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THE INVESTIGATION OF THE FLUVIAL EROSION OF THE RIO GUAMÁ, BELÉM (PA), AIMING AT THE DETECTION OF DEGRADED AREAS IN CRITICAL STAGE, USING THE SPONTANEOUS POTENTIAL METHOD

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ABSTRACT

This work presents a geophysical study of part of the riverbank subject to erosion, with the primary objective of evaluating its use in the detection of areas degraded by erosion in a critical stage, before its collapse. This area is located along 600 m along the Guamá River, between the Tucunduba River Bridge and the Canoeing Port, within the campus of the Federal University of Pará (UFPA), in the city of Belém in the State of Pará (Brazil). It has, in some sections, different types of erosion containment, including concrete wall and cement bags. The geophysical method was used: Spontaneous Potential (SP). The measurements were taken during low tide and high tide in an attempt to map the preferential subsurface paths for the entry of water brought in by high tide and, through this means, for work. erosive. The results demonstrate that Geophysics can be an auxiliary tool in the prediction of places where the erosive fall of the terrain caused by it is about to occur.

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INTRODUCTION

Inaugurated on August 13, 1968, the pioneering campus of the Federal University of Pará (UFPA) was inserted within the philosophy adopted in Brazilian universities, in the 1960s, of defining a university territory capable of centralizing administration, research activities , teaching and extension. In the case of UFPA, these activities were, until then, carried out in isolated units, installed in buildings located in different points of Belém, Pinto (2007).

The method of Spontaneous Potential (SP from English Self Potential) is based on the measurement of a potential difference between two electrodes introduced into the field in the absence of any artificially created electric field. One of the sources of this potential is the movement of water in the subsurface, which can help in detecting the direction and direction of the free aquifer's water flow. Carvalho Jr. (1997) and Carvalho Jr. & Silva (1996) show a map of SP revealing the direction and direction of the water in the free aquifer at the Bengui Cemetery in Belém (PA).

Characterization of the research area: The area under study is located inside the UFPA Guamá Campus, which occupies 450 ha between Av. Augusto Correa and Av. Perimetral in the Guamá neighborhood of the city of Belém (PA), on the banks of the Guamá River, between Tucunduba river bridge and Canoeing Headquarters, about 3 km from the center of Belém. The city of Belém is covered by the Post-Barreiras unit, which comprises recent sediments represented by fine to medium-sized, brown, unconsolidated sands, with a predominance of quartz grains. The sands are interspersed with dark clays, distributed on the edges of rivers and streams; by continental sediments of the Barreiras Group, composed of ferruginous sandstones, fine to medium, silty and clayey sands and sediments belonging to the Pirabas, Sauma Filho (1996) and Matta (2002) Formation. The Pirabas Formation consists of diversified limestones interspersed with calcareous sandstones, black clays and rhythmic shales. It presents a varied macro and microfossiliferous content of animal and pyritized vegetables, Rosseti et al. (2001). On February 4, 2010, a drill hole was drilled at the 75 NE station of the AB profile (Figure 1), about 1.8 m deep, to describe the geological section. The hydrostatic level was observed at about 0.8 m deep at low tide. Figure 2 shows the obtained geological section.

The borehole samples were dried in an oven and submitted to granulometric analysis through the sieving process, following the method for granulometric analysis described in NBR-7181 / ABNT. The results are presented in Figure 3 to 7, in which the equivalent diameters of the particles were thrown in the abscissa and the percentages retained, in the ordinates. The graphics show that the pebble content is higher at the third level and practically disappears at the 5th level. The percentage of sand and silt are higher at the fourth level. Finally, the clay percentage is relatively constant at the first four levels, growing to almost 90% at the last level. Intense erosive processes observed in the research area, directly related to the river currents, cause a sharp collapse of the margin (SILVEIRA, 1992). The susceptibility of the soil to resist erosive processes, erodibility, was related to the size of the particles by Bovoucos in 1935, as follows:

