Study of the Ponta Negra Beach Surface in Manaus / AM: Evidence and Causes of Mass Movement of the Artificial Beach Landfill

Samara Cristina dos Reis Medeiros[1]
Dept. of Geosciences, Federal University of Amazonas.
sammedeirosgeo@gmail.com

Lucindo Antunes Fernandes Filho[2]
Dept. of Geosciences, Federal University of Amazonas
lfernandesfilho@gmail.com

Roberto César de Mendonça Barbosa[3]
Dept. of Geosciences, Federal University of Amazonas
rcbarbosa@ufam.edu.br

Silfran Rogério Marialva Alves[4]
College of Agricultural Sciences, Federal University of Amazonas
silfranrogerio@gmail.com

Mauro Igor de Almeida Girard[5]
Dept. of Geosciences, Federal University of Amazonas
igorgirard11@gmail.com

Phaulla Oliveira[6]
Dept. of Geosciences, Federal University of Amazonas
phaulla.rx@gmail.com

Abstract

Ponta Negra Beach is located on the banks of the Rio Negro, in the city of Manaus, state of Amazonas, Brazil. In 2012, a revitalization of the beach was carried out, with emphasis on the construction of an artificial beach landfill, in order to perpetuate the population's access to the beach throughout the hydrological year. This work resulted in the formation of several irregularities throughout the terrain, such as cavities, plumbing and pipes exposed on the surface, and sudden cavities between shallower and deeper parts of the bed. These problems have resulted in several fatalities since the opening of the landfill. Given these questions, this study aimed to assess the changes that occur on the beach surface, through analysis of sediments, topography and space, as a result of the construction work, for a period of two to three years, and thus, to identify the cause of these problems to understand what failures occurred in the construction of the landfill that led to the formation of these irregularities. The results showed that the *grounded sediments from the artificial beach are being transported more easily by the force of the river and the rains because they are finer sediments than those of the natural beach, intensifying the erosion rates and resulting in the generation of ravines and depressions along the entire beach, being responsible for the movement of sandy mass of the ladfill and in the formation of the irregularities found. This study proves that the anthropic relationships interfered in the natural processes that act on the beach's morphology, warning the importance of serious previous studies in the execution of works with landfills and their continuous maintenance*

Keywords: Rio Negro; artificial beach landfill; movement of sandy mass; erosion.

1. Introduction

Ponta Negra Beach, located on the banks of the Negro River, originally inhabited by the Manaós Indians who gave the city its name, is one of the most important tourist spots in the city of Manaus, providing a charming landscape and numerous leisure options for those who visit it. It was built in the 1990s, modernizing about 3 km from the edge of the Rio Negro with pedestrian buildings, sports courts, restaurants, bars and an amphitheater [6].

According to the regional fluvial regime, the surface of the beach became submerged during the months related to annual floods, making access and services impossible. As a result of this, the beach underwent revitalization in 2012, with the highlight being the implantation of an artificial beach embankment, allowing the population access to the beach throughout the year, including in floods. The natural beach was covered in a stretch of 500 meters from the Tropical Hotel to about 60 meters beyond the beach line, with a thickness of 10 to 12 meters in its most proximal portion [1].

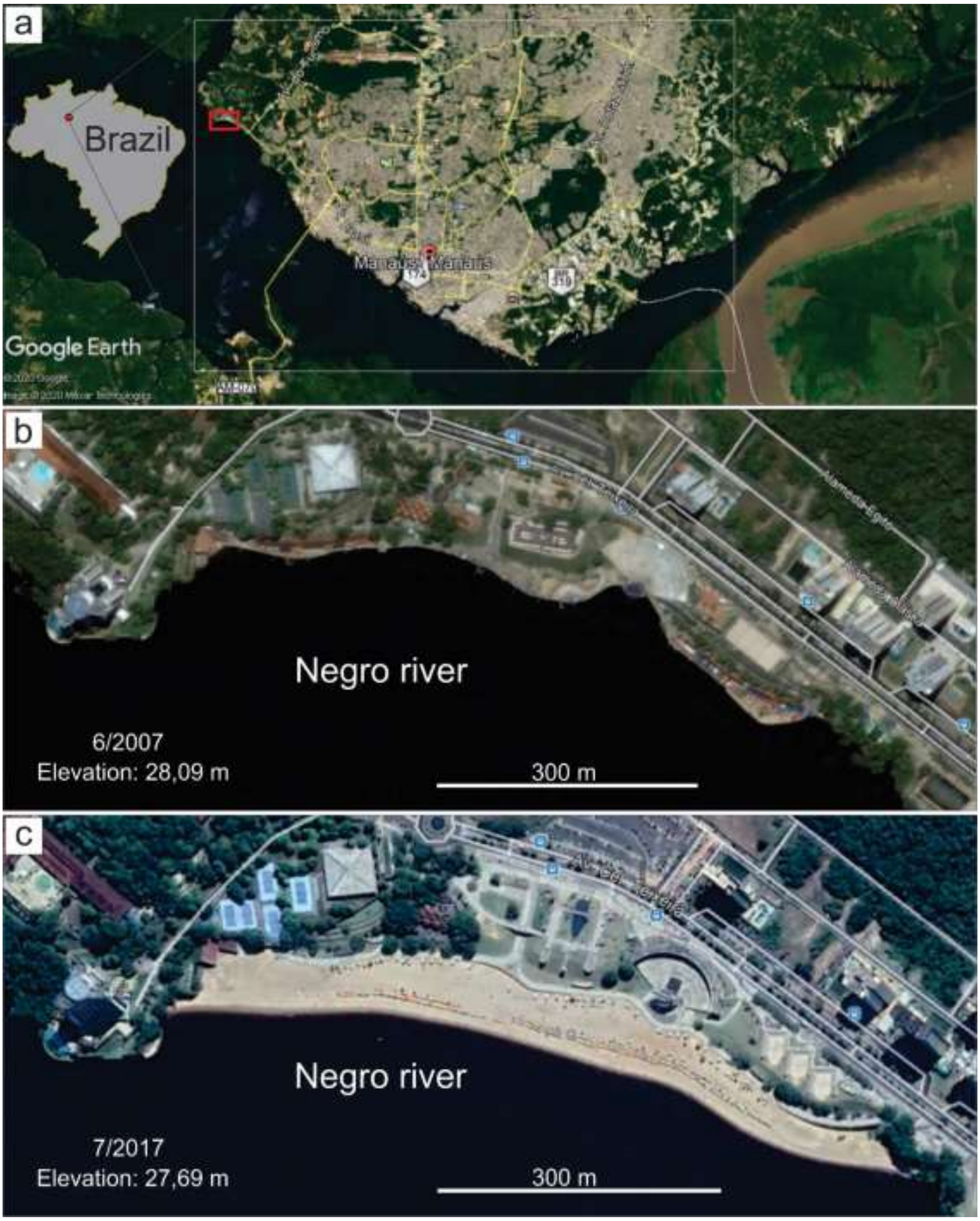

Figure 1: Location map of the area. A) Country of origin of the work area (Brazil) on the left, and city of Manaus on the right. The red square indicates the location of the beach. B) Praia da Ponta Negra before construction in 2007. D) Praia da Ponta Negra after construction, in 2017, emphasizing the artificial beach.

