Journal of Urban and Environmental Engineering, v.10, n.2, p.242-253

ISSN 1982-3932
doi: 10.4090/juee.2016.v10n2.242253

Journal of Urban and Environmental Engineering

www.journal-uee.org

GEOMORPHOLOGY OF JOÃO PESSOA MUNICIPALITY AND ITS ANTHROPOGENIC AND ENVIRONMENTAL ASPECTS

Max Furrier* and Tamires Silva Barbosa

Department of Geosciences, Federal University of Paraíba, Brazil

Received 26 June 2016; received in revised form 4 October 2016; accepted 18 November 2016

Abstract: The objective of this paper is to study the geomorphology of the municipality of João Pessoa, Paraíba State, Brazil, analyzing the outlines of the current natural landforms as well as technogenic relief. From this analysis, morphostructural and morphosculptural units, patterns and landforms, shape types and current morphogenetic processes were identified and quantified in the municipality along with landforms produced exclusively by human processes. The current forms and technogenic relief obtained through this research included sandy patch processes, sinkholes, active and inactive cliffs, mass movement-produced forms and anthropogenic excavations for limestone and clay mining.

Keywords: Geomorphology; current forms; technogenic; morphogenesis; geological and geomorphological risks

* Correspondence to: Max Furrier. E-mail: max_furrier@hotmail.com

INTRODUCTION

The study of human activities as a geomorphological factor has flourished in recent decades, creating a new subject area within the geosciences known as urban geomorphology and anthropogenic geomorphology as well as a new geological period, the Quinary.

The impact of human activities on the landscape is often insignificant when compared to endogenous processes. Thus, volcanism often has an equivalent or even greater effect relative to climate influences on exogenous surface processes (Szabó, 2010). However, human activity can directly or indirectly influence the genesis or alteration of landforms.

Landforms derived from anthropogenic processes are referred to as tecnogenic landforms (Peloggia, 1998). According to Szabó (2010), human actions are considered geomorphological dynamics and included among the most relevant geomorphological agents, especially in urban areas. Therefore, when considering the elements that generate or modify the earth's surface landscape, humans and their actions should be included.

Undoubtedly, urbanization and associated engineering works are among the actions with the greatest impact on terrestrial landscapes. According to Csima (2010), the greatest direct impacts of urbanization on landscapes are the impermeabilization of ground substrates, which alters runoff and water infiltration; the occupation of unstable steep slopes, which can trigger mass movements; and the occupation of flood plains.

Study area

The present study covers the municipality of João Pessoa, in the state of Paraíba, Brazil, and the study area is located in the central-south sector of Paraíba's coast and borders in the municipalities of Cabedelo to the north, Conde to the south, Bayeux and Santa Rita to the west and the Atlantic Ocean to the east (Figure 1). João Pessoa is located in what is known as *Paraibana* Mesoregion *Zona da Mata* and has a total area of 211.47 km² (Brasil, 2010).

The municipality presents a heterogeneous and widespread urban network along the drainage basins, including along Gramame, Sanhauá, Paraíba and Jaguaribe main rivers and others of lesser extension, which have been completely modified by urbanization and are difficult to visualize. A humid tropical climate is dominant, and the area has an average temperature of approximately 26°C and average annual rainfall of 1874 mm (Brasil, 2010).

