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A Semi-Detailed Survey of Soils in the City of Jaboatão dos Guararapes – PE: A Contribution to the Geotechnical Mapping of Suitability for Urbanization

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A B S T R A C T

The economic development of the city of Jaboatão dos Guararapes was generated spontaneously without considering the land use capacity or its position in the landscape. Due to the occupation and intensive disordered use of the city pedological coverage, there have been mass movements that have caused economic and social losses. These can be resized based on the understanding of the pedological aspects inherent to the city. The objective of the present paper was to map the soils of the city area at a semi-detailed level. For this purpose, different toposequences were used, with soil examinations at a rate of 1 for every 2.75 km², totaling 94 points. The mapping and taxonomic classification of soils were made in accordance with standards, procedures and criteria adopted by Embrapa Soils. Based on the morphological data, locations were defined for soil description and sampling, totaling 14 soil profiles. 15 soil classes were identified, and 23 mapping units were defined, which highlighted the notable role of the source material in the distribution of the city's pedological properties. The mapping units that require greater care for use are: a) in hill environments - PAdr1, PVAd1 and PVd; and b) in the fluvial-marine plains – EKu1, EKu2 and GXbd2. The expansion of urban areas must consider the type of soil and the behavior of the material, especially during the rainy season, in order to minimize risks and adverse losses.

Keywords: Pedology, Geotechnical Cartography, Soils from Pernambuco.

Levantamento Semidetalhado dos Solos do Município de Jaboatão dos Guararapes – PE: Uma Contribuição a Carta Geotécnica de Aptidão a Urbanização

R E S U M O

O desenvolvimento econômico do município de Jaboatão dos Guararapes foi gerado de forma espontânea sem levar em consideração a capacidade de uso do solo e nem sua posição na paisagem. Devido a ocupação e uso intensivo desordenado da cobertura pedológica municipal, tem ocorrido movimentos de massa que causaram prejuízos econômicos e sociais. Estes podem ser redimensionados a partir da compreensão dos aspectos pedológicos inerentes ao município. O objetivo do presente estudo foi realizar o mapeamento dos solos da área do município em nível de semidetalhe para análise da aptidão atendendo aos princípios da Carta Geotécnica de Aptidão a Urbanização frente aos desastres. Para tal propósito foram utilizadas diferentes topossequências, com exames de solos na proporção de 1 para cada 2,75 Km², totalizando 94 pontos. O mapeamento e a classificação taxonômica dos solos foram realizados conforme normas, procedimentos e critérios adotados pela Embrapa Solos. A partir dos dados morfológicos foram definidos locais para descrição e amostragens dos solos totalizando 14 perfis de solos. Foram identificadas 15 classes de solos e definidas 23 unidades de mapeamento que evidenciaram o papel marcante do material de origem na distribuição das propriedades pedológicas do município. As unidades de mapeamento que despertam um maior cuidado para uso são: a) nos ambientes de morros - PAdr1, PVAd1 e PVd; e b) nas planícies flúvio-marinha – EKu1, EKu2 e GXbd2. A expansão de áreas urbanas deve levar em consideração o tipo de solo e o comportamento do material, principalmente no período chuvoso de modo a

minimizar riscos, vulnerabilidade e perigo no planejamento e implantação de novas ocupações residenciais, comerciais, serviços ou industriais.
Palavras-chaves: Pedologia; Cartografia Geotécnica; Solos de Pernambuco.

Introduction

Between 2007 and 2011, Brazil experienced a significant number of disasters, with an unprecedented annual recurrence. In 2007, approximately 2.7 million people were affected by disasters. In 2008, heavy rains caused significant losses in the Itajaí Valley region of Santa Catarina. At the end of 2009 and the beginning of 2010, heavy rains caused destruction and deaths in Angra dos Reis and Ilha Grande. In 2010, severe weather events resulted in floods and inundations in Pernambuco and Alagoas, affecting about 12 million people. In 2011, the Serrana Region of Rio de Janeiro suffered the country's worst natural disaster, with 947 deaths, more than 300 missing, thousands of displaced and homeless people, as well as severe economic losses and infrastructure destruction due to flash floods and landslides.

In 2022, in the Recife Metropolitan Region, state of Pernambuco, one of the largest climatic catastrophes ever recorded occurred, resulting in over 127 deaths and 4,000 displaced people, along with numerous material losses. The spatial distribution of accumulated precipitation between May 23 and 29 resulted from the activity of the atmospheric system known as Easterly Wave Disturbances (EWD), which intensified and expanded its impact area, affecting cities in the states of Paraíba and especially Alagoas. The magnitude of this event was amplified by the influence of a cold front a few days prior to the rainfall event and a positive sea surface temperature anomaly in the Atlantic Ocean near the northeastern coast of Brazil. Additionally, the possibility of flooding increased due to high tide conditions (Marengo et al., 2023; Dos Anjos et al., 2024).

In 2024, the state of Rio Grande do Sul was hit by persistent and heavy rains due to a large area of low atmospheric pressure that favored the formation of new instability areas, along with the formation and displacement of a cold front. These precipitations caused flood events of exceptional magnitude in May and June, marking the state's largest flood disaster due to storms and the formation of a new frontal system (Inmet, 2024). The number of mapped mass movement scars was 6,148 as of the update on June 16, 2024, representing approximately 50% of the total area affected in the southern escarpment of the Meridional Plateau-RS (UFRGS, 2024).

Within this context of recurrent large-scale climatic disaster events, the aim is to implement public policies outlined in Federal Law No. 12.608/2012, which addresses the National Policy on Protection and Civil Defense (PNPDEC), with the goal of integrating the prevention of issues due to inadequate occupation with land-use planning, development, and environmental policies. The PNPDEC proposes essential tools such as mapping susceptible areas, contingency plans and works, control and inspection mechanisms, and the geotechnical map of urbanization suitability. The Geotechnical Map is required in the Municipal Master Plan (PDM) to identify areas susceptible to harmful geological processes and must be updated every ten years.

According to Varnes (1974) and IEAG (1976), the creation of the geotechnical map requires basic operations of addition, selection, generalization, and transformations of spatial information related to the lithology and structure of soils and rocks, hydrogeology, geomorphology, and geological processes. Cerri et al. (1996) proposed the method of progressive detailing for geological-geotechnical mapping in three successive stages, each determining the technical themes and the depth required for the next phase. Zaine (2000) named these stages as: General: Scale between 1:50,000 and 1:25,000, focusing on the characterization of the physical environment; Intermediate: Scale between 1:25,000 and 1:10,000, for densification and/or urban expansion areas, selected from the regional map; and Detail: Scale 1:10,000, with the possibility of studies at larger scales than 1:5,000 to support engineering projects and new developments.

Zuquette (1987); Souza and Sobreira (2014); Santos (2014); Antonelli et al. (2021); Coutinho et al. (2024) present methodological procedures developed by researchers associated with the Institute for Technological Research (IPT), Geological Service of Brazil (SGB-CPRM), Federal University of ABC (UFABC), Federal University of Ouro Preto (UFOP), Federal University of Pernambuco (UFPE), and Federal University of Santa Catarina (UFSC) for the preparation of Geotechnical Susceptibility Maps for processes on an intermediate scale; and the Geotechnical Maps of Urbanistic Suitability for Land Parceling in the planning scale of 1:10,000 or larger.

The primary objective of the preparation of the Geotechnical Maps of Urbanization Suitability (GCAU) is to provide information that guides land use and occupation in a sustainable manner, compatible with the physical environment's carrying capacity, preventing risks and mitigating the consequences of disasters. These maps are essential references in the licensing processes of new land parceling projects, especially in municipalities subject to geotechnical risks.

In this context, the essential basic and thematic mappings for the classification of urbanization suitability must be consistent and adequate for geotechnical analysis, considering the geodynamic and hydrological processes identified in the mapped area. These correspond to studies of topography, geology, pedology, soil permeability, geomorphology, land use and occupation, mining, inventory, and susceptibility of processes, among others.

Therefore, this paper presents how to produce a map that records various surface covers, such as residuais soil classes, colluvium, alluvium, talus bodies, detrital covers, sandy deposits, boulder fields, and soils susceptible to geohydrological and environmental processes. Thus, the map of pedological formations will show the influence of the pedogenetic processes mapped in each class by soil horizon. In addition to knowledge about soil permeability necessary to guide the installation of urban and/or risk ventures, such as cemeteries, sanitary and industrial landfills, and industries dealing with toxic inputs or effluents, these are necessary items for the recommendations of the Geotechnical Map.