$$, \qquad (2.1)$$

where k is erodibility and Sand, Silt and Clay correspond to the percentages of sand, silt and clay, respectively (BERTONI & LOMBARDI NETO, 1985 in MACÊDO, 2007). The Bovoucos ratio is a measure of the content of particle binding material, responsible for the resistance to erosion. Consequently, erodibility increases when the levels of sand and silt are high and decreases with the increase of clay contents. The result of the granulometric analysis shown in Figures 3 to 7 was used to calculate the "k" coefficient (erodibility factor), gathered in Table 1. By comparing the erodibility "k" factor, we realize that it has the highest value at level 4, where erosion probably occurs. The effect of the tide, although it occurs more markedly in the basal layer of clay, subject to the direct action of the water of the river that enters (high seas) and that leaves (low seas) every day, is visibly more accentuated in the contact of this layer with the top layer, due to its greater erodibility in relation to the other layers, as shown in Table 1. Below follows figure 8, showing erosion on the edge of the Guamá River.

Spontaneous Potential Electric Method: The Spontaneous Potential Method involves measuring the electrical potential associated with natural electrical currents that flow through the subsurface. SP was already known in the 19th century, but it only became commercial in 1913, when Schlumberger discovered a deposit of sulfides with the method, Orellana (1974). The SP phenomenon is not only caused by metallic bodies but also by sulphide bodies. The movement of fluids in the subsurface also causes the phenomenon, as well as the bioelectric activity of organic materials, corrosion and thermal gradients, among others. In this work, the interest is in the movement of fluids resulting from the rains and, especially, the tidal change in preferential zones of the subsurface, which would therefore be preferential zones of erosion.

Flow Potential: The potential generated by the movement of fluids in the subsurface is known as Flow Potential or Electrofiltration. The movement of the electrolyte through a porous membrane produces a potential difference between the two sides of the membrane. Considering the porosity of the substrate as a network of capillaries through which surface water percolates, then the behavior of the substrate can be seen as a membrane. Anions are adsorbed on the walls of capillaries and will attract cations, establishing a double electrical layer. In this way the cations are moved through the capillaries by the flows present there while the anions remain fixed. From there, a potential difference ΔV arises between the start point and the end of the course, which obeys the Helmholtz equation:

$$\Delta V = \frac{\xi \varepsilon P}{\eta \sigma} \qquad (1)$$

where is the difference in potential of the double layer, is the dielectric constant of the solution, P is the difference in hydrostatic pressure between the ends of the capillary, is the viscosity of the solution and is its conductivity, Orellana (1974). The most important flow potential is the per descensum, Schlumberger (1975) apud Orellana (1974), caused by the infiltration of rainwater in permeable terrains or along faults and fractures. Cations are removed by water and, at graphically higher top locations, electrically negative nuclei appear (Figure 9). The investigation in this work is focused on the flow potential per descensum, plus the flow potential caused by the movement of the tides.

POTENTIALS METHOD

The potential method requires that one of the electrodes be kept fixed at a base station at infinity, typically at least six times the distance between two electrodes, while the other traverses the measurement points in the survey profiles (Figure 10). The survey is carried out by connecting one of the poles of the measurement instrument to the fixed base, while the other pole of the instrument is connected to the moving electrode that is displaced. The positions N, N´ and N´´ refer to the successive positions of the traveling electrode. The displacement of the mobile electrode is carried out by means of a cable, contained in a coil, which is unwound as the lifting progresses.

ACQUISITION OF DATA

The survey of Spontaneous Potential data was carried out along the AB profile with 600 m (Figure 1), in stations spaced 2 m apart, totaling 212 stations. Data were acquired on 6 and 7 June 2010, low tide period, and on 10 and 11 June 2010, high tide period.

