Natural aggregate potential and associated environmental problems in the Aurá portion, Belém metropolitan region (BMR), State of Pará, Brazil

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Abstract: This paper presents part of the results obtained from 1:10,000 scale engineering geological mapping carried out in the Belém region, in the state of Pará, in the north of Brazil. Geologically, this region consists of Tertiary sedimentary lithologies (sandstones, claystones and siltstones of the Barreiras Formation) and Quaternary sediments (sandy materials). From the data obtained, 3 units were defined in terms of their suitability for raw materials in engineering construction. These geological materials as aggregates are widespread in the region and have been used for different kinds of embankments and civil construction. In the study area there are several sites where these materials are intensely exploited as aggregates and several environmental problems are generated, such as: erosion, flooding, silting, deforestation, water contamination and human conflicts.

Résumé: Cet article présente une partie des résultats obtenus à partir du tracer géologique de technologie effectué dans la Région de Belém, au l'État de Pará., nort du Brésil à une échelle de 1:10.000. Géologiquement, cette région est composé par lithologies sédimentaires (arénacé non-consolidable) des périodes tertiaires (grès, argillites et des cailloux de ruissellement de la formation Barreiras) et quaternaires. Des données ont definie 3 unités en termes de convenance des matériaux géologiques pour la construction civile. Ces matériaux géologiques comme agrégats ont une certaine répercussion dans la région et ont été employés pour différents genres de remblais et de construction civile. Dans le region d'étude il y a plusieurs lieux où ces matériaux géologiques sont intensément exploités pendant que des agrégats et plusieurs problèmes environemental sont produits comme: érosion, baissement du niveaux d'eau, envasement, déboisement, contamination de l'eau et conflits d'humain.

Keywords: aggregate, natural resources, regional planning, geotechnical map and environmental impact.

INTRODUCTION

The Belém Metropolitan region (BMR) is composed of the municipalities of Belém, Ananindeua and Marituba. The rate of population growth, and the demand for construction materials (mainly aggregates) has increased in similar proportions. Consequently, there is exploitation without any technical or environmental control. Several land-degraded sites were found in the region with water accumulation in pits and hollows, erosion and silting processes, and intense deforestation.

Several geological material types are used for civil construction, ceramic industries and pavement material. The Aurá portion, in BMR region is an Environmental Protection Zone but is also an important source of aggregates and it has been seriously affected due to intense exploitation of soil, sediments and sedimentary rocks. The environmental problems have increased due to the small volume of the pits, shallow groundwater level and increasing demand.

Currently the studies developed to assess the potential of geological material for civil construction follow two basic procedures: geological-geotechnical characterization of geological material in specific sites or geological-geotechnical mapping to define and delimit areas more favorable for exploitation of construction materials. The systematic studies and descriptive models of the aggregate deposit types are fundamental to develop adequate quantitative assessment.

Associated with surface mining are degrading processes as: silting, erosion, flooding, gravitational mass movements and severe geomorphologic changes, as pointed out by Marchetti & Panizza (2001)

Baraldi et al. (2001) observed that the main environmental modifications caused by quarries are : creation of regular-shaped depressions, minor isolated artificial relief and creation of artificial ponds; partial or total destruction of fluvial terraces; erosion and instability of quarry scarps; depression of piezometric surface; alteration of groundwater flow direction; formation of periodically flooded areas; permanent removal of areas from farming use; alteration of farming practices; and pedological characteristics of soil.

In the studied region, there are many sites where sand, clay, and aggregates are extracted for civil constructions. The principal problems result from exploitation of sand deposits and sandy soils are: deep excavation; intense erosion processes; silting of rivers and lakes; and forest destruction.

These activities have been responsible for negative environmental impacts in the region, such as: erosion; silting; deforestation; damage of houses; scars on the land; inadequate disposal of waste materials; and landslides.

This paper presents the procedures used to elaborate the unconsolidated material map and the evaluation of the different types as potential construction material.

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BACKGROUND

The production of maps and charts as part of the engineering geological mapping methodology, including the construction material potential zoning charts is a common practice in many countries such as Belgium, Norway, Germany, Austria, USA, Canada and others, at different scales ranging from regional (1:100,000) to more detailed scales for specific areas or sites (1:1:10,000) as noted by Bobrowsky and Kelly (2002). In Brazil, one of the fundamental types of map is the unconsolidated material map which registers all geological material types between the land surface and the rock substrate, as well as recording their geotechnical attributes. In the study portion the unconsolidated materials can reach 100 m deep and present high spatial heterogeneity.

According to Langer and Knepper (1998) the aggregate assessments can be done for regional (1:50,000 or smaller) and preliminary site investigation (1:50,000 or larger). The latter demands detailed fieldwork to evaluate spatial variability, physical and chemical characteristics, thickness and geometry.

The unconsolidated material mapping should aim to develop an analysis for several goals, among then construction material. In this study the main goal of the unconsolidated material mapping is to provide information for an evaluation about the sandy aggregates potential. According to Bobrowsky and Kelly (2002) the aggregate potential mapping should be used for a great number of clients as shows in Figure 1, for several goals (regional planning, environmental quality, civil construction, consultants), which demand different data about the geological materials and spatial distribution.