Pedological surveys involve knowledge about genesis, morphology, soil-landscape relationships, geological information, climatological information, classification and mapping. Genesis synthesizes specific characteristics of the soil due to the combined action of its factors and formation processes; morphology concerns the aspects externalized by the material (soil) reflecting its genesis in local environmental conditions; soil-landscape relationships highlight topographic influences on water migrations (lateral and vertical) and consequently on the intensity of the processes; geological information denotes the influence of the source material, especially mineralogy, on the evolution of soils; climatological information corresponds to the action of temperature and humidity on the transformations of primary minerals into secondary minerals; classification involves knowledge of horizons and diagnostic attributes to classify the soil into a taxonomic class; mapping is the art and technique of defining mapping units, mainly, according to soil-landscape relationships and source material. Because of this, the act of mapping implies the definition and ordering of mapping units based on characteristics: morphological, physical, chemical, mineralogical, degree of development and arrangement of soils in landscapes, considering the density of observations carried out in the field and correlated with the scale of the final product (map).

The greatest contribution of a pedological survey is to support assessments of the potential of land for agricultural purposes, urban planning, territorial planning projects pointing out land with arable potential and/or the implementation of engineering constructions such as roads (BRADY; WEIL, 2013). From a geotechnical perspective, soil behaves as a suitable material or not, depending on its physical conditions and the financial resources available to complete a project. From an agricultural point of view, Vezzani and Mielniczuk (2011) point out that, in nature, soil functions as a mean for plant growth, it promotes the cycling of chemical elements, regulates water flow and serves as a filter, mitigating the degradation of compounds harmful to the environment.

Soil surveys enable interpretations to identify the potential and limitations of the land and, therefore, contribute information to support land use policies based on sustainability principles. The pioneering pedological work of the 1940s began with this perspective. In the 60s, 70s and 80s, Brazil made great advances in this area with the aim of preparing the Soil Map of Brazil, published at a scale of 1:5,000,000 by EMBRAPA (1981) and updated in a partnership between EMBRAPA and IBGE, recently (EMBRAPA, 2011).

The State of Pernambuco has always been at the forefront of pedological surveys. The first soil survey paper was published in 1972 and consisted of an exploratory survey – recognition of the State's soils on a scale of 1:600,000 (BRASIL, 1973; JACOMINE et al., 2016). Subsequently, to meet a demand for economic and environmental development in the State, EMBRAPA (2000), in a partnership between EMBRAPA SOLOS UEP-Recife and the state government, published the soil survey on a 1:100,000 scale. This last paper subsidized the Agroecological Zoning of the State of Pernambuco – ZAPE (EMBRAPA, 2001).

Although the soil map at a scale of 1:100,000 constitutes an enormous contribution to planning at the state level, the scale of information and the heterogeneity of the source material (rocks and sediments) do not allow for adequate city planning to define its expansion policies based on the data at this scale. Since 1 cm (on the map) corresponds to 1 km (on the ground) and in urban space an area of 1 km² can represent a significant number of uses. So, when the objective of the soil map is to define, in the city context, the suitability of land for agricultural or urban use, the suggestion is that the product should be on a scale of around 1:25,000 or greater.

To overcome planning challenges at the municipal level and support policies for coexistence with areas most susceptible to the risks inherent to disorderly occupation, developed over more than 5 centuries, the federal government enacted Law 12,608 as the National Civil Protection and Defense Policy - PNPDEC (BRAZIL, 2012). Among the guidelines present in the previously mentioned Law, the need for the PNPDEC “must be integrated into territorial planning policies, urban development, health, environment, climate change, water resources management, geology, infrastructure, education, science” and technology and other sectoral policies, with a view to promoting sustainable development”.

In this context, the agreement signed between Secretaria Nacional de Proteção e Defesa Civil (SEDEC) / Ministério do Desenvolvimento Regional (formerly Ministério das Cidades) and the Geotechnical Engineering Group for Slopes, Plains and Disasters (GEGEP) / UFPE to prepare the Geotechnical Mapping Planning for Urbanization in the face of Natural and induced Disasters and other related products in areas belonging to the urban perimeter and urban expansion in the cities of Camaragibe; Abreu e Lima; Cabo de Santo Agostinho; Jaboatão dos Guararapes, located in the Metropolitan Region of Recife, State of Pernambuco, on a scale of 1:10,000. All projects were carried out under the coordination of GEGEP and included the participation of a multidisciplinary team divided into thematic axes (Cartography, Geology, Geomorphology, Water Resources, Geoprocessing, Pedology and Geotechnics). Regarding the second project, maps of 1:25,000 were developed throughout the municipal area. Thus, the pedological mapping for the city of Jaboatão dos Guararapes was carried out with an emphasis on urban planning.

Therefore, soil surveys, on a compatible scale, make it possible to recognize the natural characteristics of the territory, plan occupation actions and take advantage of existing infrastructure with the aim of guaranteeing the preservation of limited resources (SAMPAIO, 2008).

So, this paper refers to a semi-detailed survey of soils in the city of Jaboatão dos Guararapes – PE, Brazil. This constitutes one of the stages of the project to prepare the Geotechnical Mapping of Planning for Urbanization in an area indicated by the city hall of that city. This area indicated by municipal management concerns the territorial area where the urban area could expand depending on natural conditions. So, it was decided to prepare a soil map at a scale of 1:25,000 adjusted to a cartographic base at a scale of 1:10,000 for the entire city. This decision was based on the idea that municipality would have substantial gains if information gathering and planning were carried out for the entire city territory.

The objective of the present paper was, therefore, to classify the soil units existing in the municipality of Jaboatão dos Guararapes, Pernambuco, Brazil by presenting soil profiles and the processes that reduce stability and increase the risks of landslides, erosion, floods, inundations, or contamination due to high soil permeability, with the aim of supporting the Geotechnical Mapping of Suitability for Urbanization.

Materials and methods

Characterization of the studied area

The city of Jaboatão dos Guararapes is part of the Metropolitan Region of Recife – RMR (the acronym in Brazilian Portuguese). It has an area of 258.7 km². It borders to the north with the cities of Recife and São Lourenço da Mata, to the east with the Atlantic Ocean, to the south with Cabo de Santo Agostinho and to the west with Moreno (Figure 1).

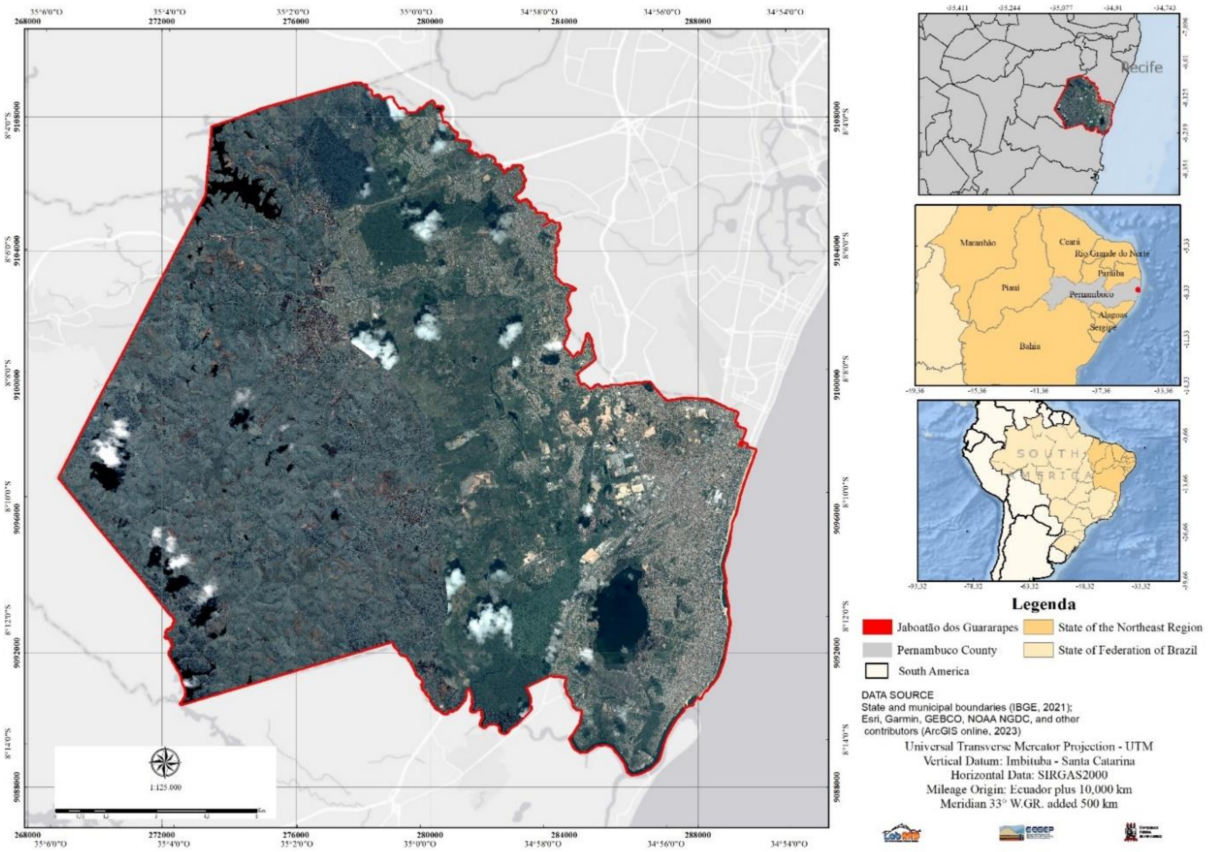

Figure 1. Location Map of the city of Jaboatão dos Guararapes – PE, Brazil. Source: the authors.

