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Influence of roof covering on the quality of rainwater in the central north region of the city of Rio de Janeiro

Influência do revestimento de telhados na qualidade de águas pluviais na região centro norte da cidade do Rio de Janeiro

Influencia del cobertura del techo en la calidad del agua de lluvia en la región centro norte de la ciudad de Rio de Janeiro

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Abstract

The use of rainwater has become a matter of vital importance in ensuring the sustainability of water resources and improving sanitary conditions in particular locations. This study aims to evaluate the influence of metal and fiber-cement roof coatings on the quality of rainwater obtained from rainwater harvesting systems in Rio de Janeiro. Fifty-seven samples of stored rainwater were collected and analyzed from first-flush (FF) and reservoir (RR) points between 2017 and 2019; these complied with the NBR 15.527/2019 and NBR 16.783/2019 standards for residual chlorine, total and thermotolerant coliforms, conductivity, dissolved organic carbon (COD), pH, and turbidity parameters. Descriptive statistics in Excel and R Studio were employed for water quality assessment. The fiber-cement roof showed alkaline pH levels, while the metal roof had higher turbidity values. The COD parameter did not comply with the NBR 16.783/2019 regulations in either of the systems. Despite this, both the metal and fiber-cement roofs met the principles and guidelines laid down by NBR 15.527/2019, and thus serve as a source of non-potable rainwater.

Keywords: *Water Resources, Rainwater, Water Quality, Surface Runoff, Coatings.*

Resumo

O aproveitamento das águas da chuva tem se tornado um tema fundamental, no sentido de garantir a sustentabilidade dos recursos hídricos e a melhoria de condições sanitárias em determinadas localidades. Este trabalho visa avaliar a influência de revestimentos de telhados metálicos e de fibrocimento na qualidade de águas pluviais obtidas de sistemas de captação e armazenamento de água pluvial, no Rio de Janeiro. Foram coletadas e analisadas 57 amostras de volumes armazenados de água de chuva nos pontos first-flush (FF) e reservatório (RR), entre 2017 e 2019, em atendimento à NBR 15.527/2019 e NBR 16.783/2019, dos parâmetros: cloro residual, coliformes totais e termotolerantes, condutividade, carbono orgânico dissolvido (COD), pH e turbidez. A metodologia utilizada para a avaliação da qualidade das águas pluviais foi a estatística descritiva com os programas Excel e R Studio. O telhado de fibrocimento apresentou resultados de pH com um teor alcalino, enquanto o telhado metálico apresentou valores maiores de turbidez. O parâmetro COD não atendeu a NBR 16.783/2019 em ambos os sistemas. Ainda assim, os telhados metálico e de fibrocimento atenderam aos principais limites estabelecidos pela NBR 15.527/2019, de modo atender como fonte de uso não potável da água da chuva.

Palavras-Chave: *Recursos Hídricos, Água Pluvial, Qualidade da Água, Escoamento Superficial, Revestimentos.*

Resumen

El aprovechamiento del agua de lluvia se ha convertido en un tema fundamental para garantizar la sostenibilidad de los recursos hídricos y mejorar las condiciones sanitarias en determinadas localidades. Este estudio tiene como objetivo evaluar la influencia de revestimientos de techos metálicos y de fibrocemento en la calidad del agua pluvial obtenida de sistemas de captación y almacenamiento de agua de lluvia en Río de Janeiro. Se recolectaron y analizaron 57 muestras de agua de lluvia almacenada en los puntos de primer lavado (FF) y en el depósito (RR) entre 2017 y 2019, cumpliendo con las normas NBR 15.527/2019 y NBR 16.783/2019 en relación a los parámetros de cloro residual, coliformes totales y termotolerantes, conductividad, carbono orgánico disuelto (COD), pH y turbidez. La metodología utilizada para evaluar la calidad del agua de lluvia fue la estadística descriptiva con los programas Excel y R Studio. El techo de fibrocemento presentó resultados de pH con un contenido alcalino, mientras que el techo metálico mostró valores más altos de turbidez. El parámetro COD no cumplió con la norma NBR 16.783/2019 en ambos sistemas. Sin embargo, tanto los techos metálicos como los de fibrocemento cumplieron con los límites establecidos por la norma NBR 15.527/2019, sirviendo así como fuente de uso no potable de agua de lluvia.

Palabras clave: *Recursos hídricos, agua de lluvia, calidad del agua, escorrentía superficial, revestimientos.*

1. Introduction

Despite the abundance of water in the world, it is a limited resource, insofar as there are clear signs of a reduced amount of fresh water and in certain regions only a limited supply. The uncontrolled global population growth, which is linked to the question of the availability and quality of water resources, has impaired the supply of water for human consumption in a way that has triggered an acute crisis of water scarcity and led to conflicts between nations (JORGENSEN et al., 2009). The Paraíba do Sul River Basin, a region where there are great conflicts of interest, was affected by the water crisis in the South-East of Brazil in the period 2014-15, which had a serious effect on the water supply of a populated region and on the greater demand for water in the country (COSTA et al., 2015). Both social and environmental tensions rose in intensity as the stocks fell in the reservoirs owing to the low amount of rainfall and outflows which were well below the historic average and reached a critical point in 2015 when only 0.33% of its volume was available for use (ANA, 2017). These conditions were the cause of growing concern with regard to the panorama of the water supply, especially in light of the fact that the National Water and Sanitation Agency (ANA, 2019) forecasted an increase of 24% in the pattern of water consumption in Brazil by 2030.

In recent decades, extreme rainfall events have become increasingly common owing to climate change, the spread of urbanization and soil use (SILVA, CRUZ AND AMARAL, 2016). These changes in the hydrological cycle have resulted in a combination of factors, the most prominent being the disorderly spread of urbanization, particularly in the main cities of Brazil. This phenomenon has a harmful effect on the people, such as surface runoff and the appearance of watertight areas (VASCONCELOS, MIGUEZ AND VAZQUEZ, 2016). However, there are alternative ways of mitigating hydrological impacts, particularly in metropolitan regions, one of which is to adopt a compensatory urban drainage technique, as a means of harvesting and harnessing rainwater.

One of the objectives of the Brazilian National Water Resources Policy, enacted by Law No. 9.433/1997 (BRASIL, 1997) is to ensure the availability of water at levels suitable for present and future generations. This Law of Waters established the need to protect the water resources of Brazil to ensure sustainable development and the maintenance of a balanced society and environment (MOTA, OLIVEIRA E MEDINA, 2020). Law 13.501/2017, which was included in the Law of Waters, provided an incentive to make use of intake systems, storage and rainwater utilisation, such as measaures for the use of rain for non-potable activities like watering gardens, cleaning floors and agricultural or industrial activities (BRASIL, 2017).

In tune with this initiative, the federal government enacted Law 14.546 in 2023, to encourage the use of rainwater in new buildings (BRASIL, 2023). These new systems for the utilisation of water have positive social, environmental and economic features (BENETTI, 2019), and can act as a tool for heightening awareness of the need for a rational use of water (SILVA and SANTANA, 2020).

Systems of harnessing and harvesting rainwater can also lead to the reduction of wastewater disposal. The intake and retention of a part of the effective volume of rainwater can assist in reducing the peak flow of the drainage system, as was noted in a study by Teston et al. (2018), while making an assessment of a condominium of houses in the city of Curitiba (Parana State). However, a number of factors should be taken into account including: the extent of the roof area, the type of material, the storage capacity of the tank or cistern, rainfall features and conditions of soil or land use.

The NBR 15.527/2019 lays down the minimum conditions required for the use of rainwater, with regard to the physico-chemical parameters of water quality for non-potable purposes. The quality of the water stored depends on a number of factors such as: i) the type of materials and roofing used for the intake and storage, ii) the physical and dynamic features of the area of study and iii) the concentration of pollutants carried during rainfall events and iv) the surface runoff of the roofing system (ABNT, 2019a).

