Revista Brasileira de Ciência do Solo

Division - Soil in Space and Time | Commission – Soil Genesis and Morphology

Urban soils in Brazil: A review

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ABSTRACT: This study analyzes the scientific production about soils within cities in Brazil, the most populous country of Latin America, to highlight significant patterns and contributions and point out gaps and future challenges. A more robust literature about urban soils in Brazil started in the 90´s decade and has intensified since 2015. Papers are mostly published in Portuguese, majority performed in cities with more than 500,000 inhabitants, many of them located in the Southern and Southeastern regions, and mainly focused on soil characterization, classification, mapping and/or contamination. Important methodological propositions (related to classification and land potential) and morphological, physical and chemical results are published. Urban soils formed from landfills are the most common, but soils developed from irregular zones of waste disposals are also frequent, showing the deficiency of proper waste management in developing countries. Properties such as pH, base saturation, soil organic matter and P amounts tend to be higher in soils marked by the addition of earthy materials and solid waste than in soils developed from the process of cutting, which commonly exposes the acid and deep saprolite of the tropical and subtropical zones. Although the attention on the Brazilian urban soils has grown in the last years, more studies, with a higher variety of morphological and analytical data, still have to be performed to obtain more representative results. Systematization of concepts, terminologies, and methodologies is also necessary, allowing a more complete understanding of the soils. In addition, the incorporation of a classification key of Anthropogenic soils, including urban soils, in the Brazilian official classification system seems urgent. Finally, it is relevant to foment international publications about the Brazilian urban soils, allowing a wider comparison between the produced data and the results obtained worldwide.

Keywords: soils within cities, morphology, physical and chemical characteristics, organic contamination, toxic metals.

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Received: August 25, 2021

Approved: November 10, 2021

How to cite: Furquim SAC, Almeida IS. Urban soils in Brazil: A review. Rev Bras Cienc Solo. 2022;46:e0210124.
https://doi.org/10.36783/18069657rbcs20210124

Editors: José Miguel Reichert and José Coelho de Araújo Filho.

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INTRODUCTION

During the 20th century, a significant increase in mankind population was registered around the world, especially in the cities. Approximately 55 and 84 % of the world (United Nations, 2019) and the Brazilian population (IBGE, 2012), respectively, are currently living in urban zones, with a projection to reach 68 % in the globe and 92 % in Brazil until 2050 (United Nations, 2019). The increase of population and the consequent growth of urban areas promote profound alterations in the organisms, air, water, rock, landform and soil, with environmental degradation in local, regional and global scales (Hardoy and Satterthwaite, 1991; Johnson, 2001; Simon, 2007; Seto et al., 2012; McDonald et al., 2014; Ameen and Mourshed, 2017).

The high magnitude of the human-induced changes, not only but significantly triggered by urban and industrial activities, led to the proposition of the Anthropocene as a new epoch in the Geological Time Scale (Crutzer and Stoermer, 2000; Crutzen, 2002). The beginning and the formal inclusion of this new geological time unit are still under debate, but suggestions of its beginning include the advent of the Industrial Revolution (post-1760), with the increased use of fossil fuel and ash deposition, and the "Great Acceleration" (post-1950), with a significant rise of atmospheric CO_2 and accumulation of persistent anthropic materials (plastic, pollutants, etc.) in the environment (Crutzer and Stoermer, 2000; Lewis and Maslin, 2015; Zalasiewicz et al., 2015).

Adverse effects of environmental degradation during Anthropocene in human health and life quality are strongly enhanced in urban areas, where cultural, social and economic activities are concentrated (Power et al., 2018). The mitigation of these impacts necessarily involves a suitable management of the city´s environment, recognizing their functions and the proper utilization of their ecosystem services. Healthy urban environments can supply, for example, the regulation of the local climate and the gas and/or water cycle, filtering of freshwater, support for plant growth and habitat for biodiversity, consequently providing good air quality, control of temperature, flood and erosion mitigation, clean water, secure food and areas for recreation (De Grout et al., 2002; McPhearson et al., 2013).

Urban soils can play a key role in all these functions and ecosystem services, depending on the degree of anthropic interference and management (Morel et al., 2015). They are able to regulate climate, gas and/or the water cycle through, respectively, carbon sequestration, participation in biogeochemical cycles and control of infiltration capacity, hydraulic conductivity and moisture retention. Also, they may have an important function in water purification, mainly by sorption of contaminants in colloidal particles, and in the sustaining of urban agriculture, parks and forests, providing physical support, water and/or nutrients to the vegetation and other forms of life (McPhearson et al., 2013; Morel et al., 2015; Herrmann et al., 2016; Setala et al., 2017; Vasenev et al., 2018).

Functions and ecosystem services related to urban soils, except their geotechnical capacity to support the city's infra-structure, have been mostly ignored or underestimated around the world (Breure et al., 2012; Bouma and McBratney, 2013; Burghardt et al., 2015). Many reasons can explain this behavior, including the much smaller interest in soils within cities than those in agricultural areas for soils scientists. Pedological maps of different scales, for example, commonly ignore the soils of the cities, representing the whole urban area as white or gray spots or only repeating the soils classes of the surroundings (Oliveira et al., 1987; De Kimpe and Morel, 2000; Burghardt et al., 2015; Morel et al., 2017; Rossi, 2017). This attitude implies insufficient knowledge about their morphological, physical, chemical, mineralogical and biological properties.

A proper comprehension of urban soils is mandatory to understand their functions, to apply appropriate management and deliver ecosystem services. The publications about urban soils of subtropical and tropical environments are still lower than in cities of Europe, North America and Asia (Gbadegesin and Olabode, 2000). However, they have been increased in the last decades, providing valuable information about these regions, which are generally under the influence of urbanization processes that are typical of undeveloped or developing countries. The population of these countries is commonly exposed to low food/water security and high geological risks. The urban soils can play a crucial role in mitigating these environmental issues.

This study aims to analyze the scientific production about soils within cities in Brazil, the largest and most populous country of Latin America, in the light of the concepts and characteristics of urban soils developed in the international literature. The goal is to understand the local state of art of the knowledge, highlight the most important results and contributions of the national literature, recognize trends and patterns in the published data, and point out gaps and research topics to be developed in the country related to urban soils.

URBAN SOILS: DEFINITIONS AND MAIN CHARACTERISTICS

The impacts of human societies on soil properties are so intense worldwide that some authors have considered anthropic actions as the sixth factor of soil formation, in addition to climate, parent material, landform, time and organisms formerly proposed by Jenny (1941). The separation of humans from other living organisms is justified mainly because anthropic activities are made with a high degree of awareness and in a much higher magnitude in time and space, interfering in the other five factors in a simultaneous, fast and profound way. Also, differently from other species, human beings present different cultures, which provoke different types and degrees of impacts and imprints a mosaic of modified soils and landscapes along time (Bidwell and Hole, 1965; Amundson and Jenny, 1991; Effland and Pouyat, 1997; Dudal et al., 2002; Dudal, 2004; Yaalon and Yaron, 2006; Pouyat et al., 2010).

The concepts of Anthrosol, Anthroposols, Anthropic or Anthropogenic soils have been used in a generic way to include all soils with layers, horizons or features strongly altered or entirely constructed by humans, both in farming or non-farming activities (Dudal, 2004; Dazzi and Lo Papa, 2015; IUSS Working Group WRB, 2015). Agriculture and animal husbandry, especially since about 10000 years BP, have modified soils by manuring, fertilizing, liming, irrigation, terracing, plowing, flooding, etc. (Dudal et al., 2002; Sandor et al., 2004). However, activities developed in urban and suburban areas, mostly since the Industrial Revolution, can cause different types and/or magnitude of changes in the soils by, for example, cutting, landfilling, leveling, sealing, mixing and disposal of wastes (Meuser, 2010; Morel et al., 2017).

Specific studies about urban soils occurred since the beginning of modern Soil Science, in the 19th century, but they were punctual and mainly focused on contamination (Lehmann and Stahr, 2007). A growing awareness about these soils has occurred after the 1950's, mainly because of the development of soils surveys in cities of Australia, Europe and North America to support cities' planning (Burghardt et al., 2015; Burghardt, 2017). However, a broader interest has occurred mainly since the 1990's, with a deeper attention on subjects and approaches more strictly related to Soil Science, such as classification, properties, pedogenesis and functions (Lehmann and Stahr, 2007; Burghardt et al., 2015; Burghardt, 2017). Although an important growth in the number of publications was registered in the last decades, the concept of urban soil is still not well defined, being used in variable contexts and with different meanings (Table 1).