However, after the reforms, the artificial beach bed presented irregularities composed of abrupt unevenness between shallower and deeper parts, as shown in the studies prepared by Serviço Geológico do Brasil (CPRM) [1, 2, 3, 4]. According to the technical reports of Ponta Negra, bathymetric studies carried out from 12 November 2012 to 20 October 2015 found that the distance from the beach edge to the risk areas is variable throughout the hydrological year, presenting little regularity in the terrain with the presence of sand banks surrounded by deep depressions and falls, both in the transversal and longitudinal directions, concluding that the constructive form used on the beach generates an irregular surface, and represents a risk for beach users, being the period most dangerous are those in which the lowest shares are observed [4].

These problems resulted in several related fatal drowning victims, 13 of which were from July to December 2012, just after the construction of the landfill. According to Department Public of Safety [5], there were a total of 55 drowning occurrences from 2012 to 2018.

These accidents may be involved with the landfill work, because when evaluating the submerged area of the beach, it was found that on the natural beach the unevenness of the riverbed happens gradually while on the artificial beach the unevenness occurs abruptly, being a danger for bathers [1].

In this context, topographic, granulometric and space-time characterization of the fluvial banks of Praia da Ponta Negra was carried out in this work, with regard to natural and landfill deposits. The analysis of changes in the surface was intended to assess and understand the behavior of the surface of the Rio Negro margin in response to anthropic interventions in the region, as well as to establish possible modifications of the natural processes in the area and surroundings caused by the landfill work, by a period of two to three years. Understanding the processes responsible for the behavior of the morphology and dynamics of Ponta Negra beach are of fundamental importance for the use of society.

2. Methodology

The methods and procedures performed in this research consisted of some subdivisions, seeking to obtain parameters for studying the region's morphology and dynamics through sedimentary, topographic and space-time analyzes, described below:

2.1 Bibliographic data

The first procedure for carrying out this work consists of acquiring basic information about the area of knowledge and geography, through research and reading of publications, articles, book chapters, dissertations, thematic maps and satellite images.

2.2 Area Monitoring

A systematic observation of the area was carried out during the successive years 2017, 2018 and 2019, through photographic records, which were able to show features on the surface composed of irregularities, their changes and evolution during the course of the project.

2.3 Topographic data

Topographic data were collected during the dry periods, in November, in 2017 and 2018, using the TOPCON Total Station, model GTS-235W. In addition to this device, the TRIMBLE brand geodetic GPS (model R6) was used in order to make it possible to survey the profiles. The collection of these points was carried out through transversal beach sessions, with a distance of approximately 10 m between the points, only in the transition area of the natural and artificial beach (Figure 02).

With the data obtained in the topographic survey profiles and maps were made, using tools from the Google Earth program and the ArcGIS geographic information system.

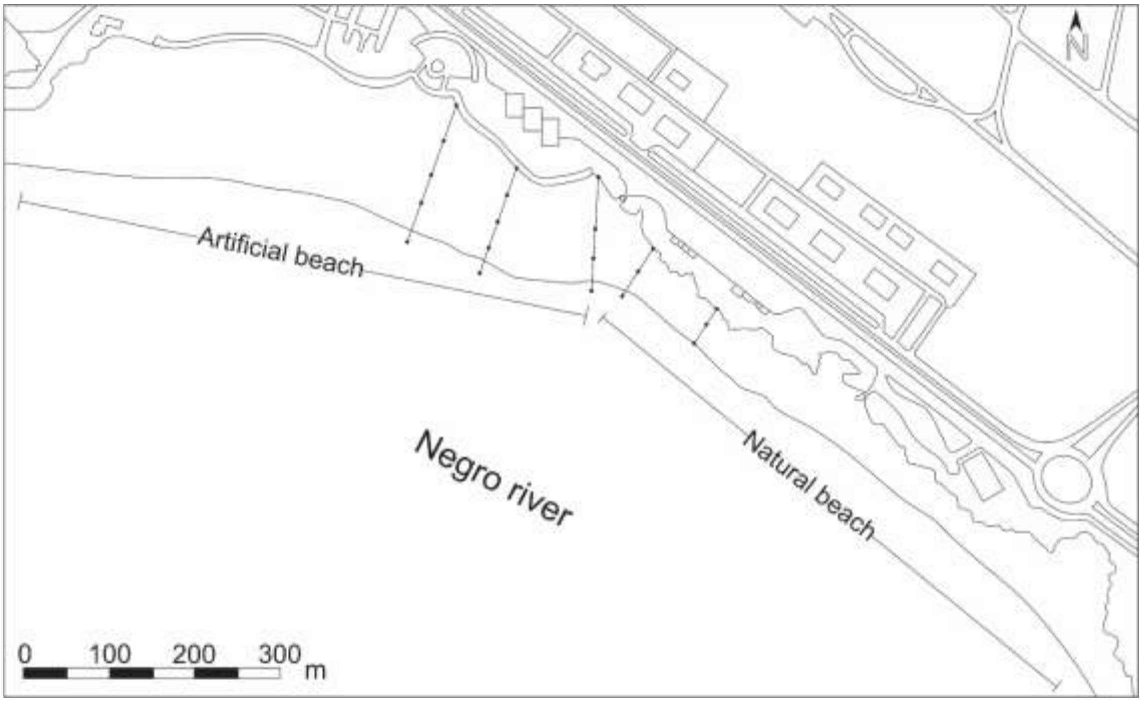

Figure 2: Schematic profile of the area and cross-sections performed in the topographic survey; the black dots were the places where the data were collected.

2.4 Sedimentological data

Sedimentological data were obtained through the collection of 18 sediment samples at scattered and distant points, covering various portions between the transition from the natural beach and the embankment. The collection was carried out during the surveying work, with 9 samples collected during the 2017 survey, and 9 samples collected during the 2018 survey, in locations with elevations similar to the collection points of the previous year.

The sediment samples collected in the field work were properly identified and taken to the laboratory, where they were subjected to granulometric separation by sieving techniques, a methodology proposed by Suguio, 1973 [7]. The collected material was dried in an oven and then sieved on an electric stirrer to be weighed according to each particle size retained in the sieves with the following intervals: bottom, 0.063, 0.125, 0.250, 0.5, 1.0 and 2.0 mm.

With the analyzes made, the weighing results were transformed into percentage values representative of the granulometric distribution, to classify the fractions in very coarse sand, coarse sand, medium sand, fine sand, very fine and fine [7] using the Sysgran 3.0 software. Through these results it was possible to verify the types of sediments prevalent in the different areas of the natural and embankment beaches.

2.5 Space-Time Analysis

Images were collected in the years 2017, 2018 and 2019, from the Google Earth Pro program, using the tool "show historical images", where satellite images were obtained in periods of flood.