The relief of the city of Jaboatão dos Guararapes exposes forms related to tectonic activities and the differential behavior of rocks. Hills made up of material from the crystalline basement and/or the Barreiras Group, marine terraces, fluvial-marine plains, floodplains and alluvial terraces stand out (BARRETO; SILVA; OLIVEIRA, 2012; FONTOURA et. al., 2021).

The climate of the area is As’, humid tropical with autumn/winter rains according to the Köppen classification (PERNAMBUCO, 1999). According to Teixeira and Galvíncio (2010) Aragão and Duarte (2023), rainfall in Jaboatão dos Guararapes and neighboring cities is controlled by the Intertropical Convergence Zone and its main driving mechanism is the East Waves, which act, mainly, in the months of May to August. The drainage is made up of rivers that flow directly into the Atlantic Ocean. Among the main watercourses, Pirapama and Jaboatão stand out. The latter constitutes the most important drainage system with a length of 72 km within the cities and shows, in its channels, a strong structural control due to its proximity to the Pernambuco Lineament. While the Pirapama River appears only in the southwest region of the city and has structural control.

The original vegetation cover was composed of plant formations from humid tropical environments, such as the Tropical Forest, Restinga Evergreen Forest and Mangrove vegetation. Land use in rural areas includes family farming and sugar cane monoculture; in urban areas, industry and services are predominantly.

Morphological Recognition for Soil Classification

The development of semi-detailed soil mapping in the city of Jaboatão dos Guararapes began with a morphological recognition of the soils in the area, in accordance with the soil description and collection manual in the field (SANTOS et al., 2015) and observing normative procedures of pedological surveys, especially for the delimitation of soil mapping units (EMBRAPA, 1995). The taxonomic classification of soils was carried out in accordance with the Brazilian Soil Classification System - SiBCS (SANTOS et al., 2018).

Morphological studies were made through soil examinations with the aid of an auger or using road cuts (gullies). To perform the examinations, the roads were covered, in general, in a direction perpendicular to the drainage lines, aiming to observe the most important soil variations existing in the city's area. The paths were registered on GPS routes and the points examined were duly georeferenced and noted on field records according to Santos et al. (2015).

The analysis of a landslide on highway PE-89 served as guidance for geotechnical analysis of soil class data. And this presents a soil profile of a landslide that occurred in two stages; the first after the cut for highway intervention that corresponds to Area 6 in figure 2; the second demonstrates the landslide scar considering the compartmentalization of areas 01, 02, 03 and 03rd. The profile presented a steep surface with great variation in percolation and impermeability in the soil layers, verified in the landslide profile that occurred after a precipitation event of around 200 mm/month in the months of April to August 1972 (Coutinho et. al., 1996).

Figure 2. Aerial view of the landslide – 1995 Source: Coutinho et. al. (1996)

Based on the morphological survey, desk research was performed where the most representative soils were selected for description and sampling of soil profiles. Considering the profiles available in the area of previous studies (BRASIL, 1973; EMBRAPA, 2001), it was necessary to describe and collect 03 more soil profiles to meet the demands of the work scale. The description and sampling of soil profiles followed the recommendations of Santos et al. (2015).

The fieldwork ended with the results of 94 exams (80 solely morphological data and 14 morphological and analytical data). The proportion of soil examinations in the field was approximately one survey (trolling/examination in a road cut or trench) for every 2.75 km².

The data obtained in the fieldwork were transcribed into a digital format and stored in shapefile extension using the ArcGIS Pro software (available by GEGEP - UFPE). Planialtimetric maps (sheets: Gurjaú, Ponte dos Carvalhos, Recife and Jaboatão) were used at a scale of 1: 25,000 from the Superintendência do Desenvolvimento do Nordeste – SUDENE (1972) as a cartographic basis to support soil mapping in the field.

Subsequently, the limits of the mapping units were adjusted to a database at a scale of 1:10,000 that includes the planialtimetric base prepared through vectorization of Orthophoto from 1970/80 with an equidistance of 5 meters, 2008 Quickbird images, both at a scale of 1:10,000 provided by CONDEPE/FIDEM to GEGEP. In addition to the aerial synthetic aperture radar imaging, carried out by the company BRADAR (EMBRAER DEFESA & SEGURANÇA) in 2013, commissioned by CPRM, the initial spatial resolution of the survey was on a scale of 1:25,000. All products delivered by BRADAR (Orthoimages, MDT and geospatial and vector databases) were corrected and calibrated through a network of geodetic points in the field, with the purpose of controlling and adjusting the georeferencing of images in planimetry and altimetry for reprocessing of the most accurate orthoimages, aiming to provide services on a 1:10,000 scale.

This procedure was carried out by the cartography team of the Geotechnical Engineering Research Group for Plain Slopes and Disasters (GEGEP), at the Federal University of Pernambuco (UFPE).

Based on the material consulted, in accordance with field examinations, an interpretation was made of the main soil patterns (mapping units), considering the patterns of geology, relief, drainage, vegetation and soil arrangement in the landscape. The final product was prepared for a 1:25,000 data scale depending on the number of exams. However, the boundaries of the mapping units were adjusted on a cartographic basis at a scale of 1:10,000 (CONDEPE/FIDEM, 2008; CPRM, 2013).

Physical and Chemical Soil Analyses for Soil Classification Adapted to Geotechnics

The physical and chemical analyzes followed the methodological procedures recommended by EMBRAPA (TEIXEIRA et al., 2017). From the results it was possible to proceed with the taxonomic classification of soils and the definition of mapping units, initially compartmentalized only with morphological data. With the completion of the delimitation of the mapping units, it was possible to prepare the caption and the final soil map of the city of Jaboatão dos Guararapes compatible with the 1:25,000 scale.

To estimate missing soil density data in profiles 1, 9 and 10, the pedotransfer function of Benites et al. (2006) was used. Regarding available water, it was estimated using the pedotransfer function of Oliveira et al. (2022). Silva et. al. (2021) evaluated the use of pedotransfer functions (PTFs) available in the literature to estimate soil density (DS) using different soil attributes determined from soils of the São Joaquim National Park, Santa Catarina, with a total of 260 soil samples collected at depths of 0-10, 10-20, 20-30, and 30-60cm.

Because this survey was the result of an interdisciplinary partnership, it was decided to explain, when necessary, some analytical results from the perspective of pedology and geotechnics. In the analysis, emphasis was placed on erosion processes, landslides, rockfalls, and the permeability of susceptible soils in each horizon of the soil profiles of the mapped classes. The use of geotechnologies, including satellite images, orthophotos, and Digital Terrain Models (DTM) obtained with radar, as well as in situ observations, contributed to the temporal analysis and evolution of processes resulting from land use changes. This approach aligns with the methodology presented by Girão et al. (2018), Arruda et al. (2021), Lima et al. (2021), Souza et al. (2023), and Pessoa Neto et al.

The aim is to facilitate reading for those who are not familiar with pedological language since some terms present in geotechnics do not have the same meaning in pedology. Therefore, whenever a term used has a different meaning for these two branches of knowledge, an asterisk (*) will be used to indicate that it is from the perspective of geotechnics.

When interpreting the results, data from the surface horizon A refer to a layer with an average thickness of 0 to 20 centimeters and those from the subsurface horizon (horizon B and/or C) refer to a layer with an average thickness of 20 to 150 centimeters deep, except for the class of Litholic Neosols whose maximum depth is 50 cm.

Results and discussion

Semi-detailed maping of the soils

The city's semi-detailed soil map, at scale 1:25,000 (Figure 3 and Table 1), allows us to recognize at suborder level eight soil classes comprising fourteen mapping units, in addition to two Permanent Protection Areas and eight Terrain Types.