All the definitions of urban soils presented in table 1 englobe Anthropogenic soils developed within cities, that is, soils strongly modified by human activities associated with the urbanization process. However, the wider definitions of Hollis (1991), Rossiter (2007), Lehman and Stahr (2007), Hazelton and Murphy (2011) and Morel et al. (2017) also include less disturbed or undisturbed soils that may occur within urbanized zones, more

Table 1. Definitions of urban soil and similar terms

Author	Term	Definition
Bockheim (1974)	Urban soil	"A soil material having a non-agricultural, manmade surface layer more than 50 cm thick, that has been produced by mixing, filling or by contamination of land surface in urban and suburban areas."
Craul (1985)	Urban soil	"A material that has been manipulated, disturbed or transported by man's activities in the urban environment and is used as a medium for plant growth."
Craul (1992)	Urban soils	"...soils composed largely by a mixture of materials differing from those in adjacent agricultural or forest areas, presenting a surface layer greater than 50 cm, and transformed deeply by human activity through mixing, importing and exporting material, and by contamination."
Hollis (1991)	Soil (definition that embraces urban soils)	"Any unconsolidated mineral or organic material at the earth's surface that has the potential to support plant growth."
De Kimpe and Morel (2000)	Urban soils	"...all soils influenced extensively by human activities in the urban landscape." "...soils that are under strong human influence in the urban and suburban landscape in order to differentiate them from other strongly disturbed soils such as quarries, mines and mine tailings, and airfields."
Pedron et al. (2004)	Urban soils	"...soils that are in the urban environment and are generally altered by urban activities."[(1)]
Lehmann and Stahr (2007)	Anthropogenic urban soil	"...this term refers broadly to soils profoundly affected by urbanization." ...covering anthropogenic inner- and extra-urban soils.[*2]"
Lehmann and Stahr (2007)	Urban soils	"Covering anthropogenic and natural soils (within cities)."
Rossiter (2007)	Urban soils	"...all soils occurring in urban and industrial areas."
Santos Junior (2008)	Urban soil	"...unconsolidated mineral and/or organic material in the Earth surface with alteration, by mixing, deposition or contamination by a variety of materials, caused by human activities in urban or urbanized areas and not related to agricultural production, that are able to support plant development...."[*2]
Meuser (2010)	Urban soils	"...are soils in urban and suburban areas consisting of anthropogenic deposits with natural (mineral, organic) and technogenic materials, formed and modified by cutting, filling, mixing, intrusion of liquids and gases, sealing and contamination...". "According to the definition urban soils are related to specific areas, namely urban and suburban areas. In this sense, industrial, traffic and mining areas may also belong to the areas of concern."
Hazelton and Murphy (2011)	Urban soils	"...can be considered as natural soil or an anthropized soil (Anthroposol) or as a Technosol (a soil developed on non-traditional substrates and largely due to intensive human activity...)."
Morel et al. (2015)	SUITMA (soils of urban, industrial, traffic, mining and military areas)	"...range from slightly modified soils to very intensively managed and disturbed soils..."
Morel et al. (2017)	Urban soil	"It is synonyms of SUITMA (soils of urban, industrial, traffic, mining and military areas)."
Morel et al. (2017)	SUITMA (soils of urban, industrial, traffic, mining and military areas)	"...all soils under strong human influence..." (the term was proposed to) "...emphasize that the so-called "urban soils" are found in a large variety of strongly anthropized areas."

[(1)] Free translation from Portuguese. [(2)] Extra-urban soils are those present in mining, industrial, infrastructure, building and war activities areas.

similar to the agricultural or forest areas. These more preserved soils may be dominant in very small cities (Lehman and Stahr, 2007) and suburban areas of metropolitan regions (Effland and Pouyat, 1997), but they may occur in any city's zone, especially in green areas such as parks, gardens, squares, backyards, horticulture areas and forest fragments. However, Rossiter (2007) argues that even the less human-affected soils inside a city have some degree of modification by urban activities, such as the addition of dust or precipitation containing organic or inorganic contaminants.

Some authors have also extended the concept of urban soils to soils occurring in industrial, mining, traffic and military areas (Table 1) (Lehman and Stahr, 2007; Rossiter, 2007; Meuser, 2010; Morel et al., 2017). This broad definition is supported by the fact that these activities, although they are often developed outside cities, strongly support urban life (Lehman and Stahr, 2007) and generally modify the soils in similar ways than in urban areas (Morel et al., 2017). Since the Working Group SUITMA (Soils of Urban, Industrial, Traffic, Mining and Military areas) was created by the International Union of Soil Science (IUSS), in the 16th World Congress of Soil Science (Montpellier, 1998), the adoption of this concept has been growing in the international literature (Burghardt, 2017).

Indeed, the soils of urban landscapes, similarly mainly to industrial, mining and traffic areas, tend to bear specific morphological, physical, chemical and/or biological characteristics due to contamination, infra-structure loads, pedestrian and vehicles traffic, intentional compaction, topography modifications, among other interferences (Greinert, 2015). Because of the variety of land uses and their fast modification over time, these characteristics usually change in short distances, producing a large lateral and vertical variability (Craul, 1985, 1994; Effland and Pouyat, 1997; Burghardt et al., 2015; Greinert, 2015). Regarding the morphological changes, these include introduction, removal or mixing of horizons/layers, abrupt and very wavy or irregular boundaries between horizons/layers, modification or destruction of the structure (Craul, 1985; De Kimpe and Morel, 2000; Burghardt, 2006), presence of anthropic artifacts, such as concrete, asphalt, brick, pottery, plastic, glass, rubber, rubble and wood products (Craul, 1985; Lehmann and Stahr, 2007; Morel et al., 2015; Greinert, 2015; Burghardt, 2017) and increase of coarse particles (sand, gravel) released by construction materials (De Kimpe and Morel, 2000; Burghardt, 2006; Burghardt et al., 2015; Greinert, 2015).

Physical transformations, in general, promoted by infrastructure and traffic loads and intentional compressions, can increase the bulk density and compaction in surface and subsurface horizons/layers, with consequent decrease in total porosity, infiltration capacity, hydraulic conductivity and moisture contents (Craul, 1985; Jim, 1993; Schueler, 2000; Lehmann and Stahr, 2007; Hazelton and Murphy, 2011; Burghardt, 2017). Compaction also reduces gas exchange, decreasing aeration and changing the composition of soil atmosphere (Jim, 1993; Kozlowski, 1999; Schueler, 2000). Additionally, heat islands commonly developed in medium-sized and large cities, tend to increase soil temperatures, especially in zones where temperature regulation is impaired, such as impervious surfaces (Lehmann and Stahr, 2007; Cheon et al., 2014; Yang and Zhang, 2015).

The chemical properties are generally associated with the input of organic and inorganic contaminants (toxic metals, platinum group elements, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, naphthalene, etc.) and to higher content of certain elements (N, P, inorganic C, S, Na and other salts) if compared with natural environments (Norra and Stuben, 2003; Lehamnn and Stahr, 2007; Pouyat et al., 2010; Greinert, 2015; Yang and Zhang, 2015; Burghardt, 2017). A change of pH is commonly reported, especially to higher values due to the elevated amount of carbonates in anthropic artifacts (cement, concrete, rubble, tiles), but also to lower values when sulfides are added as mining spoil, for example (Craul, 1985; Lehmann and Stahr, 2007; Greinert, 2015; Yang and Zhang, 2015; Burghardt, 2017). Production and release of gases, such as CO_2 and CH_4, also occur especially in zones with waste disposal and embankments with organic materials (Meuser, 2010; Turkoglu, 2010; Burghardt et al., 2015).

Morphological, physical and chemical alterations cause clear changes in the soil biology of urban areas (Guilland et al., 2018). The restriction of root penetration and poor aeration provoked by compaction difficult the proper development of plants, especially trees and shrubs (Jim, 1993; Kozlowski, 1999; Schueler, 2000). Compaction, contamination and changes in soil temperature and pH generally reduce the abundance and diversity of many species, especially of arthropods (ants, mites, springtails, beetles) and nematodes (Guilland et al., 2018). Also, Scharenbroch et al. (2005) and Guilland et al. (2018) registered lower microbial biomass and activity and different composition of microorganisms in the cities in comparison with the surrounding agricultural and forest soils However, the biodiversity is highly dependent on the land use, inasmuch as the effects of urbanization tend to be higher in central zones and lower in green areas (Guilland et al., 2018).

