

Relations Between Urban Subsoil and Climate Change in Different Neighborhoods of Rio de Janeiro

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Abstract: Most cities have grown in a disorderly manner without planning or concern for the environment while urban infrastructure networks were emerging and being implemented. Furthermore, it is known that impacts on the environment such as increasing the soil-sealing rate favor increases in temperature and the formation of heat islands leading to climate change. Therefore, the study objective was to analyze the impacts of disorderly occupation of the urban subsoil by underground infrastructure networks on permeable areas and their relationship with climate change. The methodology was based on bibliographic research and a field survey. It was found that the greater the disorderly occupation of the urban subsoil, the smaller the areas destined as green and permeable areas and the greater the vulnerability to climate change.

Keywords: Urban subsoil; Impermeability; Climate change.

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Introduction

In the subsoil of the cities there are concentrated sets of urban service-provision infrastructure networks that connect cities and are responsible for their functioning (TABA et al., 2015). That underground space is shared by public and private networks that provide water, gas and electricity supply, telecommunications, sewage and rainwater drainage and other services (GASTALDELLO, 2012). In the course of time, the disorderly growth and expansion of urban areas and the lack of planning have contributed towards increasing environmental problems in the cities. Cities have developed with no proper planning and the parallel growth in the demand for urban services has made the management of such spaces a difficult task (MICHEL et al., 2013).

Initially cities' subterranean spaces were occupied by channels, water supply networks, sewers and small tunnels. As time passed the underground space was subjected to the same disorderly process of occupation as the surface so that accidents, damage to previously installed infrastructure and environmental impacts became increasingly frequent (CAMPOS et al., 2006). The difficult management of the underground networks after their implantation can be attributed to population growth that gradually rendered them under-dimensioned for the demand and to technological progress and privatizations that made some of the networks obsolete, or even the lack of integration of the various networks which has meant that some of their ducts cross paths or occupy the same space (MICHEL et al., 2013).

Furthermore, the excavation and implantation methods usually used and the disorderly installation of underground urban infrastructure networks in the subsoil have produced various impacts on the environment insofar as they have reduced practically all the permeable areas in public spaces; a fact that is easily verifiable by observing the number and variety of manholes and inspection covers in public thoroughfares and sidewalks (OLIVEIRA et al., 2012).

Among the various impacts on the urban environment that can affect climate change the most serious, and the one with few efficient solutions is carbon dioxide emissions (HULME et al., 2002). The disorderly unplanned way in which most big urban centers have grown and the patterns of their urbanization processes have contributed towards the emergence of spaces where concern for the environment is completely lacking and that fact jeopardizes the isonomy, efficiency and continuity of the cities (GUEDES et al., 2017; UNITHANK, 2016).

Furthermore, Brazilian cities are vulnerable to the effects of climate change which vary according to the specific characteristics of the regions (PBMC, 2014). Their susceptibility to those environmental impacts poses a challenge to city planning and the search for mechanisms to reduce and mitigate carbon dioxide emissions as part of a climate change prevention effort.

Various studies have identified how the presence of green spaces in urban areas makes a significant contribution to the equilibrium and maintenance of the local microclimate for years (HEALEY, 1995). Another important aspect regarding the availability of green spaces is that is that urban areas are more susceptible to the effects of climate

change than rural ones (WILBY; PERRY, 2006). To address that situation, all over the world innumerable policies are being elaborated designed to regenerate those green spaces in urban environments in alignment with the concept of 'urban sustainability'.

The term 'urban sustainability' is associated to the broader concept of 'sustainable development' (DALBELO; RUTKOWSKI, 2015). Maclaren (1996) states that the concept of urban sustainability involves various social, economic and environmental considerations and, although there is no consensus on their relative importance, environmental demands need to be equated with social and economic ones if they are to be effective. According to Dalbello and Rutkowski (2015), urban planning and public policies are among the instruments that should be used to foster the implantation of urban sustainability.

In Brazil, the basic planning instruments for urban development and expansion policies are the Cities Statute and the Master Plan, instruments designed to reduce the negative impacts on the environment stemming from erratic, disorientated urbanization processes (ANDRADE, 2014).

Among the public policies for the regeneration of urban areas there are projects that include the creation of green spaces as a means to improving the micro-climate and reducing the amount of surface water run-off thereby contributing to the minimization of climate change effects. While it is known that green spaces help to reduce temperatures in urban centers, it is not known exactly how much green space is needed to reduce carbon dioxide emissions (BENEDICT; MCMAHON, 2002).