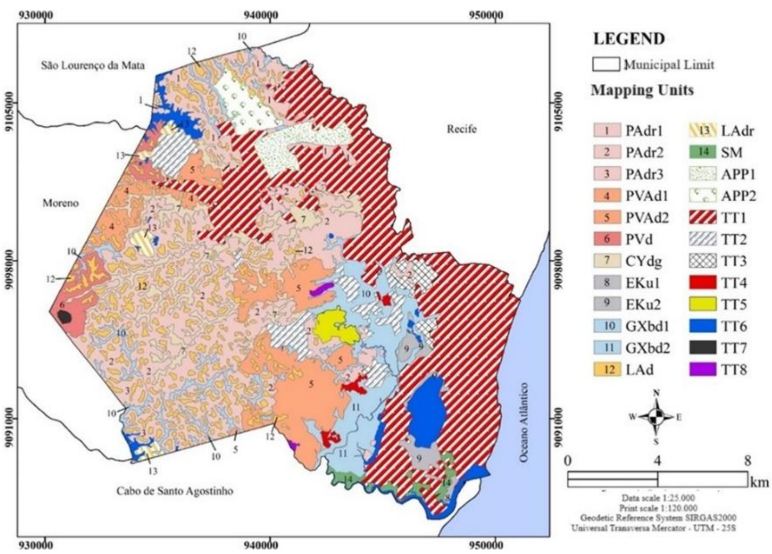

Figure 3. Semi-detailed map of the dominant soils in the city of Jaboatão dos Guararapes -PE. Source: the authors. It was decided to add a numerical sequence for the soil mapping units. Because, depending on normative criteria, there is more than one unit with the same color. Exceptionally, the LAdr unit had its color hatched to facilitate its identification, as it occurs between polygons that represent the LAd unit.

MAPING UNIT	AREA (Km)	AREA (%)	DESCRPTION OF THE MAPING UNIT
PAdr1	11,5	4,3	YELLOW ARGISOLS Rubric nitosolic dystrophic, medium/clayey texture, wavy relief phase.
PAdr2	51,3	19,8	YELLOW ARGISOLS Rubric and endoredoxic dystrophic, medium/clayey texture, wavy relief phase.
PAdr3	3,5	1,3	YELLOW ARGISOLS Rubric and endoredoxic dystrophic, medium/clayey texture, strong wavy and wavy relief phase.
PVAd1	6,5	2,5	Undifferentiated Group: ARGISOLS (RED-YELLOW and RED) Nitosolic dystrophic, medium/clayey texture, wavy relief phase.
PVAd2	18,6	7,2	Association: Undifferentiated Group: ARGISOLS (RED-YELLOW and rubric YELLOW) Leptic and typical dystrophic, medium/clayey texture + ROCK OUTCOMES + LITHOLIC NEOSOLS Eutrophic and Typical dystrophic, medium texture, substrate phase gneisses and granites, all wave relief phase (50 % - 30% - 20%).
PVd	5,7	2,2	Undifferentiated Group: ARGISOLS (RED and RED-YELLOW) Typical dystrophic and nitosolinic, medium/clayey texture, strong wavy and wavy relief phase.
CYbdg	14,5	5,6	Undifferentiated Group: Gleissolic FLUVIC CAMBISOLS and typical HAPLIC GLEYSOLS, both Tb Dystrophic, clayey texture, flat relief phase.
EKu1	1,1	0,4	HUMILUVIC SPODOSOLS Hyperthick duric, flat relief phase.
EKu2	3,2	1,2	HUMILUVIC SPODOSOLS Duric and typical hydrohyperthick, flat relief phase.
GXbd1	13,2	5,1	HAPLIC GLEYSOLS Tb Typical dystrophic clayey texture flat relief phase.
GXbd2	11,3	4,4	Undifferentiated Group: GLEYSOLS (Tb Dystrophic HAPLICS and Sodic and Ortic Thiomorphic SALICS), all typical, clayey texture, flat relief phase.
LAd	17,0	6,6	YELLOW LATOSOLS Typical dystrophic, clayey texture, flat and gently wavy relief phase.
LAdr	1,0	0,4	YELLOW LATOSOLS Rubric dystrophic, clayey texture, flat and gently wavy relief phase.
SM	2,2	0,9	UNDISCRIBED MANGROVE SOILS.
PPA1 (APP)	4,9	1,9	PERMANENT PRESERVATION AREA (BOTANICAL GARDEN).
PPA2 (APP)	4,1	1,6	PERMANENT PRESERVATION AREA (MILITARY AREA).
TT1	64,4	24,5	Type of terrain corresponding to urban areas.
TT2	9,3	3,6	Type of terrain corresponding to urban expansion areas.
TT3	3,1	1,2	Types of terrain corresponding to sediment borrowing areas (material outflow).
TT4	1,2	0,5	Types of terrain corresponding to landfill areas (over floodplains).
TT5	2,0	0,8	Types of terrain corresponding to landfill areas.
TT6	8,7	3,3	Types of terrain corresponding to internal waters.
TT7	1,1	0,4	Types of terrain related to areas with Rock Outcrops (AR).
TT8	0,4	0,2	Types of terrain related to areas with quarries (rock extraction).
Total	**258,7**	**100,0**	

Table 01. Mapping units included in the soil map of the city of Jaboatão dos Guararapes – PE.

The PPA and TT units are considered special mapping units and were individualized following the SiBCS recommendations (SANTOS et al., 2018). No official documents were consulted that determine the size of the areas belonging to the Botanical Garden and the Army (Military Area) in the city.

Argisols are the main soils found in the city and occupy an area of 97.1 km², which corresponds to 37.3% of the total territory (Table 1). This order of soils was subdivided into six mapping units based on the presence of properties related to soil color, fertility conditions, type of relief and source material (Table 1).

The PAdr1 unit occupies an area of 11.5 km² (4.3%) and appears on slopes and hilltops, with altitudes varying between 60 m and 120 m (Figure 4a), in the northwest region of the city. These are soils derived from the alteration of the Migmatite Gneiss Complex, belonging to the crystalline basement, and with strong structural geological control due to the proximity to the Pernambuco Lineament. This analysis observes soil horizons with greater susceptibility to landslides in line with research carried out by GEGEP.

The soils developed in this unit have dark colors on the surface horizon in the hue 7.5YR 3/2. In the subsurface, at the top of the Bt diagnostic horizon, the color is yellowish, but changes to a reddish color at depth (Figure 4b). In this redder part, a moderate to strong degree of development of structures stands out, which increases the possibility of risks of landslides and soil erosion.

Therefore, these are soils that, in addition to being rubric in nature, have characteristics that resemble a nitic horizon (well-developed structures with the presence of waxiness). It is these characteristics that greatly differentiate the soils of this unit in relation to others mapped in the region. As a result, they present a reduction in their stability, implying in greater risks of slippage.

Figure 4. PAdr1 mapping unit: (a) weathering blanket (b) representative profile
Source: Silva (2015).

The PAdr2 mapping unit occupies an area of 51.3 km², which corresponds to 19.8% of the entire city. It comprises the Yellow Argisols that appear in wavy relief at altitudes between 60 m and 120 m (Figure 5a and 5b) developed from granitic rocks.

They present a dark color on the superficial horizon in the 10YR 3/3 hue and yellowish in the diagnostic horizon in the 10YR 6/8 hue, and from 200 cm on, the color becomes red (2.5YR 4/8), highlighting the presence of the rubric character (Figure 5b).

There's a sequence of Ap, BA, Bt1, Bt2 and Bt3 horizons (with evidence of mottling on the Bt3 horizon). Drainage in the profiles was classified as moderate (SANTOS et al., 2015) at the points observed. The structure is composed of subangular (Ap) and angular blocks in the diagnostic horizon; the size of the aggregates varies from small to medium.

Figure 5. PAdr2 mapping unit: (a) typical landscape (b). representative profile
Source: Silva (2015).

The soils belonging to the PAdr3 unit occupy an area of 3.5 km², which corresponds to 1.3% of the entire city's territory. The Yellow Argisols appear in strong wavy to wavy relief with altitudes varying from 60 m to 140 m (Figure 6a) in the southwest region of the city. These soils were developed from rocks of the Gneiss – Migmatite Complex with strong structural control evidenced by the direction of the drainage lines. The presence of mottles (endoredoxic character) was observed from 140 cm onwards, showing drainage restrictions in the profile (Figure 6b). The surface horizon was classified as A moderate, developed in a Subevergreen Tropical Forest environment and currently used as a regenerating forest area. The structure of these soils occurs in subangular blocks in the Ap, BA and Bt1 horizons and in angular blocks in the other horizons. Regarding the degree of development of the structures, they were classified as weak to moderate, and the size varied from small to medium.

Figure 6. PAdr3 mapping: (a) typical landscape (b) representative profile
Source: Silva (2015).

The Red-Yellow Argisols were individualized into two mapping units, PVAd1 and PVAd2, depending on their thickness, the presence of waxiness and structural and textural differences.

