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Assessing rainwater quality treated via a green roof system

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Abstract. The shortage of water worldwide is increasingly worrying. Studies in the field suggest that sustainable water resource management via water recycling is fundamental to alleviate the issue. The use of rainwater is an important alternative source that must be considered, mainly, in the water crisis facing the planet. When integrated with the concept of green roofs, the capturing and treatment of rainwater in these structures becomes an even more ecological and sustainable practice. The water drained by the roof can be used for non-potable uses, such as flushing toilet bowls. One of the main concerns when using rainwater, even for non-potable uses, is the quality of the water available, so as not to put users' health at risk. In this way, the present work proposes to experimentally analyze the quality of rainwater drained in a green roof prototype for reuse purposes. The green roof prototype was installed on an experimental bench. After each rain event (four in total), two water samples were collected in the following situations: rainwater captured directly by a container next to the bench, and rainwater drained by the green roof prototype, captured by a container through existing drains at the base of the prototype. The analyzes of the collected samples were carried out at the Environmental Engineering Laboratory (LEMA / UFRJ) and performed according to the Standard Methods for the Examination of Water and Wastewater. Specifically, the experiments examine physicochemical and biological parameters following a rain event on a green roof prototype for sanitary use. Experimental results that were observed and analyzed include color, turbidity, pH, ammonia nitrogen, nitrite, nitrate, orthophosphate, total coliforms, and thermotolerant coliforms to indicate the rainwater quality from green roofs. The majority of parameters assessed were within the value thresholds indicated by the Brazilian standards, while the results of orthophosphate, fecal coliforms, color, and turbidity were not. The greatest divergence is in the concentration of orthophosphate, where a concentration of 10.88mg/L was obtained in this experimental study while other authors present values of 0.1 and 0.01mg/L. Total coliforms also presented high values, but within the expected range. Comparisons with technical documents and international references related to water quality to identify possibilities of the use of rainwater were also conducted. Results indicate that the water quality has the same order of quantity for turbidity, nitrite, and ammonia nitrogen parameters across the standards. Based on such observations, filtration and disinfection processes are therefore required in the green roof system for the use of rainwater for sanitary. Finally, the experimental study of rainwater quality on the green roof presented similar results comparing with international references. The use of green roofs combined with the use of rainwater demonstrates the potential and benefits as an alternative to face the water crisis.

Keywords. Water Demand; Alternative for Water Supply; Potential for Reuse; Sustainability; Experimental study; Water management.

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1. Introduction

Brazil has 12% of the available global surface freshwater and 28% of the availability in the Americas (Brasil 2017). The geographical distribution of this natural resource, superficial or underground, is quite irregular. This comes back to the fact that the Northern part of the Brazilian territory, which accommodates 8.3% of the total population in the country, has 78% of the water resources in Brazil. However, the Northeastern part of the country, which accommodates around 27.8% of the total population, has just 3.3% of the water resources in Brazil (Castelo and Macedo 2015). On the other hand, the Southeastern part of the Brazilian territory suffered a severe water crisis due to low rainfall (Theodoros et al. 2019). Such a comparison between the different regions of the Brazilian territory highlights the inequity in water resources distribution in the country and warns of some possible future problems in the light of global water scarcity.

With the constant increase in population worldwide, there is a growing need for water to supply the demand witnessed in food production (i.e. increased agricultural and livestock production) (Falkenmark et al. 2009), manufacturing (Charles et al. 2014), drinking and sanitary requirements (Burns et al. 2013). Measures are required to ensure that the water demand is met sustainably such that the economic and social development worldwide is not jeopardized (Jia and Duić 2021), all the while restoring a balance between water supply and demand (Green et al.2015). There is thus a need for modern alternative methods and systems to act as water sources (Loucks et al. 2017).

The motivation for this research came from the fact that in the scenario of a systematic decrease in the availability of drinking water and coupled also with water stress due to imbalance in distribution, measures aimed at conservation and reuse represent “a new paradigm” in the management of water resources. The search for alternative sources of water, which allow the reduction of this deficit between increasing demand and decreasing availability, therefore becomes increasingly urgent (Al-Damkhi et al. 2009). However, this water needs to comply with the potability standards, recommended by the current rules, according to the type of use for which it will be used (Liu et al. 2020).

Some alternatives discussed in the literature include the reuse of residential wastewater (greywater) García-Montoya et al. 2015, capturing rainwater on conventional roofs or green roofs (Mirzababaie and Karrabi 2019), reduction of water losses through efficient water use measures (Gois at al. 2015), reduction of effluent generation (Othmani and Khadhraoui 2020), and demand management to conserve existing water supplies (Emec et al. 2015). Alternative water sources, found via recycling and capturing natural rainfall, do not result in water quality that is drinkable and may require further processing to ensure they can be consumed (Cisneros 2014). Recycled water that is deemed not to be of high quality can also be adopted for other uses such as gardening and sanitary uses (Chen et al. 2013).