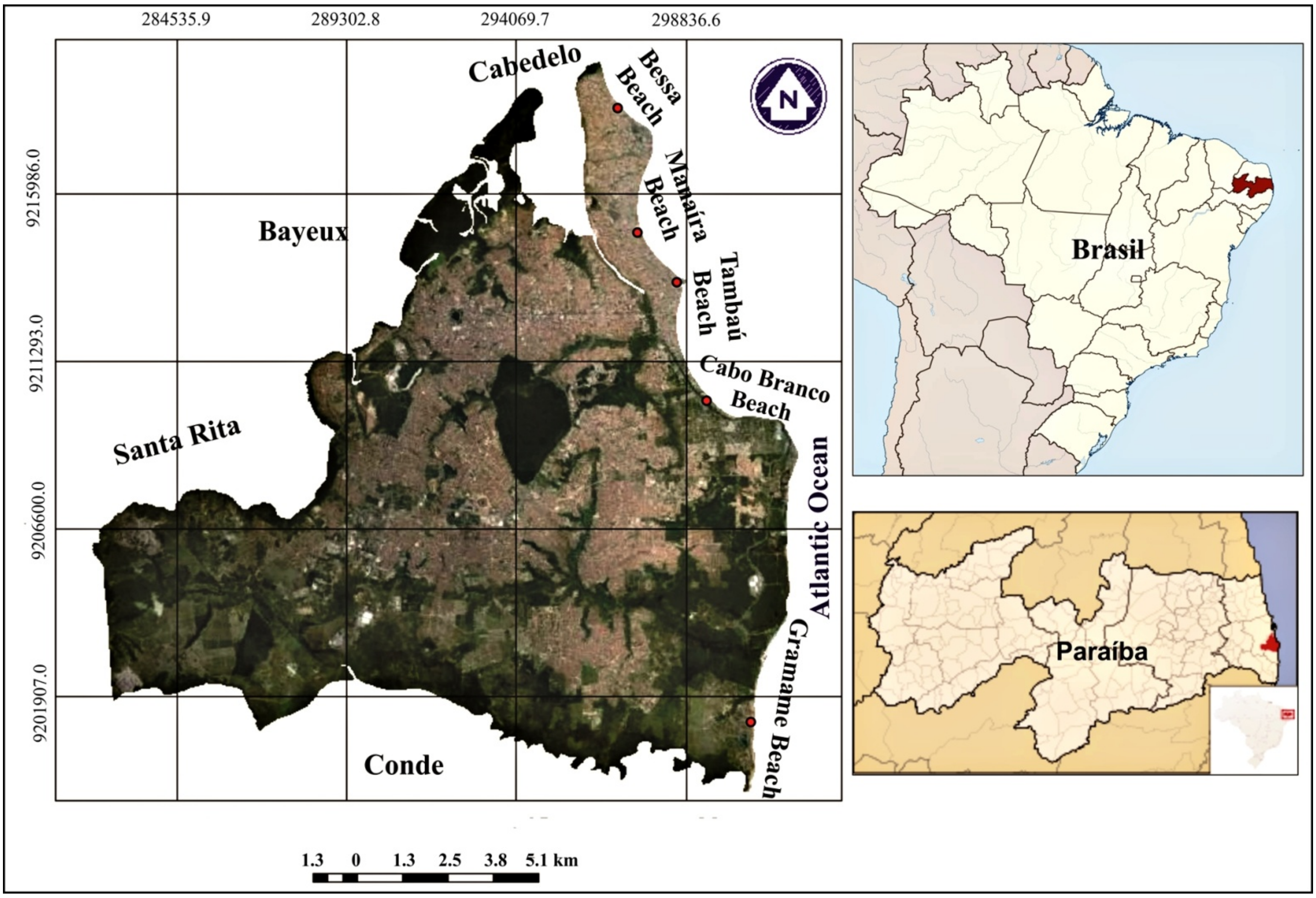

Fig. 1 Location of the João Pessoa Municipality.

Technical and Operational Procedures

Four topographic charts that cover the municipality of João Pessoa at 1:25 000 scale with equidistant elevation contours of 10 m were seamlessly joined. The topographic charts are those of Santa Rita, João Pessoa, Nossa Senhora da Penha and Mata da Aldeia (Brasil, 1974). These charts were used as a cartographic background for the present study because of their scale suitability, elevation contour equidistance and technical quality because they were produced using the photogrammetric method of triangulation with extensive ground validation of the altimetry data. Therefore, although more laborious work was required, vectorization of these topographic charts imparted enhanced precision to the images obtained by the Shuttle Radar Topographic Mission (SRTM) radar. For large-scale studies, the topographic charts produced by aerial triangulation and field support are more precise in relation to orbital images.

Subsequently, the topographic charts were digitized and vectorized in computer-aided design (CAD) software, and the vectorized products were imported into a geographic environmental information system (GIS) in order to create database, the regular and irregular matrix of the terrain, the Digital Terrain Model (DTM) and the clinographic (slope) map. These products assisted in the analysis of the relief forms through of modulation of the terrain in digital environment, and to show the main points to do the field work.

RESULTS AND DISCUSSION

The slope map shows slopes ranging from 0 to 12% and > 100% (**Fig. 2**), which indicates areas where active cliffs occur. This map is an important tool for environmental studies because identifying areas that include steeper slopes can be used to estimate areas that present higher risks to the environment and/or humans.

The majority of slopes within João Pessoa municipality range from 0 to 12%, which characterizes a typical flat landform with extensive aggradational areas, such as marine plains and terraces of the low-lying neighborhoods, including Ponta do Seixas, Cabo Branco, Tambaú, Manaíra, Jardim Oceania and Bessa. Steeper slopes are found along valleys that show a higher degree of dissection as well as on the active and inactive cliffs that separate the previously mentioned low-lying neighborhoods from the higher-altitude neighborhoods, such as Portal do Sol, Altiplano, Miramar, Brisamar (Jardim Luna) and João Agripino (Parque dos Ipês). The inactive cliff that separates the districts of Jardim Luna and Parque dos Ipês from São José district, which occupies a marine terrace, is currently under pressure from the illegal development of small dwellings, which is aggravating the geological risk of these buildings as well as buildings located at the foot of the cliff, which has slopes varying from 30 to 100%.

Slopes above 30% present an imminent geological risk; therefore, unrestricted urbanization is not permitted. However, illegal occupations are observed in this sector as well as in the areas of Distrito Industrial, as well as in Alto do Mateus, Jardim Cidade Universitária and Cuiá districts, where urbanization has invaded the steep slopes of river and stream valleys.

Areas with gentle slopes are frequently subjected to a different hazard: floods. The neighborhoods at the margins of the Jaguaribe River, including a small portion of Miramar district and a large part of São José district, which are flooded every year during the rainy season. Floods also occur nearly every year at the margins of the Sanhauá River fooding parts of Alto do Céu, Varadouro and Ilha do Bispo districts.

Table 1 shows the extent in km^2 and percentage of each slope class occurring in the municipality of João Pessoa.

Table 1. Slope classes in the João Pessoa municipality in km^2 and in percentage of total area.

Classes (%)	Area (km²)	Area (%)
0 – 12	184.45	92
12 – 30	14.1	7
30 – 47	2.15	1
47 – 100	0.72	< 1
> 100	0.02	< 1