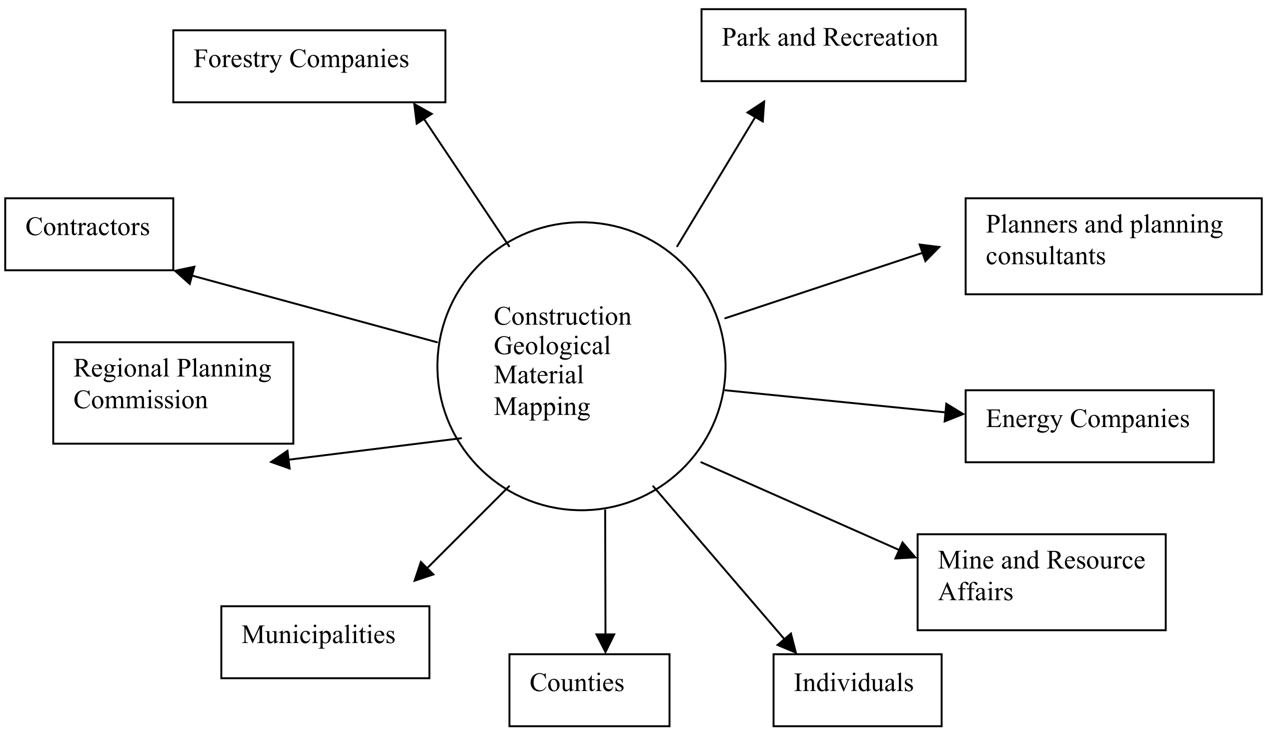

Figure 1. Variety of potential clients can use the aggregate potential mapping. (Modified from Kelly and Bobrowsky, 2002).

General characteristics

The Aura portion is located in the southern part of the Belém Metropolitan Region (BMR), state of Pará, Brazil, including part of the municipalities of Belém, Marituba e Ananindeua (Figure 2), between the latitudes 01° 02 ' 30"S and 01° 30' 00"S, and longitudes 48° 10' 00" W and 48° 30' 00" W. The predominantly climatic type is Afi, according to Koppen classification, with annual total rainfall up to 2,000 mm and annual average temperature is 35 degrees C. But, the Aurá portion and BMR presents different climatic characteristics of the Amazon region due to low altitude, proximity of the Atlantic Ocean, flat to undulating relief and tropical vegetation. Geomorphologically, the BMR is characterized by flood plain, fluvial-marine plain, fluvial terraces and flat to undulating relief. The main water bodies are: Guajará bay, and Guamá, Val de Cães and Una rivers, and a hundreds of small drainage channels, termed “igarapés”.

Geological characteristics

Geologically, the Aura portion is constituted of 3 basic Cenozoic units: Recent sediments, Pos-Barreiras sediments and Barreiras Formation, and Pirabas Formation (Table 1).

According to (IDESP, 1979 apud Farias et al, 1992), the following pedological groups occur in the BMR: Latosols, Plintosols, Argisols, Gleysols and Neosols. The concretionary soil is deep residual, composed of clay and concretions resulted from weathering of the lithologies of the Barreiras Formation, predominantly associated with flat relief and dense vegetation. The Recent sediments, Pos-Barreiras sediments and Barreiras Formation present higher potential as sources of the geological material for civil construction than Pirabas Formation, which is found 80 meters deep.

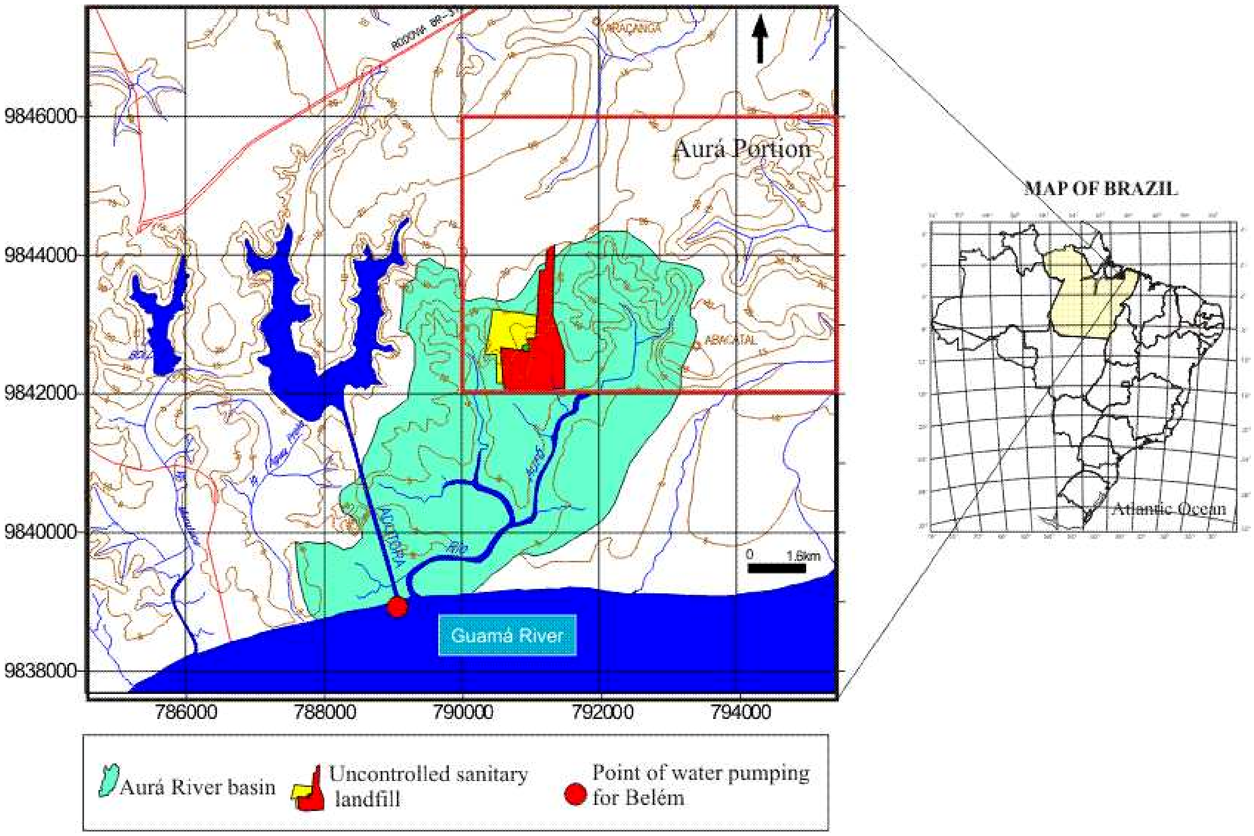

Figure 2. Location of Aurá Portion, state of Pará, Brazil.