After image collection, area calculations were performed using polygons built in the different years. These polygons were processed in ArcGis 10.5 software, where it was possible to acquire the real size of the area through a tool in the attributes table, called "calculate geometry".

2.6 Data Interpretation

With the data obtained, the study was completed with the interpretation and comparisons between the topographic maps of 2017 and 2018, and of the photographic records of the irregularities found, thus evaluating the surface behavior. Analogies were made between the granulometry of the natural beach and landfill sediments, and the difference between the granulometry found comparing the samples collected in the two years in a row. Comparisons were made to the satellite images analyzed over the years, after the construction of the landfill. And, finally, comparisons between the data found in the landfill area calculations, in order to prove the movement of the grounded sediments.

3. Results

3.1 Area Monitoring

Through visits and analyzes made in the field, it was observed that irregularities are present in the area and that their appearances are constant throughout the terrain. The features found on the beach are formed repeatedly over time and were not present before the construction of the embankment, showing that the work carried out is causing changes on this surface.

Both the natural beach and the artificial beach showed erosion in the area, mainly close to the beach line, during the entire research period. These features come in different sizes, ranging from approximately 10 to 50 cm in depth, and from 1 to 6 m in length, and are caused by processes of ravination and internal erosions due to a greater influence of the river on these banks. (Figures 3.4 and 5).

Along the entire artificial beach, the appearance of open pipes occurs, which are covered by employees with the beach sand itself, and are reexposed according to the weather, especially after rains (Figure 6). It is possible to notice the accumulation of water in some parts of the beach (Figure 7a), and also the presence of sandy movement features, where the grounded sediments are observed being transported from the surface and deposited on the riverbed (Figures 7, 8, 9, 10), forming extensive tracks of crawling sandy material with a depth of up to 30 cm, and also features of micro deltas, which have evolved over the years. These irregularities are linked to poor planning for the runoff of surface water, which in certain points occurs more intensely, such as from stairs and pipes that channel the water. This happens due to the lack of a correct infrastructure in the urban area of the beach that would work more adequately for the applicability of the landfill.

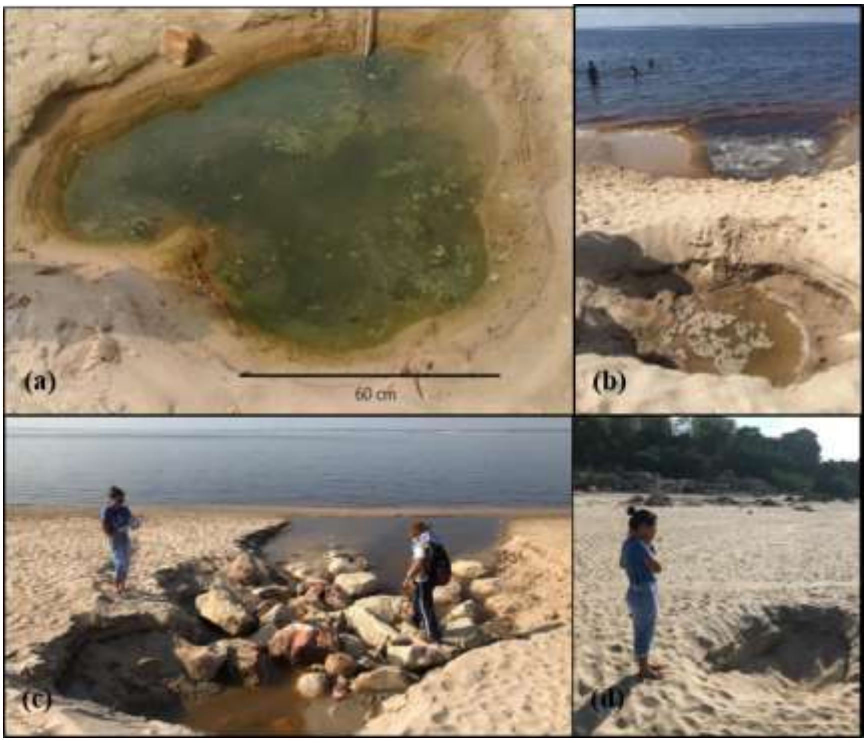

Figure 3: a) Abrupt depression / internal erosion feature in 2017 at the landfill; b) Erosion with the formation of pots on the artificial beach in 2018. c) Erosion on the natural beach, close to the beach line, of almost 6m in length in 2018. d) Cavities about 1 m in diameter in the embankment in 2018.

Figure 4: Features found on the transition surface of the embankment and natural beach, during the drought periods, in 2018 - a and b) Erosions with the appearance of the substrate rocks, approximately 2 meters wide, and 40 cm deep.

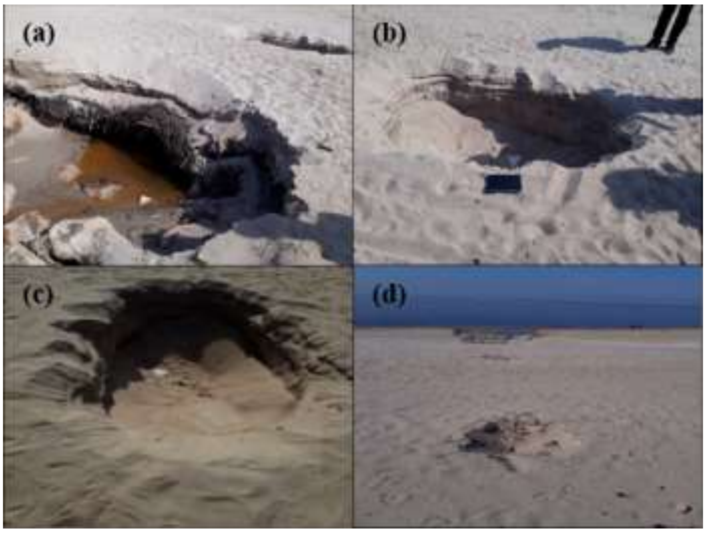

Figure 5: Features found on the landfill surface during low water periods, in 2018. a) Cavity filled with water. b and c) Cavities from internal erosions. d) Cavities being formed in the same direction, the deepest located on the beach line.

