	4.73	5.81
<i>Paleodunas</i>	-----	78.26	-----	-----	21.74
<i>Depleted wind energy</i>	-----	82.74	0.18	2.96	14.12
<i>River channels</i>	-----	-----	-----	97.86	2.14

Source: Prepared by the Authors, 2017

Table 9 - Relation of the area of the urban expansion potential with the risk of flooding in the coastal plain of the state of Piauí

FLOOD RISK	URBAN EXPANSION POTENTIAL AREA				
	GOOD (%)	REGULAR (%)	MARGINAL (%)	NOT RECOMMENDED (%)	SPECIAL (%)
<i>Very low</i>	85.72	0.11	-----	9.21	4.96
<i>Low</i>	68.14	18.65	0.31	2.99	9.91
<i>Moderate</i>	0.14	64.92	11.95	14.57	8.41
<i>High</i>	0.42	15.67	37.23	45.29	1.42
<i>Very high</i>	-----	-----	-----	97.24	2.76
<i>Most High</i>	0.43	-----	-----	96.53	2.88

Source: Prepared by the Authors, 2017

Table 10 - Relation of the area of the urban expansion potential with the risk of erosion in the coastal plain of the state of Piauí

RISK OF EROSION	URBAN EXPANSION POTENTIAL AREA				
	GOOD (%)	REGULAR (%)	MARGINAL (%)	NOT RECOMMENDED (%)	SPECIAL (%)
<i>Very low</i>	90.68	-----	-----	5.46	3.86
<i>Low</i>	31.46	13.19	-----	51.48	3.87
<i>Moderate</i>	0.22	43.47	44.79	6.18	5.35
<i>High</i>	-----	66.52	7.74	13.38	12.36
<i>Very high</i>	-----	-----	-----	98.68	1.32

Source: Prepared by the Authors, 2017

In addition to presenting mostly wetlands, where the water table is very close to the surface, the plain and fluvial terrace unit in its modeling present several nebkas, sand accumulations that occur in isolation, on the high beach, the leeward of an obstacle, which also shows a potential for median urban expansion due to non-uniformity of the surface (Figure 5).

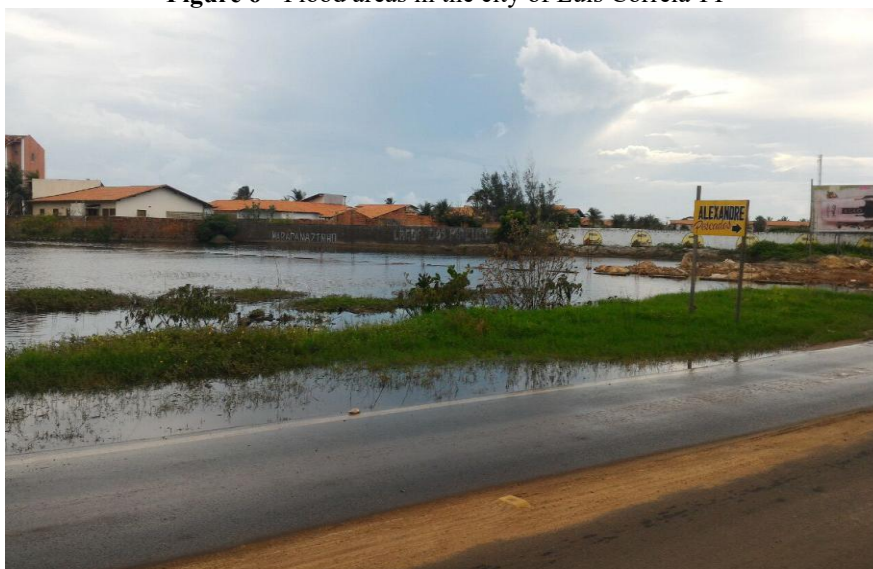
Figure 5 - Presence of Nebkas in the plain unit and river terrace present in the municipality of Ilha Grande do Piauí