The amounts of soil organic matter (SOM) in urban soils generally present higher spatial heterogeneity and standard deviation than the agricultural and forest areas (Vasenev et al., 2013). Low amounts can be found especially in densely urbanized zones and/or recent settlements (Scharenbroch et al., 2005; Vasenev et al., 2013), mainly because of the removal of the topsoil due to fills and leveling, the decrease in the inputs of organic materials due to lower presence of vegetation and the reduced soil microbial activity (Craul, 1994; Scharenbroch et al., 2005; Lehman and Stahr, 2007). However, SOM can also be very high in the urban mosaic, especially in green areas and landfills built with organic residues (Lehman and Stahr, 2007; Pouyat et al., 2010). Thus, these areas and those that suffered intense mixing during engineering operations can have both topsoil and subsurface horizons/layers enriched with organic matter (Scharenbroch et al., 2005).

URBAN SOILS IN BRAZIL

Concept and classification of technogenic deposits

Studies about urban surface materials in Brazil have been more intensively performed through an engineering and geological approach than in the light of the soil science framework. The materials that are produced and transformed by anthropic activities have been mainly described as recent deposits, formed mainly by cultural layers, landfills, channel/reservoir siltation, and industrial, construction and domestic wastes (Peloggia, 1996a,b). They are commonly called in the Brazilian geological literature as *depósitos tecnogênicos*, translated to technogenous (Ter-Stepanian, 1988) or technogenic (Chemekov, 1982) deposits, which are considered as stratigraphic units, correlative to the processes induced by intensive human activities during the Technogene era (Peloggia, 1999). This geological unit of time, proposed by the soviet Ter-Stepanian (1988), would start with the agricultural revolution (10000 years BP), being comparable to the Anthropocene in the human protagonism in the modification of the Earth Surface (Oliveira et al., 2014).

The research about technogenic deposits in Brazil has occurred mainly since the 1990's, intensifying the study of urban areas in the last decade. Most of the studies in urban areas were developed in the Southern and Southeastern regions of the country, especially in capitals of states (e.g., São Paulo-São Paulo State, SP; Porto Alegre-Rio Grande do Sul State, RS; Florianópolis-Santa Catarina State, SC) or cities with regional significance (e.g., Presidente Prudente-SP; Santa Maria-RS; Pelotas-RS; Londrina-Paraná State, PR). In general, they are published in Brazilian journals or scientific meeting proceedings, mostly in Portuguese, and are focused on spatial analyses, such as mapping and classification of the deposits and their relationship with other spatial attributes (geology, geomorphology, land use) and/or on field descriptions, with the identification of layers, colors, texture and/or sedimentary structure. Laboratory analyses are less common and more related to particle size and organic matter contents (e.g., Bertê, 2001; Silva, 2012).

Many classification systems of technogenic deposits have been proposed in the international and national literature (Chemekov, 1982; Fanning and Fanning, 1989; Oliveira, 1990; Peloggia, 1999; Peloggia et al., 2014), but the most applied in the Brazilian urban areas are the proposals of Fanning and Fanning (1989) and Oliveira (1990). The former classifies the materials in urbic (modern anthropic artefacts), garbic (anthropic organic wastes), spolic (earthy materials moved by anthropic activities) and dredged materials (mineral materials dredged from waterways). In the later system, the classification includes built-up (directly transported and deposited by human actions), induced (indirectly transported and deposited by human actions, such as by accelerated erosion processes) and modified technogenic deposits (natural materials transformed by human actions). Despite the high dissemination of the proposal of Fanning and Fanning (1989) in the country, these authors adopt the term “highly man-influenced soils or materials” instead of “technogenic deposits” in their chapter, which is inserted in a book with a clear Soil Science scope. Also, when the classification of Oliveira (1990) is applied, the term “natural soils”, transformed *in situ* by fertilizing or contamination, for example, would be considered within the class of the modified deposits (Peloggia, 1996a).

Indeed, the concepts of “technogenic deposits” and “soils” commonly overlap in the Brazilian and international geosciences’ literature, with the concept of soil being often general and ambiguous, commonly used as synonymous or analogous to deposits. Peloggia (2017) made an important effort to distinguish these concepts, defining soils by their formation *in situ*, presence of horizons, and action of pedogenesis, among other elements, and defining deposits as the materials that are product of removal, transport and deposition in the environment. In Soil Science, soil is commonly distinguished from other geological surface materials by the recognition of pedological processes (additions, losses, transfers and transformations of matter and energy) and/or the ability to support plants with roots (Soil Survey Staff, 2014). Thus, adopting the scope of Soil Science, the technogenic deposits could commonly be the parent materials of certain types of urban soils, especially those marked by the introduction of exogenous materials. However, the soils would already be marked by pedogenetic processes influenced by local external environment, including the climate, landform, organisms and, in especial, human actions.

Considering the wide use of the term “soil” as synonymous of “deposits” in the Brazilian and international geoscience field, it is important to define in the present study that the analyses inserted in the next sections will consider only the publications that adopt the concept of urban soils in the scope of Soil Science. These publications generate a different data set from the geological/geomorphological literature described before, including detailed pedological field descriptions and/or laboratory analyses that are typically measured by methods defined by Soil Science manuals. National and international classification systems are also assessed in some publications, but generally based on data and criteria produced within the Soil Science framework. This approach leads to different data applications, allowing for the identification of soils with morphological, physical, chemical and/or biological patterns within the cities and their relationship with pedogenetic processes and spatial distribution linked to human activities. This knowledge is crucial for a better recognition of the soil urban functions and a more precise identification of ecosystem services in the Brazilian cities.

Brazilian production about urban soils

An overview

A continuous and more robust literature about urban soils in Brazil started in the middle of the 90's decade and intensified significantly since 2015 (Figure 1a). They are general reviews, methodological proposals and specific cases published mostly in Portuguese as non-indexed journals, chapters of books and academic texts (monographies, dissertations and thesis) (Figures 1b and 1c), but publications in English have increased since 2010. Most of the studies were performed by groups of universities located in the Southern and Southeastern of the country, which are the more economically developed regions (Figure 1d). The research groups located in the Federal University of Santa Maria (UFSM)