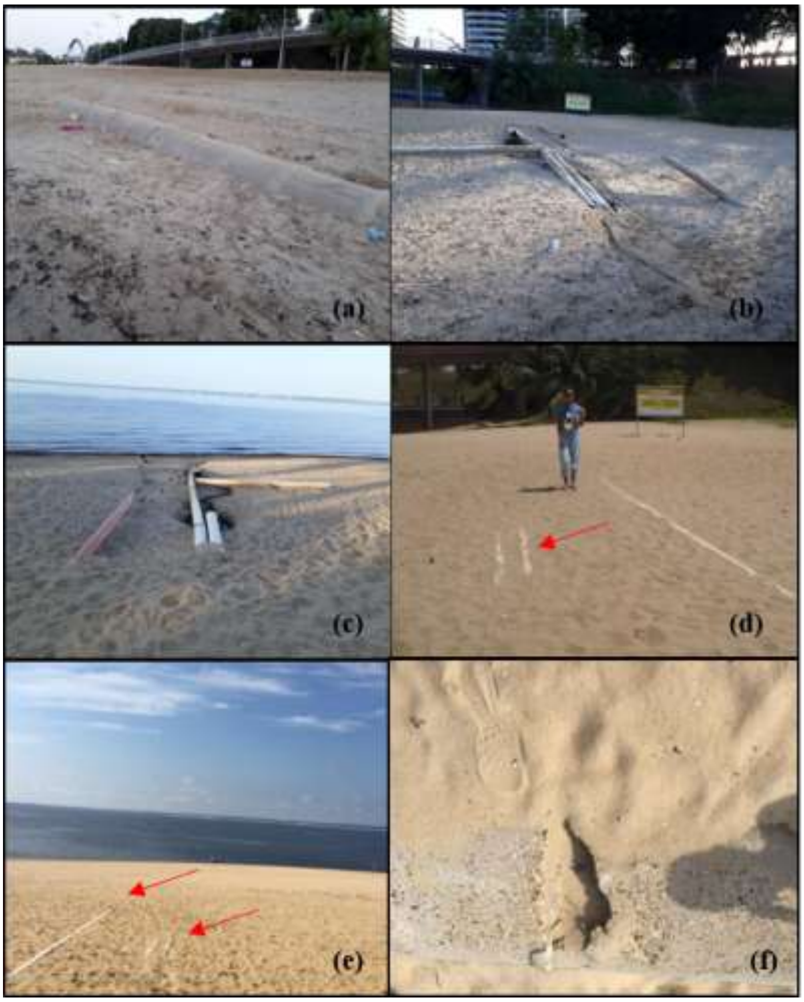

Figure 6: Features found on the landfill surface during low water periods, in 2017- a) Piping almost totally exposed for a 10-meter extension; b) Exposure of pipes above the landfill surface. Features found on the surface of the landfill during ebb periods, in 2018 - c) Resurfacing of uncovered pipes; d) Exposed pipes; e) Pipes exposed at various points in this area. f) Water pipe broken and not functionin

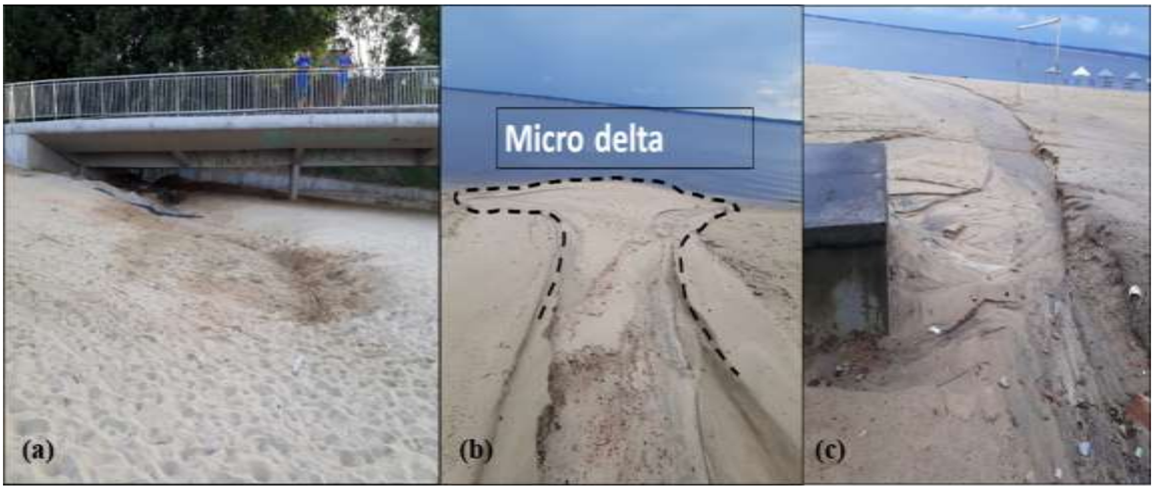

Figure 7: a) Channeling in the most proximal portion of the landfill in 2017. b) and c) Features of sandy movement due to the action of rains in 2018, at the landfill. Photo b) shows a feature formed called micro delta, indicating the movement of sediments and their deposition on the riverbed, a feature that evolved from the feature in photo a) in 2017.

Figure 8: Features found on the landfill surface during low water periods, in 2018 - Features of sandy movement due to rain. Photos a and c) show the sediments towards the river, and photos b and d) show the sediments coming from the beach.

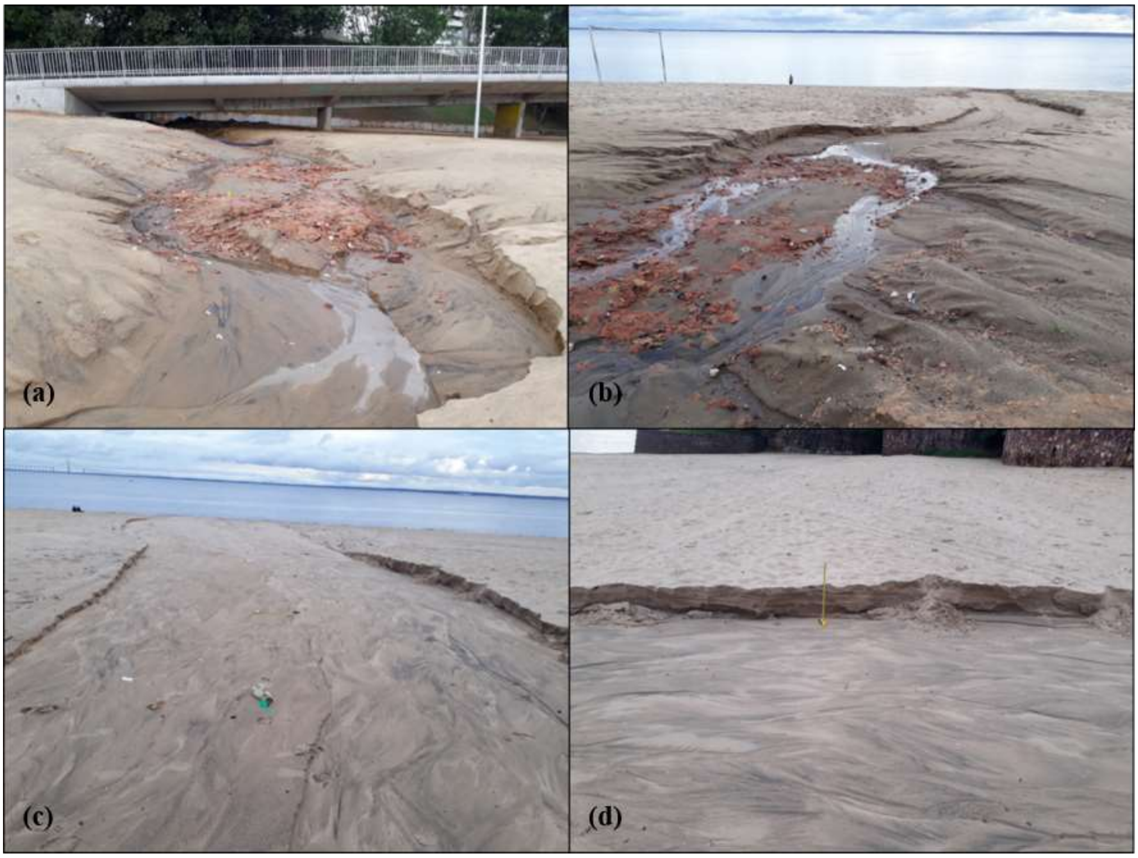

Figure 9: Features found on the landfill surface during low water periods, in 2019 - Features of sandy movement due to rain. Photo a) shows the sediments from the beach, and in photos b and c) show the sediments towards the river. Photo d) illustrates the depth of approximately 30 cm of the path caused by the transport of particles.