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The aim of this study has been to assess the quality of rainwater stored in two rainfall systems situated in the north of the city of Rio de Janeiro with regard to the type of materials used for roof covering.

2. Theoretical Framework

2.1. The use of water

In legal terms, water is a natural limited resource endowed with economic value and an asset in the public domain but at the same time, it is an essential resource for the survival of human beings insofar as it makes it easier for mankind to carry out activities that are suited to its sanitary, social and cultural needs. (BRASIL, 1997; UNESCO,2021a).

The attribution of value to water and its benefits is highly subjective when viewed in the cultural sphere. The culture of a society, group or individual influences the way that water is regarded and used and in light of this, it can be perceived as existing in other realms – for example, playing a role in mental health, spiritual well-being, emotional balance and happiness. When water has an aesthetic value in landscapes, it benefits mental health. Several cultures like those of indigenous people, form a close bond between water and their territory, which means this resource is not just a material asset but a form of symbology in which fresh water is related to life, while the water from the sea represents death (DIEGUES, 2007).

A failure to recognise the value of this resource leads to its inefficent use with high discharges of pollutants and marine or fresh water ecosystem degradation, both of which cause high levels of hydric stress. This phenomenon create a scenario in which the demand for water in a particular region is greater than its availability or capacity for renewal. According to UNESCO (2021b), about 2 billion people already live in areas subject to hydric stress and by 2030, about 40% of the world population will lack access to a sufficient water supply.

2.2. Availability of water

Although there is a huge abundance of water, the part that is available for human consumption is unevenly distributed. According to ANA (2009), the Asian and American continents hold about 31.8% and 39.6% of the world supply of fresh water respectively. Brazil has about 12% of this total. As well as this irregular pattern regarding the availability of water in different regions of the world, another factor that adds to hydric stress is its relation to population density. Latin America has about twelve times more water per inhabitant than Asia. In national terms, Brazil has more water available than it needs for consumption while countries in the Middle East are in worse conditions. (DE MELO, 2010).

According to the *International Water Management Institute (*IWMI, 2014), almost 20% of the world population, or 12 billion people, live in areas where there is a scarcity of water and where the harvesting of water for agriculture, industry and other purposes, exceeds 75% of the waterflows from rivers. In addition, about 1.6 billion people live in areas where there is an economic shortage of water and where although water is available, people have a limited capacity or lack the financial resources to have access to it. It can be concluded from this that even a locality with large water reserves is not enough to guarantee that water can be supplied to the whole population (DE MELO, 2010).

In light of this, the conditions for economic development in a particular region are an essential factor for ensuring water security. The shortage of water is aggravated by the problem of social inequality, as well as the lack of any management or sustainable use of hydric resources. The world crisis in these resources is closely linked to social inequality which is shown by the contrasting records in developed and developing countries (CETESB, 2022).

As was confirmed by evidence revealed during the COVID-19 pandemic, the most vulnerable

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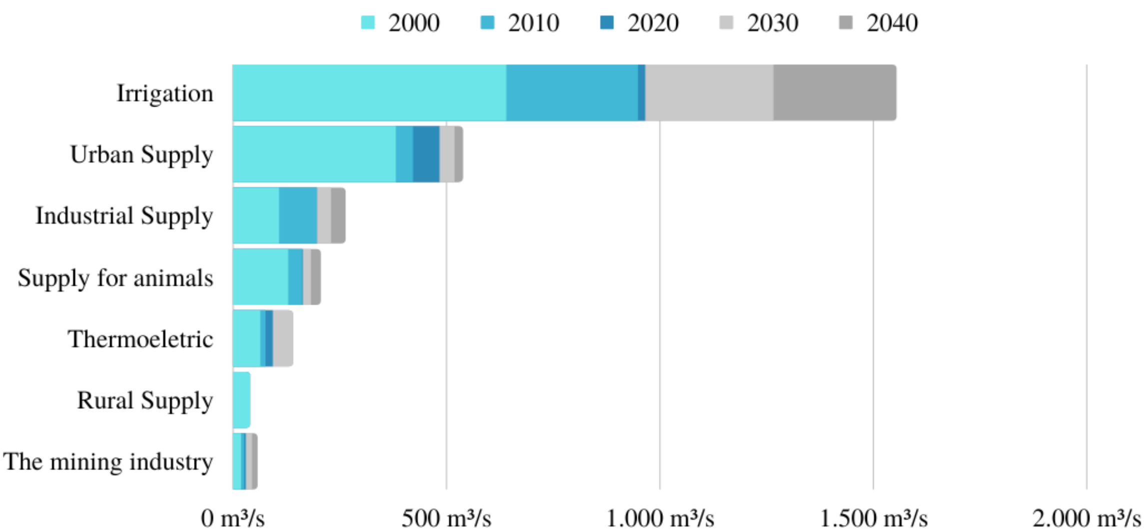
communities who live in informal settlements and urban *favel*as (shanty towns) were the hardest hit. During the pandemic, the World Health Organization (WHO) took the most stringent protective measures which, as well as social isolation, included guidelines for keeping one´s hands clean with soap and water. This meant that if there was not suitable access to water and sanitation, people would be at greater risk. More than 3 billion people do not have access to sanitary facilities related to hygiene and food security and in Brazil alone, there are more than 33 million people without access to water. (TRATA BRASIL, 2018).

2.3. Distribution of drinking water in Brazil

The consumption of water in Brazil covers the following areas: irrigation, public supply, provision for animals, industrial use, thermoelectric power generation and the mining industry (ANA, 2021). In 2020, these sectors consumed 61.46 trillion litres of water. A half of this water was used for irrigation, followed by 25% for urban supplies, 8% for animal consumption and 9% for industry.

The demand for water resources in Brazil has increased over time, particularly in three key sectors: irrigation, urban requirements and industry. Owing to the great potential for expansion in the irrigation sector, in the last 20 years, there has been an increase in consumption of about 50%, and the consumption rate has risen from 640 to 965 m³/s (Figure 1). There are forecasts for 2040 of an increase of 42% in water withdrawal which corresponds to more than 26 trillion litres in the Brazilian reservoirs.

Figure 1: Evolutionary pattern of recommended uses in different sectors of Brazil in the period 2000-2040



Source: adapted from ANA, 2021.

In 2014, the Paraíba do Sul basin underwent a severe crisis (COSTA et al. 2015). The main watercourse of the basin is 1,200 km long and flows through the States of Minas Gerais, São Paulo and Rio de Janeiro. These States are of extreme importance in the political sphere as they are where one of the main industrial hubs and populated areas are concentrated. The principal source of water supply for the city of Rio de Janeiro is the Paraíba do Sul basin, which caters for 14 million people (CAVALCANTI and MARQUES, 2016). According to the authors, the Paraíba do Sul basin is one of the strategic points for the management of water resources in Brazil. This is because its multiple uses for electric power generation, human consumption, industrial and agricultural use as well as other factors, have been the cause of conflicts and disputes that arise during periods of scarcity, the degradation of the basin or irregularities of distribution.

The predominant use of the basin is for urban supplies which in 2020 accounted for a little more than

50% of the water withdrawn from the basin. This was followed by industry and irrigation which accounted for nearly 20% and 15%, respectively (ANA, 2021).

2.4. Water consumption in the School Environment

It is becoming essential to analyse the end uses of water in the school environment because there is a tendency for large amounts of water to be wasted by users without any responsibility for paying for the service of supplying it. Tomaz (2001 *apud* Marinoski, 2007) showed that the average rate of consumption per capita in schools and universities ranges from 10 to 50 litres per day for each student and on average, 210 litres/ per day per employee, with variations depending on the building typology.