Rainwater is an underutilized water resource capable of addressing the demand for drinking water supply (Burns et al. 2015). Green roofs, as a vegetation cover for building roofs, is an example of an approach that can be adopted to recycle water; the idea involves planting vegetation on the roof of a building such that the plants provide a natural phytoremediation treatment to greywater (Rowe 2011). Other advantages are associated with green roof system including the reduced need for waterproofing on a building roof (Shafique et al. 2018), acting as a cooling cover due to increased evapotranspiration thus reducing the impact of the urban heat island effect (Coutts et al. 2013), volume reduction of water carried to drainage systems and mitigating flood problems common in urban areas (Min and Han 2015). When integrated with the concept of green roofs, the capturing and treatment of rainwater in these structures becomes an even more ecological and sustainable practice (Speak et al. 2015). However, the use of rainwater effluent to the green roof involves an important aspect that refers to the quality of the drained water. Several studies indicate that the passage of rainwater through the component layers of a green cover can improve water quality. For instance, Berndtsson et al. (2010) report the increase in the PH of drainage waters; the work by Vijayaraghavana et al. (2012) highlights that, based on USEPA standards for freshwater quality, the green roof used in this study is reasonably effective; Kok et al. (2016) report increment of pH on the green roof run-off and the run-off quality ranged between class I and II under Malaysia National Water Quality Index (WQI). Other studies indicate that green cover can reduce the effect of the acid rain phenomenon, which plagues some densely urbanized areas; and helping to retain concentrations of some metals, such as Zinc as presented in a case study in Bogotá form Galarza-Molina et al., (2016) and is also in a case study from Seidl et al. (2013) reports that green roofs retained over 80% of atmospheric heavy metal loads (Zn, Cu, Pb).

On the other hand, some studies indicate a loss of water quality, due to the introduction of pollutants due to the use of fertilizers, pesticides, and nutrients for vegetation as reported in the research by Ewa Burszta (2020) reporting that they are sources of ammonium nitrogen pollution in runoffs and Babcock, 2014 reports that green roofs can also lead to leaching some of the impurities of the substrates, plants, or used fertilizers. Most empirical studies on green roof technology are based on natural roofs, located in the United Kingdom, Europe, the United States, and New Zealand. Research in tropical countries is on the rise, with major contributions to the topic in countries such as Singapore, Malaysia, and Thailand (Kasmin et al., 2014).

In Brazil, according to Krebs and Sattler (2010), despite the growing interest of professionals and users in the theme of green roofs, the country has no tradition in this constructive technique. Live coverage has been rarely considered in national publications and, when it is, it is difficult to demonstrate practical experiences or to show project recommendations in different situations. The research carried out on the theme of green cover is still very much focused on quantitative aspects, a characteristic of a developing country, in which the concern with water quality comes in second place (since the problems of quantity are still very serious). In the national context, the experimental tests by Teixeira et al. (2011), in São Paulo, which indicates that the quality of water drained in green roofs can present values of the parameters of color, total phosphorus, and total coliforms above the limits established for reuse water for non-potable purposes in buildings; and Budel (2014), in Paraná, who points out that the green roof decreases the natural acidity of the rain.

These reviews indicate that there is a need for more research into green roof performance in an urban environment. It is recognized that despite the inherent limitations of conducting a case study, the results will serve as a benchmark for Brazil. The research presented here was motivated by the lack, still existing, of experimental studies on the theme of green cover in countries with a tropical climate, such as Brazil. Therefore, this work aims to evaluate the quality of rainwater drained by green roofs, and its potential for reuse in buildings, contributing, increasingly, to the increase of scientific and practical knowledge of this technology in the country.

The novelty of work presented herein is to carry out a practical experimental study for examining the water quality of a green roof prototype located at the Experimental Centre for Environmental Sanitation (Centro Educacional de Saneamento Ambiental - CESA), situated in the Federal University of Rio de Janeiro (UFRJ) for the use water supply in sanitary. Water quality from the green roof is analyzed, to contrast results with selected publications and existing water reuse standards and water quality recommendations. Since there are insufficient standards that address water quality collected from green roofs, this paper presents a review of the different Brazilian standards and ordinances and the USEPA manual that relates to water quality standards and with their applications later verified for water quality assessment from green roofs by conducting a practical experimental study. The aim of this work is also to encourage the standardization of water quality parameters collected from a green roof and encourage its use as a sustainable measure in buildings for the collection and treatment of rainwater. In the next section, water quality standards described in technical documents and from international references are reviewed. Later, these will be used to assess the results of the water collected from the experimentation carried out in this investigation. In the section of materials and methods, it is presented the description of the water quality parameters for the use of water in sanitary is presented, as well as the description of the steps of the experimental procedure. After theresults are showed and the analysis was carried out by comparing the experimental results with technical document recommendations and international references. Finally concluding remarks are presented.