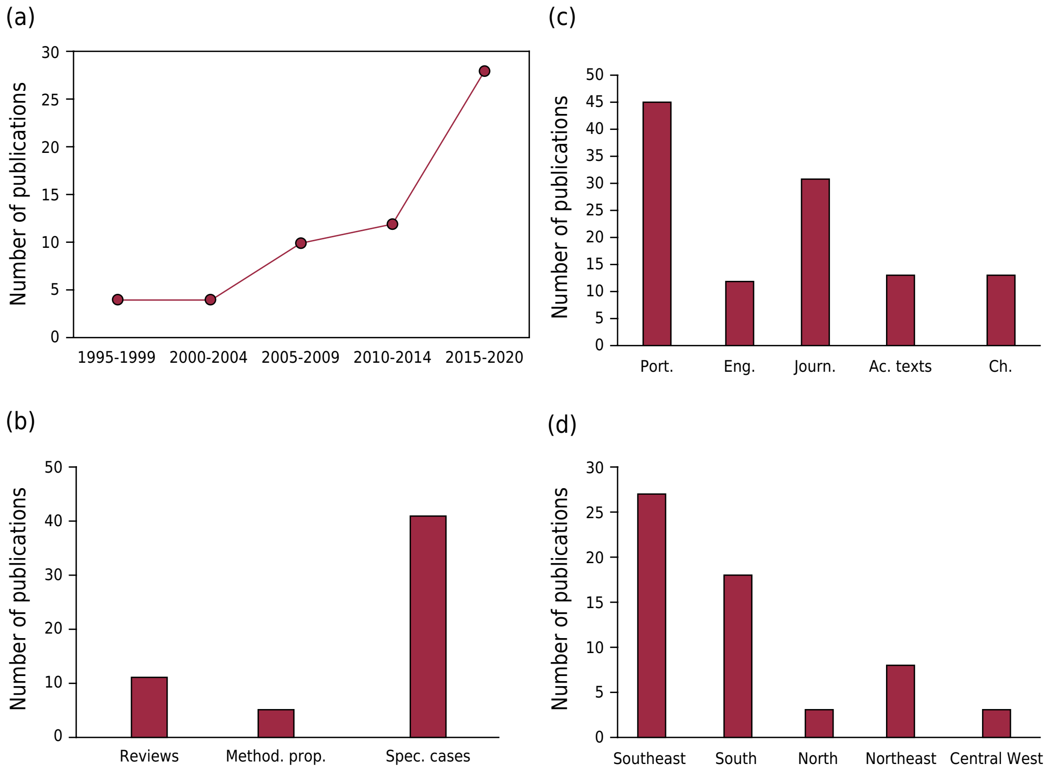

Figure1. Number of Brazilian studies about urban soils, according to: (a) year of publication; (b) type of publication (Method. prop.: methodological proposals; Spec. cases: specific cases); (c) language (Port.: Portuguese; Eng.: English) and type publication media (Journ.: journals; Ac. texts: academic texts, such as thesis, dissertations, monographs; Ch.: chapters of books and others - e.g., reports); and (d) region of the country.

and Federal University of Paraná (UFPR) stand out for concentrating a higher number of publications.

The general reviews are all in Portuguese and discuss the specific properties, functions, limitations, management, conservation and/or systems of classification related to urban soils. They introduce general concepts without focusing on the Brazilian production or in the specific properties or functioning of Brazilian and/or tropical urban soils (Pedron and Dalmolin, 2002; Pedron et al., 2004; Pedron et al., 2007; Ladeira, 2012a,b; Pedron et al., 2019). Regarding the methodological proposals, the more significant publications include a classification system of Anthroposols (including urban soils) by Curcio et al. (2004), a land use potential system for urban soils by Pedron (2005) and Pedron et al. (2006), and a protocol of qualifiers' description of urban soils by Costa (2018) and Costa et al. (2019), the latter being the only one in English.

Most of the publications are study cases developed in neighborhoods of cities located in the South and Southeast, commonly with more than 500,000 inhabitants, which are classified as medium-sized (100,000-1,000,000 inhabitants) to large cities (>1,000,000 inhabitants), according to Vries et al. (2001) (Figure 2). Large cities that are capitals of states are the main studied urban areas, such as São Paulo (SP), Curitiba (PR), Rio de Janeiro (Rio de Janeiro State-RJ), Belo Horizonte (Minas Gerais State-MG) and Recife (Pernambuco State-PE) (Figure 2). The urban population of these metropoles varies from 1,537,704 in Recife to 11,152,344 in São Paulo, but most of them have between 1,500,000 and 2,500,000 inhabitants (IBGE, 2012). Studies developed on medium-sized cities, but with regional importance, are also relatively frequent, including Campinas (SP), Santa Maria (RS) and Guarapari (Espírito Santo State-ES) (Figure 2). The publications are generally focused on soil characterization, classification, mapping and/or contamination, but themes like soil erosion, soil mineralogy, and

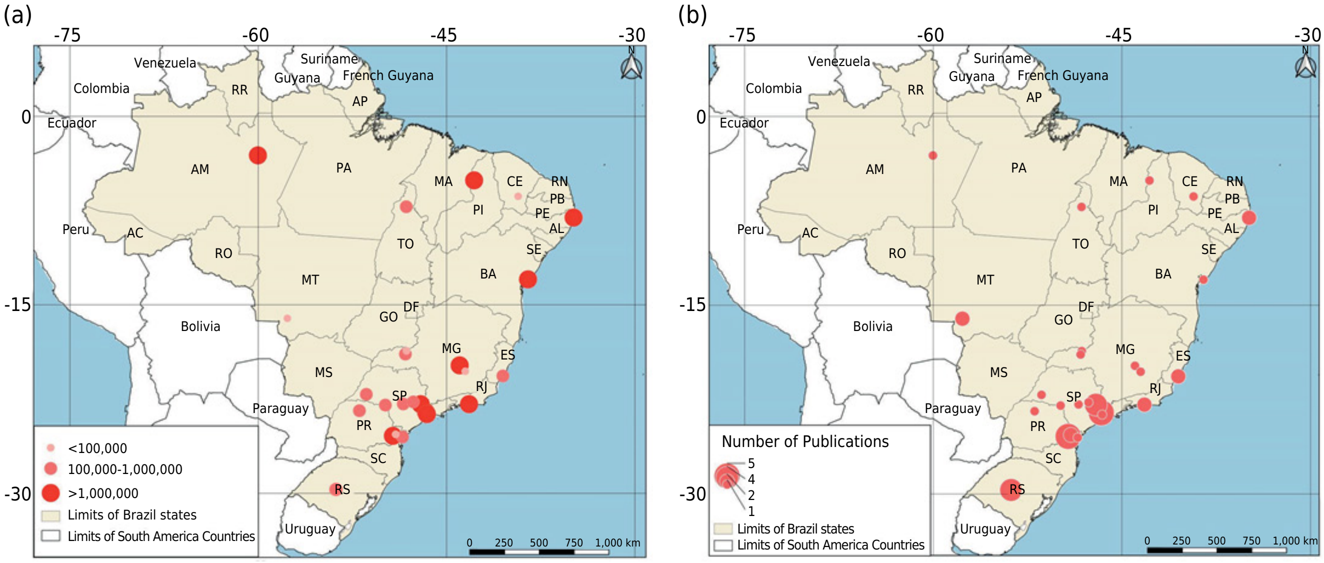

Figure 2. Spatial distribution of the main Brazilian cities with publications about urban soils, according to: (a) city population; and (b) number of publications.

the relationship between soils and urban fauna, flora and diseases are addressed in minor amounts.

Morphological descriptions in the field, especially of the soil profile, are made in some publications, especially on those focused on soil characterization, classification and/or genesis (Putrino, 2017; Costa, 2018; Almeida, 2019; Araújo, 2019; Gomes, 2019; Putrino and Ladeira, 2019). However, physical and/or chemical analyses are commonly performed only in the topsoil (0.05, 0.10, 0.20 or 0.30 first meters), which are, in general, arbitrarily pre-defined depths. Laboratory analyses are more common in publications centered on contamination (e.g., Moura et al., 2006; Gonçalves, 2011; Aniceto and Horbe, 2012; Cervi et al., 2014; Barbosa and Correa, 2015; Dias, 2017; França et al., 2017; Dala-Paula et al., 2018; Milhome et al.; 2018; Putrino and Ladeira, 2019), but they are also available in studies focused on genesis and characterization (Santos Junior and Lima, 2012; Teixeira et al., 2019), classification (Costa et al., 2019) and fauna and flora (Patucci et al., 2017; Vale et al., 2017; Lima et al., 2018). The pH, soil organic carbon (SOC), exchangeable cations, CEC and particle size are the most frequent analyses presented in the results.

Publications associated with soil contamination generally present quantification of total inorganic elements, especially Zn, Pb, Cu, Cr, Ba and Ni. However, other analyses are eventually available, such as sequential extraction of metals, soil mineralogy and/or organic contaminants (Oliveira and Brilhante, 1996; Wilcke et al., 1999; Aniceto and Horbe, 2012; Pussente et al., 2017). Other types of data are provided in publications centered on soil mapping and/or geological risk, such as spatial information related to landforms (Digital Elevation Model, hypsometry, slope gradient, landform types, anthropic interventions), which are obtained by satellite images and/or aerial photography (without a complete morphological description). Spatial distribution of the current and historical land use in the studied cities, coupled with data related to demography, may also be provided (Estevam, 2015; Santos, 2015; Antonio et al., 2017; Mysczak and Paula, 2017; Dias and Paula, 2018).

Main methodological contributions

Three methodological propositions, available in Portuguese in four publications (Curcio et al., 2004; Pedron, 2005; Pedron et al., 2006; Costa, 2018), and in English in one publication (Costa et al., 2019), deserve a highlight because they bring significant contributions for the study of Anthropogenic soils worldwide, especially regarding their mapping and classification.