In the case of universities, Vaz (2019) compiled studies that had been carried out on the demand for non-drinking water in higher education buildings that had different structural features such as whether or not there were laboratories, classrooms, administrative offices and cleaning services. According to the author, the lowest percentages found for non-drinking uses were in the SENAI Technology Center in Santa Catarina and in the Technology Center of the Federal University of Santa Catarina (UFSC), which represented 63.5% and 69%, respectively. The highest rates of non-potable consumption were in the University Library which had 85% and the Socio-Economic Center, UFSC, which had 72%.

The average rate of water consumption for purposes not requiring potable water (such as toilet bowls or urinals) was 77%. Karlinski (2015) showed that the use of water for non-drinking purposes in academic institutions are as follows: toilet bowls and/or urinals, and the requirements for cleaning the building and watering the gardens. The cleaning services and watering of gardes need a rate of non-potable water of 5 litres/m² and 1.5 litres/m², respectively (FERREIRA, 2014).

2.5. Harnessing Rainwater

The adoption of systems for harnessing rainwater cannot be regarded as a recent technique. There have been reports of this practice going back thousands of years (LIEBMANN, 1979 *apud* ROCHA and DUARTE, 2017). Nonetheless, in light of the threat of a water crisis and the search for alternative systems that can reduce dependence on surface and underground springs, the harnessing of rainwater has become a matter of great importance (KARLINSKI, 2015).

Rainwater can be used for activities that do not require drinking water such as watering gardens, cleaning, washing clothes, flushing toilets, and evaporative cooling, all of which reduce water consumption in the public system. As well as being a sustainable practice in the use of hydric resources, the harnessing of rainwater avoids wasting water which is required for purposes of high quality, as well as making it possible to economize when carrying out tasks that depend on the public supply of water.

Another benefit from installing a system of rainwater is that it provides a capacity to retain the initial anount of rainfall and thus mitigates the effects on the drainage system. In addition, it reduces the risk of flooding and damage to health, businesses and residential dwellings, through being able to store water at the particular time when extreme rainfall events occur (ROCHA e DUARTE, 2017; BENETTI, 2019).

Once the scheme has been introduced into the school surroundings, rainwater can open up opportunities for teaching and learning through a reflection on the influence of particular activities that involve sustainability and a knowledge of the customs and attitudes related to social and environmental services. Since teaching institutions in general, are catering for a large number of people, they are in a position to spread information about technically sustainable projects in a way that can encourage studies and teaching/learning in an institutional and academic environment. In addition, educational buildings usually have suitable conditions for installing catchment and harvesting systems of rainwater by exposing large areas of roofing and other covered areas available to the intake of rainfall. (MARINOSKI, 2007).

A technical, social and economic feasibility study must be carried out before a rainwater harvesting system can be implemented. As a result, the following features should be obtained and analyzed: i) rainfall data from the locality, ii) the demand for non-potable water in the locality of the implementation, iii) rainfall catchment data, iv) an assessment of the current hydraulic system of the property, v) an evaluation of the quality of the rainwater, vi) system sizing and vii) economic feasibility. These systems cannot only be used in residential dwellings but also in hospitals, prisons, airports, universities and other places (ROCHA and DUARTE, 2017).

2.5.1 Features of a rainwater catchment system

The features of a catchment and harvesting rainwater system can undergo variations depending on its planned objectives. However, there are a number of primary constituents in any system such as: catchment (roofing area, coverings, terrace or other fittings), transportation in rainwater harvesting, (vertical and horizontal conductors), storage, treatment and distribution (FRANÇA, 2011).

2.5.1.1 Rainwater harvesting from rooftop catchments

The rooftop is one of the most common ways of carrying out the catchment of rainwater, particularly in residential dwellings. The size of the catchment area or rather, the useful space on the roof where the rainwater will flow to the transport and fitting devices, is directly related to its potential capacity to harvest the water.

The Brazilian Standard (NBR 10.884/1989) stipulates the procedures that must be followed for rainwater installations on the premises, such as the declivity and divisions of the drainage flow areas. However, it makes no mention of the material for the rainwater catchment, although the different types of roof tile material for this will influence both the quality and quantity of the water obtained, as well as the losses caused by evaporation and surface absorption (KARLINSKI, 2015).

Bona (2014) shows that it is easier to drain water from tiles that are smooth and metallic, because they tend to be more waterproof than for example ceramic tiles. With regard to quality, the author states that metal tiles can remove metal in the water by surface drag and that the green coloration of tiles can leave the water turbid when kept in reservoirs. Silva (2019) showed that the metals most often found in rainwater (calcium, potassium and sodium) undergo seasonal changes. According to França (2011), the most common materials for tiles are those that are galvanized, painted or enamelled with non-toxic paint, surface concrete, ceramics, polycarbonate, and fiber-glass.

With regard to their microbiological quality, metallic tiles are recommended for the catchment of rainwater because they tend to have lower concentrations of biological indicators. This is owning to the fact that they become warm on sunny days, and this inactivates the pathogens and metallic ions released by the tiling, which inhibits the growth of these micro-organisms (MENDEZ et al., 2010).

2.5.1.2 Gutters and hydraulic installations in buildings for rainfall

After the water has been drained from the rooftop, an effective volume of water flows to the gutters and vertical and horizontal conductors. Conductor holder sizing is carried out in accordance with NBR 10.844/1989 regulations, and based on factors like the catchment capacity of the roof surface area and the intensity of rainfall in the region. The materials used for the gutters should be designed to avoid contamination by toxic particles in the water and preferably be made of inert materials like PVC or other plastics. In addition, the following are some of the materials that could be used: cast iron, asbestos cement, hard PVC, and galvanized steel.

2.5.1.3 Rainwater storage

After the rainwater has been carried by the conductors (and in certain projects by treatment devices), the volume of water reaches the tank. This must be located at a strategic point of the system so that it can allow water to be used more efficiently and thus it is recommended that it is placed close to points of consumption. With regard to the materials used for the storage tanks, the most important are: plastic materials, fiber glass or other inert material.

2.5.1.4 Water treatment

The roofwater harvesting can gather dust and soot which in turn can contaminate the water. Account should also be taken of the cleanliness of the collection area and the quality of the air where the system is located. Thus, before the rainwater can be used, there must be control over its quality and the system that is installed must, to a greater or lesser extent, include treatment devices, depending on its intended use. (Table 1).

Table 1: Different standards of water quality required depending on use

Uses of Rainwater	Treatment of Water
Watering plants	Not necessary
Sprinklers,firefighting	The equipment must be kept in a good condition
Fountains, bathroom, washing clothes and car-washing	Necessary because the water makes physical contact with people

Source: Adapted from Group Raindrops, 2002.

While the rainwater is being drained off the rooftop surface and the gutters, the volume of water can carry various materials such as the following: leaves, twigs, seeds, solid residues and even the droppings of birds that form deposits on the surface of the roof. This accumulation of waste on the surface is a phenomenon that particularly occurs during prolonged periods of dry weather.

One of the main devices against the depositing of leaves and twigs on the rainwater system is to put nets and screens between the vertical conductor and the tank. This can allow leaves to be removed more easily when screens are used for the rooftop gutters.

Another means of lessening the contamination of the rainwater is to make use of the *first flush* diverter which is responsible for the disposal or sealing of the volumes of water in the first minutes of a rainfall event (GOLDENFUM, 2006). This is needed because of the impurities that are present in the atmosphere and the rooftop collection system through damp or dry waste deposits. Studies like those of Souza (2019) and Jacob *et al.* (2019) show that the quality of rainwater improves significantly from upstream to downstream when systems are installed for the retention or disposal of sediment during the initial period of rainfall, particularly because this can help to dissolve all the deposits of solids and neutralize the chemicals in the rain.

