Environmental study of the dump of the tracuateua city (Pará, Brazil) using ground penetrating radar

Estudo ambiental do lixão da cidade de tracuateua (Pará, Brasil) usando radar de penetração no solo

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ABSTRACT

The excessive growth of human populations in recent years, associated with the unbridled expansion of consumerism, has led to an ongoing increase in the disposal of solid waste, raising concerns in the scientific community, and highlighting the need for research on the environmental impacts caused by this process. Human populations exploit natural resources across wide areas for agriculture and urban and industrial development. The present, preliminary study in the municipality of Tracuatuea in Pará, northern Brazil, focuses on an unregulated open dump located within a large tract of natural vegetation, and in the proximity of water resources (i.e. streams, rivers). Ground Penetrating Radar (GPR) was used to investigate the subsurface, and detected the presence of a plume of contamination that reaches a possible water table. The results of this study provided important insights into potential contamination of the subsurface of the study area, which should serve as an alert for the local population and municipal authorities.

Keywords: Open dump, solid waste, environmental contamination, Ground Penetrating Radar
RESUMO

O crescimento excessivo de populações humanas nos últimos anos, associado à expansão desenfreada do consumismo, levou a um aumento contínuo na disposição de resíduos sólidos, suscitando preocupações na comunidade científica e destacando a necessidade de pesquisas sobre os impactos ambientais causados por esse processo. As populações humanas exploram os recursos naturais em grandes áreas para agricultura e desenvolvimento urbano e industrial. O presente estudo preliminar no município de Tracuateua, no Pará, norte do Brasil, concentra-se em um lixão aberto não regulamentado localizado dentro de uma grande área de vegetação natural e nas proximidades de recursos hídricos (ou seja, córregos, rios). O Radar de Penetração no Solo (GPR) foi utilizado para investigar a subsuperfície e detectou a presença de uma nuvem de contaminação que atinge um possível lençol freático. Os resultados deste estudo forneceram informações importantes sobre a possível contaminação do subsolo da área de estudo, que deve servir como um alerta para a população local e as autoridades municipais.

Palavras-chave: Lixão aberto, resíduos sólidos, contaminação ambiental, Radar de Penetração no Solo (GPR).

1. INTRODUCTION

One of the principal problems generated by the growth of human populations and associated industrial and technological development is the excessive production of solid waste (SW). The disposal of this waste is a major preoccupation in Brazil, given the accentuated consumerism of this society, which has led to a drastic increase in the quantity and diversity of waste, and the increasingly preoccupying growth in environmental impacts and pollution levels, resulting in a steady growth in environmental damage [14]. The adequate disposal of this waste, which ranges from organic to chemical residues, will be essential to guarantee adequate standards of security for both the environment and public health [6].

The legal deadline set by the Brazilian government for the reduction of the number of open dumps in operation in the country terminated in 2014, but despite this, the country still struggles to cope with the adequate management of its solid waste, given that the integration of efforts continues slowly, with some sectors in complete stagnation, and in particular, the fact that the volume of the solid waste produced by the country increased by 29% from 2013 to 2014, at a rate five times higher than population growth during the same period.

The Brazilian Association of Companies for Public Sanitation and Special Waste [1] found that 78.4 million tons of SW were produced annually in Brazil, 1% more than 2016. This means that 71.6 million tons had a collection coverage index of 91.3% for the country, which shows that 6.8 million tons of waste were not collected and had an improper destination.

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Approximately 42.3 million tons of SW, or 59.1% of the collected, are disposed in landfills. The remainder, which corresponds to 40.9% of the waste collected, was dumped in inappropriate places by 3,352 municipalities, or 29.3 million tons in open dumps or controlled landfills.

The principal impacts that dumps have on the environment and public health include the pollution of the soil, subterranean water reserves and atmosphere, deforestation, fires, the risk of explosions, and the generation of unpleasant odors [12]. Open dumps are one of the world’s principal environmental problems, causing drastic impacts on the atmosphere, soils, waters, vegetation, and public health. Much of this damage is irreparable. The impacts of the leachate produced by these landfills on local aquifers have been studied in some regions of Brazil, for example, with high concentrations of metals and biological contaminants being found in the water (e.g., [17], [2]). A number of other studies have reported on the use of geophysical methods, combined with direct analyses of the environment impacted by the contaminants derived from the leachate (e.g., [13], [16], [10], [19]).