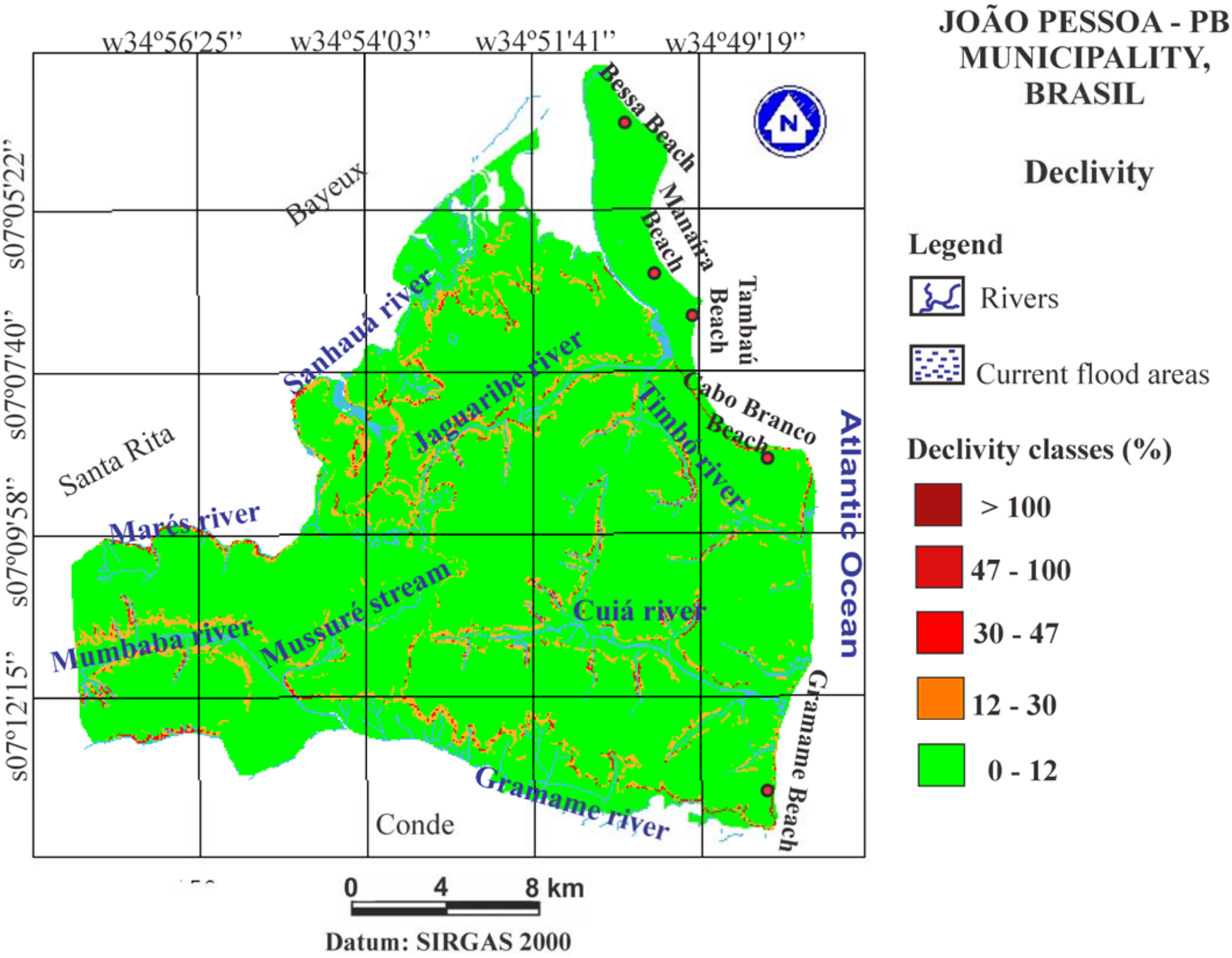

Fig. 2 João Pessoa municipality slope map.

Geomorphology and anthropogenic aspects of João Pessoa municipality

The main morphoestructure of the João Pessoa municipality is a lithostratigraphic unit known as the Barreiras Formation, which is formed of poorly consolidated clayey sands dated from the Miocene. While the main morphostructures in the area consists of coastal lowlands and coastal plateaus. The patterns and types of relief in the area can be specified as: three denudation landforms and six accumulation landforms.

The denudations landforms are represented by the letters Dp (Denudation with plateaus shapes) and Dc (Denudation with convex shapes). And by numbers that represent the relief dissection index, which is explained in **Table 2**.

Table 2. Landscape dissection index

Degree of Valley Incision	Average Inter-fluvial Distance				
	Very large (1) > 1500 m	Large (2) 1500 to 700 m	Medium (3) 700 to 300 m	Small (4) 300 to 100 m	Very small (5) < 100 m
Very low (1) < 20 m	11	12	13	14	15
Low (2) 20 – 40 m	21	22	23	24	25
Moderate (3) 40 – 80 m	31	32	33	34	35
Strong (4) 80 – 160 m	41	42	43	44	45
Very Strong (5) > 160 m	51	52	53	54	55

Source: Adapted from Ross (1992).

The denudations landforms are:

Dp 31: dissection plateau landforms showing a moderate degree of valley incisions (40 – 80 m) and average inter-fluvial distances classified as very large (> 1,500 m). This type of landform occurs in areas near the Mumbaba River and on the left margin of the Jaguaribe River. This landform pattern extends over 73 km^2 or 35% of the municipality's area.

The denudation plateau geomorphological forms (Dp 31) show the highest altitudes in the municipality and the broadest and least dissected plateaus, where the hydrographic network is less dense. The following neighborhoods of Torre, Mandacaru, Treze de Maio, Tambiá, Jaguaribe and Cruz das Armas are located in the central sector of the municipality; Mussuré, Mumbaba and Distrito Industrial located farther away in less urbanized areas; and Jardim Luna and Parque dos Ipês located near the inactive cliff that separates this landform type from the marine plains and terraces.

The area where this landform type is observed includes limestone and clay mining operations owned by the CIMPOR cement factory, and mining is also conducted illegally in the quarries of Mandacaru and Roger. In these mining areas, the Barreiras Formation, which overlies the Gramame Formation, is thin, facilitating the mining of limestone from the Gramame formation. The clay is extracted from a layer of the Barreiras Formation and used as a secondary raw material in CIMPOR's cement production.

Dp 21: denudation landforms with plateaus at higher elevations, average valley incisions classified as low (20 – 40 m) and large inter-fluvial distances (> 1,500 m). These landforms occur near the Cuiá River basin on both margins and occupy 78 km^2 or 38% of the municipality area.