Table 1. Chronolithoestratigraphic column found in the Belém Metropolitan Region (BMR). Pt = Top depth (m), E = Sedimentary Strata Thickness.

PERIOD		UNIT	DEPTH (m)	SIMPLIFIED DESCRIPTION
QUATERNÁRY	Holocene	Recent Sediments	Pt= 0m E= 0 a 70m	Clayed, Silty and Sandy Sediments.
	Pleistocene	Pos-Barreiras Formation Sediment	E= 0 to 4m	SEDIMENT STRATA - Sandy silt to Sandy Clay bed. - Sandy bed.
			E= 0 to 1m	STONE LINE – Concretion and laterite pebbles
		Barreiras Formation Pt= 0 to70 m E = 80 to 135m	E= 0,5 to 5m	NON-CONCRETIONARY ACCUMULATION OF IRON STRATUM Constituted of: Concretionary, Clayed Sand, Laterite, and Sand package.
			E= 1 to 8m	CLAYED STRATA - Thickness can reach up to 8 m. Presents 3 different lithology groups: Variegate Clay, Claystones and Hard Claystones.
TERCIÁRY	Miocene			Claystones, Sandstones interbedded.
	Miocene/ Oligocene	Pirabas Formation	Pt= 80 to 135m E > 370m	Limestone, Shale and Marls.

METHODOLOGY

The unconsolidated material map was carried out according to procedures proposed by Zuquette (1987, 1993) and Zuquette & Gandolfi (2004), as shown in Table 2.

Table 2. Basic procedures for the elaboration of the unconsolidated material map. After: Zuquette (1987, 1993), Zuquette & Gandolfi (2004).

	Spatial Distribution	
	↓	
Heterogeneous	Vertical Heterogeneity	Homogeneous
	↓	
	Thickness	
	↓	
	Basic Discontinuities	
	↓	
Undisturbed	Sampling	Disturbed
	↓	
- Void Ratio - Natural Dry Density - erodibility Index - Expansibility (potential) - Collapsivity (potential) - Compressibility -Dispersivity - Hydraulic Conductivity -Mechanical Strength	Tests ↓	- Texture - pH (H2O e KCl) / (Δ pH) - Basic Mineralogy - Gravity Density, Maximum Dry Density -C.E.C.(Cationic Exchange Capacity) and A.E.C. .(Anionic Exchange Capacity) - Salinity -Retardation Factor - Chemical Characteristics (pH, SO_3 , S, Electric Conductivity, Organic Materials - Sand Equivalent
	Result Variability	
	Complementary Sampling	

Using procedures shown in Table 03, the study phases were defined and specific conditions for fieldwork, sampling and geotechnical testing were planned. Currently, the construction material mapping presents data about landforms and terrain elements, textural characteristics of the unconsolidated materials, thickness, volume and environmental problems related to exploitation.

First phase

The topographic map and aerial photos used in this work were at scale 1:10,000, those were obtained from CODEM (Company of Development Belém Metropolitan region) and COHAB (Habitation Company). These documents were used to prepare the base map to develop the field investigations and to elaborate the unconsolidated material map.

Second phase

For the fieldwork the unconsolidated materials were characterized and classified based on texture, mineralogy, thickness, groundwater level, geotechnical aspects and spatial distribution. During the field and laboratory works the same terms about texture, geological characterization and classification were adopted as follows: genetic conditions: transported (RE), alluvium materials (Al), e residual (Rs); geological characteristics: Recent sediments (SR), Pos-Barreiras Formation sediments (SPB), Barreiras Formation (SB); Texture: 1-Sand, 1.1-Silty sand, 1.2- clayed sand 2- very silty sand, 3- very clayed sand 4- clayed silty sand, 5-Silty clay sand, 6-silt, 6.1- Sandy silt 6.2- Clayed silt 7- very sandy silt, 8- very clayed silt, 9 – clayed sand silt, 10-sandy clay sand, 11-Clay, 11.1- Silty clay, 11.2- Sandy Clay, 12- very sandy clay, 13- very silty clay, 14- Silty sand clay, 15-Sandy silt clay, and the Unified soil classification.

Third phase

Considering the defined unconsolidated material types in the field, 36 disturbed and 33 undisturbed samples were collected using a ring with fine wall. Disturbed samples were tested to obtain particle size curves (ABNT 1984a); Gravity Density (after Nogueira 1998); Atterberg limits (ABNT 1984b & c); compaction curves and graphs considering Proctor Normal energy (ABNT 1984d).

The undisturbed samples were tested to obtain natural dry density, natural moisture, void ratio and porosity. These properties combined with those obtained from disturbed samples permitted the characterization of the unconsolidated material types.

Table 3. Attributes proposed for elaboration of the construction geological material zoning chart. After: Zuquette (1993).

Component	Type				Potential Volume	Exploitation Cost	Potential Passive Environmental
	Aggregates	Ornamental stone	Sand	Ceramic			
Rock Substrate	Lithology	Lithology			Volumetric Joint Contactor		Soluble Minerals
	Petrographic Type	Petrographic Type	Petrographic Type				
	Mineralogy	Mineralogy	Mineralogy				
	Apparent Density	Apparent Density					
	Porosity	Porosity					
	Mechanical strength	Mechanical strength					
	Discontinuities	Discontinuities					
	Alterabilility	Alterabilility					
		Chemical Resistance					
	Volumetric Joint Contactor	Volumetric Joint Contactor	Size Particle				
	Methylene Blue Adsorption	Methylene Blue Adsorption	Methylene Blue Adsorption				
Unconsolidated materials			Texture	Texture			Soluble Minerals
			Mineralogy	Mineralogy			
			Sand Equivalent	Clay Mineral Type			
			Organic Material	Organic Material			
			Methylene Blue Adsorption	Chemical characteristics			
				Methylene Blue Adsorption			
Water					Groundwater Level	Groundwater Level	Groundwater Level
						Drainage conditions	
Relief							
					Declivity		
					Sterile Layer Thickness	Sterile Layer Thickness	Sterile Layer Thickness

Fourth phase

After, the geological – geotechnical characterization and classification of the unconsolidated material units an assessment of their uses as aggregates for civil construction was developed.