Against that background this study set out to analyze the impacts of the disorderly occupation of the subsoil effectuated by the installation of underground urban infrastructure networks in the urban environment of Rio de Janeiro in the aspect of climate change in the neighborhoods of Tijuca, Copacabana and Center and, based on that analysis, identify actions in the urban areas regeneration policies in a bid to obtain improvements in the urban built-up area. Accordingly, an analysis was performed of the relation between the disorderly occupation of the subsoil and the paved, impermeable areas in order to identify possible points for interventions capable of modifying and improving the urban environment.

Soil permeability in urban centers and its impact on the environment

In the field of urbanism, one of the main concerns of urban planners is the permeability of the urban soil. Badly planned urban spaces lead to a greater consumption of the available space, higher rates of impermeable areas leading to a reduced infiltration of water in the soil and a more intense rate of rainwater run-off. Those modifications affect the water cycle, contributing to higher rainfall levels, and leaving the cities more vulnerable to flooding and landslides (BEZERRA, 2015, p. 30; UNIÃO EUROPÉIA, 2012).

In recent years various studies have demonstrated the how big cities produce impacts that affect the local and regional climates as well as influencing the global atmosphere. Modifications stemming from urbanization processes in the cities include replacing

vegetation with various kinds of material that render the ground surface impermeable, contributing towards altering heat patterns, altering the quality of the air and causing the large urban centers to become areas of heat concentration known as ‘urban heat islands’ (MEIRELES et al., 2014; MONTEIRO, 1976).

The characteristic of the heat islands is that temperatures in the urban areas where they form are higher than in the surrounding rural areas (ZHAO et al., 2014). The direct cause of that phenomenon is the impacts stemming from the urbanization process (LANDSBERG, 1981) and together with the effects of climate change, they constitute a difficult challenge for city planning (RIZWAN et al., 2008). The dimension of the phenomenon also depends on the local and urban meteorological characteristics (OKE, 1987). As a result of those processes, alterations occur in the equilibrium of atmospheric radiation and in the urban energy balance leading to an urban microclimate marked by a raising of the air temperature (OKE, 1988).

Among the various factors that participate in the determination of urban soil permeability are soil texture, structure, depth and organic content, all of which influence the soil’s water storage capacity. In a fully functional soil the water storage capacity ranges from 100 to 300 liters per cubic meter of porous soil (UNIÃO EUROPEIA, 2012). Superficial infiltration of the soil is clearly affected by any reduction in the vegetation cover or increase in areas rendered impermeable. It varies from 25% (surface and at deep) in soils with 100% vegetation cover to 10% (surface) and 5% (at depth) in soils with 75% to 100% of their surface made impermeable. Furthermore, impermeability reduces evapotranspiration and increases surface runoff leading directly to higher temperatures in urban regions and susceptibility to flooding. Making the soil impermeable reduces its capacity to absorb water thereby affecting the urban microclimate (BEZERRA, 2015, p. 30).

However, despite the studies that have demonstrated the influence of increasing the areas rendered impermeable on climate change there are serious obstacles facing urban center regeneration policies. Restricting the processes that render the soil surface impermeable would be the ideal measure and should take priority over measures to attenuate or compensate for those processes given that once they have been set in motion they are practically irreversible. That being so, what would be the best way to proceed to reduce the large areas of impermeable surfaces in urban centers? Again, how would it be possible to minimize the impacts of climate change on large urban centers with very low surface permeability rates? In that context, there are studies indicating that reducing vegetation cover leads to an increase in heat islands in urbanized areas (YAO et al., 2017). It is necessary to reflect on those challenges and seek for solutions, projects and public policies for consolidated cities that embrace actions and mechanisms designed to reduce impacts on the environment and compensate for the harm done to it.

Relations between urban development and the disorderly occupation of the urban subsoil by underground networks

The urban subsoil mirrors the same process of disorderly occupation seen aboveground in the cities (CAMPOS et al., 2006). According to Lombardo (1985), the disorderly

land use and occupation patterns seen in the cities, with no planning and failing to take into account the relief or the climatic conditions of the place can result in: alterations to the local climate and discomfort in the acoustic, visual and circulatory aspects of the environment.