This landform type occurs in the southeast sector of the municipality up to the active and inactive cliffs that separate it from the marine terraces and plains. The following districts are under this compertment Mangabeira, Jardim Cidade Universitária, Bancários, Água Fria, Cuiá, Ernesto Geisel, Valentina, Portal do Sol, Barra do Gramame, Costa do Sol, Altiplano, etc. Certain areas of geological risk resulting from the presence of a pronounced hydrographic network were identified. As previously described, the steeper slopes facilitate mass movements, especially when occupied by dense urbanization as observed in the low-income community found in one of the tributaries of the Timbó River.

Dc 31: convex denudation landform types occurring in the vicinity of Mussuré stream, a tributary of the Mumbaba River. This landform type extends over 12.7 km^2 or 6% of the municipality's area. The associated neighborhoods include Distrito Industrial (Mechanical district), Funcionários, Costa e Silva and Ernani Sátiro.

These neighborhoods are densely populated and are considered low-income areas. Although these characteristics favor illegal occupations, this area is considered of low geological-geomorphological risk because of the low to moderate slopes and convex landform characteristics.

In the description of the accumulation landforms, in total, six types of depositional (aggradational) landform types were identified in the municipality.

Intertidal plain area (Atp): intertidal flats correspond to the mangrove areas. These areas extend over 17.5 km^2 or 8% of the municipality, and they occur mainly on the margins of the Sanhauá River and the lower courses of the rivers Gramame, Cuiá, Aratu and Cabelo in the northwest of the municipality.

Intertidal plain areas are under strong anthropogenic pressure from the low-income population who are illegally occupying areas belonging to the federal government. Therefore, the lack of legal documentation and inspections from competent agencies favors such illegal occupation. Deprived of basic infrastructure, these impoverished communities are confronted with floods, especially during high spring tides and pollution.

Mangrove areas are considered permanent preservation areas under federal law Nº. 9605/98, which establishes criminal and administrative penalties derived from activities harmful to this ecosystem. Preservation is required because of the ecological importance and fragility of such areas because they are considered a nursery for several species and its vegetation is of fundamental importance to the stabilization of sediments and the mitigation of coastal erosion.

Fluvial plains (Af): area that is adjacent to the fluvial channel and constantly flooded during periods of intense rainfall (Guerra & Guerra, 1997). This area extends for over 6.3 km^2 or 3% of the municipality along parts of Gramame, Jaguaribe and Cuiá rivers, the Mussuré stream and other small tributaries. Because of the high urban density, the Jaguaribe fluvial plain has the greatest impact on the local population, which often illegally occupies the area. The urbanization effects on the fluvial plain contributes to the complete elimination of riparian forests and intense siltation of the river. Siltation dramatically decreases the river flow and increases flooding; thus, frequent mechanical dredging is required.

Fluvial plain and terraces (Atf): because of the scale and the small streams that cut across the urban areas of João Pessoa, it was impossible to distinguish the terrace from the fluvial plain in certain sections of the geomorphological map. However, these areas cannot be ignored because they are becoming densely occupied or are already at risk. The fluvial terraces consist of older alluvial material formed from the river overflowing flooded areas currently at elevations higher than the fluvial plains. The fluvial plains occur along fluvial valleys that have variable widths and were formed by modern sediments and constant flooding during rainy periods. Therefore, the accurate mapping of such areas is fundamental for the support of environmental and land-use planning. In João Pessoa, this landform type occurs in the tributaries of the Mumbaba River and in some sectors of the Jaguaribe, Timbó and Cuiá rivers, occupying 3.6 km^2 or 1% of the whole municipality area.

Marine plain and terraces (Atmp): beach and inland beach ridge areas (Figure 3) formed by decreasing sea level since the last transgression, which occurred in Brazil at 5100 before present (BP) (Suguio & Martin, 1978). These areas extend for over 10.6 km^2 or 6% of the municipality and are found in Ponta do Seixas, Cabo Branco, Tambaú, Manaíra and Bessa districts. The marine plains consist of the area from the current beach to the high spring tide mark. The fluvial terraces are the old marine plains that no longer flood during high tides because of the decreases in sea level over the past 5,100 years. These areas are flat and prone to flooding during the rainy season at the sites that lack engineering works to control fluvial drainage.

Fig. 3 Aerial photograph of Bessa and Manaíra districts and their surroundings, showing the beach ridges that were not urbanized in 1985.
Source: modified from INCRA/TERRAFOTO (1985).

Colluvium, river plains and terraces (Actf): because of the scale used, colluvium areas could not be precisely delineated from terraces in the map, which justified the adoption of the adjustment proposed by Furrier (2007). Colluvium include sedimentary deposits formed by mass movements and are only found in the foothills. It is often difficult to map and delineate colluvium deposits from those of adjacent terraces or river plains. Colluvium areas present an imminent risk to nearby populations because they are formed by sedimentary material transported downhill from the top of a slope in events with high energy and a short duration that are often of catastrophic to the population. This landform type occupies 7.8 km^2 and 3% of the study area.

These landforms occur mainly along the slopes facing the middle Gramame Valley, especially in the district of Mussuré and the slopes of the middle Jaguaribe, especially in the district of Castelo Branco.

Fluvial terrace and colluvium area (Acft): colluvium deposits and fluvial terraces that cannot be precisely distinguished. These areas occupy 0.1 km^2 of the municipality area and are found along highly incised water courses cutting across urban areas of João Pessoa, mainly at the foothills of steep slopes. In João Pessoa, this landform type was identified along an unnamed tributary of the Mumbaba River in the district of Mussuré and in highly incised stretches of the Cuiá River and its tributaries in the districts of Mangabeira and José Américo.