The PVAd1 unit appears in the southeast region, occupies 6.5 km² or 2.5% of the territory, in wavy relief (Figure 6a) with altitude varying between 55 m and 130 m. These are soils developed through the weathering suffered by gneissic rocks. Within the Bt diagnostic horizon, they present waxiness and a well-developed structure characterizing a nitic Bt subhorizon, that is, intermediate characteristics for the Nitosol class (Figure 7b). These characteristics reduce soil stability by facilitating erosion and landslides. Studies conducted by Miguel (2021) corroborate the conclusion that Red Argisols in high slope areas exhibit characteristics more prone to erosion.

They are dark in color, in hue 10YR, in the superficial horizon and from yellowish to reddish in hues 7.5YR 5/6 and 2.5YR 4/8, in the subsurface horizon. Primary minerals also occur from a depth of 145 cm on.

Figure 7. PVAd1 mapping unit: (a) typical landscape (b) representative profile
Source: Silva (2015).

The PVAd2 unit appears in the central south region of the city and occupies an area of 18.6 km² or 7.2% of the mapped area. The soils in this unit are derived from granites and gneisses attributed to the Pre-Cambrian (Figures 8a and 8b). The relief forms are predominantly wavy with strong wavy parts. Altitudes vary between 20 m and 115 m.

Figure 8. PVAd2 mapping unit: (a) typical landscape (b) representative profile
Source: Silva (2015

The soils belonging to the PVd unit (Figures 9a and 9b) occupy an area of 5.7 km², corresponding to 2.2% of the city's total. They appear in wavy topography with altitudes varying between 65 m and 130 m. This unit appears in the western region close to the PVd1 unit. These are soils developed from rocks from the Migmatite Gneiss Complex. And due to the proximity to the Pernambuco Lineament, an environment with faults in several directions developed during the Brasiliano event, it requires a little more care when building urban projects. Therefore, the directions of the drainage lines show strong structural geological control.

The color in the superficial horizon is dark at hue 7.5 YR 3/2 and in the diagnostic horizon it becomes red at hue 2.5 YR 4/6. The structure varies from granular to angular blocks in the surface horizons and from small to medium with a weak to moderate degree of development in the subsurface horizons.

Such characteristics of residual soils, specifically red and yellow-red argisols, are found in the urban expansion area of the municipality, where the unplanned growth of communities, with cuts and fills for housing construction, are executed without proper planning, contributing to the occurrence of landslides during periods of high rainfall. As presented by Coutinho et al. (1996), these landslides also cause significant damage to highways on cut slopes when there is no adequate containment. Therefore, the recommendations of the Geotechnical Map of Urbanization Suitability are essential for proper land use and occupation.

Figure 9. PVd mapping unit: (a) typical landscape (b) representative profile
Source: Silva (2015).

The CYbdg unit (Figures 10a and 10b) corresponds to soils typical of floodplain environments, with altitudes varying between 10 m and 90 m. These are soils developed from sediments carried from slopes. Normally, in floodplains with better natural drainage, Fluvic Cambisols predominate. While in poorly drained floodplains, Gleysols stand out. The reflection of the drainage deficiency is noted by the presence of mottling and a grayish layer (glei horizon) in depth. The color of the soil is dark, in hue 10YR 3/1, in the Ap horizon and becomes very light-grayish with low fertile rate in hue 10YR 7/3 in the Bi diagnostic horizon (with common, medium and distinct mottling). While the Gleysols in this unit are typically poorly drained, with dark colors in the 10 YR 3/2 hue on the Ap horizon and turning gray, in the 10YR 7/2 hue, in the subsurface diagnostic horizon. The structure is massive and/or weak in the Ap horizon and in subangular and angular blocks in the subsurface diagnostic horizons.

Figure 10. CYbdg mapping unit: (a) typical landscape (b) representative profile sampled using an auger
Source: Silva (2015).

Spodosols occupy a total area of 4.3 km² corresponding to 1.6% of the total area, they appear in sandbank areas in the southeastern part of the city. These are soils developed from sandy sediments of fluvial-marine origin. These soils were individualized into two mapping units, EKu1 and EKu2, according to environmental drainage.

The EKu1 mapping unit (Figures 11a and 11b) appears in flat relief, with altitudes varying between 5 m and 35 m, with the soil structure being simple grain. These restinga environments are used for construction (residential and commercial) and there are few areas with remnants of the restinga vegetation. They have a diagnostic horizon below 2 meters.

These areas are characterized by the presence of organic clay with low load-bearing capacity, making them susceptible to settlements that can occur rapidly or slowly. Constructions in these regions must consider the possibility of flooding and the effects of tides, in accordance with the recommendations of the Geotechnical Map of Urbanization Suitability (Coutinho, 2019).


Figure 11. EKu1 mapping unit: (a) typical landscape (b) representative profile
Source: Gomes (2015).

The EKu2 unit consists of soils developed in a fluvial-marine environment with an altitude of up to 5m. These soils have a water table at a depth of 60 cm. This unit is close to the urban expansion area of the city (Figures 12a and 12b).


Figure 12. EKu2 mapping unit: (a) typical landscape (b) representative profile
Source: Araújo Filho (2015).

Gleysols occupy an area of 24.5 km², which corresponds to 9.5% of the entire territory. These are soils from floodplain environments, formed from sediments with varied minerals, and are permanently saturated by water that remains stagnant internally in the profile or in lateral flow. These soils were separated into two mapping units, GXbd1 and GXbd2, because of the concentration of more soluble salts, at a concentration that is toxic to most crops, in addition to a high concentration of exchangeable sodium. Among the most important limitations are the oscillation of the water table and the possibility of acidification if the floodplain environments, in the river mouth areas, are drained due to the presence of oxidizable sulfur (thiomorphic character) in the GXbd2 unit.

The soils from unit GXbd1 (Figures 13a and 13b) are present in the floodplains of areas in the center, southwest and northwest of the city. These are soils developed from sediments carried from slopes and deposited in floodplains, with altitudes varying between 5 m and 12 m. The source material of these soils comes from sedimentary structures (Barreiras Group) and/or metamorphic structures (Gneisse Migmatite Complex). They have a darker color, in hue 10 YR 3/2, in the Ap horizon and grayish in color in hue 10YR 7/2 in the subsurface diagnostic horizon (glei horizon). The dominant structure is weak or even solid at the surface and weak to moderate in the subsurface.

These areas can be affected by material from landslides originating from the slopes that form the river channel. They exhibit low urbanization suitability and are considered by Santos (2014), Souza and Sobreira (2014), and Coutinho (2024) as flood passage zones, as this part of the river section functions hydraulically and allows floodwater flow. The authors recommend that any urban planning should aim to keep this zone unobstructed.

Figure 13. GXbd1 mapping unit: (a) typical landscape (b) representative profile sampled using the auger
Source: Silva (2015).

The soils of the GXbd2 unit are developed on Pleistocene and Holocene marine terraces, formed by sediments of fluvial/lagoon and marine origin. The altitude of these areas varies between 5 m and 10 m. The water table appears at a depth of 60 cm. The color of the surface horizon is darker and occurs in hue 10 YR 4/2 and becomes grayish in hues 10 YR 5/2 and 2.5YR 6/2 in the subsurface horizon (glei horizon) (Figures 14a and 14b).

Marine terrace areas formed through the contribution of marine sediments, with occasional input of terrestrial sediments, are restricted for land parceling according to Federal Law No. 12.651-2012 (Forest Code). These areas are susceptible to marine erosion due to the influences of tides, winds, and sea-level rise. Any intervention in these areas or adjacent areas must include Environmental Impact Assessment (EIA), resulting in an Environmental Impact Assessment Report (RIMA) with recommendations and assessments of the developments, as advocated by Coutinho (2024).

Figure 14. GXbd2 mapping unit: (a) typical landscape (b) representative profile sampled using the auger
Source: Silva (2015).

Latosols occupy a total area of 18.0 km², which corresponds to 7.0% of the entire city. This order of soils was subdivided into two mapping units, LAd and LAdr, due to variations in colors and structures with effects on the behavior of the material, denoted by the morphology along the soil profile.

The LAd unit appears in the southwest and northwest regions of the studied area, in features with flat and/or gently wavy tops, with altitudes varying between 85 m and 155 m. These are soils derived from the rock structure of the Migmatite Gneiss Complex. These soils have a dark color in the shade 7.5YR 3/3 in the superficial horizon and gradually reach a yellowish color, in the shade 7.5 YR 5/8, in the Bw horizon. These are well-drained soils with slight laminar erosion. The soil structure has a granular shape to subangular blocks (Figures 15a and 15b).