The measurement stations were prepared in such a way as to have small holes on the order of 5 cm deep, free of grass and surface roots, made with dredge from the beginning of the Tucunduba bridge up to 30 m before the Canoagem Port (Figure 11). Some holes were not drilled, as erosion had already reached the site, thus preventing the installation of measurement stations. Non-polarizable copper electrodes were used in a saturated copper sulfate solution (Cu-Cu2SO4) and a high input impedance voltmeter (in the order of 1014 ohms), Figure 11. The measurements were performed using the potential method with the electrode of the fixed base placed 6 m from the beginning of the first station, close to the side lane, while the second electrode traversed the stations in the SW to NE direction, performing the measurements until station 478 HUH. Another fixed base was placed 6 m from the last station, while the second electrode traversed the stations in the NE to SW direction, taking measurements from station 600 NE to station 470 NE. The difference between the reference bases was 19 mV, a value used to correct the measurements obtained with the different bases. The land survey was recorded in a field book with the day and time and the identification of the tide.

INTERPRETATION

The data were submitted to the following operations:

- Correction between measures acquired with different bases;
- Multiplication of data by -1 so that high data corresponds to positions from which the water went to the 'shallows' (inverse to that observed in (Figure 9), which simplifies the interpretation - the data thus treated will be called mirrored voltage;
- Adjustment of degree 6 polynomial to the measurements, in order to minimize the noise of low and intermediate spatial frequencies existing in the data;
- Calculation of the residual between the polynomial adjusted for data obtained at low tide and the polynomial adjusted for data measured at high tide.

Figure 12 presents the raw data and the adjusted polynomial for both low and high tide. In all the graphs there is a considerable amount of noise (sudden oscillations of the punctual or almost punctual data) that may have been caused by the data collection operation itself, roots, trees, bamboo, power poles, etc. The graphs show that the SP measurements vary with the tide, being much richer in oscillations at high tide, probably because it increases the water supply available for the phenomenon of electrofiltration. It is the measures of the high tide profile that draw the most attention, especially those that, despite oscillations, form a high mirrored voltage that would represent the "channel" or "channels" along which the water would flow perpendicularly to the profile as well as to its sides. Below are highlighted some areas of the SP profile shown in Figure 12 that show the general pattern of SP anomaly generated by flow potential (high values flanked by low mirrored voltage values). *Zone 1*: The measurements at high tide have many oscillations, but they form a high of mirrored voltage flanked by lows in relation to the measurements obtained at low tide, suggesting that the zone functions partially as a "channel". In fact, erosion assumes a maximum value between 110 and 145NE, with cement bags shown in Figure 12, between 117 and 124NE, where a low mirrored voltage occurs, which could be indicative of the blockage formed by the containment. On the other hand, around 60NE, where a minimum voltage occurs, erosion approaches the profile as shown in figure 12; in December 2016, the GPS survey detected the site collapsing. The observations, therefore, suggest that the areas most susceptible to erosion are characterized by intense fluctuation of the measures, high values and, occasionally, low values, the latter, often, related to containment areas. In zone 1, for example, the SW portion of 110NE may be about to collapse.

Zone 2: There is a high voltage mirrored at high tide, approximately coinciding with the pit, illustrated by the photo in figure 12.

Zone 3: The measurements at high tide form high values of mirrored potential in relation to the measurements obtained at low tide. A zone of probable cultural noises cuts this zone of high mirrored values in half. A difference of this zone in relation to zone 1 is the lower incidence of fluctuations in the measurements, which may be related to the presence of vegetation and, also, to the greater distance from the profile to the shore.

Zone 4: In this stretch, voltage rises at high tide, keeping a certain analogy with zone 1. Here, too, the profile is closer to the shore. In the zone there is a pit (T), but it is noteworthy that it occurs after the end of the containment zone.

The comparison between the data obtained for the two tides, Figure 12, below, shows what follows.