According to Tomaz (2009), the amount of rainfall captured by the *first flush* system depends on the degree of contamination in the locality. NBR 15.527/2019 recommends a rate of 2 mm for the separation or sealing of the initial rainfall. When there is a sufficient frequency of rain to keep the rooftop clean, the locality can be regarded as having low contamination and adopt the rate of 0.5 mm for the initial disposal. However, if there is a high level of waste disposal from animals, atmospheric pollution or there are a lot of trees in the surrounding area, a rate of up to 8 mm can be found.

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2.5.2 The legal aspects of a rainwater system

Drummond *et al.* (2021) conducted a research study about the legislative standards (both offering guidelines and being mandatory in a technical sense) that are related to studies and projects concerned with the harvesting of rainwater. Six of the country´s technical norms were selected. The principal ABNT standard for rainwater is NBR 15.527/2019, which lays down the conditions for harvesting water in rooftops for non-drinkable purposes in urban areas. The study also examines the following norms: (i) NBR 5.626/2020 for hot and cold water systems in buildings; (ii) NBR 16.782/2019 – Conservation of water in buildings – required conditions, procedures and guidelines; (iii) NBR 16.783/2019 – Use of alternative sources of non-drinking water in buildings; (iv) NBR 16.098/2012 – the minimum requirements for testing appliances to improve the quality of drinking water and (v) NBR 10.884/1989 which stipulates what procedures must be followed for rainwater installations in buildings.

2.5.2.1 Brazilian Technical Standard ABNT NBR 15.527/2019

NBR 15.527 (ABNT, 2019a) stipulates the required conditions for collecting rainwater on rooftops for non-drinkable purposes and which is destined for harvesting systems.

With regard to the standard of rainwater, quality parameters are laid down which must be monitored periodically, at least every six months. Table 2 shows four key parameters used for non-drinkable purposes which are as follows: *Escherichia coli*, pH, Turbidity and Residual Chlorine.

Table 2: NBR 15.527/2019 quality parameters for rainwatrer used for non-drinkable purposes

Parameter	Standard
Escherichia coli	< 200 em 100 ml
pH	6 a 9
Turbidity	5 uT
Residual Chlorine	0.5 to 2 mg/L

Source: ABNT, 2019.

Thus, the coliform count should be less than 200 organisms for each 100 mL in the sample, which is the result whether they are absent or present. The pH should be in the band between 6 and 9, and can be characterized as alkaline. The level of turbidity should be below 5 NTU turbidity. If chlorine is used as a disinfectant, its residual level must be between 0.5 and 2.0 mg/L, with a maximum of 5 mg/L.

2.5.2.2 Brazilian Technical Standard (ABNT NBR 16.783/2019)

The NBR 16.783 (ABNT, 2019b) was established to meet people´s needs and the demand for diversification in the urban supply matrix, encourage good practices and reduce potential risks. It gives directions for the following: characterization, sizing, use, operations and the maintenance of systems for alternative sources of non-drinkable water in buildings.

NBR 16.783/2019 lays down seven physical, chemical and biological parameters to be adopted when monitoring water for non-drinkable purposes, excluding water for cooling. These are as follows: pH, *Escherichia coli*, turbidity, free residual chlorine, BOD_5, electric conductivity and total organic carbon (TOC). The value for the four first parameters correspond to those of NBR 15.527 (ABNT, 2019a). The standards for the other parameters can be found in Table 3.

Table 3: NBR 16.783/2019 parameters for non-drinkable water

Parameter	Standard
DBO_5	< 20 mg O_2/L
Electric Conductivity	< 3.200 µS/cm
COT	< 4 mg/L

Source: ABNT, 2019b.

3. Methodology

3.1. Characterization of the rainwater system and area of study

The analysis of the amount of rainwater was carried out through the collection of volumes of water stored in two rainwater catchment systems, referred to as CAP1 and CAP2, which were located in the central-north region of the city of Rio de Janeiro. Since they cover densely populated urbanized areas of commercial activities and residential dwellings, there is heavy traffic in the region which is close to the huge Tijuca Forest (Figure 2). The monitoring systems for rainfall can be found on the basis of the morphology of a densely populated urban area and the typology of a rooftop surface for the catchment and harvesting of rainwater. The pluviometric station of Tijuca was used to obtain data for carrying out this study and is located in the district of Tijuca, which is at a distance of 1.60 km from CAP1 and 2.65 km from CAP2.

Figure 2: Location of the CAP1 and CAP2 rainfall systems in the city of Rio de Janeiro

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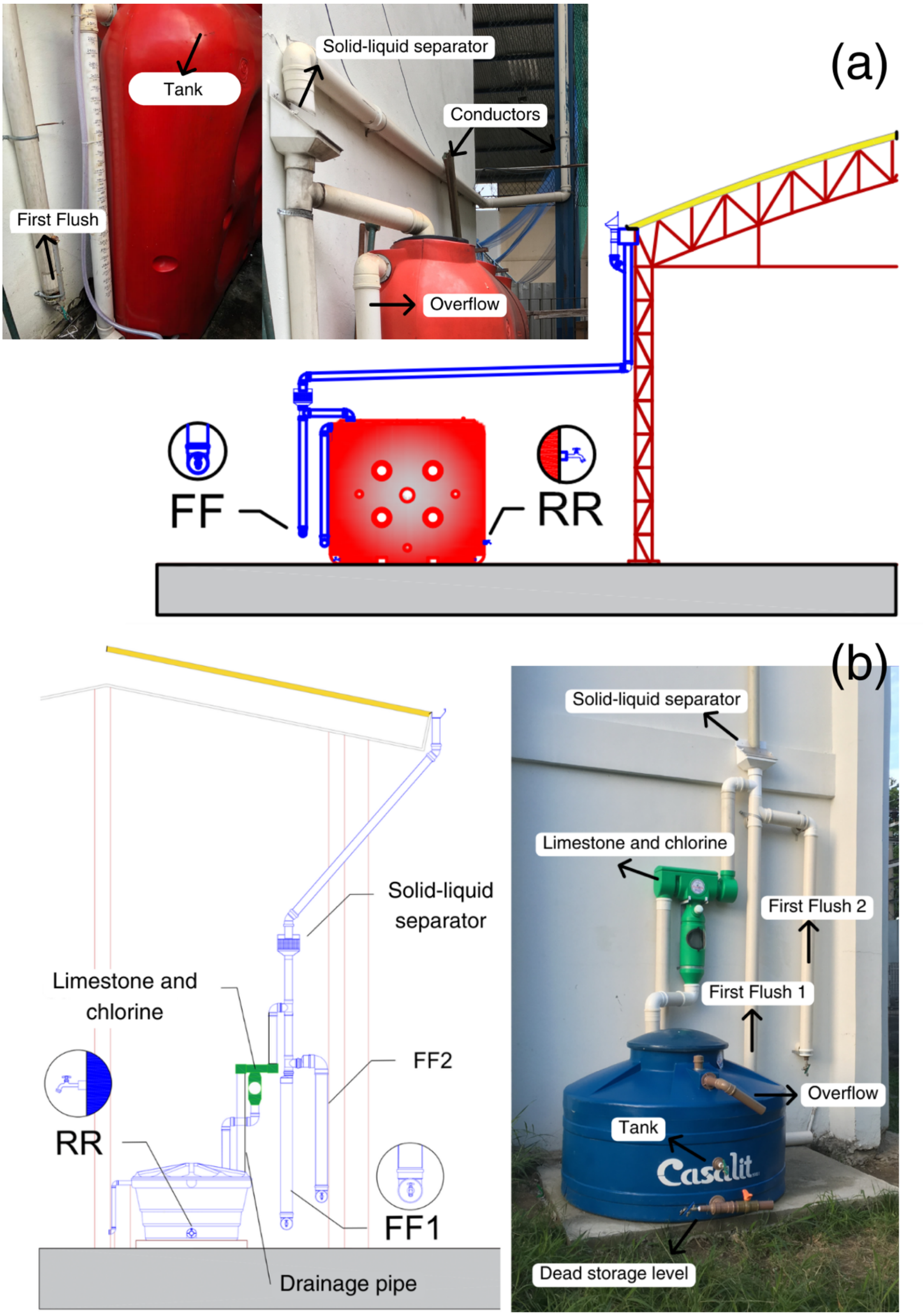
Figure 3: Components of the rainwater systems - CAP1 (a) and CAP2 (b)