RESULTS

Unconsolidated material map

The unconsolidated material map elaborated for Aurá portion (Figure 3) shows the three defined units at a scale of 1:10,000 and defined according to genetic, mineralogical, textural and stratigraphic characteristics. The Unit I is related to Recent (Holocene) sediments, Unit II Pos-Barreiras Formation sediments and Unit III – Fe – rich strata of the Barreiras Formation divided into 4 subunits (Concretionary layer, Clayey-sand layer, Non-concretionary accumulation of iron sand layer and Clay layer).

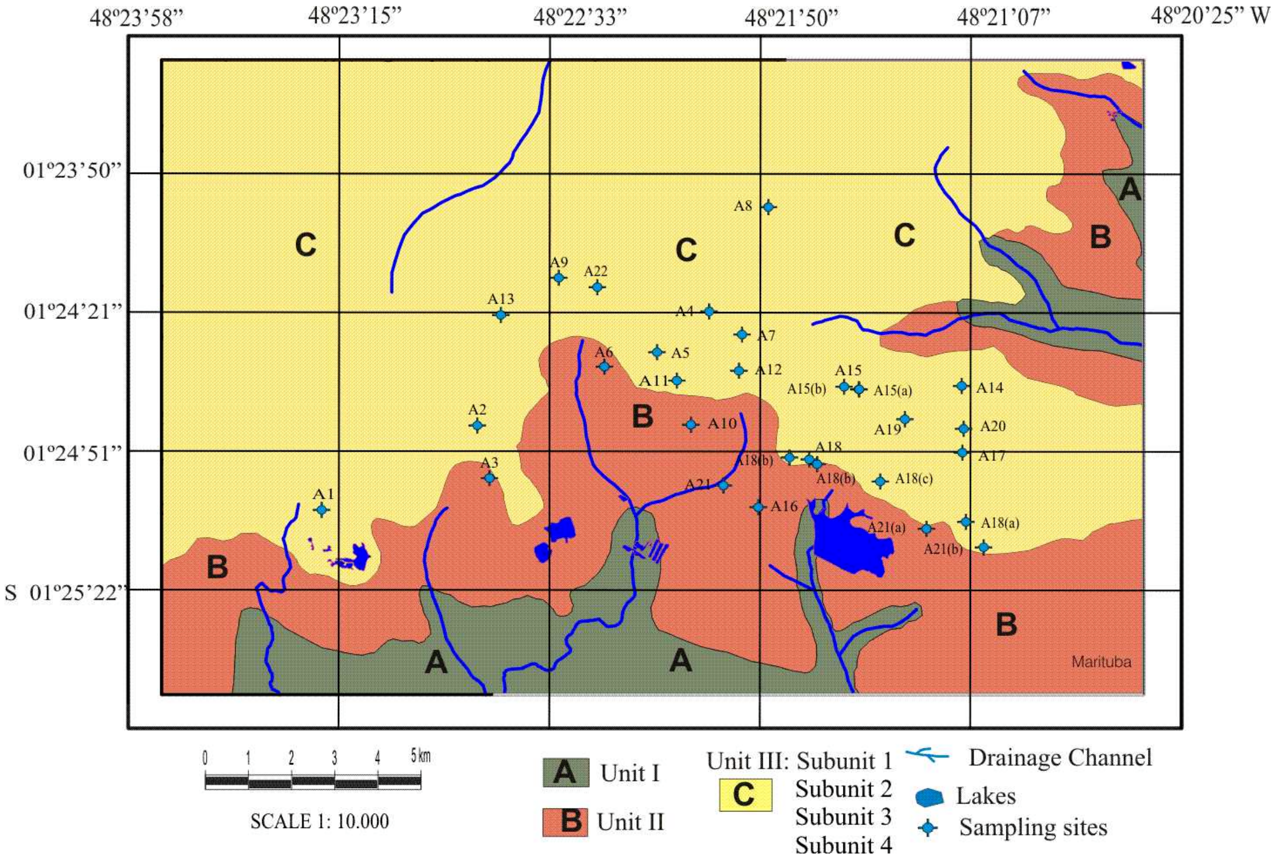

Figure 3. Unconsolidated material map of the Aura portion with sampling sites.

Unit I

This unit (Unit A in the unconsolidated material map – Figure 3) is found close to the main drainage channel (Alluvium) of the area (Figure 4), with declivity values less than 2%, and constituted alternate sand-silty beds and clay lenses. The restrictive attributes for exploitation of these materials are the shallow groundwater level and temporary flooding. The clay lenses are intensely exploited as construction material for ceramic industries to manufacture bricks and roofing tiles. The thickness of this unit varies from 1 to 3 meters. Based on Unified Soil Classification the main types are: MH, CH and SC.

Figure 4 - Sand and silty beds and clayed lenses are found close to the main drainage channel of the area

Unit II

This Unit is composed of transported sandy unconsolidated materials (Unit B in the unconsolidated material map, Figure 3) presenting a low degree of heterogeneity, thickness varying from 0.5 to 4 meters, and some interbedded stratum or sedimentary lens. When in surface, the first meter deep is sandy silt to sandy clay, with high content of organic material. The Figures 5, 6 and 7 show the particle size curves (sand - 60 to 70%, silt – 15 to 22%, clay < 10%), liquid limit results and compaction curves (optimum moisture content about 12%, maximum dry density - 17.5 to 18.5 KN/m3), respectively. There are SC, SC and SP types according to Unified Soil Classification. These sediments are ideal for fill and are intensely used in the region for mortar.

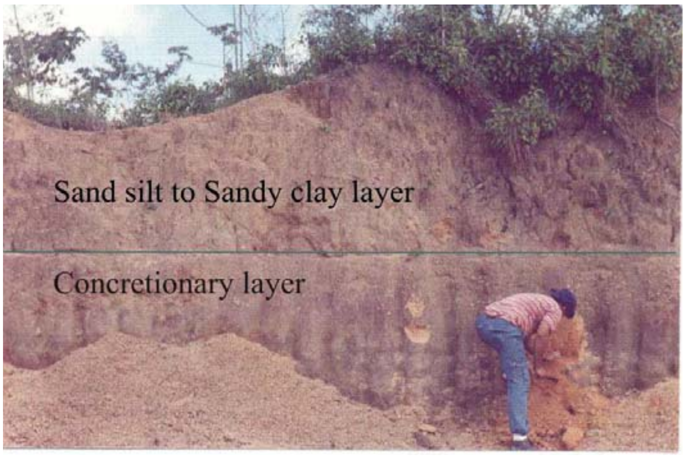

Figure 5. Sand Silt to Sandy clay layer (Unit II) above the Concretionary layer (Subunit 1 Unit III).

