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URBAN GULLY ASSESSMENT IN SÃO LUIS CITY (MARANHÃO STATE), BRAZIL, USING PENETROMETER DATA AND SOIL PROPERTIES

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ABSTRACT

This paper investigates soil erosion assessment in São Luis City, reporting an ongoing programme of field measurements (penetrometer measurements and gully monitoring), topsoil sampling and laboratory analyses. From the database, it is evident that the urban sector of São Luis is very prone to gully erosion, especially where land use promotes land degradation. This research work is part of the larger European Union Project 'BORASSUS', which investigates soil erosion assessment and rehabilitation in 10 different countries, including Brazil. In our case, we are the only country investigating urban gully erosion. Therefore, this paper presents some preliminary results, both in terms of penetrometer measurements and soil properties, and we make some initial conclusions regarding the four studied gullies, which are situated in São Luis City, Maranhão Island (2º19'9"-2º51'S; 44º1'16"-44º19"37" W). In order to achieve the research objectives, we have carried out both field and laboratory work, so that penetrometer data could be related to laboratory data. On each one, we selected different parts, around each gully, to take three penetrometer measurements, to calculate the site mean. On completion, we calculated the mean for the whole gully, taking into account the mean for each site. We collected topsoil (0-10 cm) samples to determine selected soil properties in the laboratory (particle size distribution, particle density, bulk density and porosity), using EMBRAPA (1997) protocols. Although most penetrometer studies are related to agricultural situations, for this study we have used penetrometry to assist our understanding of gully evolution and behaviour. The whole study area shows a high sand content and low silt and clay contents; textures being sandy loams. In 60% of analysed soil samples, the silt content is higher than the clay content, confirming the higher detachability and transportability of fine sand and silt. Penetrometer measurements are related to soil compaction, due to people walking on tracks around the gullies. Those values showed direct association with parameters related to vegetation cover. We can conclude that this area presents high sensitivity to erosion, expressed by high bulk density values, high fine sand and silt contents, low clay content and low porosity.

Keywords: Penetrometer measurements, gully erosion, soil compaction, bulk density and land use.

INTRODUCTION

This paper assesses urban gully erosion in São Luis City, Maranhão State, Brazil (Figure 1). The study incorporates measurements taken with a Solotest penetrometer, together with analysis of topsoil properties, both collected during fieldwork in December 2005. During this field trip, multiple photographs were taken, together with gully border monitoring, which are also reported in this paper.

This research work is part of the larger European Union Project ‘BORASSUS’, which investigates soil erosion assessment and rehabilitation in 10 different countries, including Brazil. In our case, we are the only country investigating urban gully erosion. The assessment is fundamental in order to target the correct gullies for rehabilitation, and evaluate the most time and cost effective soil conservation and rehabilitation techniques. Therefore, this paper presents some preliminary results, both in terms of penetrometer measurements and soil properties, and we make some initial conclusions regarding the four studied gullies.