- From 0 to about 250NE, the two polynomial curves show the same trend indicative of the groundwater flow walking in the SW direction.
- Between approximately 250 and 525NE, the polynomial curves behave differently. This stretch is the most affected by erosion, so the increase in SP obtained at high tide must reflect the saturation in water, especially in the eroded stretch between 400 to 500NE. This main "channel" would allow the movement of water in the SE-NW direction and, secondarily, for both SW and NE.
- From 525 to 600NE, the curves have the same direction, indicating water flow in the NE direction.
- In the residual SP graph shown in Figure 13, the largest growth of the mirrored voltage at high tide occurs between 250 to 550NE. It is this stretch that would function as the main channel of erosion and where water would also migrate to its sides.

FINAL CONSIDERATIONS

The investigation was based on the survey of measurements both at low tide and at high tide and the comparison between the results, as a way of tracking the water penetration in the terrain brought by the high tide, the greater the more effective the path introduced by the phenomenon of erosion. In the investigated area, erosion and, locally, different types of containment appear, which makes it a testing ground for modeling on a full geological scale. The results obtained with all the geophysical methods used - Spontaneous Potential (SP) shows that the data obtained at high tide vary considerably in relation to the data obtained at low tide and that their behavior indicates areas where erosion is more prominent and areas where it it is contained.

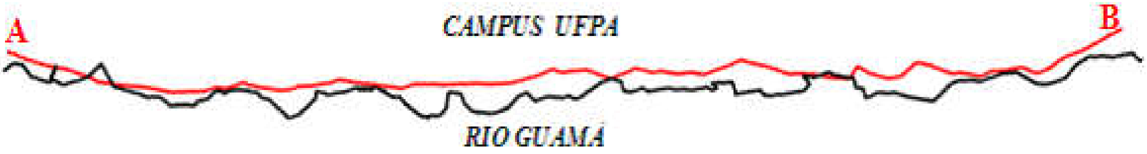
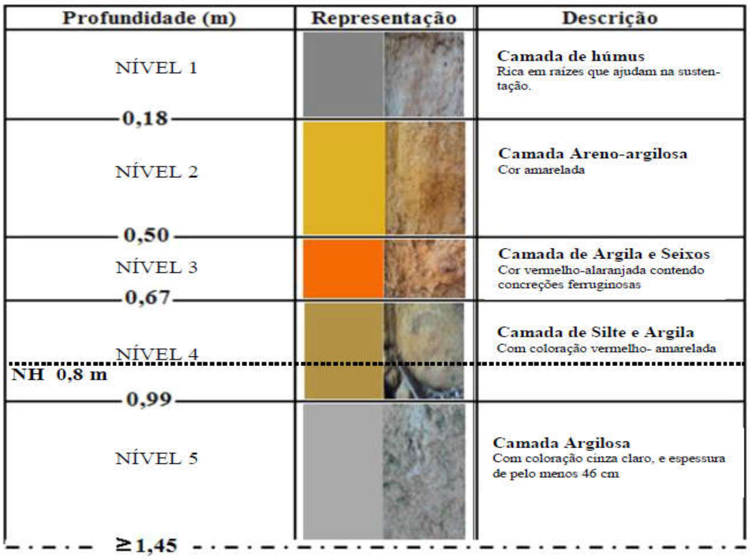


Figure 1 AB profile (higher) and river contour (lower and more pronounced) surveyed using GPS that occurred on 12/01/2010, while the fieldwork ended on 9/3/2011, before the collapse of some stretches of the shore. Source: Authors



Profundidade (m)	Representação	Descrição
NÍVEL 1		**Camada de húmus** Rica em raízes que ajudam na sustentação.
0,18		
NÍVEL 2		**Camada Areno-argilosa** Cor amarelada
0,50		
NÍVEL 3		**Camada de Argila e Seixos** Cor vermelho-alaranjada contendo concreções ferruginosas
0,67		
NÍVEL 4 NH 0,8 m		**Camada de Silte e Argila** Com coloração vermelho- amarelada
0,99		
NÍVEL 5		**Camada Argilosa** Com coloração cinza claro, e espessura de pelo menos 46 cm
≥1,45		