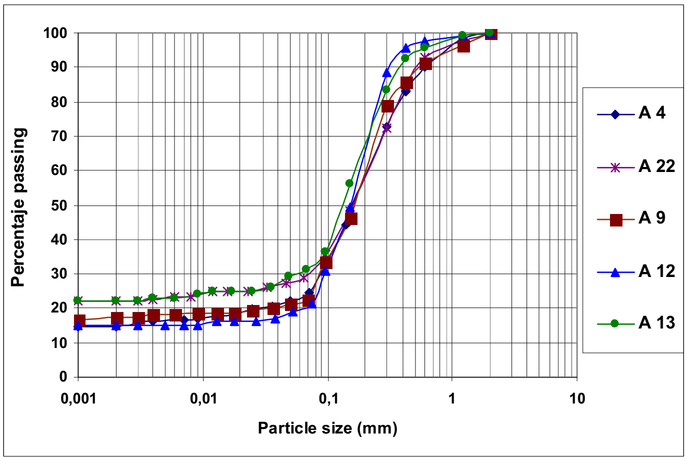

Figure 6. Size particle curves for unconsolidated materials of the Unit II.

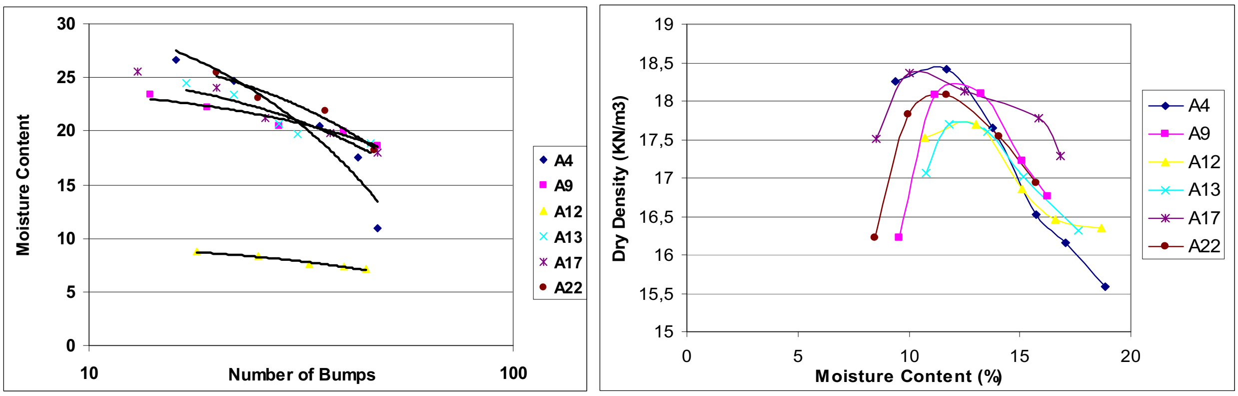

Figure 7. (A)Liquid limit results and graph for unconsolidated materials of the Unit II and (B) Compaction curves for unconsolidated materials of the Unit II.

According to Unified soil classification these unconsolidated materials are classified as sand with little fines (SP).

Unit III

This unit is constituted of Barreiras Formation (named as unit C in the unconsolidated material map, Figure 3) divided into four subunits with basic characteristics shown in Table 4.

Table 4. Top and base layer depth and soil classification based on Unified Soil Classification for Subunits of the Unit III.

Subunit	Basic Description	Top and bottom depth layer (m)	Soil Classification		
			Genetic aspect	Texture	Unified Soil Classification
01	Concretionary layer	0,5 - 5m	RE	Sand with silt and clay	SC, SM
02	Clayed sand layer	0,5 - 4m	RE	Sand with little clay	SW, SP
03	Non-concretionary accumulation of iron sand layer	0 - 4m	RE	Sand with little clay	SW, SP
04	Clayed layer	2 - 8m	RE	Clay with sand and silt	MH, CL

Subunit 1

This sub-unit lies underneath Unit 2 and is separated by one stone line composed of laterite gravels, concretions as we can observe in Figure 6. It is called the Concretionary layer but texturally varies from sand with little silt, to clayey silty sand. The liquid limit, maximum dry density and optimally moisture range between 35 and 55, 14 and 17 KN/m3, 13 and 19 %, respectively (Figures 8 and 9a).

Figures 9b show the particle size and compaction curves, respectively. These results represent clearly the variability of the material within the layer. Due to these characteristics the unconsolidated material that constituted this sub-unit, it is intensely exploited in the Aurá portion.

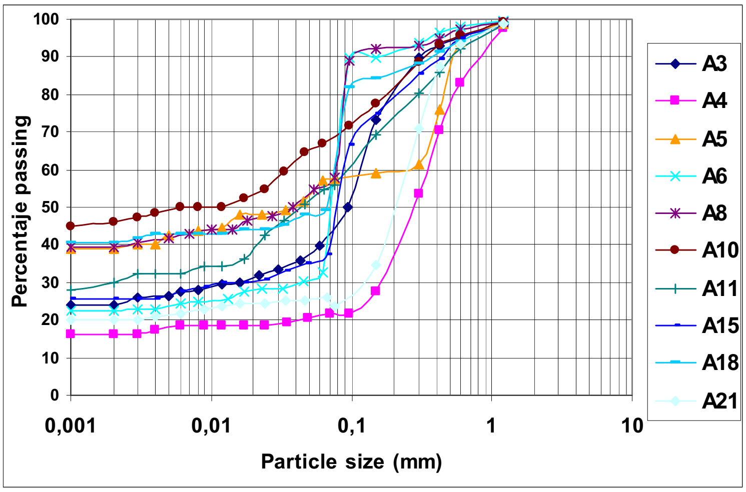

Figure 8. Size particle curves for unconsolidated material of the subunit 1- Unit III.