Source: Frota, 2017

In the regular potential class, the aeolian plain unit, where the entire city of Luís Correia is located despite having a potential for regular urban expansion, also presents a certain limitation regarding the risk of flooding, since these features present the water table very close of the surface, which gives them in times of rain, the flood of areas near the coastline, flooding streets, avenues, and houses. (Figure 6)

Figure 6 - Flood areas in the city of Luís Correia-PI



Source: Frota, 2017

It is worth inferring that part of this class of Regular Potential, corresponding to the aeolian plains, are formed by Quartzarenic Neosols, that is, this unit is formed by soils that have little pedogenetic development and that present a certain fragility and therefore, a very high risk of erosion as observed in the mapping of the risk of erosion of the study area, which shows that these lands are suitable for edification, however, they present some restrictions regarding the risk of flooding and the risk of erosion.

The so-called "marginal urban expansion potential" comprises 63.68 km² of the study area, which corresponds to 7.29% of the total area. This class is mainly associated with the sand cord and part of the plain and fluvial terrace unit.

Although there is a higher percentage of low vocation for urbanization compared to the other two classes above, the sand cord unit also presents a high percentage of area with a marginal vocation of 92.44% as shown in Table 7 because in these areas of the coastal plains of the state of Piauí there are many tents, that is, they are areas that present low potential for urban expansion and, nonetheless, present small buildings in their surroundings.

This class, accompanied by the regular potential class, houses the entire city of Ilha Grande and part of the city of Parnaíba in the plain unit and river terrace, which determines that these cities have areas with potential for urban expansion, however, they present restrictions regarding the flood and erosion risk that vary from moderate to high in some areas.

It was observed that the main part of the city of Parnaíba was urbanized in areas very close to the floodplain of rivers, as is the case of the Igarçu River (Figure 7) demonstrating low suitability to urbanization. However, it is noticed that in rainy times, parts of these residences are flooded, due to poor land management and lack of urban planning.

Figure 7 - Construction of homes in the city of Parnaíba-PI, near the Igarapé river



Source: Google Earth, 2013

In the city of Ilha Grande, these areas also suffer restrictions regarding the advance of the dunes. Houses are built very close to the active dune fields and with mainly wind actions in the coastal plain of the state, these dune fields tend to invade the built urban space, causing significant losses for the resident population (Figure 8).

Figure 8 - Advancement of the dunes on the city of Ilha Grande do Piauí and nearby communities



Source: Google Earth, 2016

The class of "Expansion potential not recommended" corresponds to areas that are inappropriate for urban occupation. This class was considered the second largest in terms of a territory of the study area, representing about 273.56 km² of the area, which corresponds to 31% of the same.

In this class, taking into account geology and geomorphology, as can be observed in (tables 7 and 8), 100% of the areas of the geomorphological units: beaches and sea terraces were considered as without vocation for building and about 96.36 %; 93.36% and 84.52% of the area of the fluvial-marine plain, lake plains and active dunes were also considered without vocation for building. This is due to the natural limitations they present with a very high risk of flood and erosion.

The beaches are areas totally vulnerable to erosion and flooding and in the coastal plain of the state of Piauí, they have been suffering enough with the issue of coastal erosion. They are, therefore, environments of enormous fragility and that do not present favorable conditions to urbanization. It is worth noting that in this class of "not recommended" especially in these geomorphological units, in the city of Luís Correia, Parnaíba and Cajueiro da Praia, it is possible to visualize the existence of houses very close to the beach line and the presence of many tents in beach areas, which end up suffering from marine erosion.

The fluvial-marine plain is a permanently flooded area with sediments rich in organic matters of continental origin and marine additions, with Gleysols coated by mangroves, therefore, being unstable environments with high vulnerability to urban occupation. The main soils that are associated with this unit in the coastal plain of the State of Piauí are the (Gleysols), that is, hydromorphic soils. These, in turn, present limitations for urbanization, due to the lack of support capacity for the construction of buildings.

In addition, these areas present an environment conducive to the production of organic matter, which guarantees food and natural protection for the reproduction of several marine and estuarine species. They also have a huge landscape patrimony, which provides environments of great scenic beauty, especially the beaches and fluvio-lacustre islands, which favor leisure activities and tourism, with emphasis on ecological tourism.