2. Water Quality Technical Documents

Brazilian standards related to water quality and its reuse for different purposes are available do not specifically address the use of green roofs as a water treatment mechanism in buildings. Thus, this study carried out a study of the existing standards and recommendations related to the use of rainwater, water quality, and green roofs, since there is no specific standard in Brazil dealing with green roof projects. This study will also serve to assess the relevance and approximation of the standard or recommendation with the situation of rainwater use in buildings using a green roof. One of the Brazilian drinking water standards is Ordinance NBR 15527 (2019) - Rainwater NBR 15527 (2019), which provides the requirements for the use of rainwater from roofs in urban areas for non-potable purposes, without covering green roofs. Further, NBR 15527 (2019) indicates that the designer should define the intended use and then verify the quality standards. **Table 1** presents the parameters that should be considered with the respective analysis frequencies recommended.

Table 1 Standards of Rainwater quality according to NBR 15527 (2019)

Parameters	Analysis Frequency	Values
Apparent Color (uH)	Monthly	<15
Turbidity (uT)	Monthly	<2.0 (More restrictive uses) <5.0 (Less restrictive uses)
pH	Monthly	Between 6.0, and 8.0
Total Coliforms (NMP/100mL)	Semester	Absence

Thermotolerant Coliforms (NMP/100mL)	Semester	Absence
Free Residual Chlorine (mg/L)	Monthly	Between 0.5, and 3.0

Another Brazilian drinking water standard is Ordinance 2914 (2011) of the Ministry of the Environment (Ministério da Saúde 2011). This standard provides procedures for water quality for human consumption and its potability standard, including the method for performing collections and validating results, without applying directly to water quality analysis of a green roof. Ordinance 2914 (2011) presents various information about the potability standard, the way of performing collections, and validating results. The most relevant parameters are presented in Table 2. In this study, Ordinance 2914 will be used for comparison purposes.

Table 2 Standards of Water potability according to 2914 (2011)

Parameters	Values
Color (uH)	<15
Turbidity (uT)	<5.0
pH	Between 6.0, and 9.5
Total Coliforms (NMP/100mL)	Absence
Escherichia Coli (NMP/100mL)	Absence
Residual Chlorine (mg/L)	Between 0.5, and 2.0
Nitrite (mg/L)	<1.0
Nitrate (mg/L)	<10.0
Ammonia (mg/L)	<1.5
Total Dissolved Solids - SDT (mg/L)	<1000

Besides, Resolution 357/2005 of the National Environmental Council CONAMA 357 (2005), provides the classification of water bodies, environmental guidelines for their classification, and the conditions for the discharge of effluents. CONAMA 357 (2005) also sets the water quality parameters for each class. Freshwaters are classified into 4 classes, being: class 1 for supply for human consumption, after simplified treatment, class 2 for supply for human consumption, after conventional treatment, class 3 for supply for human consumption, after conventional or advanced treatment, and class 4 for navigation and landscape harmony. The parameters of most interest for the study related to this work were separated and summarized in Table 3. However, the importance of the analysis of CONAMA 357 (2005) is due to the specificity that is attributed to each class, depending on the purpose of the water.

Table 3 Parameters of Freshwaters quality according to CONAMA 357 (2005)

	Freshwater		
Parameters	Class 1	Class 2	Classes 3 and 4
Color (mg Pt/L)	True color	<75	<75
Turbidity (UNT)	<40	<100	<100
pH	Between 6.0, and 9.0	Between 6.0, and 9.0	Between 6.0, and 9.0
Ammoniacal Nitrogen (mg / L)	<3.7 for pH<7.5; <2.0 for 7.5<pH<8.0; <1.0 for 8.0<pH<8.5; <0.5 for pH>8.5	<3.7 for pH<7.5; <2.0 for 7.5<pH<8.0; <1.0 for 8.0<pH<8.5; <0.5 for pH>8.5	<13.3 for pH<7.5; <5.6 for 7.5<pH<8.0; <2.2 for 8.0<pH<8.5; <1.0 for pH>8.5
Nitrite (mg/L)	<1.0	<1.0	<1.0
Nitrate (mg/L)	<10	<10	<10
Orthophosphate (mg/L)	<0.02	<0.03	<0.05

Thermotolerant Coliforms (NMP / 100mL)	<200 in 80% of samples	<1000 in 80% of samples	<2500 in 80% of samples

The document of Water Quality for Irrigation designed by the Brazilian Agricultural Research Corporation (EMBRAPA 2010), provides recommendations on the water quality used for irrigation as presented in Table 4.