Albeit population growth and the urban expansion it gives rise to are natural processes over which there is no total control it is nevertheless of fundamental importance to conduct planning with a view to reducing impacts on the environment and guaranteeing good quality of life for the population (TUCCI, 2008). Urban planning and organization, according to Pinto (2007), must take into account environmental, social and economic factors, as only an orderly occupation of the land will make it feasible to preserve the environment.

It is in that sense that the Cities Statute and the City Master Plan are the urban policy tools that favor urban planning; albeit their guidelines do not they specifically address the question of the use of the urban subsoil in the aspect of the implantation of subterranean urban infrastructure networks (CAMPOS et al., 2006).

Relations between the occupation of the urban subsoil and urban microclimates

Various interdisciplinary aspects interfere in urban climates and one of them is the interactions among soil, built environment and the atmosphere (DUARTE; MONTEIRO, 2016). Marengo et al. (2009) consider that sealing off the soil surface reduces infiltration, boosts surface runoff and can lead to flooding, heat islands and other phenomena. Schueler (2000) defines the impermeable area of cities as being the sum of the thoroughfares, parking lots, sidewalks, roofs and other impermeable surfaces in the urban scenario. By their very nature, civil engineering and construction activities actively participates in the process of making the soil impermeable, leading to various impacts on the environment such as an increase in surface runoff and a lowering of the water table level (FERREIRA et al., 2005). Modern society, according to Mendonça et al. (2011), is well aware that it is significantly altering air temperatures as a consequence of the environmental unbalance caused by ever increasing urbanization. The modifications of the ground surfaces can affect air temperature variations insofar as different surfaces have different properties in regard to the quantities of solar energy they can reflect or absorb (ZEMAN, 2012, p. 82-85).

Torres and Machado (2011) state that the reflection of rays of sunlight that hit the surface is responsible for heating the air in the atmosphere. Thus the progressive sealing off of the soil in urban centers contributes to climate change insofar as it leads to increased temperatures in urban centers and the formation of heat islands (ZEMAN, 2012, p. 80-82).

The urbanistic characteristics associated to zones are used to define the intensity of land occupation and they are usually associated to the predominant forms of land use in them. The urban fabric is marked by differences in parameters such as the form of land division, geographic and economic situations and other factors. In regard to population

and construction densities, the urban zones are classified as low, medium or high density or special density. According to the Law governing land use and occupation in the city of Rio de Janeiro the stretch of Tijuca analyzed in this study is part of Multi-family Residential Zone 3 (*Zona Residencial Multifamiliar 3 - ZRM3*) which has residential neighborhoods and a diversity of commerce and services; it is considered to be of medium and high occupation density. The part of Copacabana studied here belongs to the Commerce and Services Zone (*Zona Comercial e de Serviços - ZCS*) and it has neighborhoods located near to the main transportation corridors in areas where land use is predominantly commercial and for service provision with medium to high density occupation. The study area 'Center' is in the Central Commerce and Services Zone (*Zona Central de Comércio e Serviços - ZCC*) which comprises the city's central area where the financial center is located as well as a diversity of commerce and services and is considered to be of high density occupation (PREFEITURA DA CIDADE DO RIO DE JANEIRO, 2017).

The laws that regulate land use and settlement in the Brazilian municipalities also takes into account the permeability of the soil. According to the Draft Bill for Complementary Law nº 33/2013 (*Lei de uso e ocupação do solo – LUOS*), the desired Permeability Rate is defined as the percentage of the area of the terrain that must be kept permeable and the permeable area is that area entirely free of any type of construction whatever to ensure the free infiltration of rainwater into the soil and subsoil and impede any form of alteration to the natural environment. To ensure the permanence of permeable areas, local or specific legislation on land use and occupation should establish a minimum percentage of permeability that takes into account the characteristics of the area where they are located in such a way as to make the implantation of population groups and their respective edifications compatible with the protection and valuation of the environment and the city landscape (RIO DE JANEIRO, 2013). Increasing the percentage of vegetation cover, insofar as it contributes to enhancing the permeability of the urban soil and environmental comfort (Art. 161, sub-heading VI), is among the directives of the Environmental Policy inserted in the city of Rio de Janeiro's Master Plan (RIO DE JANEIRO, 2011).

According to Mizuno et al. (1990), paving and covering horizontal surfaces is largely responsible for heat increases in low latitudes regions and the nature of the selected paving or covering material is an element capable of providing beneficial micro-climate effects. Studies have shown that the centers of heat islands in cities are frequently located over areas with the highest density of buildings. It is common for temperatures to be higher in areas with denser agglomerations of buildings (SANTOS et al., 2003).