In the specific case of the municipality of Tracuateua, in the northeast of the Brazilian state of Pará, the area selected as the site for the present study, an open dump is located within a large tract of natural vegetation, in the vicinity of water resources, which makes the local environment vulnerable to contamination by the landfill. In this type of scenario, in particular, the preservation of the quality of edaphic resources is a priority [5], given the potential for contamination by slurry and other harmful compounds with high concentrations of heavy metals, that may contaminate the soil and possibly also the water table.

This preliminary study was based on the application of the Ground Penetrating Radar (GPR) geophysical tool, and the findings provide important insights into the environmental impacts caused by the contamination of the subsoil by the leachate produced by the solid waste disposed of in the open dump of the municipality of Tracuateua.

2. CHARACTERISTICS OF THE STUDY AREA

2.1 LOCATION

The study area (Fig. 1) is located near the town of Tracuateua, in Pará state, Brazil, at an open dump. The municipality of Tracuateua covers an area of approximately 936.13 km², and is located in the Northeast Mesoregion of Pará state, as part of the Bragança Microregion. The
town is located at 00°46’18” S, 47°10’35” W, and had 27,455 inhabitants in the 2010 census [8].

The open dump is located on an extension of Mário Nogueira Avenue, approximately 3 km from the town center, on an unpaved road. The open-air disposal of waste tends to result in the dispersal of residues outside the area of the dump during rainy periods, and may cause related problems, such as the proliferation of animal disease vectors, the contamination of standing and subterranean water, and the soil, as well as other processes, such as the eventual encroachment of the area by trash pickers (Fig. 2).

Figure 1. Study area (outlined by the red rectangle) located in the municipality de Tracuateua (Pará) showing the open dump in the vicinity of the town of Tracuateua. Modified from [7]
2.2 GEOLOGICAL CHARACTERISTICS

Geologically, the municipality of Tracuateua is characterized by granitic pre-Cambrian rocks, covered with Phanerozoic substrates [4]. The Tracuateua Granite covers part of the Tracuateua-Quatipuru basin, over an area of approximately 282 km², which corresponds to 20% of the geological composition of the site [11]. According [15] two geotectonic units are found in the region, the São Luís Craton and the Gurupi shear belt, which are separated by the Tentugal-ZCT (NW-SE) shear zone. The granitogenesis of this region is consistent with a geotectonic environment characterized by occasional collisional interactions between the island arcs and the volcano-sedimentary basin, with Archaean nuclei, which may be correlated with the trans-Amazonian event. The dating of this rock indicated an age of approximately 2.0 Ga, which corresponds to the Paleoproterozoic Era.

The most prominent outcrop of Pre-Cambrian Granite is found in the outskirts of the town, and is made up of a mechanically homogeneous and fragile material, with a lumpy fracturing pattern in different stages. This body includes rocks of colours ranging from pinkish and pinkish-gray to whitish gray, and has an isotropic, phaneritic, hololeucocratic to leucocratic texture with medium to coarse granulometry. The constituent minerals include quartz, microline, albite-oligoclase, muscovite, and biocide, with zircon, apatite,
and opaque minerals as accessories [15].

3. METHOD

The present study was based on underground surveys conducted using Ground Penetrating Radar (GPR), a geophysical tool. The GPR is an electromagnetic procedure that uses high frequency radio waves (normally 10–1000 MHz) to locate structures and shallow geological features in the subsurface, or to identify the location of man-made objects buried in the ground [3]. The GPR method is based on the emission, reflection, and reception of the electromagnetic waves, which respond to the dielectric properties of the ground through which the signal is propagated. The GPR data were obtained using the common-offset configuration required by the GPR equipment used (GSSI SIR3000 (Geophysical Survey Systems, Inc.) (Fig. 3). The data were collected during the rainy (February) and dry (July) seasons of 2017, using two antennas, one 200 MHz and one 400 MHz, with time windows of 100 ns, 150 ns, 200 ns, and 250 ns.

The use of a given time window will depend on the target depth of the study, and may vary according to the aims of the survey. It is essential to predefine the time window, which will be valid only for the specific study [9]. The signals were generated at 10 meter intervals along each profile of the geophysical survey.