The system for the catchment and harvesting of rainwater (CAP1 - Figure 3a) is located in the Rio

Comprido district, in the central zone of the city, in the premises of the old Fernando Rodrigues da Silveira Laboratory School, of the State University of Rio de Janeiro (CAP-UERJ), close to the ¨elevado Engenheiro Freyssinet¨ (or Paulo de Frontin viaduct). This is situated in an area of serious exposure to pollutants released by, on average, 20,000 vehicles per working day in the locality (MUNICIPAL GOVERNMENT OF RIO DE JANEIRO, 2017). With an area of 80 m² of a partially covered multisports-court, CAP1 consists of the following: galvanised steel tiles, a galvanised sheet metal gutter, PVC vertical and horizontal conductors, an initial *first flush* diverter of 0.2 mm, an overflow syphon, a level gauge, collection points and a water tank of 2,460 litros.

The CAP2 system for the catchment and harvesting of rainwater (Figure 3b) is located in the district of Maracanã, Rio de Janeiro State University campus in the center-north region of the city of Rio de Janeiro, which is completely urbanized and has a heavy flow of traffic in São Francisco Xavier Street and Radial Oeste Avenue, which is the road that connects the north zone with the center of the city (BALTAR, 2014). CAP2 which has a fiber cement roof and a catchment area of 30 m², also includes the following: vertical conductors and PVC gutters, a system involving a *first flush* diverter of solids (primary and secondary), a preliminary treatment system, a *Chovechuva* filter (limestone and chlorine), a tank with a storage capacity of 1,000 litres, an overflow system, a syphon, a level gauge and collection points. The *Chovechuva* equipment (Figure 3b), includes a separating box for leaves and residue, limestone, and a chlorinated device with chlorine tablets.

Table 4 displays the main features of the CAP1 and CAP2 rainwater systems in a way that allows an assessment to be made of the ability of the *first flush* device to remove pollutants as a result of the typology of the tiled roof surface. For the purposes of assessment in this study, the rainwater samples were obtained from the *first flush* points and the water tank, since the water from the primary *first flush* was assessed in the CAP2 system which has a capacity of 0.5 mm of rainfall. Tomaz (2009) noted that 0.5 mm of separation from the initial rain would be the minimum adopted in a rainwater system. Despite this, on account of the limited space available, the CAP1 system was initially designed to dispose of 0.2 mm of effective rainfall.

Table 4: Features of rainwater systems - CAP1 and CAP2, in City X

CAP	Locality	District	Roofing	Area	Volume *first-flush*	Volume of tank
1	CAP[a]	Rio Comprido	Metallic	80 m²	0.2 mm	2,460 L
2	UERJ	Maracanã	Fiber-cement	30 m²	0.5 mm[b]	1,000 L

[a] Laboratory School; [b] Primary *first flush* volume.

3.2 Sampling Procedure

3.2.1. Samples of catchment systems

During the collection and analysis of the *first flush* (FF) points and the water tank (RR), on average, there were 9 samples per year of effective amounts of rainfall in each catchment and harvesting system between January 2017 and December 2019, as shown in Table 5. It was impossible to collect or analyse the samples in certain months (such as, among others, CAP1 in February, September and December 2017 and August 2019), because there was not enough storage volume to conduct the analyses.

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Table 5: Control of the samples analysed in the systems

					Month							
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
						CAP1						
2017	x	-	x	x	X	x	x	x	-	x	x	-
2018	x	X	x	x	X	x	x	x	x	x	x	X
2019	x	X	x	x	X	x	x	-	x	x	x	-
						CAP2						
2017	x	X	-	x	X	x	x	-	-	x	x	X
2018	x	-	-	x	X	x	-	x	x	-	x	X
2019	x	X	x	x	X	x	x	-	x	-	-	X

Caption: X Sample analysed; - without enough volume of analysis in one of the points.

The quality of the samples included the following analytical parameters: residual chlorine, electric conductivity, dissolved organic carbon (DOC), *Escherichia coli*, pH and turbidity. The parameters were analysed in the Sanitary Engineering Laboratory (SEL-UERJ), at the Engineering Faculty of the State University of Rio de Janeiro, in accordance with the methods described in Table 6.

NBR 16.783/2019 states that Total Organic Carbon (TOC) should be a parameter, although this parameter had to undergo filtration by order of the laboratory before the analysis of the samples could be carried out and thus the results refer to dissolved organic carbon (DOC).

The parameter for *Escherichia coli* was observed through the analyses of total and thermotolerant coliforms. Total coliforms TC) can be viewed as environmental indicators because their presence in water is not necessarily a sign of intestinal bacterial contamination. Thermotolerant coliforms are predominantly indicators of human or animal intestinal origin but can also indicate the presence of free living bacteria that only resist the high temperatures of laboratory analyses. (VON SPERLING, 2014). The parameters for total and thermotolerant coliforms were obtained from the FF and RR points of the CAP1 system in 2018, and analysed in the OCEANUS – HIDROQUÍMICA Laboratory located in the Rio Comprido district of RJ.

Table 6: Methodologies employed for the analysis of the quality of rainwater

Parameter	**Method[1]**
Residual Chlorine	Method 4500-Cl B. Iodometric Method I
Electric Conductivity	Method 2510 B Laboratory Method
DOC	METHOD 5310 B. High-Temperature Combustion Method
Total Coliforms	MPN – Most Probable Number[2]
Thermotolerant coliforms	9223 A and B – Multiple-tube technique[2]
pH	Method 4500 H+ B Electrometric Method
Turbidity	Method 2130 B Nephelometric Method

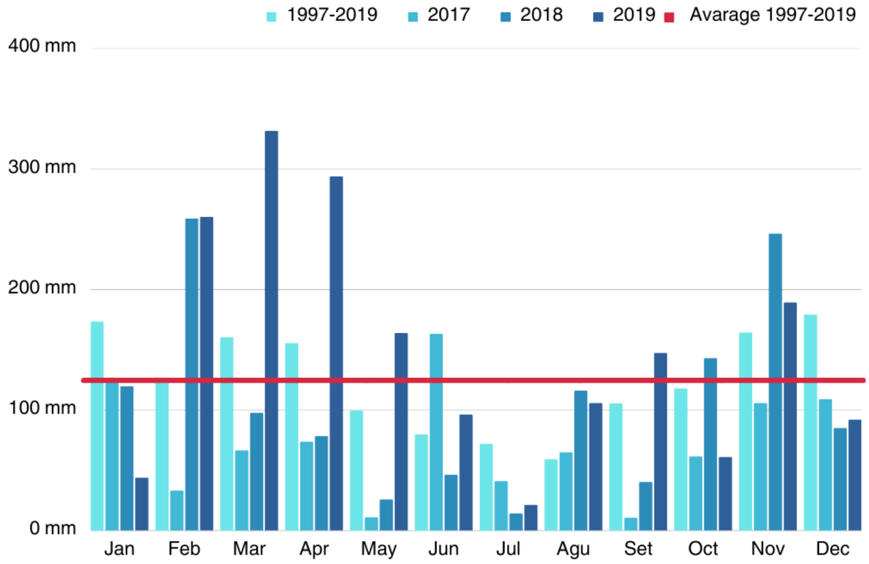
[1] Described by AWWA [2]SMEWW.

3.2.2. Characterization of precipitation in the region

The characterization of the level of rainfall relied on the historic pluviometric station of Tijuca, which is situated in the University Studies Center of Sumaré, in the precincts of the Palácio Apostólico, of the Rio Early Warning System (Municipal Authority of RIO DE JANEIRO, 2020).