Increasing the occupation density of badly planned built-up areas leads to increased 'space consumption' and a higher rate of surface sealing which, from the urban morphology standpoint, cause increased temperatures, favoring the formation of heat islands and an increase in rainwater runoff, aggravating the problem of flooding (BEZERRA, 2015). Lack of planning for the occupation of underground space means that infrastructure networks occupy the entire subsoil so the urban soil has little or no permeability. According to Patches and Price (2013), using urban infrastructure of a type that enhances the perme-

ability of the urban soil should be among the directives of sustainable urbanism planning.

Over the years, various modifications have influenced urban design and the use and occupation of the urban underground space, leading to a situation with no articulation. In other words, environmental, urbanistic and hydrological concepts have not been taken into consideration (ANDRADE, 2014). Against that background this study set out to analyze the influence of the disorderly occupation of the urban subsoil with underground infrastructure networks on the increase in impermeable areas and its contribution to temperature changes in the urban environment which in turn contribute to climate change.

Methodology

Contextualization

This research consisted of a bibliographic review and a field survey adopting a qualitative, descriptive approach, in an endeavor to reflect on and analyze the reality, identify patterns and produce explanations for the very high rate of impermeability in the study areas stemming from the disorderly occupation of the urban subsoil by underground urban infrastructure networks. The research also describes and establishes relations and comparisons that involved data gathering and took the form of a survey. Furthermore, given the comparative nature of the analysis, areas with similar urbanization characteristics were selected (GODOY, 1995; GIBBS, 2009).

The study focused on underground urban infrastructure networks implanted in three stretches of Rio de Janeiro neighborhoods (1-Tijuca, 2-Copacabana and 3-Center). In each stretch the areas occupied by the networks were delimited to identify the areas that had been made impermeable by their installation. Data for the three study stretches obtained in the field work were compared and the relations between the occupation of the subsoil by the underground infrastructure networks and the reduction of permeable and green areas were examined. Lastly an analysis was made of the possible relations of the reductions of permeable and green areas with climate change.

Study area

In the period from August 2018 to June 2019, in the city of Rio de Janeiro, three stretches within a 50-meter radius around crossroads of main roads, one in each of three neighborhoods were selected for study purposes (1-Tijuca, 2-Copacabana and 3-Center) The selection endeavored to ensure that the three stretches had similar urbanization and urban layout characteristics and obeyed the following criteria: the presence of installed infrastructure; the presence of both new and old networks; located near to metro stations; presence of residential and commercial or essentially commercial buildings; and being located in parts of the city with consolidated infrastructure. In the selected stretches around the crossings all manhole cover and inspection chamber covers were carefully mapped and the same was done for all the trees, patches of vegetation and planted beds.

The covers identified were marked out on the City Hall's official registration map on a scale of 1:50 based on field measurements made with measuring tape or yardstick and located with the help of reference points observed in the areas such as shops or items of urban equipment. The data obtained from the field survey was inserted on the City Hall's official registration map using AutoCad software (Autodesk, 2016 version).

The next step was to mark out two distinct areas on the maps: areas occupied by underground urban infrastructure networks (AUUIN) and Areas of Vegetation (AV). To demarcate the areas corresponding to the AUUIN the limits of the areas occupied by the manhole covers and inspection chamber covers were used. The AVs were those areas occupied by trees, patches of vegetation or planted beds, generally speaking with dimensions ranging from 1 to 1.44 square meters (Figure 1-A).

The AUUIN correspond to sewers, rainwater drainage networks, electricity, water and gas supply networks, and telecommunication networks. The study also identified other complementary networks associated to street lighting, security surveillance systems and firefighting installations for example and there were even some inspection lids that could not be identified. The Areas of vegetation consist of small beds with or without vegetation and trees of various sizes (small, medium and large). Two other distinct kinds of areas were marked on the map as well: permeable areas and impermeable areas. To delimit them, in addition to the information gathered in the field, the study made use of Google Maps to verify the visualizations obtained with satellite images (Figure 1-B).

Figure 1: A – Characterization of the Areas occupied by Underground Urban Infrastructure Networks (AUUIN) (red hatched) and the Areas occupied by Vegetation (AV) (green) in the urban fabric of the stretches of the Tijuca, Copacabana and Center neighborhoods. B – Characterization of the impermeable areas (grey and black) x permeable areas (green) in the stretches of the Tijuca, Copacabana and Center neighborhoods



Source: Elaborated by the authors, 2019.