Figure 10: Places where the movements of sandy masses in figures 7, 8 and 9 occur, and water accumulation in figure 7a, caused by the presence of pipes and stairs that channel rainwater more intensely.

Figure 11: Features found on the landfill surface during low water periods, in 2019 - a) and b) Beach surface presenting, in general, the sandy mass movement features.

3.2 Topographic Data

With the analysis of the maps generated by topographic survey, highlighted in the transition from the artificial and natural beach, it was possible to study and interpret the dynamics of the beach surface.

In the dry season in 2017, the map generated showed significant differences in the topographic levels of the area (Figure 12), where the artificial beach (west edge of the map) presented the highest levels, with a maximum of 30 meters, and the natural beach (eastern edge of the map), the lowest dimensions with a maximum of 22 meters, presenting an expressive narrowing. The contour lines of the map have a non-linear shape, with numerous ascents and descents on the surface, showing that it is a non-flat terrain, which may have been caused by the movement of sandy masses from the landfill.

It is observed in the upper part, numerous sinuosities that indicate channeling in the land towards the river, being one of the causes for the irregularities in the topography.

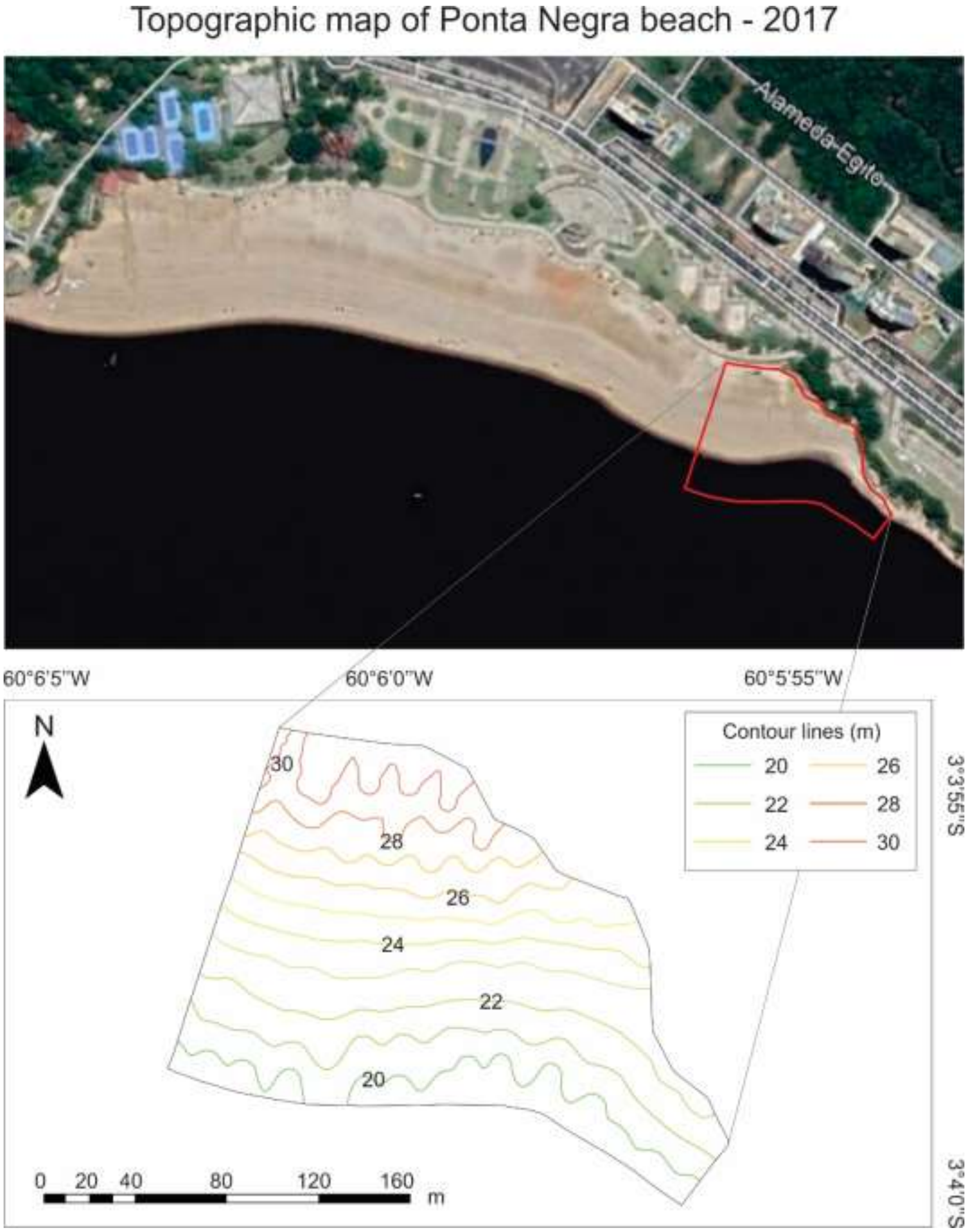

Figure 12: The image shows the place where the topographic survey was carried out, in the transition from the artificial and natural beach; and the topographic map of the area with minimum elevation, represented by the first green color, in the value of 20 m, and the maximum elevation, in red, with the value of 30 m.

From the topographic map generated in the 2018 drought (Figure 13), it can be noted that the relief of the beach has decreasing elevation levels towards the river with a variation of eleven meters. The terrain continues to show significant differences in the topographical levels of the area, which in addition to demonstrating a non-flat terrain, has lowerings and elevations along the terrain, with a maximum height of 30 meters on the artificial beach, and now 21 meters on the natural beach.