As regards the aspects of anthropogenic landforms, a large number of modern, natural and anthropogenic landforms are widely spread across the study area, included sandy patch processes, sinkholes, active and inactive cliffs, mass movement-produced forms and anthropogenic excavations for limestone and clay mining.

The cliffs are not conspicuous along the entirety of the municipal coastline because the northern coastal districts are built on the marine terraces and plains. A line of inactive cliffs extends to the vicinity of Shopping Manaíra, where river Jaguaribe is diverted from its natural course (Figure 4). A line of inactive cliffs extends southward and reaches the active Cabo Branco cliff. Towards the southernmost sector of the municipality, there is a sequence of active and inactive cliffs. Therefore, it is unlikely that increases of sea level are the main cause of cliff erosion; otherwise, all the cliffs along the coastline should be active. All the active cliffs show slopes steeper than the inactive cliffs. The active cliffs present potential geological risk, mainly in the rainy season. The cliffs are formed by the Barreiras Formation, which is characterized by high porosity and permeability; therefore, rainfall increases the weight and decreases the cohesion of the cliff face. Cliff retreat is greatly enhanced when higher waves over short periods coincide with the high spring tides during storms.

The inactive cliffs are visible and easily identified at the inland of São José district, north of the municipality

(**Fig. 4**). This community is clearly exposed to geological risks because of the likelihood of mass movements because the cliff has been impacted by new dwellings, and frequent floods occur because of the heavy geomorphological degradation of the Jaguaribe River and colmatation caused by excessive garbage dumping. Unfortunately, the neighborhood of São José is directly affected by the river Jaguaribe and is at risk of mass movements of inactive cliff that separates the districts of Jardim Luna and Bairro dos Ipês (**Fig. 4**).

In the active cliffs located at the south of the municipality, the main risk is related to landslides because the cliff base is undermined by wave action, which is enhanced when the spring high tide and storms coincide. Urbanization on the cliff tops increases the weight affecting the landforms and increases the risk during construction and with increased traffic, particularly by heavy vehicles. It is worth noting that the local geology consists solely of poorly consolidated sediments of the Barreiras Formations (extremely soft rocks). Evidence of localized frequent landslides has been observed on the active cliffs that separate the southern area of Cabo Branco district from the northern area of Ponta do Seixas district (**Fig. 5**).

Landforms observed at an active cliff indicate the recent movement of sedimentary material and cliff instability, which prevents the colonization of pioneer vegetation. Darker material usually of deep red color found at the cliff base (Figure 5) is not part of the landslide but is formed at the base of the cliff by intense precipitation of iron and hydroxides oxides solidifying the porous sandstone, increasing their resistance to waves and transportation by littoral drift. These deposits cemented by iron oxides and hydroxides are known as ferricretes, and they can be used to measure the rate of cliff retreat. Because the *ferricretes* are formed at the base of the cliff, they represent its previous position, which can be compared with the position of the current cliff base; therefore, they provide an accurate method of measuring cliff retreat (Furrier, 2007). These concretions can also form abrasive marine terraces, such as those found in front of Cabo Branco cliff, which is mistakenly referred to as reefs. These marine abrasion

Fig. 4 The line of inactive cliffs covered by vegetation is visible in the background. The São José neighborhood developed over the marine terraces is shown in the foreground. The line of inactive cliffs relates to the last transgressive event, which reached its peak in Brazil at 5,100 BP (Suguio & Martin 1978).

Fig. 5 Rock falls at the active cliff of Cabo Branco. Photo taken by the author in 2014.

terraces described by Furrier (2007) are strong evidence that the Cabo Branco cliff experienced a retreat long before the settlement that originated João Pessoa City. Therefore, the construction of the Science Station (*Estação Ciência*) on the cliff top should have considered the ongoing coastal erosion, which is a long-term process; thus, its containment will not be a simple task.

The mass movement sites observed in the municipality are caused by different processes. Certain processes were observed but not mapped because of their small dimensions, and they include landslides, slumps, solifluction and creep. These processes may occur naturally because of the slope gradient, geology type and rainfall intensity, and they can also be intensified by anthropogenic action. Human actions play a greater role in these processes in densely populated areas and along road cuttings and steeper slopes.

The coastline of the João Pessoa Municipality extends for over 23.46 km, and 10.93 km is eroding. The longest eroding shoreline stretches for over 4.36 km between the beaches of Seixas and Cabo Branco beach to the south.

It should be emphasized that 70% of the sandy beaches in the world are undergoing processes of erosion (Souza et al., 2005). The dominance of eroding coasts in the world can be grouped into natural and anthropogenic causes.

Coastal erosion in the municipality of João Pessoa can be attributed to natural and anthropogenic processes. Therefore, attributing coastal erosion solely to rising sea levels caused by global warming represents a gross misunderstanding.

An example of coastal erosion driven by natural causes is the retreat of Cabo Branco cliff because the cliff retreat has been proved to date back from the periods before the settlement of João Pessoa. The presence of a large marine abrasion terrace at the cliff face indicates secular or millennial erosion processes. This long-term erosion should have been considered before construction of *Estação Ciência*. Naturally eroding areas are the most complex to revert through engineering constructions.

The most emblematic coastal erosion in the state of Paraíba was caused solely by anthropogenic causes which occurred during the construction of the Hotel Tambaú in the 1970s. The hotel construction provoked the interception of littoral drift flowing south to north because of the southeast trade winds, especially from 160º quadrant. The littoral drift transported beach sediments northwards along the Paraíba coast. The Hotel

Tambaú intercepted this sediment transport to the south of the hotel, which contributed to the progradation of Tambaú Beach.