Based on that mapping it was possible to quantify the areas of each of the studied stretches and the percentages of them occupied by AUUIN, AV and the other areas in regard to the total area occupied by the sidewalks and to quantify the permeable and impermeable areas. To that end a visual representation and simplified methods were used.

Lastly, to analyze the influence of high rates of occupation of the urban subsoil on the heat islands, data on temperature variations in the study areas over the years was acquired the temperature data was made available by Data Rio (IPP, 2020) for the years 2011 to 2019 and those of the National Meteorological Institute (*Instituto Nacional de Meteorologia*) (INMET, 2020) for the years 1980 to 2017.

Results and discussion

Analysis of the Areas: permeability of the urban soil

It was found that in the three areas studied the AUUIN occupied areas corresponding to practically half of the area designated for the sidewalk. The areas occupied by vegetation, on the other hand, a mere 1 to 3% of the sidewalk area (Table 1). The remaining areas are those without the presence of inspection chamber covers or manhole covers but that does not necessarily mean that there are no urban infrastructure networks under them. The degree of occupation of the subsoil by the urban infrastructure networks was found to be very high. In some parts of the stretches the AV interfere with the AUUIN because the underground space is so intensely occupied by the underground networks that the two kinds of areas end up dividing the same space between them (Figure 1-A and Table 1).

Table 1: Survey of the areas occupied by the underground urban infrastructure networks (AUUIN) and the Areas occupied by Vegetation) as percentages of the total sidewalk area in the selected areas of the Tijuca, Copacabana and Center neighborhoods

TYPE OF OCCUPATION	TIJUCA		COPACABANA		CENTRO	
	m ²	%	m ²	%	m ²	%
AUUIN	841	56	800	66	1,366	73
AV	44	3	27	2	13	1
REMAINING AREAS	610	41	389	32	478	26
SIDEWALK (TOTAL)	1,495	100	1,216	100	1,857	100

Source: Elaborated by the authors, 2019.

Although the areas designated as sidewalks in the studied stretches are around 1,495m² (Tijuca), 1,216m² (Copacabana) and 1,857m² (Centro) only 3% (Tijuca), 2% (Copacabana) and 1% (Center) of those areas are occupied by vegetation (AV) (Table 1). Thus, the fact of a sidewalk area's being large does not mean that larger areas of them are destined to be green areas; the quantity of AV is related to the quantity of the areas occupied by UUIIN. The greater the disorderly occupation of the urban subsoil, the lesser the green areas and consequently the smaller the permeable areas will be. That being so, the pressures that climate related and non-climate-related factors exert such as lack of access to public water supply and sanitation services, the non-existence of proper land use and settlement planning, the absence of public housing policies and the growth of the

population in situations of social vulnerability can boost the effects of climate change. Furthermore, the impermeable surfaces can not only intensify problems with flooding but are also considered to be determinants of the heat island effect (ROSENZWEIG et al., 2011b). The non-existence of land use and settlement plans that fosters the disorderly occupation of the urban subsoil boosts the pressures that climate change exerts on the cities (PBMC, 2014).

Another observation was the scarcity of permeable areas in the three stretches analyzed by the study; the impermeable areas occupied from 97 to 99% of the total (Figure 1-B). The areas where land use was predominantly for commercial purposes have the greatest areas occupied by AUUINs and consequently the smallest areas of AV as can be seen from the data for the Center neighborhood (73% de AUUIN and 1% of AV) (Table 1). That being so, it can be stated that in consolidated cities in which the subsoil is densely occupied by subterranean infrastructure networks and whose growth processes were marked by an absence of planning, the greater the percentage of AUUIN, the smaller that of the AV.

It was also found that in the three stretches, each with the same total area (6,806m²), representing the sum of the impermeable areas (in tones of grey and black) and the permeable areas (in green) (Figure 1-B) there was little variation in the percentages occupied by impermeable areas: Tijuca 99.3%, Copacabana 99.6% and Center 99.8% (Table 2). The highest impermeable areas percentage (99.8%) and lowest permeable areas percentage (0.2%) were registered for the stretch in the Center (Table 2).