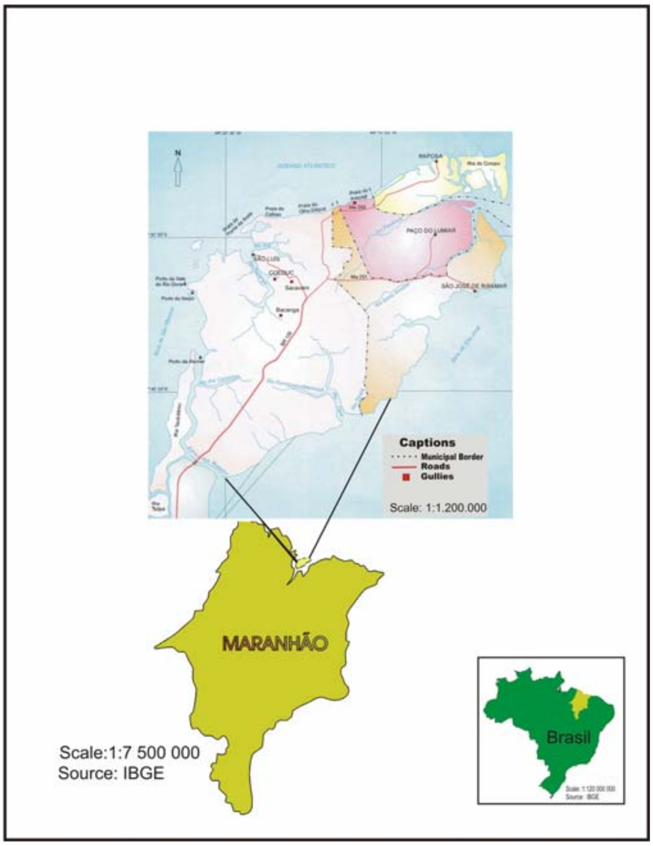

Figure 1: Location of the study area.

STUDY AREA

The physical characteristics of the four surveyed gullies are rather similar and so we present them as part of a general overview of the study area. However, there are some minor differences in soil properties between gullies (particle size distribution, particle density, bulk density, porosity and penetrability), which are reported later.

The four investigated gullies are situated in São Luis City, Maranhão Island (2º19’9”-2º51’S; 44º1’16”-44º19”37” W) (Figure 1). To date, several papers have reported the main physical characteristics, socio-economic conditions and the use of palm mats to rehabilitate gullied and degraded areas (Mendonça, *et al.*, in press; Guerra, *et al.*, 2004; Guerra, *et al.*, 2005a,b,c; Sathler *et al.*, 2005).

There are two distinct seasons: a dry and a rainy season. The dry season runs from August to November and has a precipitation deficit, with mean monthly rainfall ~30 mm. The rainy season runs from December to July, with mean monthly rain ~250mm, March being the rainiest month, with ~400 mm of precipitation. This is the season of most active gully erosion and poses most risk for the people who live adjacent to gullies.

The local geology is mainly Tertiary, dominated by sandstones and, to a lesser extent, shales, argillites and siltstones, all of them belonging to the *Barreiras* Formation (Mendonça, *et al.*, in press; Guerra *et al.*, 2004, 2005a). The rocks have high porosity and are rather friable, presenting a high degree of laterization. Such characteristics make these rocks susceptible to weathering and erosion. The local geomorphology presents low relative relief (10-40 m) and gentle slope angles (0-15º).

The soils (mainly Podzolics and Lithosols) are very susceptible to erosion, especially where the landforms are hilly. Soils are also sandy and silty, due to weathering of sandstone and siltstone from their parent materials. Soil organic matter contents are usually low and the combination of these characteristics make this soil subject to high erosion risk, especially where vegetation clearance occurs.

In the historical past, the main vegetation cover of the region was tropical rainforest, although it has been subject to intense deforestation, since urban growth started during the nineteenth century. Nowadays the main vegetation type is secondary, called *Capoeira* in Brazil. This vegetation community appears when the original vegetation is cut down and is different from the original tropical forest (Mendonça, *et al*., in press; Guerra, *et al.*, 2005a, Sathler *et al*., 2005).

METHODOLOGY

In order to achieve the research objectives, we have carried out both field and laboratory work, so that penetrometer data could be related to laboratory data. Taking into account those data, together with other results, we believe that we can make a preliminary assessment of the São Luis City gullies.

We selected four urban gullies (Araçagi (2a), Bacanga (2b), COEDUC (2c) and Sacavém (2d), the greatest distance apart being 3 km (between a and b) and the least distance being 1 km apart (from c and d). On each one, we selected different parts, around each gully, to take three penetrometer measurements, to calculate the site mean. On completion, we calculated the mean for the whole gully, taking into account the mean for each site. We have taken three measurements for each site, in order to obtain a more representative mean result.

Figure 2a: Soil sample collection using a rope technique on Araçagi gully wall.

Figure 2b: Use of the penetrometer on a track around Bacanga gully.

Figure 2c: Soil sample collection and GPS measurement, at COEDUC gully.

Figure 2d: Digital meter being used to monitor Sacavém gully retreat.