Costa and Alves (2006), in a study about the potential of urban land use and occupation in the municipality of Campos dos Goytacazes - RJ, also defined these areas as non-urbanizable areas; however, they highlighted them as areas that deserve greater attention with relation to preservation.

The active dunes represented by non-vegetated aeolian deposits were also considered areas not recommended for urbanization. This is because these areas present a high degree of erosion since they do not present stability for the construction of allotments. Moreover, it has great touristic potential and unique scenic beauty.

The class considered "Special" refers to a future scenario of expansion of the dunes based on their dynamics between the years of 1994 and 2015, imagining the advance of the dunes in an interval of approximately three decades. This, in turn, deserves special attention because it takes into account future problems that may occur in the coastal plain of the state of Piauí.

In this way, this class comes as a way of demonstrating the areas that may present a risk of advancing the dunes on the buildings in the next years and with the purpose of also demonstrating the importance of not constructing very close to the dunes due to the high landscape value that these features present, mainly taking into account the tourist potential that they present.

This class corresponds to 48.82 km² of the study area, representing about 5.58% of the total area. Thus, it is noteworthy that, as shown in the map (Figure 3), these special areas are areas that, despite having or not a potential for urban expansion from a geological and geomorphological point of view, should be carefully studied, since the surrounding areas of the active dunes:

- In the future, they may present risks for an already existing urbanization and for future urbanizations with the advance of the dunes. Some areas can be compromised with this

advance, mainly areas that present residences, as already observed in the coastal plain of the state, in the municipality of Ilha Grande.

- In addition, these areas have a high landscape value, of cultural and ecological importance. These have great tourist potential for their landscape diversity and/or scenic beauty, which are extremely sought after for leisure and contemplation of the landscape. The dunes are located in public property areas, where preservation efforts must be developed, as they are highly valuable for educational, cultural and recreational uses by various segments of society.

According to (Tables 7, 8, 9 and 10), these special areas may later compromise lands that have a good urban expansion potential to marginal, such as paleodunes and stable dunes, some areas of the Barreiras Group and part of the devastated aeolian deposits.

In the study area, taking into account the issue of environmental vulnerability, Sousa (2015) shows that the older the lithology, the less vulnerability and the more recent it is, the greater is its degree of vulnerability. Thus, the entire study area being composed of Quaternary and Tertiary sediments brings us a great homogeneity of values, characterized from moderate to very high vulnerability and yet deserves a lot of attention in urban planning assessments.

In view of this, based on the analysis of the generated map, it was found that the coastal plain of the state of Piauí presents many lands with potential for urban expansion and, therefore, has a high potential for urban growth, however, construction on lands that present low or no potential must be avoided, without invasion of environmentally fragile areas.

CONCLUSION

The coastal plain of the state of Piauí is composed of a diversity of landscapes and factors that act in interdependence in the formation and dynamics of the same. These, by acting together bring significant transformations to the environment by modifying and modeling it.

Based on the environmental assessment carried out about the characterization of the physical and environmental aspects of the study area, through the multifactorial criteria used (geology, geomorphology, flood risks, erosion risks and dune advance) it was possible to identify and characterize the areas with and without potential and vocation for building in the lands of the coastal plain of the state of Piauí. The generated map presented five classes, in which the areas that present good expansion potential were the lands associated with the coastal tablelands and the lands considered not recommended for urbanization.

Thereby, the coastal plain of the state of Piauí presents many areas with potential for urban expansion and, therefore, has a high potential for urban growth, however, construction on lands that present low or no potential must be avoided.

The growth and expansion of urbanized areas in the coastal plain of the state of Piauí have been disregarding aspects such as the prevention of geological, geomorphological and hydrological risks and geodynamic processes, which has generated troubles to society and the environment. However, it is essential to carry out adequate urban planning with the interdisciplinarity of the urban environment and the perspective of long-term solutions, aiming at a better land use and the preservation of inadequately urbanized areas. It is also clear the need for public policies to make the population aware of the importance of complying with the laws and guidelines that establish the urban perimeter as appropriate, considering a sustainable development.

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