Table 2: Survey of impermeable X permeable areas in the studied stretches of the Tijuca, Copacabana and Center neighborhoods

TYPE OF AREA	TIJUCA		COPACABANA		CENTRO	
	m ²	%	m ²	%	m ²	%
IMPERMEABLE	6,762	99.3	6,779	99.6	6,793	99.8
PERMEABLE	44	0.7	27	0.4	13	0.2
TOTAL	6,806	100	6,806	100	6,806	100

Source: Elaborated by the authors, 2019.

Thus, in consolidated cities with characteristics similar to those of the stretches investigated in this study, the greater the percentages of AUUINs the smaller will be those of AVs and the greater the percentages of occupied areas that are impermeable the lesser will be the occupation by permeable areas. Therefore it can be concluded that the disorderly occupation of the urban subsoil contributes towards reducing the permeability of the soil in urban areas.

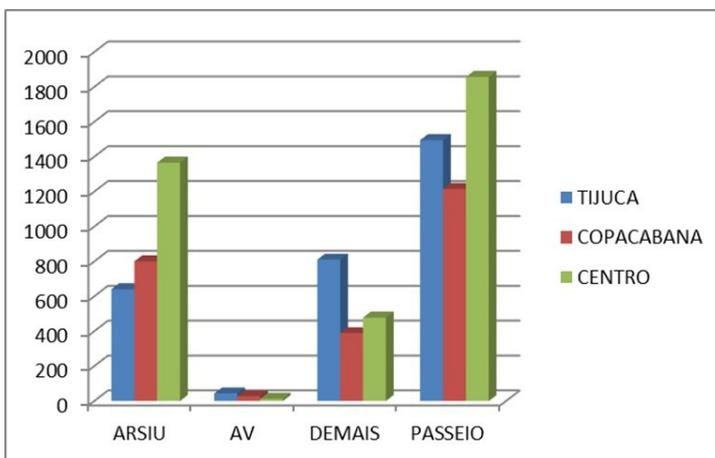
It was found that in the stretches investigated the subterranean space was densely

occupied and that the occupation had a direct influence on the implantation, quantity and type of local vegetation; the greater the occupation of the subterranean space, the lesser the quantity of vegetation and permeable green areas (beds).

Analysis of the relations between disorderly occupation of the subterranean space and climate change in the cities

The stretches of the neighborhoods with a mixture of residential and commercial land use or predominantly residential use, Tijuca and Copacabana, had similar percentages of AV: 3% and 2%, respectively. The stretch in the Center neighborhood however, where land use is predominantly commercial had the lowest percentage of AV of the three areas (1%). The differences among the three areas in terms of AV are more accentuated in regard to the presence of tall or short trees and beds of vegetation. Tijuca and Copacabana have very similar urban development and design profiles which explains their very similar patterns of AUUIN and AV occupation (Tables 1 and 2). In the case of the stretch in the Center neighborhood, however, the rate of AUUIN occupation is greater than in the stretches in Tijuca and Copacabana (Figure 2). Those statements underscore the need to make use of urban infrastructure that enhances the permeability of the soil (PATCHETT; PRICE, 2013). Accordingly, the diversification of land use and occupation modalities in the central areas of cities should be a guideline in the quest for sustainable urbanism ((RICHARDS, 2013).

Figure 2: Survey of the areas (in m²) occupied by underground urban infrastructure networks (AUUIN) and areas (in m²) occupied by vegetation in relation to the total areas (in m²) of the stretches analyzed in the neighborhoods of Tijuca, Copacabana and Center. Legend: ARSIU = AUUIN; DEMAIS = Other areas; PASSEIO = Sidewalk



Source: Elaborated by the authors, 2019.