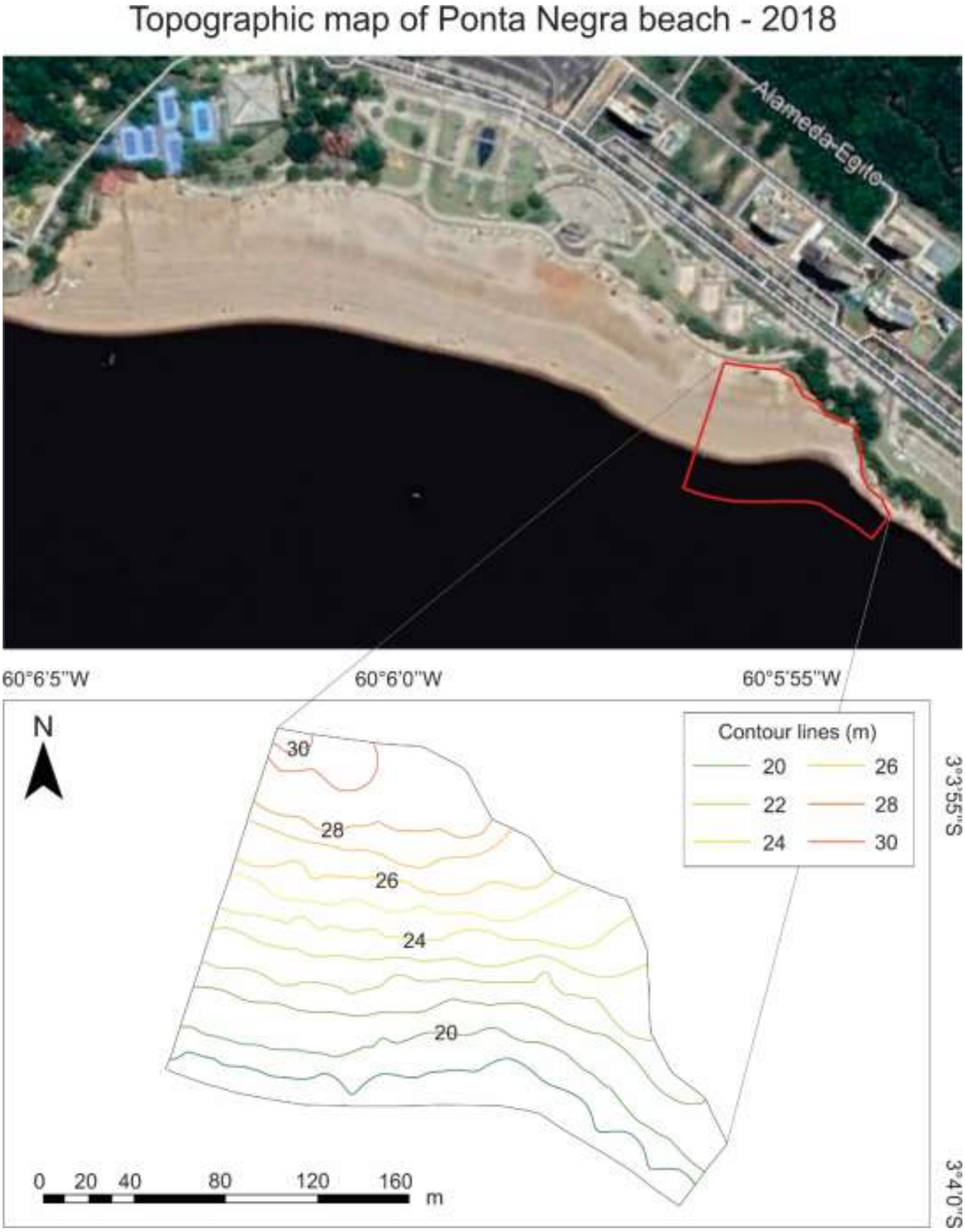

Figure 13: The image shows the place where the topographic survey was carried out, in the transition from the artificial and natural beach; and the topographic map of the area with minimum elevation, represented by the first green color, in the value of 19m, and the maximum elevation, in red, with the value of 30m.

It is important to note that looking at the two maps, it can be concluded that the surface has changed significantly during the two years of research. The shapes of the contour lines showed great variations from one year to the next and some quotas changed, as in the natural beach. In 2017 it is possible to find more apparent sinuosities at the top of the beach, which indicated a greater concentration of channeling on the surface towards the river, in 2018, these sinuosities are no longer present. This shows that the sediments on the surface of the beach terrain are constantly moving and that they generate a major change in the morphology of the beach in a short period of time.

3.3 Sedimentological data

During the topographic survey in 2017, sediment samples were collected at 9 points and taken for analysis in the laboratory (Figure 14). As a result of the analyzes, characteristics of moderately selected sediments, from rounded to angular, were revealed, with the predominant granulometry of medium sand (0.250 to 0.50 mm), being also possible to verify great variations in the presence of silt and clay size sediments.

Samples with a higher content of silt and clay granulometry sediments from the artificial beach occur with greater predominance close to the top line of the land, indicating that the greater quantity of fine sediments placed on the beach may have already been remobilized by the action of the river and rains (Figure 15). It is possible to notice that the granulometry of the sediments varies according to the sampled area, proving that the terrain is composed of heterogeneous material (Figure 15).

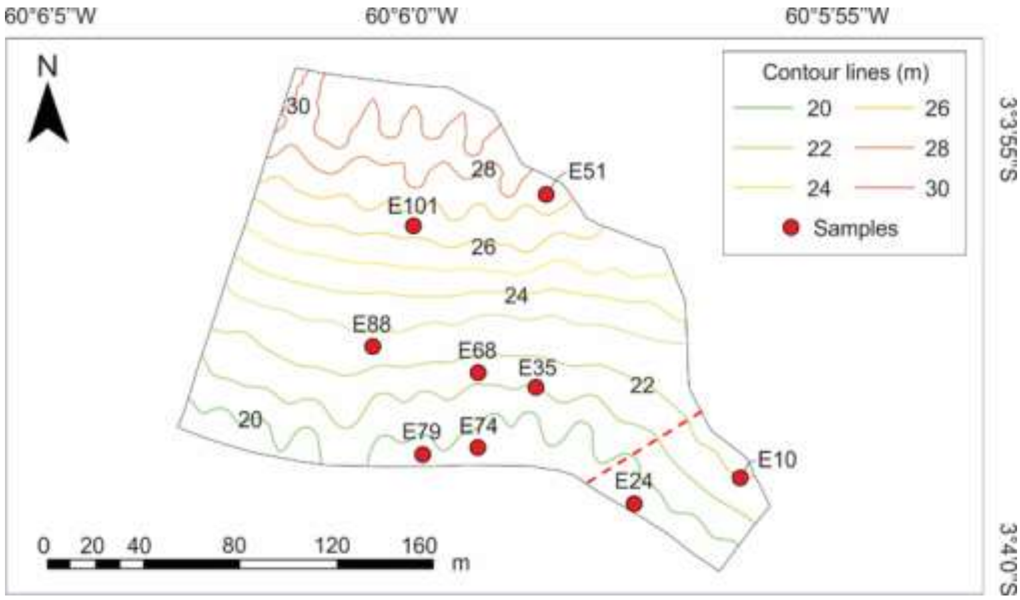

Figure 14: Map of the location of samples collected in 2017, indicated by red dots. The red dashed line shows the transition between the artificial beach (to the west) and the natural beach (to the east).