Figure 4 shows the average rates of monthly rainfall accumulated in the period 1997-2019 and also separately for the respective years analysed in this study. The year 2017, which had an annual total of about 863 mm, had the lowest volume of rainfall in the period and corresponded to an average of 69% of the whole period, since it represented the lowest volume collected from the samples. The monthly average in 2017 was 72 mm, which was the lowest average in the period under study. In 2018, there was an increase in the volume of rain which reached 1.271 mm, and an increase of 47% of the average volume of rain compared with 2017. In 2019, there was also an increase in the volume of annual and monthly rain compared with 2018, with respective rates of 1.804 mm and 150 mm.

Figure 4: Historic monthly average of rain, accumulated on a monthly basis in the district of Rio de Janeiro



Source: adapted from ALVES *et al.*, 2021.

3.3. Analysis of results

The descriptive statistical analysis was prepared by the Excel®, program of the *boxplot* command in the Program R Studio® language, version 3.4.4. The descriptive analysis by Excel also took account of data on consecutive dry days without any rainfall (i.e. zero precipitation) which led to samples that went beyond physico-chemical parameters.

The *boxplot* analysis made it possible to visualize the discrepancy in the *outliers* of the data, since the information about the variability of the data in the sample indicated atypical values which can influence the calculations, such as the arithmetic average of the sample. According to Tukey (1977), an *outlier* is an uncommon value that is at an extreme point from a central value and can be best examined in a *boxplot* graph which can show errors in measurement or the way the analysis was conducted. Apart from the *outlier*, another key factor for the interpretation of the *boxplot* are the quartiles. These represent percentages of 25, 50 and 75, or in other words, in quartile 25, a total of 25% of the samples are either less than or equal to it. Quartile 50, or the second quartile represents the median of the data. The dispersion and symmetry of the datasets can be determined while reading the *boxplot*.

4. Results and Discussion

The residual chlorine was not analysed like the other parameters in the statistical analysis, owing to the large number of analyses that were conducted throughout the study and only formed two samples in the CAP system in 2019. The results obtained for residual chlorine in these two analyses were 0 and 0.1

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mg/L.

De Amorim (2001) stated that after chlorine has been added to the harvesting system of rainwater during the analysis, to determine the parameters of quality, its presence can indicate whether the water was effectively disinfected or if any organic material had been introduced and there were micro-organisms that might have been consumed. In light of this, it is recommended that chlorine tablets should be added more often and there should be constant monitoring to check that the regulations of NBR 15.527/2019 are being complied with This can be carried out with a level of residual chlorine of between 0.2 and 5 mg/L obtained from a sample of the harvesting system of rainwater.

Table 7: Statistical description of the qualitative variables of the rainwater collected in the CAP1 system (metallic)

CAP1 system (metallic tiles)													
Point		**FF²**						**RR³**					
Variables/ Indices		Mín	Max	Av.	σ	Lim.sup	Lim.inf	Mín	Max	Av.	Σ	Lim.sup	Lim.inf
DSC		0.0	22.0	5.0	5.19	-		0.0	22.0	5.0	5.19	-	
Rainfall		1.0	40.4	9.95	10.89			1.0	40.4	9.95	10.89		
Conductivity		217	589.3	107.25	119.03	238.55	0	8.85	91.2	37.77	19.50	77.62	0.0
COT		0.0	128.3	10.18	28.11	14.57	0	0.0	97.72	744	21.65	6.52	0.0
E.Coli¹	Coli.Totais	Aus	350.0	.127,66	193.25	-		Aus	1600	250.87	551.30	514.62	0.0
	Thermo.	Aus	8.2	5.33	462			Aus	130.0	20.97	44.78	50.0	0.0
pH		5.15	7.53	6.42	.48	7.19	5.71	5.14	7.34	6.41	0.38	7.17	5.69
Turbidity		0.00	140.0	30.95	37.55	122.15	0.0	0.0	2.7	0.62	0.64	1.46	0.0

CDD: Consecutive dry days; Rainfall: high precipitation (mm); Conductivity (µs/cm); COT (mg/L); Coli. Total: Total Coliforms (NMP/100mL); Therm.: Thermotolerant coliforms (NMP/100mL); Turbidity (uT); Mín: Minimum; Max: Maximum value: Average; : standard deviation; Up. Lim.: Upper limit; Low.Lim: Lower Limit; Abs: Absent. ¹ Analyses conducted: 3 (FF) e 8 (RR ; ² Average number of analyses: 31; ³Average number of analyses: 30. Source: the authors, 2022.

Table 8: Statistical description of the qualitative variables of rainwater collected in the CAP2 system (fiber-cement)

CAP2 system (fiber-cement tiles)												
Point	**FF¹**						**RR²**					
Variables/ Indices	Mín	Max	Av	σ	Lim.sup	Lim.inf	Mín	Max	Av	σ	Lim.sup	Lim.inf
DSC	0.0	21.0	5.4	5.0	-		0.0	21.0	5.4	5.0	-	
Rainfall	1.6	40.4	10.15	10.10			1.6	40.4	10.15	10.10		
Conductivity	53.12	222.10	105.11	35.97	180.01	23.85	36.20	150.70	73.57	27.72	126.45	6.05
COT	0.4	7.07	3.35	1.97	8.27	0.0	0.96	9.76	3.63	2.18	7.70	0.0
pH	5.77	9.48	7.34	0.77	8.20	6.18	6.07	8.19	7.02	0.51	7.96	6.27
Turbidity	0.0	101	16.27	26.92	42.12	0.0	0.0	3.70	0.84	0.90	1.97	0.0

CDD: Consecutive dry days; Rainfall: High precipitation (mm); Conductivity (µs/cm); COT (mg/L); Turbidity (uT); Mín: Minimum value; Max: Maximum value; Av: Average; σ: standard deviation; Up.Lim: Upper Limit; Low Lim.Inf.: Lower limit; ¹ Average number of analyses: 31; ²Average number of analyses: 24. Source : the authors, 2022.

Table 7 and 8 show the results of the statistical descriptions of the analyses of the rainwater samples obtained from the *first-flush* (FF) points and the water tanks (RR) of the CAP1 and CAP2 systems respectively. These provide a comprehensive view of the central features and the dispersion of the data on the water quality between the systems. In this way, it makes it possible to determine significant diferences between them, as well as to calculate and visualize the atypical values (*outliers*). For this

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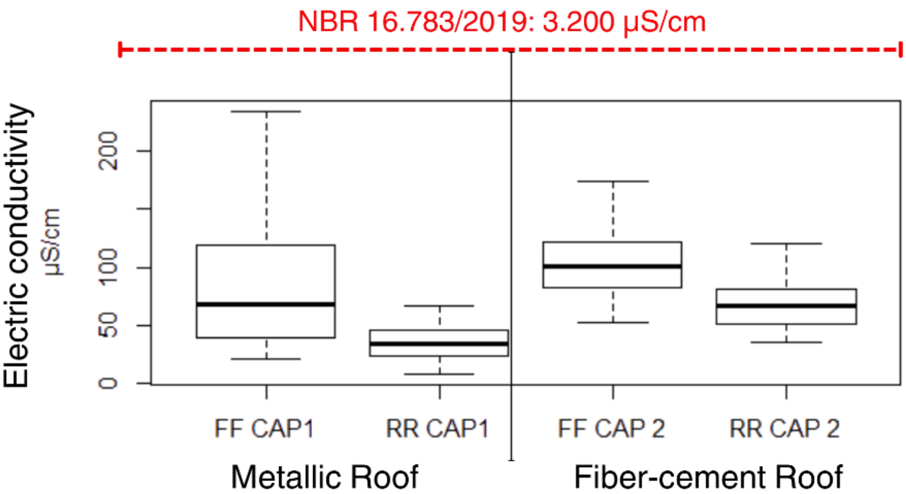
reason, Figures 5 to 9 show the results of the statistical description without including the values of the *outliers*, but are in accordance with the representation of the *boxplot* of each of the physico-chemical and biological parameters analysed.