Figure 3. The GSSI SIR3000 Ground Penetrating Radar equipment used to collect geophysical data in the present study
4. RESULTS

The location and orientation of the GPR profiles surveyed during the present study are shown in Figure

1. Rainy season 2017

A total of 12 GPR profiles were surveyed during the rainy season (February) of 2017. The processed profiles are presented in Figs. 4–7.

In the AB profile (Fig. 4), a strong sub-horizontal reflector was detected at a depth of 0–0.3 m. A number of hyperboles of energy dispersion were also identified, which may be related to the presence of buried pipes or tubes. A strong sub-horizontal reflection was also detected at a depth of approximately 5.5 m which corresponds to the occurrence of a water table that was confirmed by [18] and also corroborated by the artesian well excavators at the site.

A subsurface zone was also detected in the AB profile (Fig. 5), which may represent a plume of underground contamination (red dotted ellipse). In this profile, it was identified a pile of layers separated by curved interfaces at a depth between 5.5 and 8 m.

Figure 4. Radargram of the AB profile (February 2017) obtained using an antenna with a frequency of 400 MHz and a time window of 150 ns
As in Fig. 4, the CD profile (Figure 6) revealed a number of reflection events of hyperboles of energy dispersion, which may be related to the presence of buried pipes or tubes. Similarly, a strong sub-horizontal reflection was also detected at depths of between 5.5 m and 6.0 m related to the presence of a water table.

The AB profile (Fig. 8) detected the presence of a strong sub-horizontal reflector at depths of between 0 m and 0.3 m, similar to that detected during the rainy season (Figs. 4–7).
Similar patterns to those presented in Figures 4 and 6 were also identified in the CD profile (Fig. 7), including the detection of a strong reflection at depths of between 0 m and 0.3 m, as well as the occurrence of a number of hyperboles of energy dispersion at between 0 m and 2 m, which may be related to the presence of buried pipes or tubes.

2. Dry season 2017

Twelve GPR profiles were also surveyed during the dry season (July) of 2017. The processed profiles are presented in Figs. 8–11. Similarly, a number of hyperboles of energy dispersion were detected, which may indicate the presence of buried pipes or tubes, in particular at depths of 0–2 m, and below approximately 2 m (Figs. 8 and 9). A strong sub-horizontal reflector was also detected at a depth of approximately 5 m, with a dip angle of approximately $3^\circ$, which may be related to the presence of a water table (Figs. 9 and 10).

In the CD profile (Fig. 11), a sub-horizontal reflector was also detected close to the surface, at depths of 0–0.3 m, together with hyperboles of energy dispersion at depths of 0–2 m, which indicate the presence of buried material or waste. A strong sub-horizontal reflector
was also detected at a depth of approximately 5 m (Fig. 12), similar to that shown in Figs. 9 and 10, and which may be related to the above water table.

Figure 9. Radargram of the AB profile (July 2017) obtained using an antenna with a frequency of 200 MHz and a time window of 200 ns

Figure 10. Radargram of the AB profile (July 2017) obtained using an antenna with a frequency of 200 MHz and a time window of 150 ns

Figure 11. Radargram of the CD profile (July 2017) obtained using an antenna with a frequency of 400 MHz and a time window of 200 ns

Figure 12. Radargram of the CD profile (July 2017) obtained using an antenna with a frequency of 200 MHz and a time window of 150 ns
5. CONCLUSIONS

The GPR geophysical tool provided important insights into the underground characteristics of the environment influenced by the presence of the open dump in the town of Tracuateua in Pará, northern Brazil. The radargrams obtained during the present study detected the presence of a sub-horizontal reflector at a depth of 0–0.3 m.

A possible zone of contamination was also detected at the dump, at depths of between 2 m and 5.5 m, whose specific characteristics can only be confirmed through the application of complementary geophysical techniques. A number of hyperboles of energy dispersion were also detected, which may be related to the presence of pipes, materials or tubes buried at depths of between 0 m and 2 m, and below approximately 2 m. It seems likely that these compartments existed prior to the operation of the dump and were filled indiscriminately with solid waste, which was then compacted, as indicated by the sub-horizontal layer detected under the surface. In addition, a strong sub-horizontal reflection was detected at a depth of approximately 5 m, with a dip angle of between 1º and 3º, which may be related to the possible presence of a water table. The materials and solid waste buried at the study site may come into contact with the possible water table detected during the surveys.

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