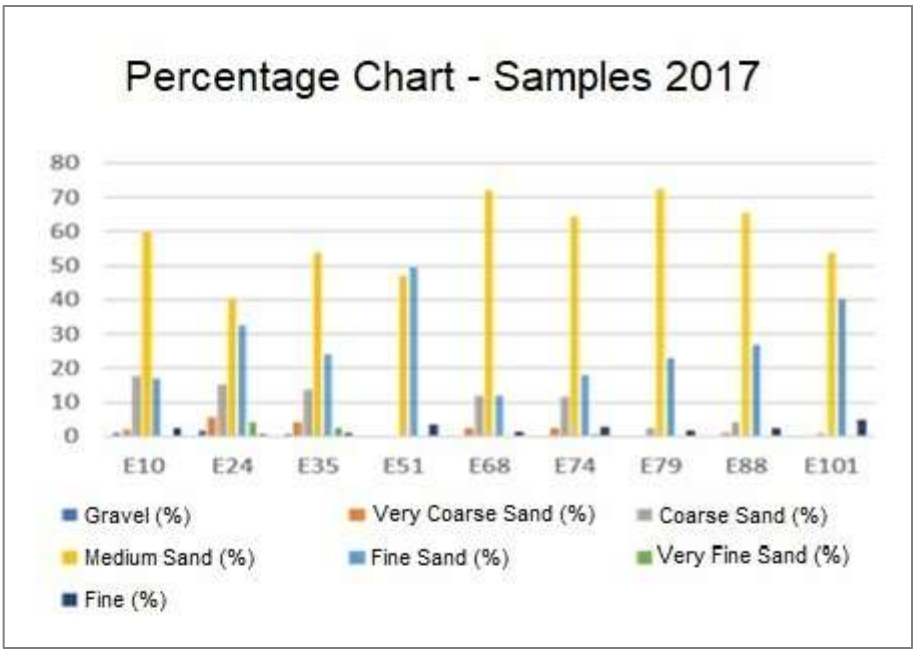

Figure 15: Percentage graph of the granulometry of the samples. The granulometry of the sediments varies widely, and the predominant type is medium sand.

In 2018, sedimentological analyzes of samples collected during this year's topographic survey (Figure 16), revealed that sediments are moderately selected, from rounded to angular, also having predominant grain size of medium sand grains (0.250 to 0.50 mm) in all samples (Figure 17). The sediments still show a great variation according to the collected area, however the fine sediments presented a significant reduction.

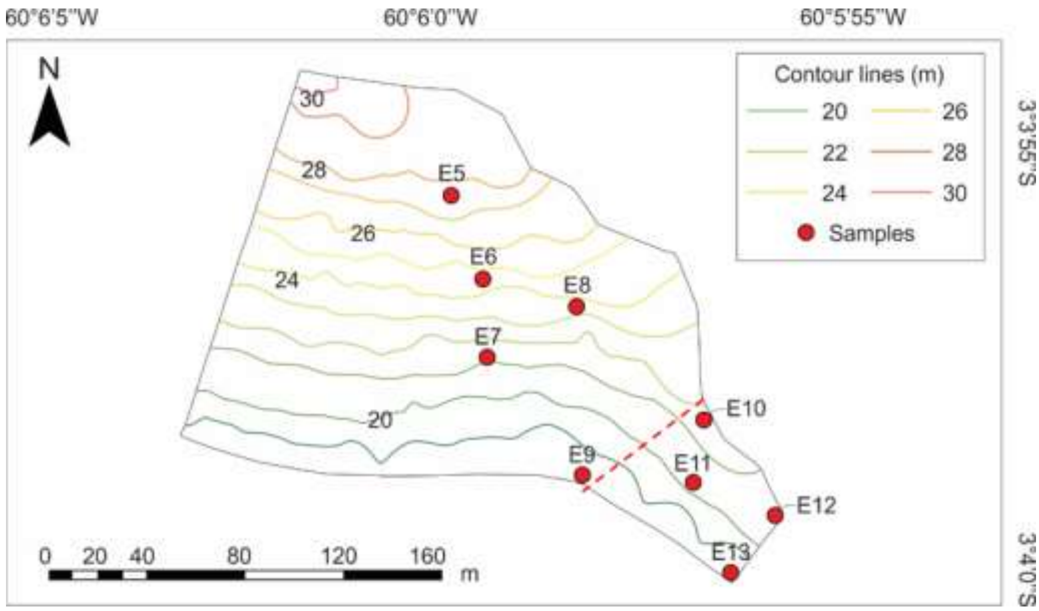

Figure 16: Location map of samples collected in 2018, indicated by red dots. The red dashed line shows the transition between the artificial beach (to the west) and the natural beach (to the east).

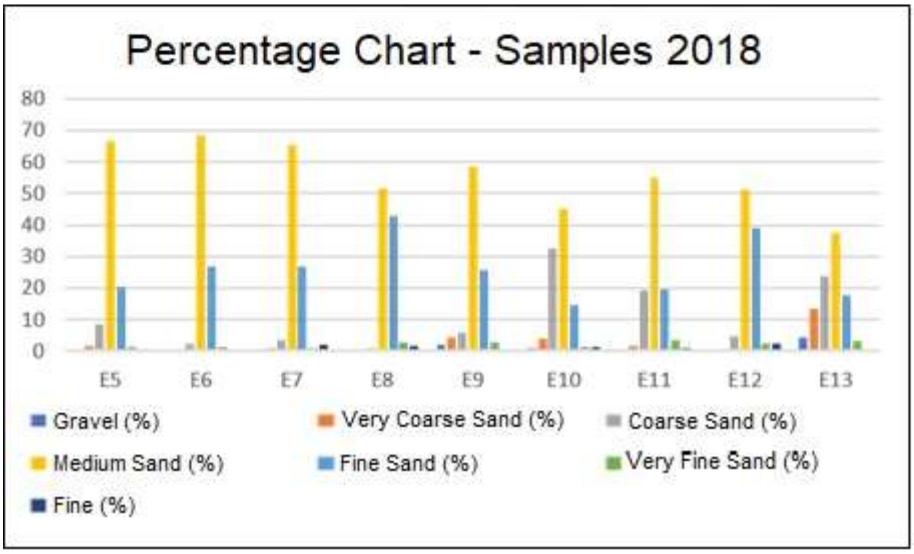

Figure 17: Percentage graph of the granulometry of the samples. The granulometry of the sediments varies widely, and the predominant type is medium sand. There is a reduction in fine sediment (black color) when compared to the 2017 graph (Figure 15).

Comparing the sediments of the two beaches, different granulometries were found. In the natural beach there is a greater presence of sediments of coarser granulometry (samples E24 and E10 in 2017 and; samples E10, E11, E12 and E13, in 2018) showing that the landfill work is made up of finer material than the sediments of the existing beach (Tables 1 and 2).

Table 1: Values as a percentage of each type of granulometry on the natural beach and landfill in 2017, it is observed that there is a greater presence of coarse sediments on the natural beach.

Beach 2017	Gravel (%)	Very Coarse Sand (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	Very Fine Sand (%)	Fine (%)
Artificial	0,21	1,49	6,45	61,2	27,61	0,51	2,46
Natural	1,23	3,845	16,425	50	24,75	2,2	1,5

Table 2: Values as a percentage of each type of granulometry on the natural beach and landfill in 2018, it is observed that there is a greater presence of coarse sediments on the natural beach. It is important to note that the amount of fine sediment from the artificial beach has been reduced.