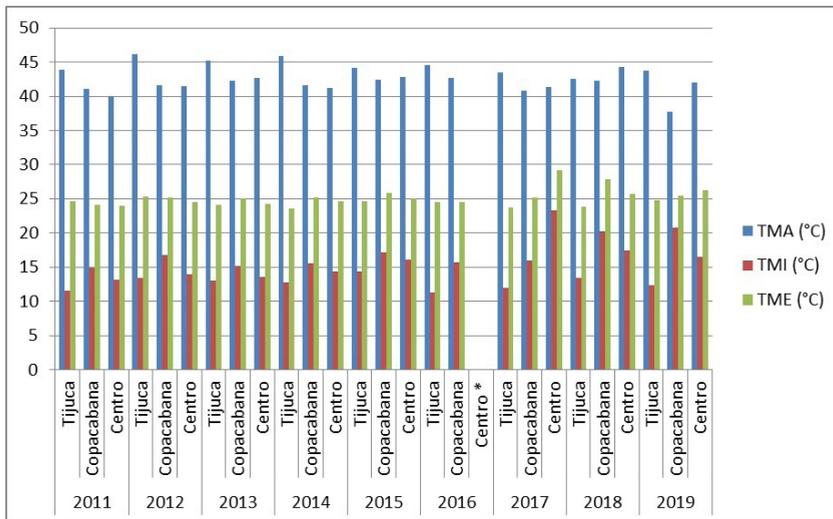
Another observation was that in areas that are essentially commercial centers the density of occupation of the urban subsoil by infrastructure networks is much greater and therefore so is the concentration of areas rendered impermeable. The occupation of the subsoil by such networks is inversely proportional to the areas of permeable surface; the greater the AUUIN the lesser the AV (Table 1 and Figure 2). Thus it is highly important to institute, promote and reinforce actions for the regeneration of green areas in urban centers whether they be actions to recuperate former ones or create new permeable green areas, through tree-planting in the urban environment or other such means (PREFEITURA DA CIDADE DO RIO DE JANEIRO, 2016). In those areas where the subterranean space is intensely occupied, impermeability rates are high and that can favor an increase in the formation of heat islands (Table 2).

To verify the effects on climate change of high impermeability rates stemming from disorderly occupation of the urban subsoil, the study gathered meteorological data for the areas embraced by the study. The meteorological research institutes of the city of Rio de Janeiro do not have records for the years 1970 to 2000 for those areas. However, in his study Lucena (2007) verified the occurrence of an increase in the surface temperatures in urban centers in the decades 1980 to 2000 and with a string indication of heat islands formation, especially in the decade of the years 2000.

The city's central and northern zone regions (Tijuca is in the northern zone) are consolidated urban areas and they show themselves to be the main accumulators of urban energy (heat) with a considerable similarity between the Copacabana neighborhood and the Center and Northern zone of the city, contributing with them to the increase in the thermal gradient.

To analyze the temperature increases in more recent years the study used the meteorological data of the Data Rio (IPP, 2020) for the years 2011 to 2019. They show that there have been times when the minimum temperature was relatively high and others when the maximum temperature was relatively low and there is even a period with no records at all, the year 2016, which was apparently because the meteorological station equipment was de-activated for maintenance and repairs. Over the respective period of years however there were subtle but observable variations in maximum temperatures. In the year 2012 the variation between the maximum and minimum temperature in Tijuca was 32.7°C (Figure 3).

Figure 3: Maximum (TMA), mean (TME) and minimum (TMI) temperatures in the Tijuca, Copacabana and Center neighborhoods in the years 2011 to 2019. * Period when equipment was deactivated



Source: IPP, 2020. Elaborated by the authors, 2020.

Comparing the data for the city of Rio de Janeiro as a whole and the neighborhoods where the study stretches were located, both the neighborhoods and the city reveal a tendency to an increase in maximum and minimum temperatures as the years go by. For the city, the maximum went from 27.67 °C in 1990 to 32.43°C in 2017, an increase of 4.76 °C, while the minimum went from 21.22 °C in 1990 to 25.09 °C in 2017, an increase of 3.87 °C in 27 years (INMET, 2020).

Although there is a difference between atmospheric temperature and surface temperature insofar as the former refers to the temperature of the continental surface and the latter to the temperature of the immediate surface nevertheless it can be said that there is a link between the atmospheric temperature and the increases in urbanization and the extent of areas rendered impermeable, corroborating the studies of Lucena (2012). Thus it was verified that an increase in disorderly urbanization can be associated to an increase in atmospheric temperature whose effect is the formation of heat islands and climate change.

As has been shown, the disorderly occupation of the urban subsoil by underground infrastructure networks contributed to the reduction of green areas and an increase in impermeable areas where materials such as concrete and asphalt are commonly used to pave the streets and sidewalks. The effects caused by the use of concrete and asphalt coupled with the cities' geometrical and morphological characteristics and increased pollution levels lead to increased temperatures and the formation of heat islands (GARTLAND, 2010; KOWALSKI, 2019; SANTAMOURIS, 2011).