Sediment deposition in the northern sector of Tambaú Beach created a sediment deficit (Figure 6) in the southern sector of Manaíra Beach, where intense coastal erosion resulted in the collapse of an old pier and allows waves during spring tides to reach the seawall that protects the promenade.

Therefore, the intense urbanization of the waterfront without adequate planning, the occupation of beach ridges, and the soil impermeabilization caused by increased amounts of pavement are the key factors to the direct cause of erosion because they obstruct the sediment supply to the beach and interfere with littoral drift, which is responsible for sediment transport along the coast.

The Hotel Tambaú acts as a sediment trap because it influences littoral drift by abruptly separating a shoreline under progradation from a sector experiencing shoreline retreat by a few hundred meters, thereby eliminating the possibility that shoreline erosion in Manaíra was caused by natural processes. The presence of the hotel will always promote the accumulation of sediment updrift and erosion downdrift causing serious problems of coastal erosion along the southern sector of Manaíra Beach.

Current processes of lesser geographical importance are observed across the municipality, such as the arenization process occurring along plateaus, especially at two sites in the western sector in the vicinity of the rivers Marés and Camaço and in Mumbaba and Mussuré districts. The first one shares borders with the municipality of Santa Rita and the latter with the municipality of Conde. It must be emphasized that many sandification areas were extensively modified or even suppressed by urbanization, and they are impossible to study or mapped.

Arenization in João Pessoa is a natural process of etchplanation, which is common in plateau areas where infiltration dominates over runoff. In this process, the most soluble minerals are leached into the groundwater, leaving the surface profile enriched in the mineral that is most chemically resistant to the solubilization process, which is quartz in this area. Although it is a natural process, it is important to note that widespread sand mining primarily for civil construction, which has occurred in the area, modified the original landform and produced an anthropogenic landform.

In João Pessoa municipality, sandification extends over an area of over 1.46 km^2, although historical accounts suggest much larger areas than what is currently mapped. In many areas, the sand cover was totally extracted, whereas in other areas they are now covered by recent urbanization.

Other recent (Quaternary) morphologies of João Pessoa's landscape include shallow depressions closely related to limestone of the Gramame Formation. These depressions can occur with or without the presence of water, and they are classically referred to as sinkholes and typical of karst landscapes.

Regarding to karst landforms, the most notable but still poorly studied is found at the urban center of João Pessoa, where it forms the lake at Solón de Lucena Park. This landform is a sinkhole of slow subsidence because of the gradual dissolution of the underlying limestone of the Gramame Formation. This sinkhole has a centripetal radial basin extending over a total area of approximately 1.0 km^2 and a perimeter of approximately 4.0 km (**Fig. 7**). Urbanization in this region is relatively old and did not take into consideration the geomorphological aspects of the area. Urban sprawling advanced closer to the area around the park which is served by a radial centripetal drainage network, which converging into the lagoon and frequently causes floods and disruptions to the population and public transportation. In addition to the radial centripetal drainage network, soil impermeabilization caused by intense urbanization greatly enhances runoff. Any engineering work to minimize the effects of flooding at the Solón de Lucena Park cannot ignore the fact that the lake is a sinkhole receiving discharges from the centripetal radial drainage network. This drainage network cannot be observed because of current urbanization, with superficial maximization.

Fig. 6 Hotel Tambaú showing the prograding Tambaú Beach to the south and the eroding Manaíra Beach to the north.