Pedron (2005) and Pedron et al. (2006) proposed an Urban Land Use Potential System, inspired in technical systems applied in rural areas, in order to employ the maximum potential of urban soils for human activities and avoid land degradation. A Map of Urban Land Use Potential is produced based on a semi-detail survey, classification and mapping of urban soils and in the spatial distribution of other variables, such as hillslope declivities, drainage system, land use, and permanent preservation areas. Four different classes of soils' use are defined: waste disposal (nontoxic organic and nontoxic inorganic; toxic organic and toxic inorganic), urban construction (recreational/ green areas, commercial/ residential and industrial), urban agriculture (silviculture, pasture, olericulture, fruit-culture, annual culture) and environmental preservation. According to soil characteristics and environmental properties, the zones defined in the map are classified as suitable, restricted, and unsuitable for each of the four classes of soil uses. For example, zones classified as suitable for organic and inorganic toxic wastes involve those with deep soils, high CEC, undetectable watertable level in the profile, low permeability, low declivities, and low susceptibility to floods. Another example is related to the zones intended for environmental preservation, which are regulated by federal, state or municipal legislation or classified as unsuitable for other uses, such as areas susceptible to flooding or with high rock fragments.

Costa (2018) and Costa et al. (2019) proposed a protocol for urban soils description and the incorporation of qualifiers to describe a Technosol (IUSS Working Group WRB, 2015), based on the study of soils of a medium-sized city (Santa Maria - RS). The protocol for field description incorporates morphological variables that highlight the heterogeneity and the influence of anthropic interventions in urban soils. Thus, the authors suggest to use the term layer instead of horizon to highlight the low pedological development commonly found in the profiles; the inclusion in the description of the type and percentage of anthropic artifacts (such as plaster, concrete, paper, ceramic, glass, etc.); and the use of the term color mosaic, applied where spots with three or more colors are recognized as a reflection of the diversity of the technogenic deposits. Five new qualifiers are proposed to emphasize aspects common in soils highly affected by human actions. The saprolitic and saprorockic qualifiers are related to the presence of layers of *in situ* and transported saprolite, respectively. The stonic and multigranic qualifiers correspond to the occurrence of a layer with, respectively, stoniness ≥40 % and presence of different textures, both generally provoked by the introduction and/or mixing of different materials by anthropic actions. Finally, the impervic qualifier should be employed when a sealed or impermeable layer is found within 1.00 m from the surface.

Finally, the classification system of Anthrosols (*Antropossolos*) proposed by Curcio et al. (2004) is another important Brazilian methodological contribution. The main goal of the proposition is to assist the Brazilian Soil Classification System (Santos et al., 2018) to incorporate a taxonomy dedicated to soils highly modified by human activities. The system is organized into four taxonomic levels: order, suborder, great group and subgroups, the first three based on morphological features and the last mainly in laboratory analyses. The suborders of the *Antropossolo* order were defined as *Líxico*, *Sômico*, *Decapítico* and *Mobílico*. *Líxico* implies in the addition of toxic wastes; *Sômico* requires the combination of mobilization and addition of non-toxic materials; *Decapítico* is dedicated to the removal of materials from the profile; and *Mobílico* is exclusively used for the *in situ* mobilization and mixing of soils and other materials. The great groups involve the presence of the water table, occurrence of layers, similarity with natural soils and the total or partial removal of the soil and other materials. Finally, the subgroups are mainly related to chemical characteristics of the soils, including occurrence of contaminants and/or pathogenic microorganisms, base saturation, Al saturation and clay activity. Although this classification is widely used by Brazilian authors, it is not official in the country since it was not incorporated in the Brazilian Soil Classification System.

Urban soils in the Brazilian cities: main results and interpretations

Urban soil concept

Estevam (2015), Dias (2017), Putrino (2017), Dias and Paula (2018) and Putrino and Ladeira (2019) postulate, based on the concepts of Pedron et al. (2004) and others, that urban soils are those found in the urban environment and, in consequence, generally modified by anthropic interventions that are typical of the cities. Although an explicit definition is not provided in most other analyzed studies, it is possible to consider the context in which the term “urban soil” is applied by observing the selected study areas and the results, especially the descriptions and/or classifications of the soils. Thus, some studies englobe only soils that are strongly modified by human actions in the cities, such as those in highly populated neighborhoods and irregular, dense settlements (slums) (e.g., Wilcke et al., 1999; Guerrini et al., 2017; Schneider et al., 2018). These Anthropogenic soils that are highly impacted during urbanization are included in all the definitions of urban soils exposed in table 1.

Another important number of the analyzed publications includes less disturbed soils located inside the cities, especially in parks and agricultural zones (e.g., Aniceto and Horbe, 2012; Putrino, 2017) or in peri-urban areas with low density of occupation (e.g., Santos Júnior et al., 2012; Mysczak, 2013; Costa et al., 2019). This approach corroborates with the definitions of Hollis (1991), Lehman and Stahr (2007), Rossiter (2007) and Hazelton and Murphy (2011) (Table 1), which comprise more altered as well as more preserved soils located within urban and suburban areas. An even broader definition, similar to SUITMAS (Lehman and Stahr, 2007; Rossiter, 2007; Meuser, 2010; Morel et al., 2017), has been rarely adopted in Brazil (e.g., Moura et al., 2006), although the use of this concept has increased in the international literature, as explained before.

Morphological results

As exposed, only some publications show complete morphological descriptions of urban soil profiles. The data are available mainly for soils located in medium (e.g., Santa Maria – RS) and large cities (e.g., Campinas and São Paulo - SP) under subtropical climate (e.g., Almeida, 2019; Costa et al., 2019; Gomes, 2019; Putrino and Ladeira, 2019) and in a small city (<100,000 inhabitants, according to Vries et al., 2001) under tropical climate (Cáceres - Mato Grosso State, MT), (Araújo, 2019). The thickness and boundary of the horizons/layers are variable, but many are 0.20 to 0.30 m thick, with dominance of abrupt or clear distinctness and smooth or wavy topography. Red (5R to 10R) and yellow red hues (2.5 to 10YR) are predominant, with a great variation of colors and regular presence of three or more matrix colors [mosaic colors, according to Costa et al. (2019)]. Structureless materials occur in most soils, although surface horizons/layers commonly present blocky subangular or granular structures. Intermediate textures (e.g., loam, sandy loam, silty loam, clay loam) are the most common, but this characteristic tend to be quite heterogeneous in most of the soils, either within the profiles or from one profile to another. Human artefacts can be found in different proportions and types, including concrete, brick, asphalt, pottery, tile, plastic, glass, paper, styrofoam, cloth, wire and wood products.

The described soils are mainly classified as Urbic Technosols (IUSS Working Group WRB, 2015) in the medium and large cities and as *Antropossolos Sômicos* and *Líxicos* (Curcio et al., 2004) in the small city. Some of these publications generally adopt the term “horizon” in the description, using the horizon designations proposed by FAO (2012) or Santos et al. (2018). Thus, in Putrino and Ladeira (2019), the profiles generally have a sequence of A and/or AB horizons or A and C horizons, many of them in vertical discontinuity with the overlying horizons, whereas in Araújo (2019), the soils present mainly AC, CA and A horizons at or near the surface and Bw, Bf, Bg, Bgfc and C horizons in the subsurface. On the other side, Costa et al. (2019) utilize the term "layers" in all the described profiles, which are identified by numbers. As exposed before, these authors propose the use of the term "layer" instead of "horizon" in urban soils. Finally, Almeida (2019) adopts an intermediate position, which is in accordance with IBGE (2007), with the utilization of "layers" for sections that are low affected by pedogenesis and "horizons" for sections with more evident interference of pedogenesis (e.g., presence of structure, SOC accumulation, etc.). This last approach seems more appropriate for Anthropogenic soils, since it recognizes the action of pedological processes.