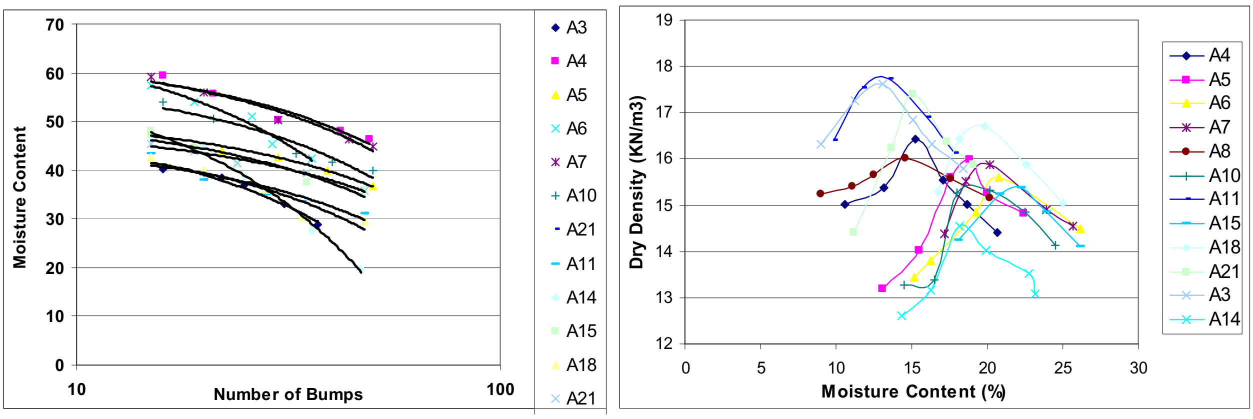

Figure 9. (A) Liquid limit results and graph for unconsolidated material - Concretionary layers, Subunit 1 - Unit III and (B) Compaction curves for unconsolidated materials - Concretionary layer, Subunit 1 - Unit III.

Subunit 2

This sub-unit (clayey sand layer) is laterally positioned to sub-unit 1 with abrupt or gradational contact, and presents predominantly clayey sand texture (Figure 10). The size particle and compaction curves confirm the low heterogeneity degree of this sub-unit.

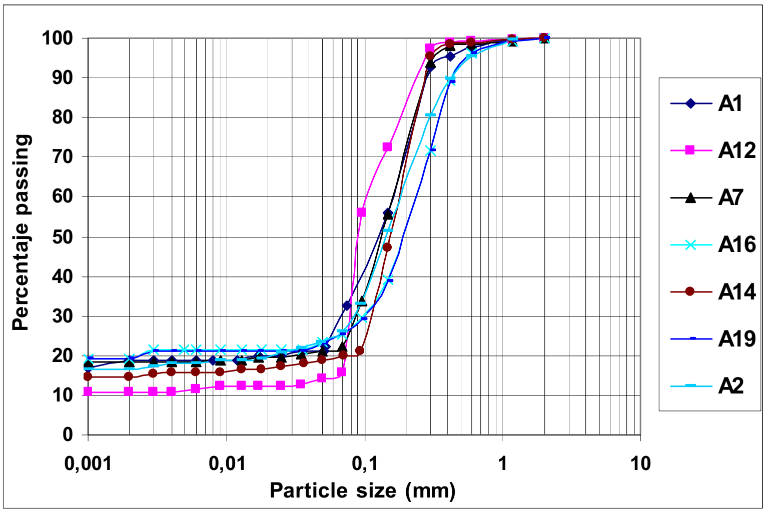

Figure 10. Size particle curves of the unconsolidated material - Clayed sand layer of the subunit 2-Unit III.

The basic geotechnical characteristics obtained from compaction tests (optimally moisture between 10 and 12%, maximum dry density varying from 17.9 to 18.6 KN/m3 – Figure 11a) and liquid limit values are showed in Figure 11b. The geological materials of sub-unit 2 and sub-unit 3 when combined, are used with good behavior as sanitary landfill cover.

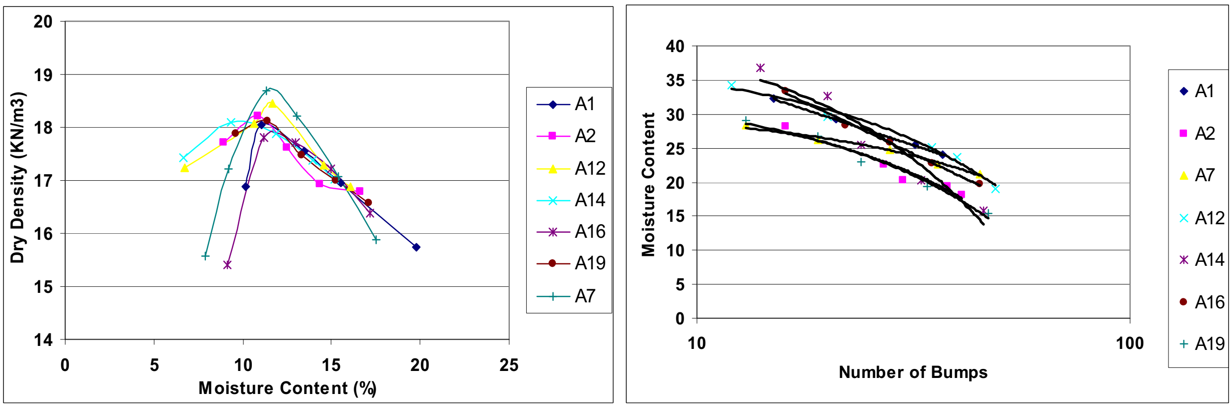

Figure11. (A) Compaction curves for unconsolidated materials – Clayed sand layer, Subunit 2 - Unit III and (B) Liquid limit results and graph for unconsolidated materials – Clayed sand layer, Subunit 2 - Unit III.

Subunit 3

This sub-unit underlies sub-units 1 and 2 with abrupt contact and is characterized by non-concretionary accumulation of iron-rich loose sand. This material presents low cohesion and is easily eroded, leading to the slide of the geological material above (sub-units 1 and 2) which is transported to the drainage channel affecting the water quality and generating silting processes.

The particles sizes and compaction curves, and liquid limit graph for, Figures 12, 13a and 13b, respectively, show the desirable characteristics of this sub-unit for fill.

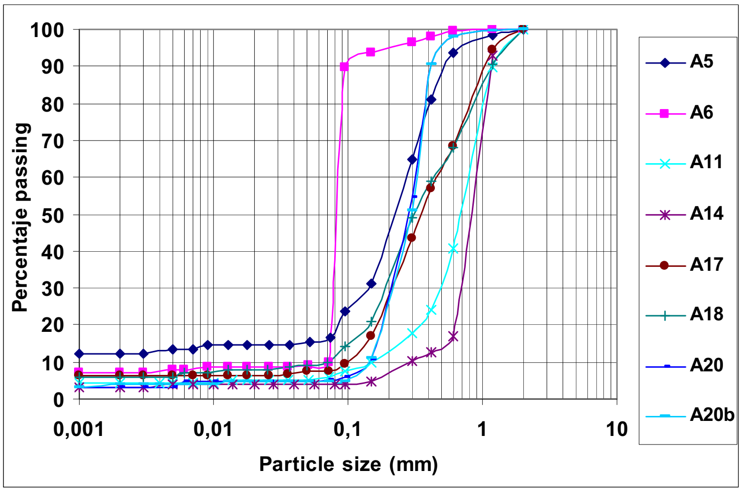

Figure 12. Size particle curves of the unconsolidated material of the subunit 3 of the Unit III.