Electric conductivity is the capacity that the water has to conduct an electric current which can vary depending on the ionic concentrations present, together with its temperature. The conductivity will also be greater, to the extent that there is a greater presence of dissolved solids. This parameter shows the amount of salts that are in the water and this information is used as an indirect means of measuring the concentration of pollutants. The natural waters have values ranging from 10 to 100 μS/cm, and if the water has a value higher than 100 μS/cm, it suggest that pollution is having a serious effect on the environment and affecting the water with corrosivity (JAQUES, 2005).

The *outlier* values of conductivity led to discrepancies between the systems with regard to the maximum indices and standard deviation, as well as to the *first flush* (FF) point. The upper limit for CAP1 showed a value of 238.55 μS/cm and for CAP2 it was 180 μS/cm (Figure 5).

Figure 5: Electric conductivity of the rainwater samples at the FF and RR points obtained from the metallic and fiber-cement tiles



Despite this, the averages for this parameter had similar values and bearing in mind that these values, as well as those put forward by Jaques (2005), are higher than 100 μS/cm, it can be assumed that the region where the systems are located, was seriously affected by atmospheric pollution. The one exception to this is the water tank in the system which had electric conductivity measurements below 100 μS/cm, with a value of 37.77 μS/cm for CAP1 and 73.157 μS/cm for CAP2. However, the standard for the conductivity parameter is defined by NBR 16.783/2019 for non-potable uses as 3,200 µS/cm, and thus the two systems were shown to comply with the regulations in all the features analysed.

Silva (2018) also conducted a study of rainwater with regard to the roof tile materials of the harvesting system. The water in the tanks of two systems was analysed: one tank had zinc metal tiles and the other fiber-cement. The metal tiles had less conductivity (between 5 and 23 μS/cm) than the fiber-cement which had between 25 and 45 μS/cm.

The analysis of the DOC parameter indicated the presence of bacteria and algae because carbon provides a source of energy for these elements. Although it had the highest values in the CAP1 (metallic tile) system, it had values compatible with those of other studies, such as that of Miorando (2017), which showed an average of 9.54 mg/L. The CAP2 system (fiber-cement tiles) obtained lower results with 3.35 mg/L and 3.63 mg/L for the *first-flush* (FF) and water tank (RR), respectively.

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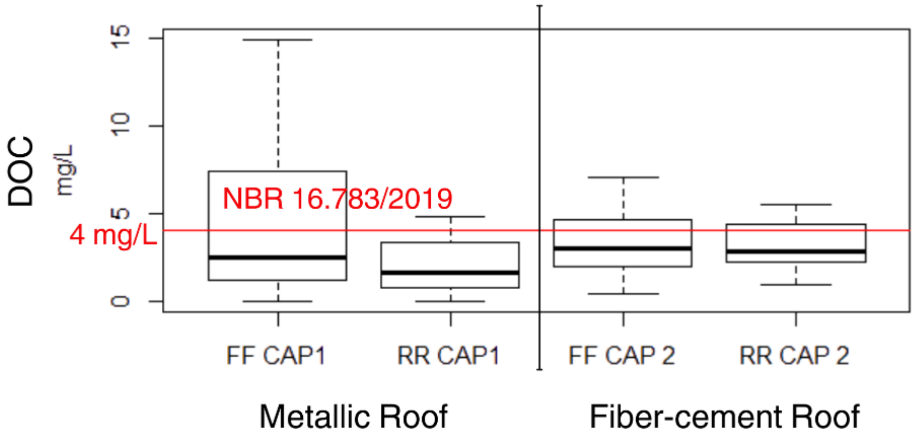
Figure 6: Total Organic Carbon (TOC) in rainwater samples at the FF and RR points obtained from metal tiles and fiber-cement



According to Ganem (2019), the analysis of this parameter is not very widespread in studies on the quality of rainwater, although the DOC is becoming an indicator for assessing the capacity of water to absorb chemical oxidants. In addition, if rainwater undergoes a process of disinfection, such as when chlorine is added, this can be important for the monitoring as it can have the potential to form trihalomethane (MIORANDO, 2017).

With regard to NBR 16.783/2019, the standardized value for the COT is 4 mg/L for the non-potable use of water. All the 25 and 50 quartiles of the two catchment areas (FF and RR) of the two systems (CAP1 and CAP2), were found to be below the stipulated value (standard or otherwise) of the 75 quartile of the CAP1 tank. The samples analysed in the CAP2 system behaved in a similar manner in the FF and RR catchment areas (Figure 6)

The analyses of the thermo-tolerant coliforms were conducted in three samples for the FF point of the CAP1 system. In this phase, the indicators were only shown as absent in one of the these analyses. This fact might be related to the large amount of excrement from birds or small mammals that can be found on the rooftop during a period of rainfall (COSTA *et al.,* 2020). In the case of the water tank point (RR), contamination by these organisms also originates from the waste of animals and the leaves that can pass through the filtration and initial disposal system.

The values found had results below those in the literature. Cipriano (2004) found results that were, on average, 1,569 ± 1,340,74 and 913,32 ± 925,91, for the total and thermotolerant coliforms at the point of the *first flush* (FF). With regard to the water tank (RR), the values showed a reduction from 1,251.34 ± 601.15 NMP/100mL total coliforms, to 326.10 ± 535.45 NMP/100mL thermotolerant coliforms.

The results of the indicators used to represent the E.Coli proved to be appropriate when compared with the NBR 15.527/2019 standard of de 200 NPM/100 ml, shown by the red line in Figure 7.

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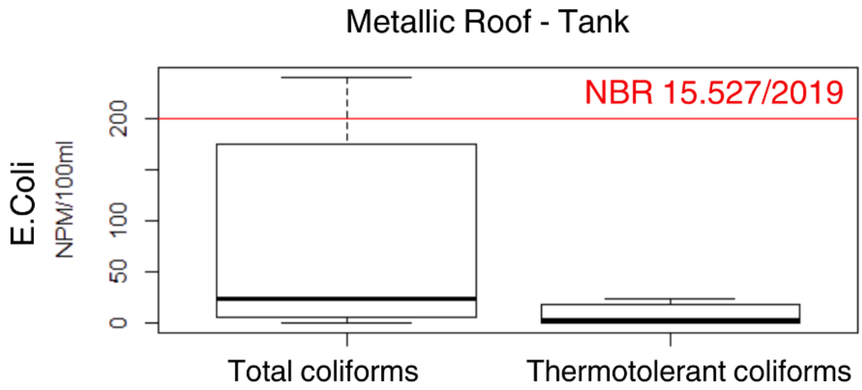
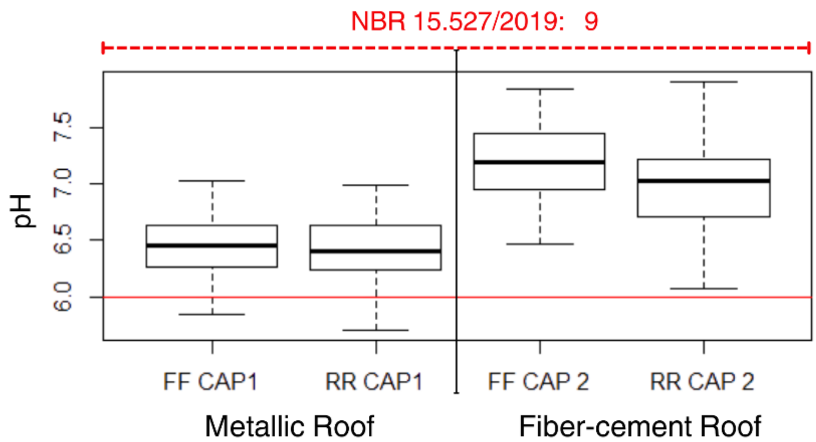
Figure 7: Parâmetro E.Coli parameter in samples of rainwater obtained from the tiled roof at the RR point



The total coliforms are used as environmental indicators although they are not necessarily an indicator of fecal contamination. It can be seen from an analysis of the results obtained that the median of the total coliforms is higher for the thermotolerant coliforms which are indicators of organisms originating from the intestines of animals or free-living bacteria. Hence, it can be inferred that most of the organisms found within the water tank do not originate from the excrement of animals.