Many of the described soils are influenced by materials likely transported from the surroundings to fill and level the terrain (e.g., Almeida, 2019; Costa et al., 2019; Gomes, 2019). The large input of these materials is corroborated by many horizons/ layers with thickness between 0.20 and 0.30 m, in accordance with the maximum of 0.30 m of each layer specified by the Brazilian technical procedures of landfill (ABNT-5681, 2015), by the dominance of abrupt and smooth boundaries between horizons/layers, as generally observed in landfilling, and by the occurrence of human artifacts inserted in the imported materials, such as construction residues. Thus, landfilling, which generates technogenic deposits, seems to be the main responsible for the high morphological heterogeneity of most of these soils, expressed mainly by mosaic colors and differences in texture and quantity and/or type of human artefacts in each horizon/layer (Almeida, 2019; Araújo, 2019; Costa et al., 2019; Gomes, 2019; Putrino and Ladeira, 2019). Mapping of urban soils in other cities (Campina Grande do Sul-PR, Guarapari-ES, Curitiba-PR) (Santos Junior and Lima; 2012; Estevam, 2015; Teixeira, 2015), using mainly aerial images and topographical attributes (without a complete morphological description), also shows an important influence of landfilling in the morphological configuration, which is expressed in the classification of most soils as *Antropossolos Sômicos*, according to Curcio et al. (2004).

The morphological descriptions also suggest irregular and continuous waste disposal into the urban soils, such as construction materials and domestic garbage, which is mainly shown by accumulation piles of these materials or the presence of specific human artifacts (e.g., Araújo, 2019; Putrino and Ladeira, 2019). The occurrence of *Antropossolos Líxicos*, classified according to the system of Curcio et al. (2004) and identified by aerial images and topographical attributes (without a complete morphological description) (Mysczak, 2013; Estevam, 2015; Mysczak and Paula, 2017), points it as a common process in cities of undeveloped and developing countries. The deficit in solid waste management is usually attributed to insufficient coverage and frequency of waste collection, lack of sanitary landfills, poverty and low awareness of part of the population (Ejaz et al., 2011). In Brazil, 40.5 % of the total of approximately 73 millions tons of solid waste are discarded in inadequate areas (ABRELPE, 2020). Brownfields and zones temporarily not occupied by buildings are commonly used to dispose domestic and construction materials, responsible for considerable amounts of waste and human artifacts in the urban soils. Putrino and Ladeira (2019), for example, reported that dumping of solid waste from other places continued even after the implementation of the studied park (1999/2002), which was corroborated by the identification of a cereal bar packing with a later fabrication date (2012) within the soil.

Layers built by deposits, irregular inputs of solid wastes and/or remobilization of materials are majority massive and may be compacted, which can collaborate with the increasing erodibility of urban soils (Zanata and Perusi, 2010). However, as exposed before, granular and blocky structures are common in surface horizons (Araújo, 2019; Costa et al., 2019; Gomes, 2019; Putrino and Ladeira, 2019), which can potentially increase the infiltration capacity of urban soils, decreasing runoff and soil erodibility. Putrino and Ladeira (2019) identified domestic garbage with the fabrication date of 1992 and 2012 in deeper horizons of urban soils is Campinas (SP), which suggests, respectively, the development of weak, small blocky structure in decades and weak, small granular structure in less than ten years in the overlying horizons. This possible high rate of structure formation may be partially related to the previous materials that form the technogenic deposits, which reflect the iron oxides-enriched soils of the source areas, as expected in tropical and subtropical areas. This high presence of iron oxides is corroborated by the red (5R to 10R) and yellow-red (2.5YR to 10YR) dominant hues registered in the soils.

Gomes (2019) and Putrino and Ladeira (2019) were able to identify *in situ* saprolite underlying the transported materials, based mainly on the deep position in the profile, the absence of human artifacts and/or the typical reddish mosaic colors of saprolites developed from crystalline rocks. Costa et al. (2019) also identified *in situ* saprolite in some soils of Santa Maria (RS), but exposed on the surface by cutting, being the upward material likely transported and used to build landfills in the surroundings. After landfilling, cutting is the second dominant engineering intervention observed in the soils studied in the last study and in others focused on mapping of urban soils, based on aerial images and topographical attributes (without a complete morphological description), accomplished by Santos Junior and Lima (2012) in Campina Grande do Sul (PR), Teixeira (2015) and Teixeira et al. (2019) in Guarapari (ES) and Dias (2017) in Paranaguá (PR). Erosion forms (sheet erosion, linear erosion) are not the focus of these specific papers, but the relationship between the exposition of saprolites at the surface, high annual precipitation means and erosion susceptibility may be a subject to be investigated in tropical and subtropical zones, since saprolites tend to have low shear strength, commonly attributed to lack of structure, low amounts of clay and/or high amounts of silt and very fine sand (Scholten, 1997; Morais et al., 2004; Heimsath and Whipple, 2019).

Physical, chemical and biological results

Similar to the morphological data, physical and chemical properties tend to show large vertical and/or lateral heterogeneity within a Brazilian city or even in shorter distances, such as in a neighborhood, an urban park, or in the surroundings of an erosional form. Although some authors used different methods of laboratory measurements, it is possible to draw a general comparison among the published data, identifying initial patterns.

Particle size accompanied the high texture variation obtained in the morphological description performed by some authors. Putrino and Ladeira (2019), for example, show values between 136-535 and 21-669 g kg^{-1} for clay and sand, respectively, in a single profile (Campinas, SP), which is characterized by the addition of human artifacts in the near-surface horizons. Laterally, in topsoils (up to 0.20 m), Wilcke et al. (1999) and Santos Júnior and Lima (2012) registered, respectively, a range of clay of 110-700 / 60-500 g kg^{-1} and a range of sand of 109–810 / 240-800 g kg^{-1}. In general, the random distribution of particles is attributed to human interferences in the cities, especially the accretion of coarser construction materials (e.g., Zanata and Perusi, 2010; Santos Júnior and Lima, 2012; Putrino and Ladeira, 2019), as usually observed in urban soils (De Kimpe and Morel, 2000; Burghardt et al., 2015; Greinert, 2015).

Bulk density (BD) measurements, available mainly from topsoil (up to 0.20 m) or indiscriminate by depth (mean, minimum, maximum), reach high values in most of studied soils (e.g., up to 1.89 Mg m^{-3} in clayey, 1.77 Mg m^{-3} in loamy and 1.63 Mg m^{-3} in sandy soils) (Zanata and Perusi, 2010; Santos Júnior and Lima, 2012; Almeida, 2019; Costa et al., 2019), commonly arriving at critical values for vegetation growing (Reichert et al., 2009). As widely observed in urban soils, these elevated bulk densities are usually connected with compaction caused by urban activities, such as intense walking, traffic and landfilling (e.g., Santos Júnior and Lima, 2012; Almeida, 2019). In Brazil, the high bulk densities occurring in regular landfills are associated with a compaction degree ≥95 % in relation to a Proctor compaction test, which determines the maximum dry density related to a specific moisture content (ABNT-5681, 2015; ABNT-7182, 2016). Gomes (2019) observed

BD between 1.1 and 1.3 Mg m^{-3} in surface horizons of soils originated mainly from landfills, characterized by strong granular and moderate subangular blocky structure, and BD majority higher than 1.47 Mg m^{-3} in massive subsurface horizons, demonstrating the importance of the development of structure in the quality of urban soils.

Values of pH(H_2O) and pH($CaCl_2$) range mostly from acid to neutral or alkaline in the same profile or surface samples (commonly up to 0.30 m) (e.g., Wilcke et al., 1999; Santos Júnior and Lima, 2012; Dias, 2017; Almeida, 2019; Araújo, 2019; Putrino and Ladeira, 2019). In general, the highest values of pH (neutral or alkaline) are associated with carbonate-bearing human artifacts (cement, concrete, tiles), as expected in urban soils around the world (Craul, 1985; Lehmann and Stahr, 2007; Greinert, 2015; Yang and Zhang, 2015; Burghardt, 2017), as exposed before. This is clearly demonstrated by Almeida (2019) and Putrino and Ladeira (2019), since the highest values are often registered in horizons with a high presence of manmade artifacts, as registered by soil description. Neutral and alkaline pH are frequent in soils characterized by massive addition of materials, such as landfills and zones of irregular waste disposal (in Brazilian Portuguese known as *lixões*). On the other side, the lowest pH values are registered where cutting is the main engineering intervention, likely reflecting the naturally acid subsurface horizons and/or saprolite exposed at the surface, commonly found in tropical and subtropical zones (Teixeira, 2015; Dias, 2017; Araújo, 2019).