At the same sites, we collected topsoil (0-10 cm) samples to determine selected soil properties in the laboratory. Particle size distribution, particle density, bulk density and porosity have been determined, using EMBRAPA (1997) protocols. Furthermore, we monitored each gully border, using a digital meter. Thus, for each gully it was possible to accurately draw its perimeter and calculate its size (3-dimensions and volume). Thorough notes on gully characteristics were made and an archive of photographs taken. A selection of representative photographs is presented.

Soil penetration resistance is an important mechanical property that can indicate soil compaction and is relevant in determining the least limiting water range (Vanags *et al*., 2004). Although most penetrometer studies are related to agricultural situations, for this study we have used penetrometry to assist our understanding of gully evolution and behaviour. Soil strength is an important characteristic affecting many aspects of agricultural soils, such as the performance of cultivation implements, root growth, least limiting water range and trafficability (Vanags *et al.* 2004).

Soil compaction is characterized by a notable decrease in the number, size and inter-connectivity of soil macro-pores and thus, it limits water infiltration and water redistribution through the soil and decreases oxygen availability. By mechanical obstruction, root growth is impeded, which reduces agricultural yield and productivity (Beutler and Centurion, 2004). This is yet another example how most penetrometer studies are related to agricultural soils and not to urban situations. Herrick and Jones (2002) outlined that the recognition of the importance of soil compaction is increasing, but instrument cost, measurement repeatability and data interpretation limit its measurement on agricultural soils and rangelands. Nevertheless, for this research, we took several measurements using a Solotest penetrometer (Figure 2b), on top of soils around four different gullies, to assess soil compaction in urban São Luis.

4. Results and Discussion

Because the whole study area is situated on *Barreiras* Formation, soil properties are very similar among the four gullies (Table 1) with a high sand content and low silt and clay contents; textures being sandy loams.

Table 1: MEAN SOIL PROPERTIES OF SÃO LUÍS GULLIES (n = 5 samples per gully)

GULLY	TEXTURE (%) SAND	SILT	CLAY	SOIL CLASS	PARTICLE DENSITY) (g/cm^3)	BULK DENSITY (g/cm^3)	POROSITY (%)
Araçagi	73.25	12.11	14.63	Sandy loam	2.53	1.65	35.19
Bacanga	82.88	10.81	6.31	Sandy loam	2.54	1.51	40.21
COEDUC	68.74	22.16	9.09	Sandy loam	2.66	1.60	39.95
Sacavém	68.88	15.41	15.71	Sandy loam	2.54	1.61	36.66

Topsoil samples with high sand contents (53.68-85.53%) and low silt (6.43-19.33%) and clay contents (5-26.98%) indicate high erodibility, especially due to the high fine sand contents (21.98-64.03%). In 60% of analysed soil samples, the silt content is higher than the clay content, confirming the higher detachability and transportability of fine sand and silt (Table 1). Most erodible material tends to be of intermediate size, which is silts and sands, which are not cohesive and are small enough to be transported by the flow rates characteristic of rills (Fullen and Catt, 2004).

Because of intense human action, bulk density values are high (1.51-1.65 g/cm^3), whereas porosity values are low (35.19-40.21%). Generally, soils with lower bulk density (1.51 g/cm^3: Bacanga Gully) and higher sand content (85.53%: Bacanga Gully) have higher porosity (40.21%: Bacanga Gully). On the other hand, the soils with the highest clay content (14.63%: Araçagi Gully) present the highest bulk density (1.65 g/cm^3).