Beach 2018	Gravel (%)	Very Coarse Sand (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	Very Fine Sand (%)	Fine (%)
Artificial	0,81	1,54	4,25	62,08	28,5	1,84	1,11
Natural	1,84	4,8	20,07	47,26	22,75	2,55	1,2

Comparing the sediments of the samples from 2017 and 2018, it is possible to see that the amount of fine sediments reduced in almost all samples (Tables 3 and 4). Comparing the top of the beach, in 2017, the samples (E51, E101) were composed of 4% of fine sediments, in 2018 (samples E5 and E6), this value decreased to 0.6%; on the beach line, in 2017, fine sediments (E79, E74) consisted of 2.28% of the samples, in 2018 (E9, E13) this value dropped to 0.5%, showing that the landfill sediments are being remobilized (Tables 5, 6, 7 and 8).

Table 3: Values of very fine and fine sand sediments in 2017.

Samples	Very Fine Sand (%)	Fine (%)
E10	0,3	2,31
E24	4,13	0,8
E35	2,52	0,91
E51	0,11	3,36
E68	0,01	1,42
E74	0,49	2,85
E79	0,36	1,71
E88	0,1	2,28
E101	0,03	4,74

Table 4: Values of very fine and fine sand sediments in 2018.

Samples	Very Fine Sand (%)	Fine (%)
E5	1,36	0,66
E6	1,17	0,56
E7	1,02	1,97
E8	2,77	1,83
E9	2,92	0,57
E10	1,31	1,28
E11	3,44	0,74
E12	2,35	2,34
E13	3,13	0,44

Table 5: Percentage of fines at the top of the beach in 2017.

Samples	Value
E51	3,36%
E101	4,74%

Average: 4.05% of fines in top samples in 2017.

Table 6: Percentage of fines at the top of the beach in 2018.

Samples	Value
E5	0,66%
E6	0,56%

Average: 0.61% of fines in top samples in 2018.

Table 7: Percentage of beach line fines in 2017.

Samples	Value
E79	1,71%
E74	2,85%

Average: 2.28% of fines in samples of the beach line in 2017.

Table 8: Percentage of beach line fines in 2018.

Samples	Value
E9	0,57%
E13	0,44%

Average: 0.49% of fines in samples of the Beach Line in 2018.

3.4 Space-Time Analysis

The following images (Figure 18) were used to perform area calculations in times of floods, in order to state that the landfill is being remobilized, and consequently, decreasing over the years.

Figure 18: A) Flood on 7/29/2017, elevation: 27.69 m; B) Flood on 07/20/2018, elevation: 28.15 m; C) Flood on 7/31/2019, elevation: 28.34 m. The polygons in each image were used for area calculations. Source: Images taken in the Google Earth Pro program and elevations data taken from the Porto de Manaus website.

Area calculation:

Since the analyzes were carried out on dates close to each year and the elevations values are very similar, the calculation created (Table 9) reveals a significant reduction in the size of the areas over the years, inferring that this reduction was due to action to remobilize the grounded material.

Table 9: Comparative data showing the size of the area in each year and the elevations obtained on the respective dates. The colors are in accordance with the polygons of the calculated area represented in each image in figure 19. Source: Elevation data taken from the Porto de Manaus website.

DATE	ELEVATION (m)	AREA (m^2)
29/07/2017	**27,69 m**	**45.526,320206 m^2**
20/07/2018	**28,15 m**	**41.014,850545 m^2**
31/07/2019	**28,34 m**	**39.103,040328 m^2**

4. DISCUSSION AND CONCLUSION

From the results found, it was observed that the beach presents several irregularities arising from the construction of the landfill, proving that its elaboration was done in an improper way, and with the consequence of several fatal victims.

According to Serviço Geológico do Brasil (CPRM) [2,3], due to the fluvial dynamics of the Rio Negro, the environment is strongly influenced by the river and generates strong fluvial erosion. From this, it was already expected to occur changes in the work, such as accommodation of the land and transportation of grounded material, due to the river seeking its natural conditions.

However, these changes have been intensified. In view of the sedimentological analyzes of the work, it was found that the sediments used in the artificial beach landfill are finer than those of the natural beach. This difference makes the river erosion caused by the river to happen much easier and more intensely, and consequently, this contributes to the formation of tunneling processes, causing the depressions found on the surface, and for the removal of material by the river, explaining the irregular subsurface and the abrupt unevenness between the shallower and deeper parts near the banks of the Rio Negro.

Due to the finer material used in the landfill, it is also easier to remove these sediments by draining surface water from the rains, being responsible for the large presence of pipes exposed on the beach and the transport of sediments from the landfill and its deposition in the river. In addition, the construction and transport of water on the surface also affects the adjacent natural beach, where you can see the presence of large cavities close to the beach line (Figure 3c).

Through topographical studies it is possible to observe that this removal of the sandy material from the work generates significant differences in the morphology of the beach and in a short time. In view of the analyzes, it was found that the top part of the topographic map in 2017 (Figure 12), which presented sinuosities, was composed of a large percentage of fine materials (Figure 15, samples E51 and E101), and indicated plumbing in the area. This indicates that a large part of the fine sediments at the landfill had already been remobilized and that the upper part was still in the process of being transported. In 2018, there was a drastic reduction in the amount of fine sediment in the samples, and the sinuosities of the map were no longer observed, indicating that the sediments from the upper embankment were remobilized.

Spatio-temporal studies, through the analysis of images of the area, helped to prove this removal of sandy material. Area calculations have revealed that the size of the artificial beach is decreasing significantly over the years. In addition to the calculations, these studies have shown that the differences in landfill and natural beach sediments are not only in the granulometry, but also in the color, indicating different compositions, which may influence a greater destabilization on the ground or not. During the temporal analysis, it was possible to identify that the construction of the landfill permanently affected the surface morphology, mainly in the shape of the beach line.

According to the passage of time, the environment seeks its equilibrium conditions, so greater accommodation of the landfill is expected. However, without the containment of the artificial beach, monitoring and revitalization, the beach will continue to present irregularities on the surface, which may cause, in addition to the accidents that have already occurred, greater problems for the environment, such as silting up the riverbed, due to the intense transport of grounded sediments. Continuous monitoring in the area is necessary to avoid the evolution of these problems and more fatal accidents. In addition to these reforms, it is necessary to revitalize the urban area of Praia da Ponta Negra, which can channel rainwater directly into the river, preventing runoff from passing directly through the landfill sediments, thus preventing further transport sediment landed to the river.

The results obtained with the methodology of this work were satisfactory and could prove that the construction of the artificial landfill originated several changes and problems in the Ponta Negra beach. The realization of this project is of vital importance for society, as it serves as an alert for the construction of works in beach environments, which needs sufficient specific studies and elaboration made by specialized professionals.

5. Referências

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