Cation exchange capacity (CEC) values can change, for example, from 47 to 134 $mmol_c$ kg^{-1} [low to high, according to Sobral et al. (2015)] in profiles of Campinas (SP) (Putrino and Ladeira, 2019) and from 50 to 232 $mmol_c$ kg^{-1} [medium to high, according to Sobral et al. (2015)] in surface samples (up to 0.20 m) in Ourinhos (SP) (Zanata and Perusi, 2010), likely reflecting the large texture and SOM variations. Eutrophic (V% >50 %) soils or specific horizons/layers are regularly observed and, such as the higher pH values, seem to be mainly a consequence of cations input by landfilling or waste disposal (e.g., Aniceto and Horbe, 2012; Teixeira, 2015; Almeida, 2019; Araújo, 2019; Putrino and Ladeira, 2019). Dystrophic soils (V% <50 %) occur mainly in areas that are less influenced by human interferences, such as urban forests (Patucci et al., 2017; Vale et al., 2017), or in subsurface horizons or saprolite exposed at the surface by cutting, accompanying the lowest pH values (e.g., Teixeira, 2015; Dias, 2017). The main exchangeable cations in most soils are Ca^{2+}, H^+ and Al^{3+}. (e.g., Moura et al., 2006; Araújo, 2019; Putrino and Ladeira, 2019). Contents of Ca^{2+} are likely enhanced by introducing carbonate-bearing human artifacts, increasing the pH values. Even in eutrophic soils, when Ca^{2+} assumes the highest values, H+Al tend to be in the second most abundant position in the exchange complex, which may indicate an inherited acid condition, previous to urbanization, typical of soils in tropical and subtropical climates.

Soil organic carbon (SOC) is commonly lower than 2 % (e.g., Barbosa and Correa, 2015; Guerrini et al., 2017; Costa, 2018), which may be a consequence of the faster C turnover in tropical and subtropical zones (Six et al., 2002), low vegetation cover and/or low microbial activity in urban areas (Craul, 1994; Scharenbroch et al., 2005; Lehman and Stahr, 2007). Another reason can be the common addition of saprolites and construction wastes in landfilling, depleted materials in SOC, or the exposition of saprolites in the surface by cutting, as verified by Araújo (2019), expressing the removal of the SOC-enriched topsoil. As pointed out by Lehman and Stahr (2007) and Pouyat et al. (2010), higher values of SOC are registered in Brazilian urban soils of green areas, such as urban forests (SOC: 2 to 4 %) (Patucci et al., 2017; Vale et al., 2017), or in soils marked by the addition of organic residues (up to 9 %) (e.g., Aniceto and Horbe, 2012; Dias, 2017; Milhome et al., 2018; Araújo, 2019). It is common to observe progressive decreasing of SOC contents from the surface to deeper horizons/layers (Rocha, 1995; Araújo, 2019; Putrino and Ladeira, 2019), but the erratic distribution of SOC down in the profile is also registered, mainly in zones of earthy materials and solid waste deposition (Aniceto and Horbe, 2012; Araújo, 2019).

Phosphorus results were obtained by different methods: ion-exchange resin, according to Camargo et al. (2009) (Zanata and Perusi, 2010; Putrino and Ladeira, 2019); extraction with H_2SO_4 1:1, according to Claessen (1997) and Donagemma et al. (2011) (Teixeira, 2015; Patucci et al., 2017; Araújo, 2019); extraction with Mehlich-1, according to Silva (2009) (Lima et al, 2018). These values tend to be high [based on the parameters of Sobral et al. (2015)] in soils characterized by massive waste disposal , reaching extreme values such as 1096 mg dm^{-3} (Dias, 2017) or 2765 mg dm^{-3} (Araújo, 2019). Urban soils that are mainly characterized by the addition of earthy and other anthropic materials may have low to high P contents, following the parameters of Sobral et al. (2015) (Zanata and Perusi, 2010; Putrino and Ladeira, 2019), whereas soils of urban parks or forests (Patucci et al., 2017; Vale et al., 2017; Lima et al., 2018) or significantly affected by cutting generally present low P levels (Teixeira, 2015; Dias, 2017). The high presence of P in the urban soils is related to the common disposal of P-bearing materials, such as food additives, pet food, detergents and human/animal excreta (Friedman, 2004). Besides the high presence of inappropriate discarded solid waste, undeveloped and developing countries are also characterized by insufficient sewage collection and treatment coverage, leading to a potential accumulation and contamination of P and other substances in soils and waters. In Brazil, a mean of 61.9 % of the urban population has access to sewage collection, with a great contrast between the Southeastern (83.7 %) and Northern (15.8 %) regions, whereas a mean of 78.5 % of the collected sewage receives suitable treatment (Brasil, 2020).

As postulated before, data focused on soil mineralogy are less frequent in Brazilian cities. The general methods applied in the mineralogical analyses did not reveal the typical heterogeneity observed in other parameters. The assemblages are dominated by minerals that are commonly formed in subtropical and tropical soils, such as kaolinite and Fe/Al oxides (hematite, goethite and gibbsite), especially in the clay and silt fractions (Gonçalves, 2011; Aniceto and Horbe, 2012; Almeida, 2019). However, a mix in the topsoil with 2:1 phyllosilicates, which is more frequently found in the weathering front in the tropics, possibly indicates an infilling with saprolite of the surroundings (Gonçalves, 2011; Almeida, 2019). Amorphous and poorly crystalline materials, especially composed by Fe, are also identified in the assemblages (Wilcke et al., 1999; Aniceto and Horbe, 2012). The soils studied by Aniceto and Horbe (2012) showed both positive and negative delta pH, indicating that poorly or highly crystalline materials of the clay fraction may adsorb cations and anions. Additionally, these authors identified the presence of calcite, attributed to the introduction of construction materials in the soils.

Finally, a few studies focus on soil organisms and/or soil-plant relationships in Brazilian cities. Patucci et al. (2017) investigated the soil biota biodiversity in an urban park of São Paulo city (SP), identifying oligochaetes and families of the orders Araneae, Chilopoda and Coleoptera. The increase of SOC is related to a higher density of individuals (ind m^{-2}), and the large frequency of *P. corenthurus* (Oligochaeta Glossoscolecidae) indicated anthropic interventions, since it is a species typically found in human-disturbed environments (e.g., deforested areas, monocultures). Vale et al. (2017) performed a phytosociological survey in an urban forest in Araguari (MG), identifying a community in an intermediate stage of succession formed by a high number of families (total 39, mainly Fabaceae-8, Myrtaceae-7, Lauraceae- 7) and species (94), but also marked by human impacts, as showed by the important presence of edge species in the whole fragment. Soil pathogenic agents, such as fungi (dermathophytes) and *Leptospira spp* are studied in urban and rural areas of Paraíba State (PB) by Pontes et al. (2013) and in a slum in Salvador (Bahia State-BA) by Scheineder et al. (2018), respectively. The urban areas of PB are more suitable for the dermatophytes than rural areas, especially brownfields, schools and slums, which tend to present soils enriched in human wastes and animal keratin. In Salvador (BA), an important capital of the Northeastern region, *Leptospira spp* was found in one-third of the soil samples, indicating soils as an additional reservoir in its life cycle, together with sewage or freshwater. These two studies reveal the potential risk of the urban population of developing countries to soil pathogens, particularly those living in slums.

Soil contamination by toxic metals and organic substances

Publications centered on contamination of urban soils are mostly from samples collected in pre-determined depths at the topsoil, without the definition of horizons/layers by morphological descriptions. The most common metals with contents above the reference limits established by the Brazilian Environmental Council (CONAMA 420/2009) are Zn, Pb, Cu and Cr, but Ba and Ni are also registered by some authors (Moura et al., 2006; Aniceto and Horbe, 2012; Barbosa and Correa, 2015; França et al., 2017; Dala Paula et al., 2018; Milhome et al., 2018; Putrino and Ladeira, 2019).

In most cases, the metal contents are above the Reference Values of Quality, which is the quality level for healthy soils. However, in some of the analyzed soils, the quantities of these metals are above the Prevention Values, which already requires monitoring, identification of the pollution sources and control. Only Pb content in irregular waste disposal area (*lixão*) in Iguatu (CE) is above the Intervention Value (Milhome et al., 2018), requiring a detailed investigation and the adoption of emergency actions to minimize the exposition of the population to the contaminated area (CONAMA 420/2009).