Figure 2. Geological section for the hole on the edge of UFPA. Dashed hydrostatic level

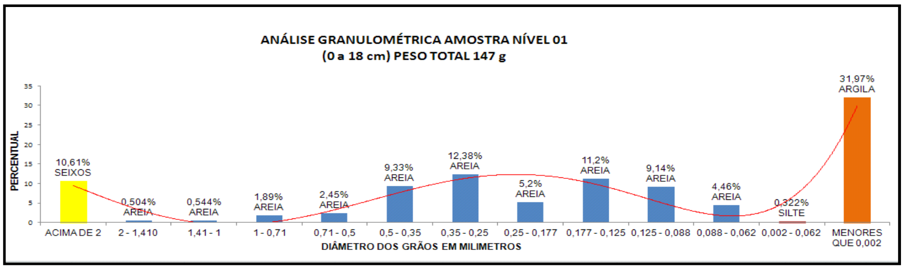


Figure 3. Result of the granulometric analysis of the level 1 sample (0 to 18 cm), weighing 147 grams

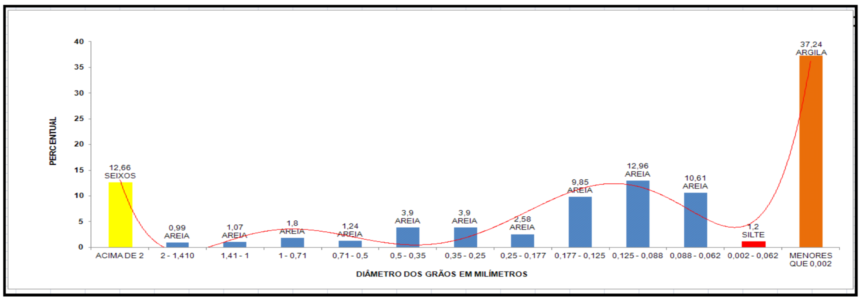


Figure 4. Result of the granulometric analysis for the level 2 sample (19 to 50 cm), weighing 155 grams

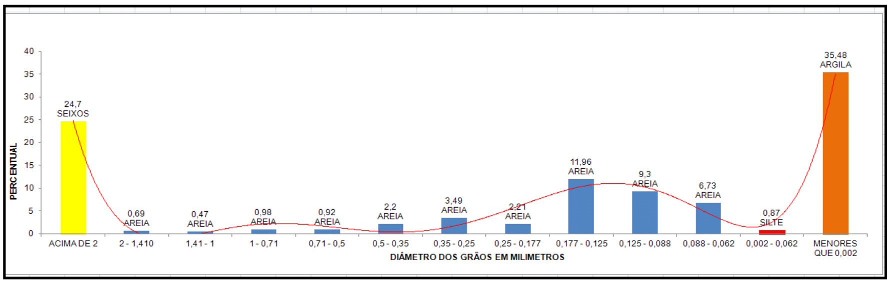


Figure 5. Result of the granulometric analysis for the level 3 sample (51 to 67 cm), weighing 162 grams

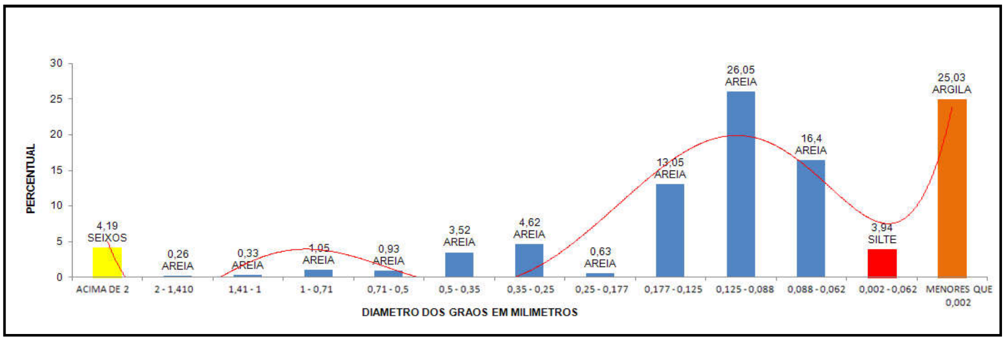


Figure 6. Result of the granulometric analysis for the Level 4 sample (68 to 99 cm), weighing 128 grams