Figure 15. (a) LAd typical landscape (b) LAd representative profile sampled using the auger
Source: Silva (2015).

The LAdr mapping unit appears occasionally in the western region in topographies with altitudes between 80 m and 125 m and is also derived from the Migmatite Gneiss Complex (Figures 16a and 16b). These soils have a relatively dark color in the shade 10YR 4/3 in the Ap horizon. In the subsurface, in the first meter of depth of the Bw, the color varies from yellowish, in the shade 7.5YR 5/6, to red, in the shade 2.5 YR. This color variation in the diagnostic horizon implies the presence of the rubric character. This indicates a mineralogical change, commonly accompanied by the degree of development of structures and, consequently, the stability of the soil. These are soils used for the cultivation of sugar cane and more recently used for urban expansion (Alphaville Residence). Land use characteristics presented by Silva and Girão (2020), highlighting sugarcane cultivation and pasture. The research conducted by Vaz, Ramos, and Froehner (2021) provides a substantial analysis of the importance of soils less susceptible to erosion. Empirical evidence points to the ability of these soils to withstand construction structures and agricultural cultivation more resiliently compared to more vulnerable soils.

However, it is important to consider that the use of these areas for urban purposes requires careful planning. The lack of adequate infrastructure in urban expansion areas can result in communities vulnerable to risks and disasters. The absence of urban planning can, therefore, lead to scenarios of environmental and social degradation.


Figure 16. LAdr mapping unit: (a) typical landscape (b) LAdr representative profile.
Source: Silva (2015).

The mapping unit called Indiscriminate Mangrove Soils occupies an area of 2.2 km² (Figures 17a and 17b). It is made up of Gleysols (Salic, Sodic and Thiomorphic), Organosols and also sediments that do not yet constitute soils. They are rich in biological activities and have an accelerated and constant deposition of plant remains. The soils occur in the context of the mixture of fresh water from rivers with brackish water from the sea, constituting a rich environment for the development of flora and fauna. These soils are very difficult to examine and, consequently, to separate and distinguish their horizons depending on the fluctuation of the water table.


Figure 17. Mangrove sediment: (a) typical landscape (b) representative rofile sampled using the auger.
Source: (Gomes, 2015).

The special mapping units were individualized depending on the predominant use and they are divided into two types: Permanent Preservation Area and Types of Land.

The Permanent Preservation Areas, PPA1 (APP1) and PPA2 (APP2), have an approximate area of 9.0 km², which corresponds to 3.5% of the entire territory.

The special mapping unit PPA1 corresponds to the land of the Botanical Garden and the fragment of Atlantic Forest surrounding it. During field studies, the construction of new properties near the Botanical Garden was observed. So, greater attention from the public manager is suggested so that urban growth in the area guarantees the maintenance of this space, which has such importance for civic education and the development of research aimed at environmental sustainability.

The special mapping unit PPA2 corresponds to an area of Atlantic Forest on the premises of the Northeast Military Command. No pedological observations were made in the area, since the objective of pedological observations is to classify soils for agricultural or urban purposes (different types of constructions) and there is no demand for these uses in this institution.

The special mapping units classified as Terrain Types (TT) occupy an area of 90.2 km², corresponding to 34.5% of the entire territory, and were subdivided into 8 groups according to use. For this paper, Terrain Types 1 and 2 are typically characteristic of urban environments, already established and expanding, respectively. They were differentiated from each other to point out to managers that there are areas with recent urban expansion, as urban constructions are not always preceded by registration with the appropriate agencies.

A dynamic revealed only in fieldwork was the modification of the base level in an area of 6.7 km², which corresponds to 2.7% of the territory. This value when compared with the size of the city (Table 1) seems irrelevant. However, the changes were mainly in areas of urban growth, part of which occurred during the collection of field information for this paper. Where, within a 30-day interval, collection points were defined that needed to be changed due to the slope no longer existing. So, changing the local base level will alter the dynamics of surface runoff, erosion, transport and sedimentation rates in the section. Therefore, the distinction between types of terrain was essential to delimit the areas that were under human pressure and, at the same time, facilitate the interpretation of future events.

Information about types of terrain can help the technician who will work, for example, with hydrological modeling and/or with defining the terrain's susceptibility to erosion or mass movement. Consequently, when using a model that has topographic parameters of the terrain as input, it is necessary to cross-reference it with field data or a recent pedological map to find out whether a certain elevation continues to exist, as an attempt to increase the effectiveness of the model. For example, in the PAdr1 unit, figure 3a illustrates an undulating slope, with a slope between 8% and 20%, which due to the removal of the material now has (in the cut area) a relatively steep angle.

The TT3 unit corresponds to the sediment borrowing areas. Throughout the fieldwork it was possible to identify two of them: the first corresponds to the area of well-weathered hill derived from sedimentary rocks, where the elevated area is razed and becomes an extension of the nearest flat surface (Figure 18). The second borrowing area corresponds to coastal lowland areas consisting predominantly of sandy deposits. Where quartzarenic material is extracted and used in a glass factory in the Metropolitan Region of Recife (Figure 11a).

Figure 18. Typical landscape of the TT3 unit. Source: Silva (2015).

Environments classified as TT4 must be observed with greater care because interventions in the field are, for the most part, made considering the specific situation without understanding the processes as a whole and that it could cause adverse losses. For example, the following image (Figure 19) illustrates a section of the river fluvial plain of the Jaboatão River that was filled in to expand the urban area. However, constructions carried out in this type of intervention may suffer consequences during the rainy season, when the river will have a higher flow.

Figure 19. Typical landscape of the TT4 unit in the city. Source: Silva (2015)

The special mapping unit TT5 corresponds to the landfill. This structure was created to dispose the urban solid waste from part of the Metropolitan Region of Recife (Figure 20). Therefore, this strategy aims to guarantee the reduction of environmental damage and the public health of populations residing in the vicinity of the landfill (ELK, 2007; IPEA, 2020).

Figure 20. Typical landscape of the TT5 unit in the city Source: Gomes (2015).

The mapped internal waters (TT6) occupy an area of 8.7 km², which corresponds to 3.3% of the entire city. They represent areas of constructed reservoirs or river channels with thicknesses to be represented in polygon format in this survey.

Rock outcrops (TT7) are types of terrain with more than 90% rockiness. In Jaboatão dos Guararapes, they occupy an area of 1.1 km², which corresponds to 0.4% of the entire city.

The TT8 unit corresponds to the mineral extraction areas, it covers an area of 0.4 km² and corresponds to 0.2% of the entire city (Figure 21). Igneous and/or metamorphic rocks are extracted from this environment.

Figure 21. Typical landscape of the TT8 unit in the city. Source: Silva (2015).

Main physical and chemical characteristics of soils

The laboratory results (Figures 22 and 23) confirmed the textural variation observed during field morphological recognition. The soils have a predominantly clayey and/or medium/clayey texture due to the source material derived, mainly, from crystalline rocks (Figures 21 and 22). The granulometric analysis of the Argisols demonstrated that the yellow ones have a higher silt value in the superficial horizon than the Red Argisols. Coutinho et. al. (2019) analist the Argisols the data obtained in the laboratory and on site enabled characterization of the materials involved in the landslide (Barreiras Formation and granite residual soil) and understanding of the mechanism, its stability analysis at the failure stages, and reactivation. Both were developed from the weathering suffered by the crystalline basement rocks. Therefore, the most likely explanation for a greater presence of silt in the superficial horizon of yellowish soils is caused by its position in the landscape, since these soils occupy lower areas than reddish soils.

Spodosols (P06 and P07) are sandy soils, due to their source material being essentially quartzose (P06). In floodplain environments, where Gleysols, Cambisols and Neosols stand out, three profiles were analyzed. On the scale of this paper, the units are predominantly composed of Gleysols and Cambisols. Fluvic Neosols do not have sufficient extension to individualize a mapping unit or compose a unit at this survey scale.

Soil density varied from 1.11 to 1.55 g/cm³ in the surface horizons and from 1.21 to 1.55 g/cm³ in the subsurface horizons. These values are relatively close to those found by Santos et al. (2010), in the range of 1.17 to 1.58 g/cm³ in the classes of Gleysols, Cambisols and Argisols, in a toposequence in the Paraíba do Sul River. Brito et al. (2006), by analyzing the physical attributes of Latosol, found lower soil density values and related the presence of gibbsite mineralogy and organic matter contents.