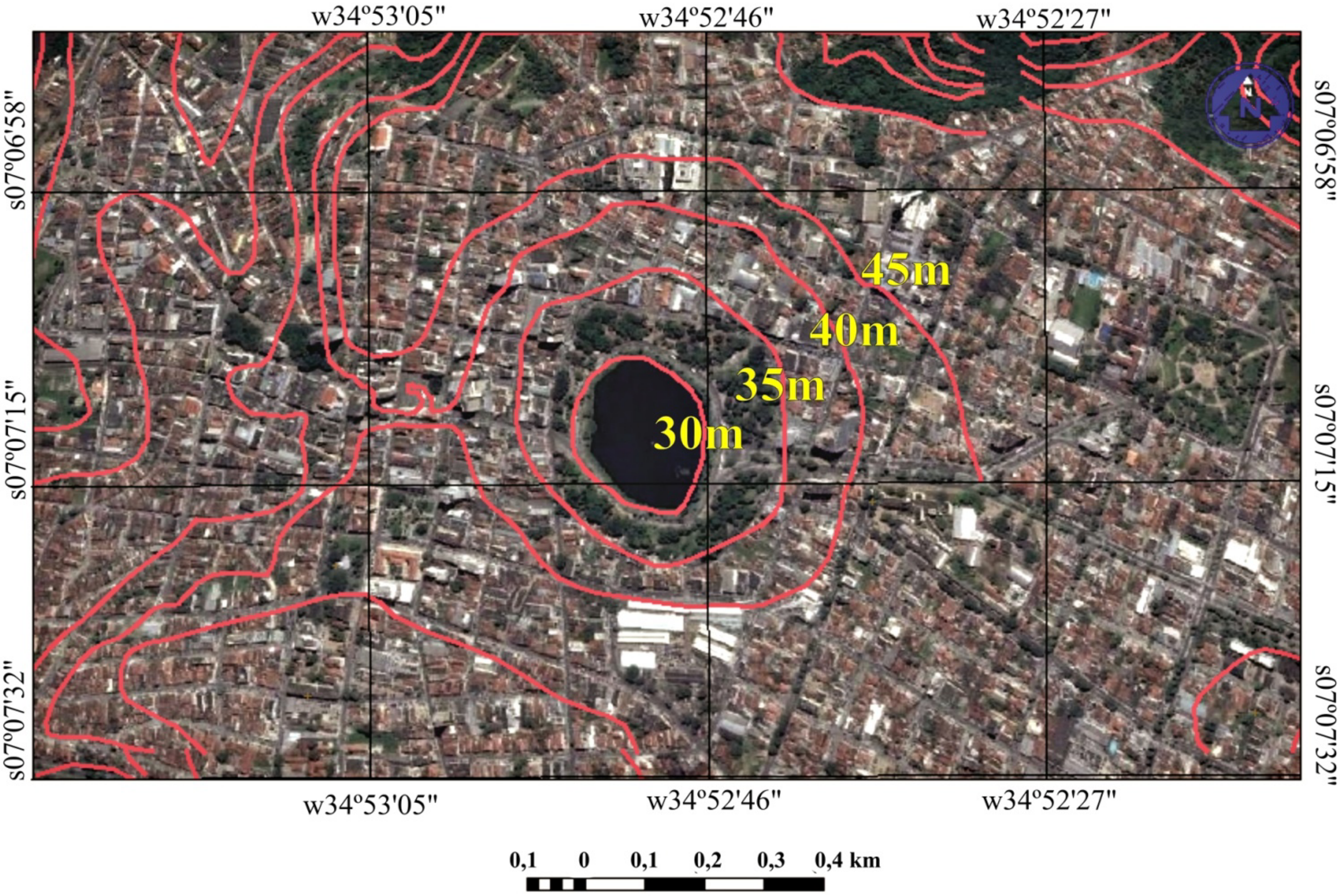

Fig. 7 Centripetal basin of the Solón de Lucena Park, with contour lines shown in red and their respective altitudes also shown. Central area of the João Pessoa Municipality. Modified from Google Maps.

The morphologies created by mining activities fall under anthropogenic landforms, which are studied in the field of anthropogenic geomorphology, which was created in Europe and is still incipient in Brazil. The development of this area of geoscience in Brazil would be of fundamental importance in the preparation of environmental impact assessments (EIAs) and environmental impact reports (EIRs) and an essential tool in the formulation of the Program for the Recovery of Degraded Areas (PRDA). All of these mechanisms have been established in the Brazilian environmental legislation.

In João Pessoa Municipality, limestone mining activities have occurred since the 19th century. Currently, mining is conducted illegally in the quarries of Mandacaru and Roger and legally by CIMPOR company at Ilha do Bispo district. CIMPOR also extracts clay from clayey layers found within the Barreiras Formation for the production of cement.

It is beyond the scope of the present work to provide a detailed explanation of the close relationship between mining activities and the local geology/geomorphology. This study focuses solely on the description and mapping of geomorphological features. As described by Dávid (2010), the excavation of quarries results in a landscape with intense and visible changes. The variability of landforms resulting from mining is classified into three main groups: negative landforms (denudational); positive landforms (aggradational); and leveled landforms. Leveled landforms result from the destruction (levelling) of the two other landform types.

Mining is evaluated in the present study in the sixth taxon of the geomorphological mapping because it is a recent process that generates individual landforms through anthropogenic action. The mines in João Pessoa are landforms artificially characterized by a negative relief (**Fig. 8**).