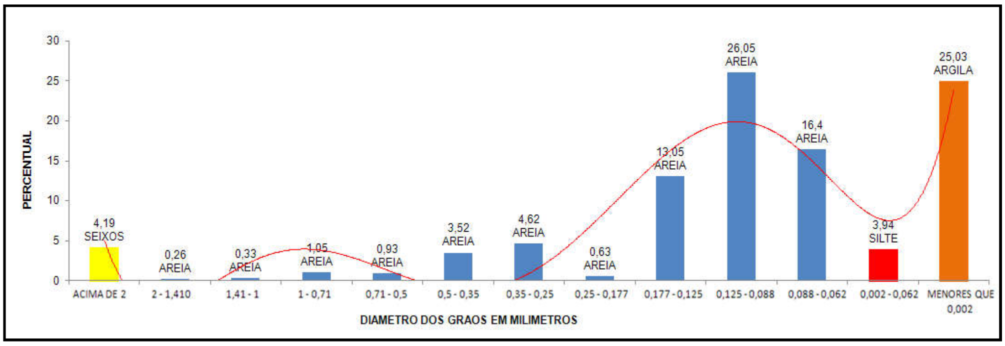


Figure 7. Result of the granulometric analysis for the Level 5 sample (100 to 149 cm), weighing 200 grams

Table 1. Erodibility to the levels sampled by the hole on the edge of UFPA Highlight in bold the highest erodibility value found for level 4.

ERODIBILIDADE				
NÍVEL 1	**NÍVEL 2**	**NÍVEL 3**	**NÍVEL 4**	**NÍVEL 5**
$k = \frac{57{,}42}{31{,}97} = 1{,}79$	$k = \frac{39{,}82}{35{,}48} = 1{,}12$	$k = \frac{50{,}1}{37{,}24} = 1{,}35$	$k = \frac{70{,}78}{25{,}03} = \mathbf{2{,}82}$	$k = \frac{11{,}65}{86{,}88} = 0{,}14$

Figure 8. Photo showing in detail the erosion at the edge of the Guamá River at UFPA, making the illustrative comparison with a pen in the center. Source: authors

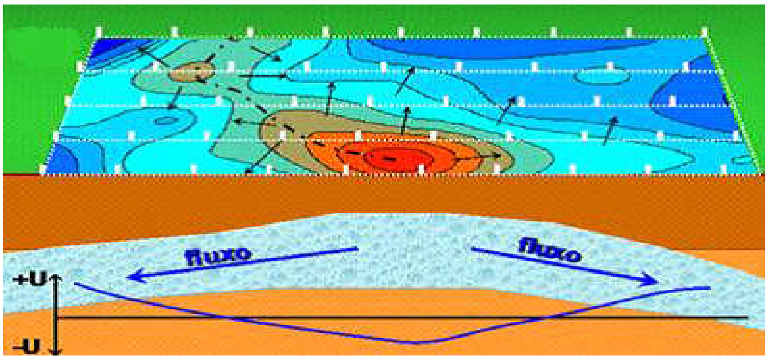


Figure 9. Electrofiltration. Braga (2008)

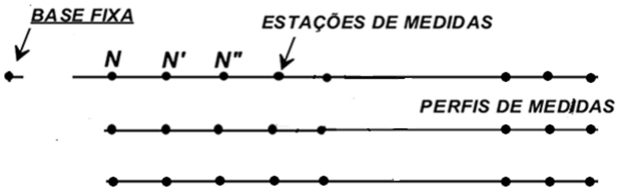


Figure 10. Scheme for acquiring SP data using the Potentials Method

Figure 11. A - Photo illustrating the electrode immersed in a saturated copper sulfate solution. B - Illustrative scheme. C - Voltmeter used in the survey.