On the question of the pH, the CAP1 (metal tiled roof) system did not show great variations with regard to the collection points and had values of 6.42 ± 0.48 for the *first flush* (FF) and 6.41 ± 0.38 for the water tank. Of the two systems, CAP2 (fiber-cement tiled roof) had a slightly more basic concentration of pH, although there were not any big variations between FF and RR.

Figure 8: Results of the pH parameter in rainwater samples at points FF and RR obtained from metal and fiber-cement roofing tiles



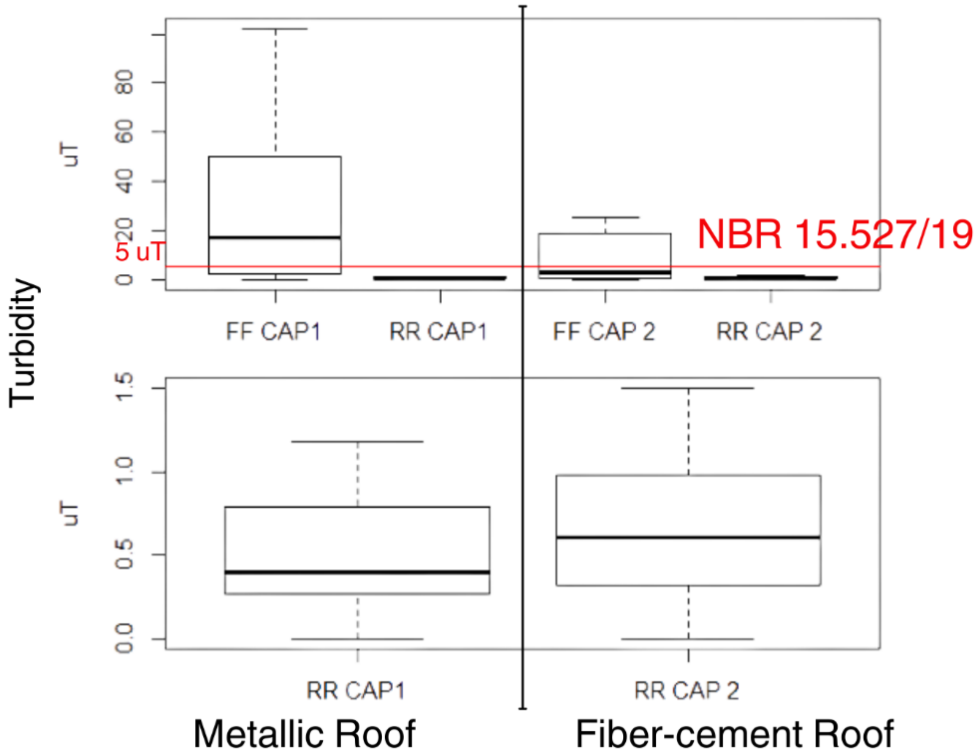
Costa *et al.* (2020) argue that the catchment systems that depend on fiber-cement tiling tend to have these higher values of pH because of the chemical compounds of natural alkaline species such as: limestone, clay, Ca+2, Mg+2, OH^-, HCO^{-3} e o CO^{-3}. This fact was also demonstrated in the studies carried out by Lee *et al.* (2012), in which the results of pH in the fiber-cement tiles proved to be higher than other materials with an average of pH equal to 7.2 that was found in the two points. In Silva (2018), the samples of rainwater obtained from the fiber-cement tiles had more basic values of pH.

NBR 15.527/2019 fixes a standard value for pH between 6 and 9. As seen in Figure 8, the CAP2 (fiber-cement tiled roof) system falls completely within this standard with a more basic level at the point of the *first flush* (FF), as well as with regard to the CAP1 (metal tiles) system.

All the quartilhes of the CAP1 system were found to be in compliance with the norm although the minimums for the two FF and RR points exceeded the minimum limit of 6.

Acording to Jaques (2005), the presence of these suspended particles that cause turbidity, can be dangerous because they can shelter pathogenic micro-organisms, as well as reduce the effeciency of chlorination.

Figura 9: Results of the turbidity parameter in rainwater samples at the FF and RR points obtained from the metal and fiber-cement tiled roof



The turbidity of the rainwater tank samples (RR) had similar values with an average of 0.62 ± 0.64 uT for CAP1 (metal tiles) and 0.84 ± 0.90 uT for CAP2 (fiber-cement tiles). In contrast, the CAP1 system had better results at the *first flush* (FF) point with an average of 30.95 ± 37.55 uT compared with the average of 16.27 ± 26.92 uT of CAP2 (Figure 9). The results provide evidence of the *first flush* phenomenon, when one bears in mind the difference in the distribution of the data and the values found at the FF and RR points in both systems.

5. Conclusion

The quality of the water obtained by the harvesting rainwater system is characterized by a significant variability in time and space. This means its physical, chemical and microbiological composition depend on factors such as the following: atmospheric pollution, the type of catchment and surface runoff, soil use in the vicinity, local microclimate (proximity to the ocean or ocurrence in seasons of the year) and its conservartion and maintenance.

The material for the roof tile coverage of the building is a key factor in the analysis when it is borne in mind that the rainwater system depends on the catchment area and thus can affect and impair the quality of the water stored in the tank. However, there was no significant alteration to the materials of the roof surface under study with regard to their potential non-potable use. When the first rainwater was collected in the *first flush* (FF), the metal tiled roofing had higher values for DOC and turbidity parameters. This situation can be explained by the location of the CAP1 (metal tiles) system, since it is in a region of heavy traffic in the ´elevado Engenheiro Freyssinet´ which as a result of burning fossil fuels can bring about an alteration in the parameters. In addition, the accumulation of dust in the area of the catchment system, as well as leaves and other residue from birds and animals, leads to an increase in turbidity. The fiber-cement tiles displayed a larger amount of conductivity and pH, with a higher level of alkaline than the metal tiles. This alkaline level can be explained by the presence of alkali chemical compounds in the composition of the fiber-cement tiles.

The characterization and assessment of the parameters of rainwater quality in the CAP1 and CAP2 systems are of great importance to ensure the health and safety of the users. In accordance with the requirements of NBR 15.527/2019, the CAP1 and CAP2 systems proved to suitable for use as a source of non-potable water, as a result of the catchment area of rainwater in the tank (RR). Thus, on the question of selecting the right type of tiles for harvesting rainwater, both the materials analysed (ceramics and metal) proved to be equally suitable. However, in areas that experienced frequent acid rain, the fiber-cement tiles might be a more appropriate choice, owing to the evidence that alkalinization of water occurs when they are used.

In the case of NBR 16.783/2019, which is concerned with alternative sources of non-potable water in buildings, the COT parameter did not prove to be suitable for either of the systems analysed. In view of this, a periodical inspection is recommended with frequent cleaning of the FF and RR in the harvesting system, as suggested by NBR 15.527/2019.

When one looks at the systems located in teaching units, these can provide opportunities for environmental education with respect to sutainability, the rational use of water and the knowledge of environmental services. Encouraging the use of rainwater in this environment can be viewed as essential insofar as schools and universities can make use of collected water, with hygienic and sanitary adaptations, for purposes of flushing, as well as for watering gardens or cleaning outdoor spaces and patios.

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