Soil penetration resistance (Table 2) ranged from 76-2,560 kPa and is associated with soil compaction due to people walking on tracks around the gullies. At Bacanga Gully (Figures 2b and 3b), which is inside a State Park, the highest penetration resistance (1,079 kPa) is related to a track which links a poor settlement to the State Park, where the inhabitants cut wood illegally. At Araçagi Gully (Figures 2a and 3a) the highest value (796 kPa) is related to an area where local people dump rubble and there is a nearby car park. The lowest mean value (167 kPa) is related to good vegetal cover. At COEDUC Gully (Figures 2c and 3c) the highest value (659 kPa) is related to an unvegetated topsoil containing concretions. The lowest value (228 kPa) was measured on the soil on the gully talus. At Sacavém gully (Figures 2d and 3d), the highest value (1,056 kPa) is due to the topsoil having no vegetation cover and the soil is sealed and crusted with concretions. Sealing results from clogging of pores by soil compaction and the resultant infilling of surface pore spaces by fine particles, detached from soil aggregates by raindrop impact (Morgan, 2005). The lowest value (305 kPa) is located on the gully sidewall, possibly due to the weak structure resulting from talus collapse.

Table 2: Penetrometer measurements (kPa)

SITE: Araçagi (Club)

Date: 04/12/05

Site	1	2	3	Mean	SD	GPS
Next to the avenue	864	460	800	708	217.2	LAT:2º28'11,0" LONG:44º12'11,5"
Gully head I	161	1696	532	796.3	800.9	LAT:2º 28' 10,7"LONG:44º12'9,6"
Gully head II	920	144	191	418.3	435.1	LAT:2º28'11,6" LONG:44º12' 7,5"
Gully head III	76	225	49	116.7	94.8	LAT:2º 28' 11,5"LONG:44º12'6,7"
Gully border	192	896	320	469.3	375	LAT:2º28'9,2"LONG:44º12'8,1"
Mean				**501.7**		

Site: Sacavén

Date: 05/12/2005

Site	1	2	3	Mean	SD	GPS
Gully head I	2560	440	169	1056.3	1309.2	LAT:2º33'38,6" LONG:44º15'28,8"
Gully head II	792	652	48	497.3	395.4	LAT:2º 33' 38,6"LONG:44º15'28,5"
Gully border I	636	552	1064	750.7	274.6	LAT:2º33'38,9" LONG:44º15' 27,8"
Gully border II	110	149	656	305	304.6	LAT:2º 33' 38" LONG:44º15'27,6"
Mean				**652.3**		

Site: COEDUC

Date: 06/12/2005

Site	1	2	3	Mean	SD	GPS
Gully border	288	236	160	228	64.4	LAT:2º33'36,5" LONG:44º16'17"
Gully head	1440	416	120	658.7	692.6	LAT:2º33'36,6" LONG:44º16'16,5"
Mean				**443.3**		

Site: Bacanga Park

Date: 7/12/2005

Site	1	2	3	Mean	SD	GPS
Bottom I	1712	150	832	898	783.1	LAT:2º34'49,4" LONG:44º16'1,9"
Bottom II	396	384	460	413.3	40.9	LAT:2º34'47,7" LONG:44º16'01,4"
Border	2224	740	272	1078.7	1019.1	LAT:2º34'51,5" LONG:44º16'3,1"
Average				**796.7**		