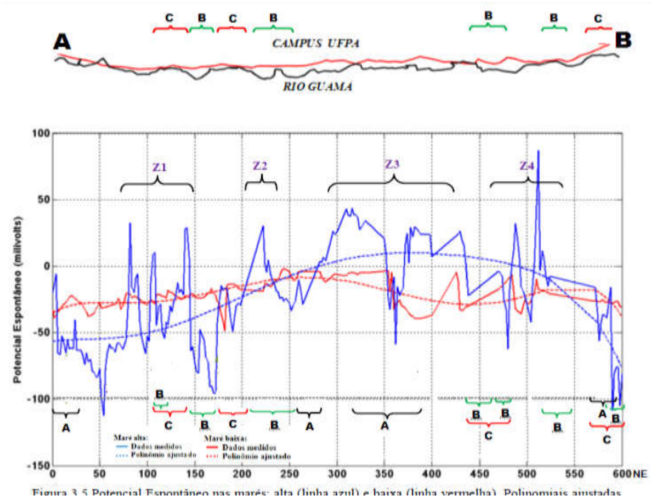


Figure 12. Spontaneous potential at tides: high (higher line and with more shade) and low (lower line and with less shade). Dashed polynomials (grade 6). The letters A: indicates erosion, B: containment, C: more intense erosion. Keys above showing the zones highlighted in the interpretation (Z1, Z2, Z3 and Z4). Above: line AB (profile above) and river outline (below).

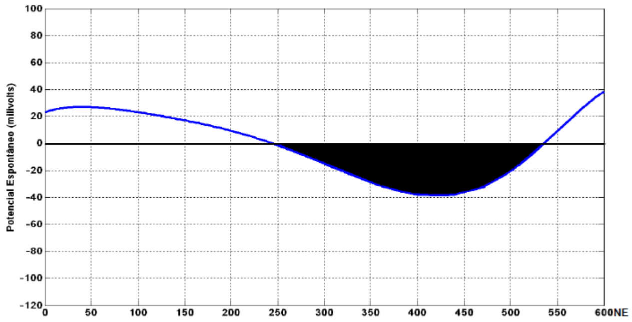


Figura 13. Resíduo entre as polinomiais ajustadas aos dados de maré baixa – maré alta

These indications can consequently assist in the prediction of places where the collapse of the land caused by erosion is about to occur as well as in the analysis of the effectiveness of the containment work carried out. The SP measurements, in the Z1 zone (75-150NE) (Figure 12), for example, form a negative voltage peak (positive of the mirrored voltage) around 85NE, which, could reflect the erosion action, which may indicate a zone with imminent collapse. The same occurs in zone Z3 (292-427NE) (Figure 12), especially around 370-385NE. In this stretch there was a collapse after fieldwork, around 380NE.

The problem, however, is not simple, because the water infiltrated into the soil from the surface can be divided into three parts. The first remains in the unsaturated zone (zone where the soil voids are partially filled with water and air), above the water table. The second part, called Inter flux (subsurface flow) can continue to flow laterally, in the unsaturated zone, at small depths, when there are little permeable levels immediately below the surface of the soil and reach the watercourse beds. The third part can percolate down to the water table constituting the renewable resources of the aquifers, Feitosa (2000). All of these are, therefore, paths that can offer contrast in electrical properties. The preferential subsurface water paths can also represent routes for the inflow of water brought in by high tide and, by this means, for erosive work. It is also necessary to consider that lithological variations also contribute to the data. Finally, for the area studied, it encounters erosion events with sometimes different contention. Despite the difficulties, the results confirm that Geophysics can be an auxiliary tool in the prediction of places where the collapse of the land caused by erosion is about to occur as well as in the analysis of the effectiveness of the containment work carried out.

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