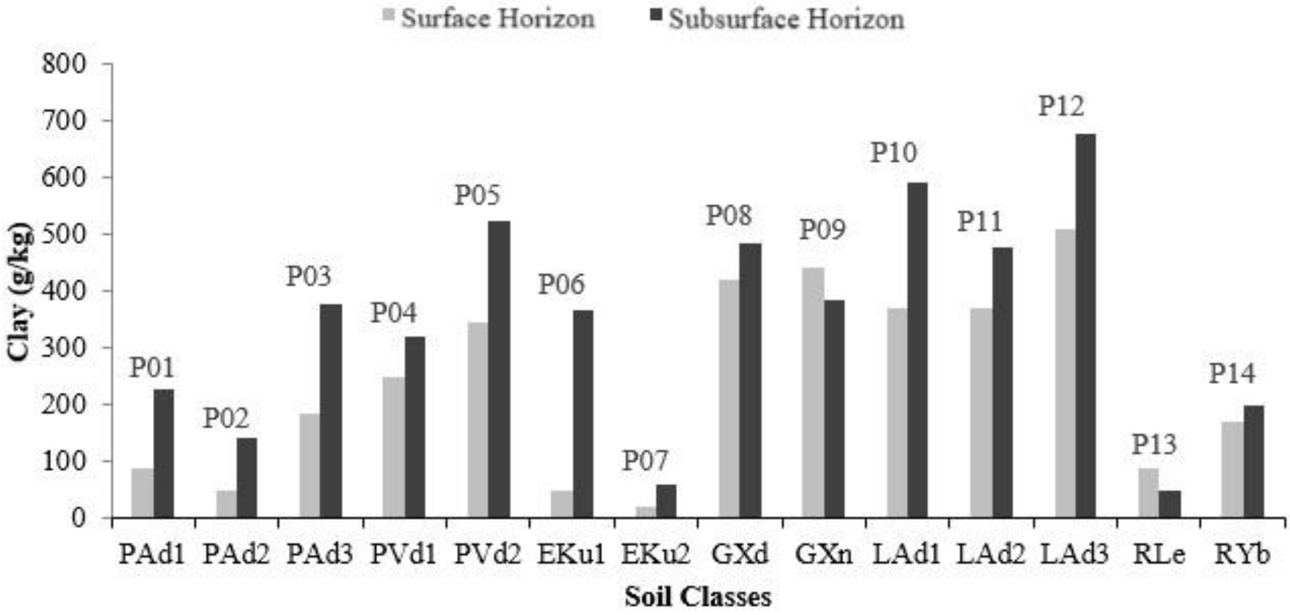

Figure 22. Average contents of the clay attribute in the surface and subsurface horizons in soils in the city. Souce: the authors. NOTE: Soil classes-acronyms of the available mapping units in Table 1

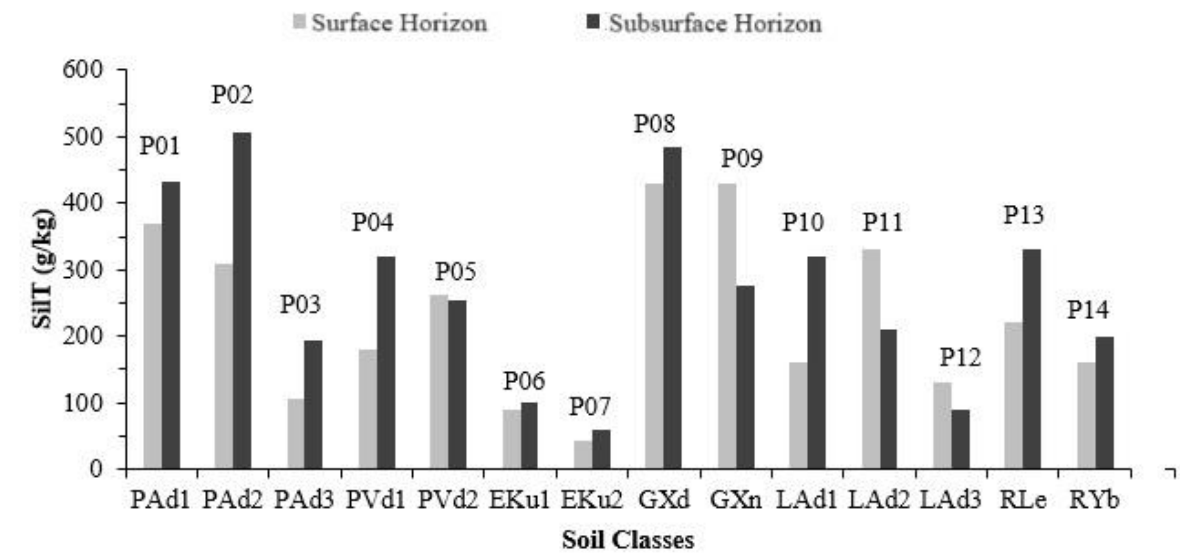

Figure 23. Average levels of the silt attribute in the surface and subsurface horizons of soils in the city. Souce: the authors. NOTE: Soil classes-acronyms of the available mapping units in Table 1

The Available Water Capacity – AWC (Figure 24a) demonstrates that the greater the predominance of fine fractions, the greater the capacity to retain moisture (Figures 22 and 23). The data is in line with other works that addressed AWC and correlates with textural parameters (BEUTLER et al., 2002; SILVA et al., 2020; ANDRADE et al., 2020). AWC directly influences water storage for root growth, nutrient absorption, crop production and chemical reactions occurring in the soil. The AWC results in this paper show similarities with the data from BEUTLER et al. (2002) who, by analyzing Latosols under different uses, concluded that AWC is directly influenced by the texture of the material. Additionally, the type of management that changes the size and distribution of pores also changes the AWC of the soil (SILVA et al., 2017; Borba et. al. 2020).

Andrade et al. (2020), by comparing predictive methods with expeditious methods for quantifying AWC, demonstrated that the structural attributes of the soil, as well as its texture, are fundamental for the constitution of a Pedotransfer Function – PTF. Therefore, the use of a predictive method for quantifying AWC demonstrated compliance of the results of this work with current literature and with expedited laboratory results as well.

The soils are predominantly acidic with pH varying between 4.30 and 6.80 in the surface horizons, while in the surface horizons the acidity found was 4.17 to 5.70. This range of soil acidity is justified by the location of the study area, which is in a context of humid tropical regions, with high rainfall and temperature, favoring chemical weathering reactions, resulting in a greater proportion of secondary minerals such as iron oxides and aluminum and clay minerals from the kaolinite group. In these environments, acidity is usually one of the main obstacles to agriculture (LEPSCH, 2021). It is noteworthy that from the perspective of Geotechnics, the soil pH parameter is important to understand the interaction between soil and concrete (used in constructions). According to Wanderley Neto, Camapum Carvalho and Capuzzo (2019), who evaluated the variation in pH in well-weathered soils (lateritic*) and younger soils (saprolite*), they noticed variation in the pH content when monitoring soil/concrete contact in the laboratory during a time interval. From the results, the authors recognized that changes in the chemical characteristics of the soil, caused by the interaction of concrete with the soil, must influence internal stability. Therefore, observing the analytical results present in pedological surveys can support decision-making in the development of geotechnical projects.

Sousa et. al. (2021) Analysis of the unsaturated behaviour of compacted lateritic fine-grained tropical soils for use in transport infrastructure, the lateritic sandy soils and showedboth resilient behaviour and deformability characteristics satisfactory, ratifying the characteristics of the soil classes originating from the Barreiras Formation.

The sum of bases (Figure 24a), Cation Exchange Capacity - CEC (Figure 24b) and base saturation (Figure 25) presented higher values in the surface horizon to the detriment of the subsurface horizons. These results are consequences of a greater concentration of organic matter on the surface horizons. The only profile that presented a higher CEC value in the subsurface horizon was profile 13 (Litholic Neosol) due to a higher concentration of base-rich minerals as it is a young soil. On the other hand, aluminum saturation (Figure 26) shows a greater concentration of aluminum in subsurface horizons, a consequence of leaching processes in tropical, acidic and well-developed soils. In this line of reasoning, profile 13 presents the lowest aluminum saturation values precisely due to the degree of weathering in its constitution. It is important to highlight that the CEC is affected by four factors according to Lepsch (2021): a) the amount of clay (clays are sources of negative charges and the more clay the higher the CEC); b) the quantity of humus (they are good sources of negative charges); c) the type of clay (1:1 or 2:1 clay); and d) the pH (the more acidic the soil, the lower the CEC).