*1...Mean = Kpa; SD = Standard Deviation; GPS = Global Positioning System

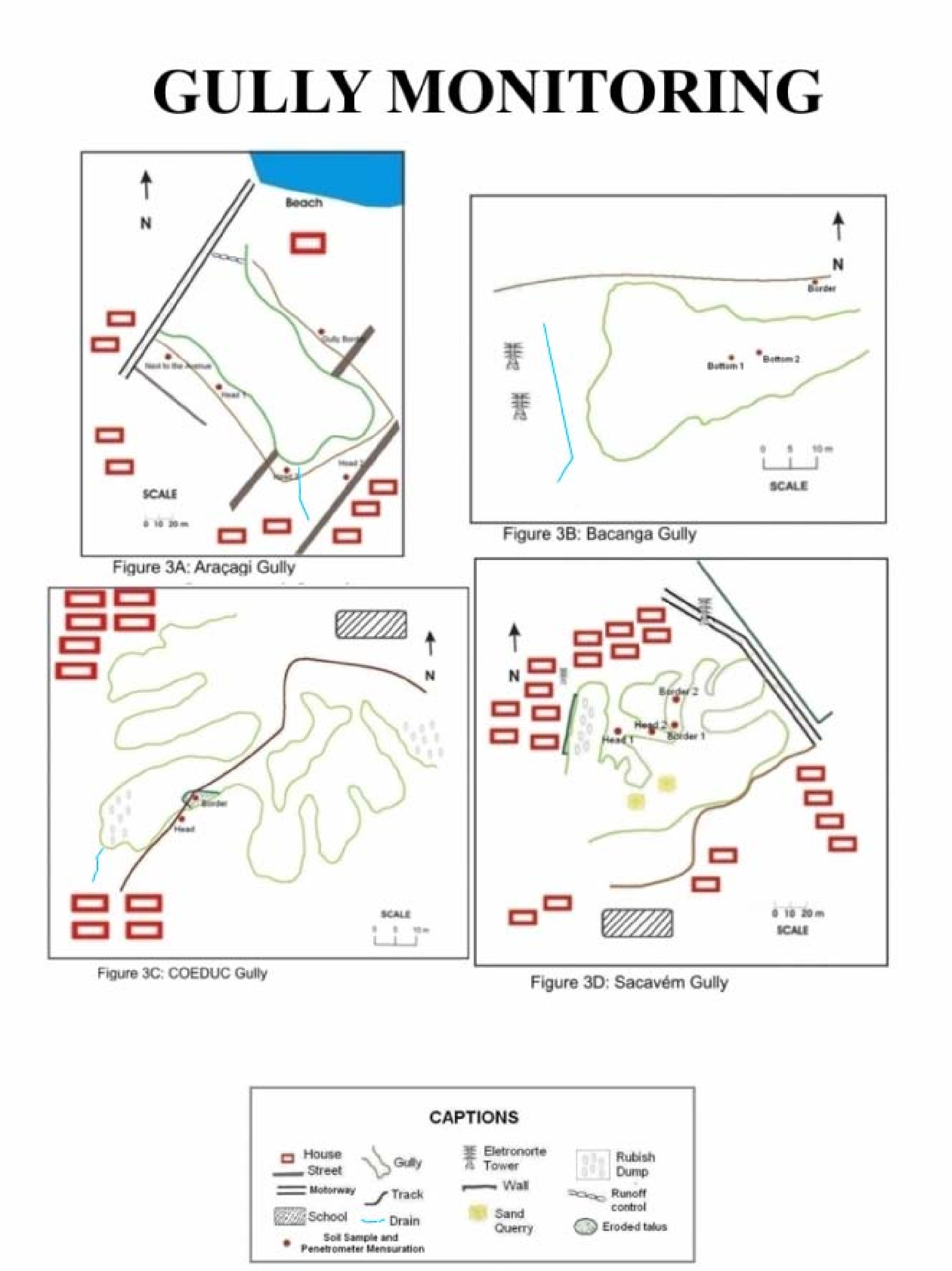

Figure 3: Monitoring

CONCLUSIONS

1) Despite the geographical distance (about 2 km) between the gullies, there are many similarities, in terms of texture, bulk density and porosity. All soil samples had high sand contents and lower silt and clay contents.

2) Low variations, in terms of sand and clay, correspond to variations in bulk density such that the soils with higher sand content present lower bulk density and soils with higher clay content have higher bulk density.

3) Penetrometer measurements are closely related to human action, therefore higher values were found adjacent to rubbish dumps, animal tracks and human access tracks. In addition, those values showed direct association with parameters related to vegetation cover, that is, high penetrability values were found on soil without vegetation cover, sealed by rain splash. In contrast, areas under dense vegetation and without tracks had the lowest kPa values.

Synthesizing these results, we can conclude that this area presents high sensitivity to erosion, expressed by high bulk density values, high fine sand and silt contents, low clay content and low porosity. Furthermore, the high impact of human action on all gullied areas, with its multitude of tracks around the gullies, rubbish dumps, vegetation clearance, burnt areas and sand quarries, all contribute to the high soil erosion risk. All these activities increase soil compaction, as evidenced by the high soil penetrability (kPa) values.

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