In general, the accumulation of these contaminants in the studied soils is attributed to anthropic activities. Human artifacts can be a major source of toxic contaminants, since ceramic fragments may contain Pb, Ni, Zn and Ba; electronic residuals can provide Pb, Zn, Cu and Cd; plastic residuals can release Pb and Ni; glass fragments may have Ba; and rubber can release Pb and Zn (Barbosa and Correa, 2015; Milhome et al., 2018; Putrino and Ladeira, 2019). In Campinas (SP), the association between a detailed morphological description of entire profiles with metals quantification allowed the association between high Ba accumulation and high presence of artifacts in horizons of different depths (Putrino and Ladeira, 2019). Part of Pb contents in the Brazilian soils is also derived from atmospheric inputs provided by gasoline combustion, but the compound tetraethyl lead, presented in the gasoline, was replaced by alcohol in the whole country in 1999 (*Decreto-lei 186/99, 31/05/1999*). However, higher amounts of Pb in the topsoil of old avenues of Teresina (Piauí State-PI), for example, are attributed to a heritage of atmospheric inputs by Moura et al. (2006).

Wilcke et al. (1999) used sequential extraction in topsoils of Uberlândia (MG) and Aniceto and Horbe (2012) in different depths of soils developed from *lixões* in Manaus, capital of Amazonas State (AM). These authors observed high accumulations of toxic metals in amorphous oxides and/or crystalline Fe-oxides. The amorphous materials are mainly associated with Cu, Cr and Ni in Uberlândia (MG) and Cu, Zn and Pb in Manaus (AM), whereas the crystalline phases are connected with Cu, Cr, Zn and Ni in Uberlândia (MG) and Cu, Zn and Pb in Manaus (AM). Aniceto and Horbe (2012) attributed the presence of amorphous phases especially to Fe-bearing residuals (wires, nails) in the soils. However, urban soils tend to be Fe-enriched in tropical and subtropical zones also because of the abundance of this element in natural soils and saprolite. Thus, adding earthy materials or cutting, which exposes common Fe-rich subsurface materials, can improve the amounts of Fe phases in the cities. Wilcke et al. (1999) also reported an important correlation between the metals with silicates (Cu, Cr, Ni, Pb, Zn) and, to a lesser extension, to SOM (Cu, Pb, Zn). In addition, a significant correlation of Zn with SOM contents is described by Milhome et al. (2018) in soils originated from *lixões* in Iguatu (Ceará State - CE), but the authors do not consider the association of metals with other fractions, such as amorphous or crystalline Fe-materials or silicates.

As commented before, contamination by organic substances in urban soils is registered only in few publications. Oliveira and Brilhante (1996) detected high levels of the pesticide hexachlorocyclohexane (HCH) in a terrain occupied by an orphanage in Duque de Caxias (RJ), but previously used by a HCH factory. Higher concentrations are commonly related to higher presence of SOM in the surface horizons, but the HCH concentrations do not directly accompany the progressive decrease in SOM down in the profile. Polycyclic aromatic hydrocarbon (PAH) in Uberlândia (MG) (Wilcke et al., 1999) and polychlorinated biphenyls (PCBs) in Uberlândia (MG) and Belo Horizonte (capital of MG State) (Wilcke et al., 1999; Pussente et al., 2017) show lower contents, especially when compared with urban soils located in industrial nations under temperate climate. Wilcke et al. (1999) attribute the results to stronger leaching, higher volatilization and faster degradation of these substances in tropical than temperate zones. Additionally, these authors show that PAH tend to have a similar profile in tropical areas over the world, which seems to be related not only with fuel combustion, but also with vegetation fires and biological production.

Main gaps and future challenges

The publications about Brazilian urban soils embrace a wide variety of themes, focusing on characterization, mapping, classification, and/or contamination. Soil erosion, mineralogy and the relationship between soils and urban fauna, flora, and diseases are addressed in minor amounts. Important methodological propositions and morphological, physical and chemical results were published, contributing to a better comprehension of these soils. However, facing that the country contains 5570 cities (IBGE, 2021) with different sizes, physical settlements (climate, landform, geology, original soils), social and economic structures and land-use history, a much greater number of studies still has to be performed to obtain representative data. Also, it is important to highlight the low accessibility of most of the published data due to a high “scientific endemism”, that is, their restriction mainly to Brazilian scientists because many publications are in Portuguese.

Although the set of publications provides a considerable number of laboratory analyses, a greater variety of analytical procedures in each study is necessary to improve the interpretations about the soils processes, including the most common physical and chemical methods, but also mineralogical and micromorphological analyses. Furthermore, the concentration in the first centimeters of the soils can restrict a more complete knowledge about the soil system, especially if the study’s objective is related to the comprehension of soils genesis and classification, which aid to assess their functioning. Additionally, the sampling procedure based on pre-defined depths, without a proper distinction of horizons/layers by field description, has to be improved in Brazilian studies. Because the morphology is not described in these cases, a mix of different horizons/layers can be the source of the physical, chemical, mineralogical and biological analyses, avoiding a correct interpretation of the results and complicating the establishment of a more realistic relationship between the soil characteristics.

Another important perception is that different areas of knowledge (e.g., Geography, Geology, Agronomy, Engineering) tend to examine the urban soils with specific approaches, without a systematic understanding of concepts, terminologies and methodologies. The meaning of terms, such as technogenic deposits, soils, urban soils, layers and horizons, is commonly unclear in the publications, which can make difficult the comparison between data and the comprehension of the general characteristics and functioning of the soils. Although mapping of urban soils using methodologies based on aerial images and topographical attributes (without a complete morphological description) gives some useful results, this type of approach should be re-evaluated as it could provide imprecise information about the study area, whereas integration with a complete and systematic soil survey would lead to more comprehensive and precise conclusions.

It is also important to highlight the lack of proper, detailed inclusion of the Anthropogenic soils in the Brazilian Soil Classification System (Santos et al., 2018). The national proposal of Curcio et al. (2004) is among the most used by the Brazilian publications, although the identification of the type and/or the predominant engineering intervention that defines the orders may not be easy without more specific laboratory analyses. However, interesting relationships between the orders defined by Curcio et al. (2004) and chemical characteristics are found in different publications, such as higher pH, base saturation, SOC and P contents in *Antropossolos Sômicos* and *Líxicos*, pointing to a suitability of this system, or at least part of it, to the tropical and subtropical conditions. It is important to underline that, in some publications, the classification following the Curcio et al. (2004) system and the mapping of urban soils are based on aerial images, which can lead to major mistakes in the spatial distribution of the soils. Anyway, it is important to analyze the available national and international proposals for the classification of Anthropogenic soils, to establish a broad and systematic discussion about this subject and to incorporate a robust protocol into the official Brazilian soil classification system.

CONCLUSIONS

The growth of the number of publications about Brazilian urban soils since the beginning of the 21th century is evident, with important contributions to the knowledge of soils located under tropical and subtropical climates and in developing social-economic conditions. The publications are mostly in Portuguese and are majority performed in cities with more than 500,000 inhabitants, many of them located in the Southern and Southeastern regions of the country. Urban soils formed from landfills and irregular zones of waste disposals are the most common, showing the deficiency of waste management in developing countries. Properties such as pH, base saturation, SOC and P contents tend to be higher in soils marked by the addition of earthy materials and solid waste than in soils developed from cutting, which commonly exposes the deep acidic saprolite of the tropical and subtropical zones.

Although scientific production is increasing, more studies are needed to obtain more representative patterns. It is also important to advance in the discussion and systematization of concepts, terminologies and methodologies in the different areas that embrace this subject, providing a complete interpretation about urban soils. In addition, complete field descriptions and a greater variety of analytical procedures must be considered in future studies to obtain more consistent data. Furthermore, it is urgent to analyze the available national and international proposals of classification of Anthropogenic soils and incorporate a robust system in the official classification of the country. Finally, it is relevant to improve the accessibility of the Brazilian scientific production, with more international publications, allowing the comparison between the national data and the results obtained worldwide.

Thus, broader and deeper research about the urban soils must be established in the country, coupled with efforts to incorporate soils in the urban planning to contemplate potential ecosystem services and improve the life quality of the cities' population. Transdisciplinary management instruments, including all the environmental matrices (air, water and soil), must be developed by scientists, politics, urban planners and population to arrive in more sustainable cities, which seems a major challenge worldwide, but especially in undeveloped and developing countries, such as in Brazil.

ACKNOWLEDGEMENTS

The authors thank to *Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)* by the fellowship to I.S.A.

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