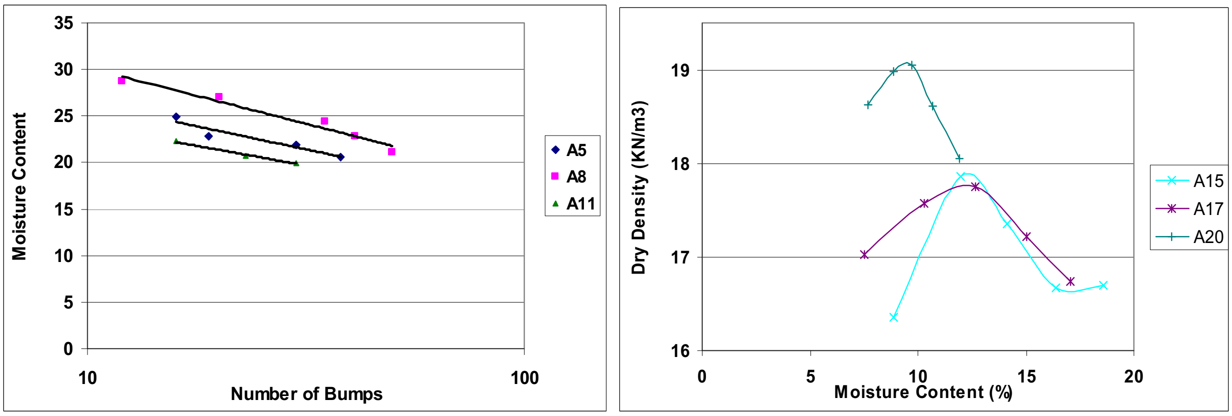

Figure 13. (A)Liquid limit results and graph for unconsolidated material - Non-concretionary accumulation of iron sand layer, Subunit 3 - Unit III and (B) Compaction curves for unconsolidated materials – Non-concretionary accumulation of iron sand layer, Subunit 3 - Unit III.

Subunit 4

A very thick clay layer underlies the other sub-units of Unit III, with abrupt contact. This sub-unit contains more than 50% clay (Figure 14) and the liquid limit varies from 50 to 60 (Figure 15a). It is predominantly used in the ceramic industries.

Figure 16 shows the variation of the profile of the Unit III. At the top is the sub-unit 1 (Concretionary layer) and sub-unit 4 is at the bottom which presents low cohesion and high erodibility index. When erosion occurs the upper layers collapse.

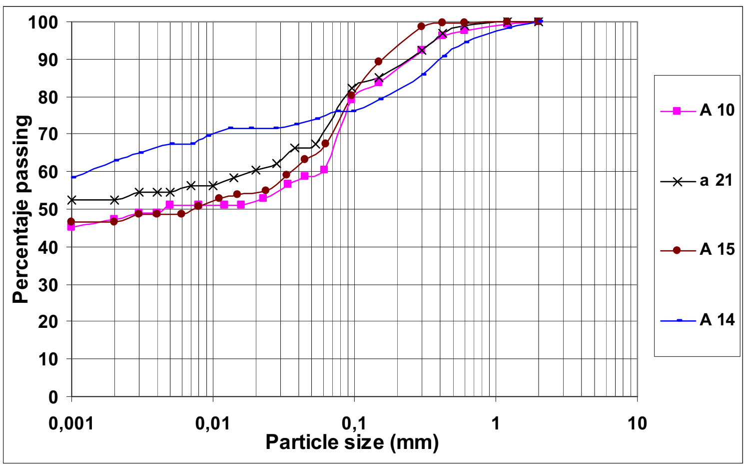

Figure 14. Size particle curves of the unconsolidated material of the subunit 4 of the Unit III.

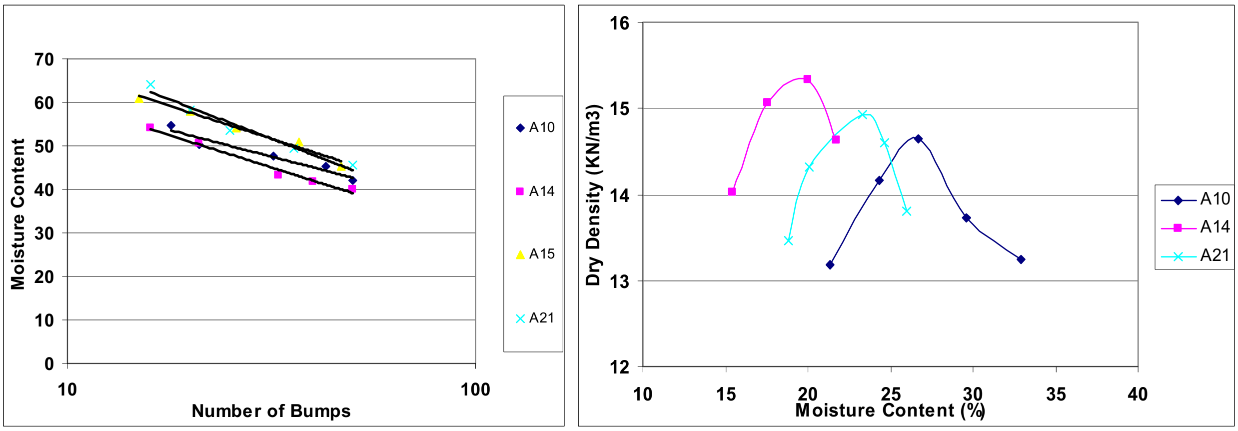

Figure 15. (A) Liquid limit results and graph for unconsolidated material- clay layer, Subunit 4 - Unit III and (B) Compaction curves for unconsolidated materials - clay layer, Subunit 4 - Unit III.

Figure 16. Vertical profile showing Concretionary and – Non-concretionary accumulation of iron sand layer, Subunit 3 - Unit III.

The main unconsolidated material characteristics mapped in the Aurá portion and uses can be observed in the Table 5.

Table 5. Defined units and main geological material and potential uses.