Thus, in order to minimize the impacts generated by the disorderly occupation of the urban subsoil and their influence on climate change, it is necessary, first of all, to map the subsoil and identify the AUUINs and based on that mapping, to identify areas of them susceptible to interventions designed to transform them into permeable areas occupied by vegetation or semi-permeable areas by making use of materials that include open spaces in their structure that allow water to pass through them such as porous concrete or porous asphalt or paving surfaces with interlocking blocks or blocks with spaces for the passage of water in them or other similar solutions (MARCHIONI; SILVA, 2010). The mapping process can also provide information for urban administrators and public authorities of great value for urban planning and planning the city's future development.

It must be stressed that as the underground networks can interfere directly in the permeability of the urban soil so it is important to design large green areas to improve biodiversity (DOUGLAS, 2011).

There is, therefore, an urgent need to create alternatives for the adaptation of urban infrastructure and that could include a review of the regulations concerning land use and occupation of the subsoil by infrastructure networks and the creation of green spaces that can provide better drainage and permeability of the soil and reduce the effects of urban heat islands (PBMC, 2014). Furthermore, a broad discussion of the relations between disorderly occupation of the subterranean space and the associated impacts on the environment that lead to alterations in the micro-climate will make it possible to elaborate adaptation strategies and proposals for the regenerations of the built-up urban environment.

Conclusions

The analysis of the occupation of the urban subsoil by urban infrastructure networks made by means of a mapping of AUUINs and AVs and of the permeable and impermeable areas revealed that the greater the disorderly occupation of the subsoil, the greater the extension of the surface rendered impermeable and the smaller the spaces occupied by green areas. Furthermore, disorderly growth, lack of planning and failure to consider environmental aspects contribute to higher percentages of impermeable surfaces which, coupled with other factors, contribute to climate change in the cities

The challenge is to propose interventions in the built-up urban areas capable of making them more sustainable and of improving peoples' quality of life and minimizing the effects of climate change and other environmental impacts.

Studies and measures designed to regenerate urban spaces and regulate the use of the urban subsoil, reducing its occupation and increasing permeable areas are capable of minimizing the impacts on the urban environment and that in turn could lead to reducing the rate of acceleration of temperature increases and climate change.

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Tensionamentos socioambientais em comunidades costeiras: um estudo interdisciplinar nos manguezais do sul da Bahia

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*Tema em destaque:
Urbanização, Planejamento e Mudanças Climáticas*

Resumo: A maioria das cidades cresceu de forma desordenada, sem planejamento e preocupação com o meio ambiente. Também assim, foram surgindo e sendo implantadas as redes de infraestrutura urbana. Além disso, diversos impactos no meio ambiente podem provocar mudanças climáticas, como o aumento da taxa de impermeabilização do solo que favorece o aumento da temperatura e, assim, a formação de ilhas de calor. Portanto, objetivou-se analisar o impacto da ocupação desordenada do subsolo urbano pelas redes subterrâneas de infraestrutura no aumento das áreas impermeáveis e suas relações com as mudanças climáticas. A metodologia aplicada baseou-se em pesquisa bibliográfica e levantamento de campo. Assim, verificou-se que, quanto maior a ocupação desordenada do subsolo urbano, menor as áreas destinadas às áreas verdes e permeáveis, e, maior a vulnerabilidade às mudanças climáticas.

Palavras-chave: Subsolo urbano; Impermeabilização; Mudanças climáticas.

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Relación entre el Subsuelo Urbano y el Cambio Climático En Diferentes Vecindarios en Río de Janeiro

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*Tema en Destaque:
Urbanización, Pl-
anificación y Cambio
Climático*

Resumen: La mayoría de las ciudades crecieron de manera desordenada sin planificar y sin preocuparse por el medio ambiente. Además, las redes de infraestructura urbana estaban emergiendo y siendo implementadas. Además, varios impactos en el medio ambiente pueden causar el cambio climático, como aumentar la tasa de sellado del suelo, lo que favorece el aumento de la temperatura y, por lo tanto, la formación de islas de calor. Por lo tanto, el objetivo era analizar el impacto de la ocupación desordenada del subsuelo urbano por las redes de infraestructura subterráneas en el aumento de áreas impermeables y su relación con el cambio climático. La metodología aplicada se basó en la investigación bibliográfica y la encuesta de campo. Por lo tanto, se descubrió que cuanto mayor es la ocupación desordenada del subsuelo urbano, más pequeñas son las áreas destinadas a áreas verdes y permeables, y mayor es la vulnerabilidad al cambio climático.

Palabras-clave: Subterráneo urbano; Impermeabilización; Cambios climáticos.

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