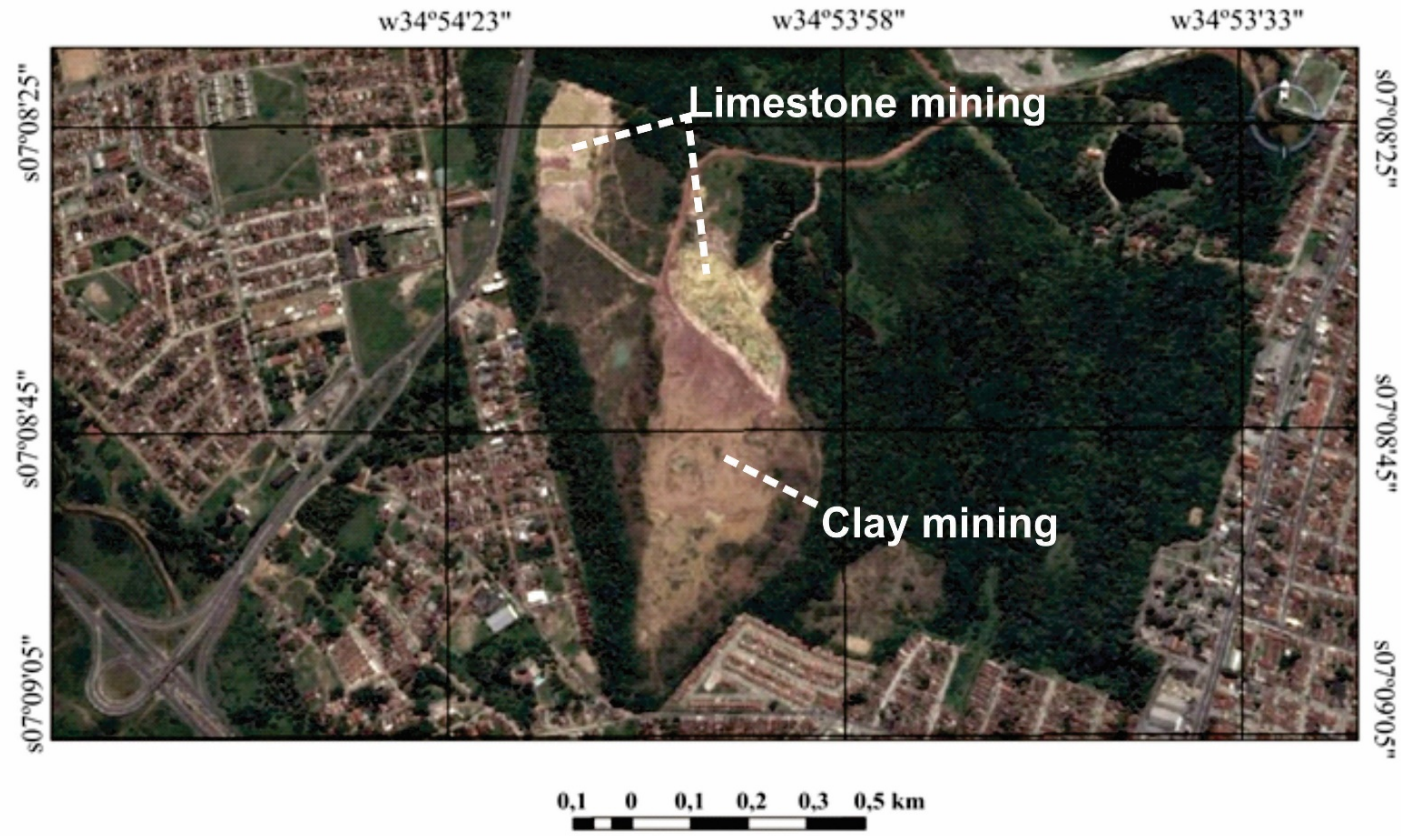

Fig. 8 Aerial photo of the Sampaio clay mine. Modified from Google Maps.

According to the report drafted by PROMINER company for the PRDA by CIMPOR (2010), limestone and clay mining activities are performed in three mines. Limestone is extracted from the mines of Graça and Riacho Poente and clay is extracted from the Sampaio mine. Observations during field work indicated that limestone extraction at Graça occurs at 8 m below the average sea level, resulting in an anthropogenic relief characterized as an absolute depression.

CIMPOR mining operations occur within an area of approximately 0.59 km^2 for limestone (mining of Graça and Riacho Poente) and 0.51 km^2 for clay extraction. The illegal Mandacaru and Roger limestone mines have an area of approximately 0.16 km^2. In all, the municipality includes approximately 1.26 km^2 related to limestone and clay mining. Therefore, potential environmental liabilities occur within an area of 1.26 km^2, and they affect the least disadvantaged population of the city. For comparison, Bica Park (Parque Arruda Camara) has an area of only 0.43 km^2, which is only 1/3 of the area occupied by mining.

CONCLUSIONS

Generally, the geomorphology of João Pessoa can be differentiated into two morphosculptural groups: coastal plateaus and coastal lowlands. The plateaus cover 79% of the municipality's area and consist of gently convex to flat surfaces. The lowlands cover 21% of the municipality's area and consist of colluvium, terraces and plains and contain areas adjacent to rivers, streams, beaches and backlands.

The present study illustrates the importance of geomorphological knowledge for urban management and/or future anthropogenic interventions in the municipality. It is a good instrumental to the study area, and the information presented can serve several purposes, such as detailing geomorphological information, which is poor and scattered in the municipality, or providing support to ecological, geotechnical and environmental studies. A primary requirement is to obtain robust and accurate data, such as the data obtained in the present work, which is unprecedented for the João Pessoa Municipality.

REFERENCES

Brasil. (2010) Instituto Brasileiro de Geografia e Estatística. IBGE. Censo demográfico de 2010. Available in: http://cidades.ibge.gov.br/xtras/temas.php?. Acessed in: september 2013.

Brasil. (1974) Ministério do interior. Superintendência de desenvolvimento do Nordeste. Folhas Nossa Senhora da Penha, Santa Rita, João Pessoa e Mata da Aldeia. Recife: SUDENE. Escala 1:25.000.

Csima, P. (2010) *Urban Development and Anthropogenic Geomorphology*. In: Anthropogenic geomorphology: a guide to man-made landforms. ed. Szabó et al. SPRINGER Science + Business Media B. V., Dordrecht-Heidelberg London–New York.

Dávid, L. (2010) *Quarrying and Other Minerals. In: Anthropogenic geomorphology: a guide to man-made landforms*. ed. Szabó et al. SPRINGER, Dordrecht-Heidelberg London–New York.

Furrier, M. (2007). Caracterização geomorfológica e do meio físico da folha João Pessoa 1:100.000. 213p. PhD Thesis – Faculty of Philosophy, Leters and Human Sciences, São Paulo: USP.

Guerra, A.T. & Guerra, A.J.T. (1997) *Novo dicionário geológico-geomorfológico*. Rio de Janeiro: Bertrand Brasil.

Peloggia, A.U.G. (1998) *O homem e o ambiente geológico: geologia, sociedade e ocupação urbana no município de São Paulo*. São Paulo: Xamã.

Prominer Projetos LTDA. (2010) *Plano de recuperação de áreas degradadas Minas da Graça, Riacho do Poente e Sampaio*. João Pessoa – PB. São Paulo.

Ross, J.L.S. (1992) O registro dos fatos geomórficos e a questão da taxonomia do relevo. *Rev. Depart. Geog.* **6**(1), 17–29.

Souza, C.R.G., Souza Filho, P.W.M., Esteves, L.S., Vital, H., Dillenburg, S.R., Patchineelam, S.M., Addad, J.E. (2005) *Praias arenosas e erosão costeira*. In: Souza, C.R.G, Suguio, K., Oliveira, A.M.S., De Oliveira, P.E. (eds.). Quaternário do Brasil. Ribeirão Preto: Holos Editora. p. 130–152.

Suguio, K. & Martin, L. (1978) Quaternary marine formations of the State of São Paulo and southern Rio de Janeiro. *Proc. International Symposium on Coastal Evolution in The Quaternary*, São Paulo. Special Publication, n. 1.

Szabó, J. (2010) *Anthropogenic Geomorphology: Subject and System*. In: Anthropogenic geomorphology: a guide to man-made landforms. ed. Szabó et al. SPRINGER Science + Business Media B. V., Dordrecht-Heidelberg London–New York.