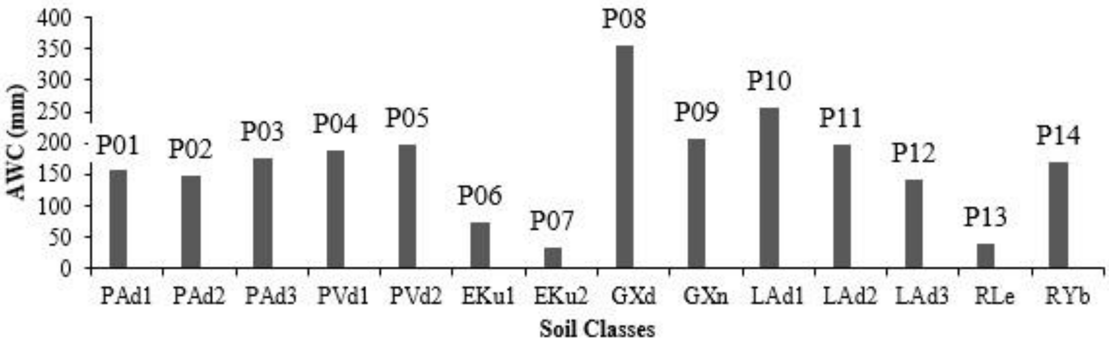

Figure 24. Average value of the AWC attribute in soils in the city of Jaboatão dos Guararapes - PE.

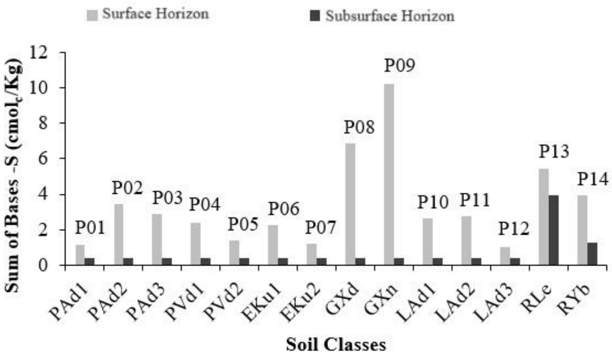

Figure 24a, Average value of the attribute sum of the bases of the surface and subsurface horizons in soils.

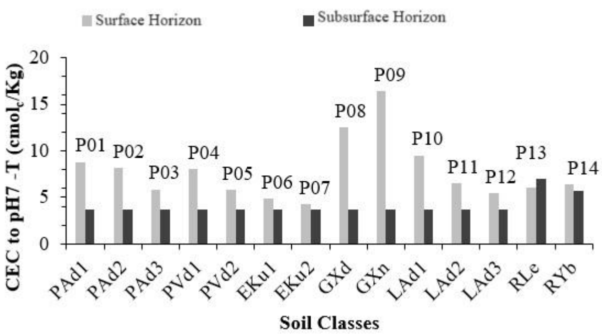

Figure 24b. Average value of the CEC attribute in surface and subsurface horizons in soils

NOTE: AWC = Available Water Capacity. The AWC was calculated for 150 cm depth, except for the RLe with only 50 cm; Sum of bases (S) = Ca2+ + Mg2+ + Na+ + K+; CEC = Cation Exchange Capacity (T) = S + (H+ + Al3+).

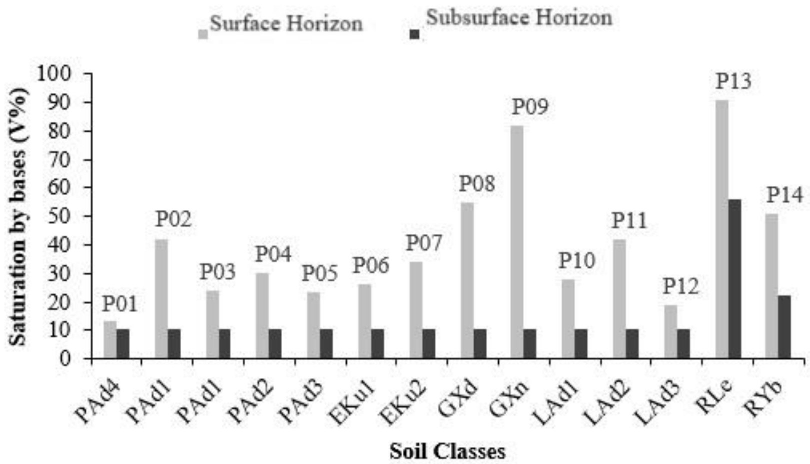

Figure 25 – Average value of the saturation attribute by bases in the surface and subsurface horizons in soils.

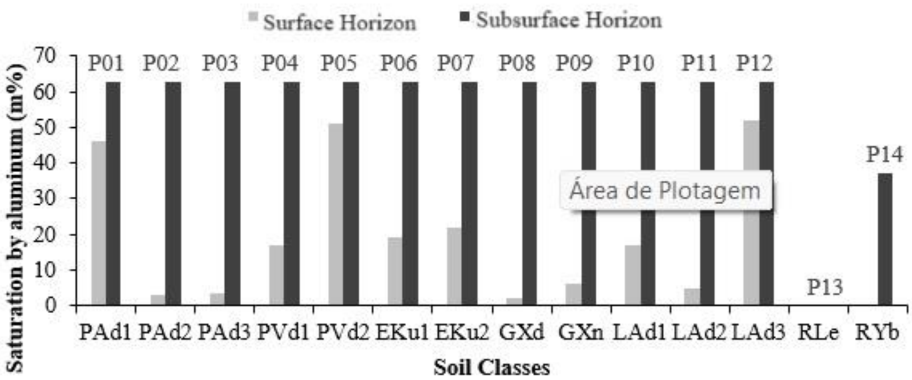

Figure 26 – Average value of the aluminum saturation attribute in the surface and subsurface horizons in soils

Therefore, high CEC values should alert the project executor to the possibility of the presence of expansive clay and assist in decision-making regarding the work and/or type of intervention necessary to avoid future losses. Coutinho et al. (2024) presented research results using data overlay in a GIS environment and geotechnical tests to identify expansive soils on a highway. Pathologies such as premature cracks originating in the sub-base layer and longitudinal cracks appearing on the road surface were detected. The study found that the cracks were due to the presence of expansive minerals in the soils underlying the state highway in Pernambuco, highlighting the importance of identifying expansive soils for urban infrastructure installation.

The organic carbon values observed in the study area ranged from 6.30 to 1.36 g/kg on the surface and from 4.20 to 0.32 g/kg in the subsurface, except in the Sposols with greater amounts of carbon in the spodic B horizon, being 16.10 on the surface and 22.90 g/kg in the subsurface.

The sodium saturation parameter distinguishes layers and/or horizons that have a higher concentration of sodium and that can be harmful to some agricultural crops. Thus, among the soils mapped in this survey, soil profile 09 (floodplain environment) received the sodic character as it presented a high value, above 15% of the saturation of this element in the exchange complex (SANTOS et al., 2018). On the other hand, profiles 01, 02, 04, 06, 08, 10, 11, 13 and 14 presented sodium saturation values of less than 1% in the surface and subsurface horizons. While the other profiles presented values close to 3% sodium (profile 03 (3.25% and 3.19%), profile 05 (2.33% and 3.00%), profile 07 (3.05% and 10.11%) and profile 12 (2.00% and 3.00%)).

Conclusions

The results made it possible to show the semi-detailed pedological cartography of the city of Jaboatão dos Guararapes – PE and the main potentialities and limitations of the soil mapping units. The morphological and analytical data demonstrated that the Yellow Argisols derived from the Migmatite Gneiss Complex (unit PAdr1) present characteristics that favor erosion and greater susceptibility to mass movement. This behavior prediction is conditioned by the busy relief associated with the moderate to strong degree of development of soil structures within two meters depth.

It should be noted that on the scale adopted for this work (1:25,000) it was not possible to individualize each component of the Red Yellow Argisols derived from granites and gneisses (PVAd2 unit) depending on the time and financial resources available. However, for geotechnical planning of the area, it is recommended that detailed surveys be carried out, increasing the density of pedological data that allows for a final map on a scale equal to or greater than 1:10,000. Especially, because there are areas within the unit with blocks of rocks in the soil mass. So, increasing the mapping scale of that unit is of great relevance.

The studies indicate that the slope length factor and slope degree are determinants in determining erosive processes in the Argisol class, consistent with findings presented by Miguel et al. (2021).

On the other hand, soils in floodplain environments, in flat relief, also demand attention in the development of projects, since, during the period of greatest water recharge, in the rainy season, there is a risk of flooding and/or possibilities of cracks in the built structures. The latter are caused by the activity of clays (expansion and contraction) in wet and dry periods in the soils of this environment. Therefore, it is necessary to follow the legislation to carry out surveys and obtain the geotechnical parameters of the soil for urban occupation, planning constructions and types of foundations to be carried out where this Unit occurs.

As developments for future projects, it is recommended to survey pedological information in urban areas, especially on elevations (slopes), on a scale of greater detail not included in this survey, depending on the time and resources available, but of utmost importance for construction projects. Emphasizing the importance of soil mapping for the development of the geotechnical suitability map for urbanization

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