Unit of unconsolidated material		Geological material used as construction material	Main uses
(UNIT1)		Red clay	Brick, roofing tiles, ceramic products
		White clay	Brick, roofing tiles, ceramic products
(UNIT2)	Sandy clay silt layer	Fine sediment	Mortar
STONE LINE		Coarse aggregate	Mortar, gabion, embankment
(UNIT 3)	Concretionary layer	Concretion	Pavement base and sub base, fill
	Clayed sand layer	Clayed sand	Fill
	Non-concretionary accumulation of iron sand layer	Sand	Hydraulic fill
	Clay layer	Clay	Ceramic products

Environmental problems

Aggregate exploitation affects other types of land-use and occupations causing socio-economic problems. Aggregate exploitation has been responsible for several environmental problems in the Aurá portion such as: deforestation to prepare the site for vehicle movements and road construction; removal of surface soil to expose the geological material for excavation; abandoned cavities as a result of excavation; lowering of groundwater level; water contamination with chemical products used by vehicles; erosion of the unconsolidated material exposed during excavation and deforestation; and silting of the drainage channel. Aggregate extraction is, in general, in disagreement with mineral and environmental legislation.

Figure 17. Example of abandoned exploitation site showing several environmental problems: water accumulation, deforestation, and removal of surface soil bed.

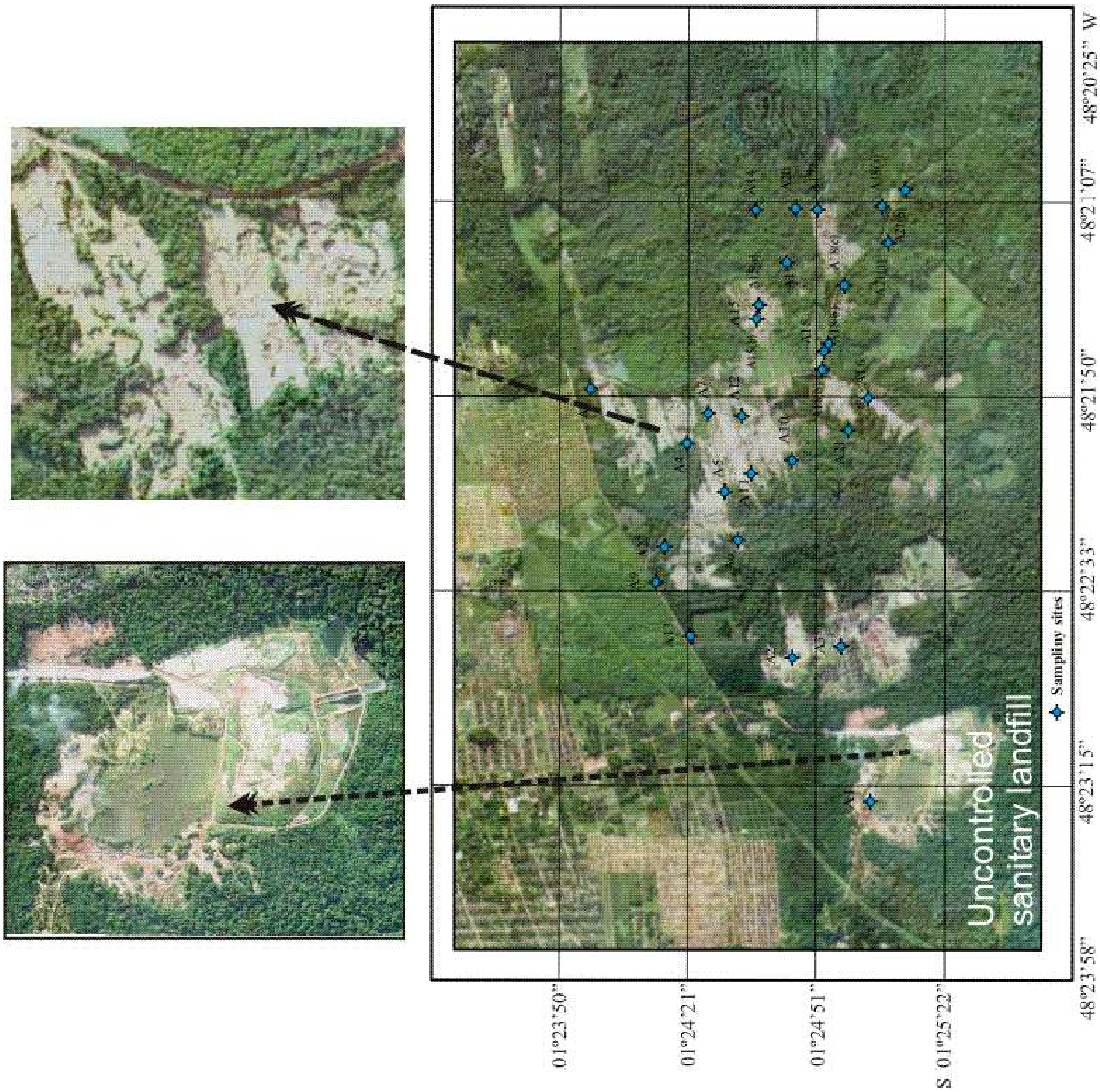

Figure18. Aerial photo (2000) of the Aurá portion showing land degraded sites by aggregates exploitation and examples of degraded sites.

In Figures 17 and 18 the conflicting situation between occupation and aggregate exploitation sites can be seen, as well as the environmental damage caused by the extraction process.

CONCLUSIONS

The geological material layer of the Unit I, II and III presents favorable conditions for brick, roofing tiles, ceramic products, mortar, gabion, embankment, pavement base and sub-base, fill and hydraulic fill.

The unconsolidated materials of Unit III (concretionary layer, clayey sand layer, non-concretionary accumulation of iron sand layer, clay layer) are more adequate for exploitation than the units I and II. But, some exploitation practices should be adapted for the Unit III due to the degree of heterogeneity and quantity of waste materials. The thickness of layers and groundwater level are the main restrictive characteristics for exploitation.

The spatial distribution combined with geotechnical properties of the layers has led to some operational problems during the extraction operations such as: sliding of material, erosion process, mainly in the Unit III. The total land degraded area in the Aurá portion is around 20% of the study area.

Such exploitation has produced deep excavation; intense erosion processes; silting of rivers and lakes; water contamination; and deforestation. There are no control, rehabilitation or restoration measures adopted by owners or public institutions. Mineral and environmental legislation is important to orientate the uses and occupation, as well as to minimize negative environmental impacts.

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