Table 4 Parameters of Water quality according to EMBRAPA (2010)

Parameters	Values
pH	Between 6.0, and 8.5
Nitrate (mg/L)	<10.0
Ammonia (mg/L)	<5.0
Orthophosphate (mg/L)	<2.0

The United States Environmental Protection Agency USEPA (2012), has guidelines for water reuse, covering possible water reuse current technologies, the guarantee of human health and environmental protection, treatment levels, and water quality. For water quality, the guidelines are specific for each reuse, such as reuse in urban areas, agriculture, industry, dammed environments, the environment, groundwater replenishment, and drinking water. Table 5 presents the recommended values studied in this paper for urban water reuse for urban areas.

Table 5 Guidelines for urban water reuse for urban areas according to USEPA (2012)

Parameters	Values
Turbidity (uT)	<2.0
pH	Between 6.0, and 9.0
Thermotolerant Coliforms (NMP / 100mL)	Not detectable

For the use of water in toilets, it is also needed to guarantee user comfort and not to damage the toilets. Water should not contain odor and appearance, and acceptable levels of color and turbidity are lower than water used for garden irrigation. For garden irrigation, color and turbidity values are not so important, so that Embrapa's (2010) recommendations do not mention any restrictions for these parameters. Still related to irrigation, CONAMA 357 2005 also establishes restrictions on water quality parameters for irrigation. In general, the technical standard that best suits the use of green roofs in buildings is NBR 15527 2019, because it is rainwater utilization in urban building coverage.

2.1. Literature review to Water Quality

A scientometric analysis is conducted herein, consisting of a survey of international publications related to experiments of water quality analysis drained from green roofs. Papers that had relevant partial discussions, experiments, or analysis of water quality collected from a roof green were selected, totaling almost 289. In the end after filtering the articles based on their relevance, fifty publications were found in the main research databases including Google Scholar, Web of Science, Scopus, and Science Direct. The United States had the largest number of publications, with a total of 18. The period comprising the studies found runs from 2002 to 2018, and 2014 was the year with the most publications, totaling 10. A summary of the 3 articles, that have greater relevance in the academic environment, due to the number of citations and with open access is next presented. In these terms, the first work of Teemusk and Mander (2011) analyses water quality on eight green roofs, two experimental roofs, and one steel roof, all located in Estonia; both rain and snow conditions were assessed, but only the rain condition will be addressed in this study, reducing the scope to three different green roofs. The Tartu experimental roof had a 20º and 1.5m² area, with a 70mm substrate layer. Two rain collections were made on this roof, one for moderate rain and the other for intense rain, and, for this paper, these collections were called Roof 1 and Roof 2, respectively. The Viimsi roof had 15º of large and an area of 35m². The substrate was 100mm thick. For this work, this roof was called Telhado 3. The Luunja roof, also had 15º large and 50m² areas, with the thickness and characteristics of the

Viimse roof (roof 3). For this work, this roof was named Roof 4. The values found for the water quality parameters for each roof are presented in Table 6.

Table 6 Drained water quality analysis of a green roof (Teemusk and Mander 2011)

Green Roof Drained Water Quality Analyses					
Teemusk and Mander (2011) - Estonia					
Parameters	Rain	Roof 1	Roof 2	Roof 3	Roof 4
pH	6.570	8.240	8.060	8.150	8.130
Ammoniacal Nitrogen (mg / L)	0.100	0.540	2.400	0.010	0.300
Nitrate (mg / L)	0.100	2.000	1.100	0.005	0.030
Total Nitrogen	0.400	3.800	6.400	4.900	0.400
Total Phosphorus (mg / L)	0.020	0.200	0.300	0.640	0.160
Orthophosphate (mg / L)	0.004	0.120	0.170	0.630	0.120

Gregoire and Clausen (2011) analyzed a 248 m^2 green roof located on a square at the top of a building in the United States in Connecticut. The green roof consisted of 334 modules whose dimension was 1.2m length x 0.6m width x 0.102m height. The substrate was 102mm thick, consisting of 75% light expanded shale, 15% composted biosolids, and 10% perlite. Each module had 10 plants of the genus Sedum. As soon as it was built in September 2009, the green roof received fertilization, just as in May of the following year. The average values found for rain events between September 2009 and February 2010 for the nitrogen and phosphorus parameters are presented in Table 7.

Table 7 Quality analysis of drained water from a green roof (Gregoire and Clausen 2011)

Green Roof Drained Water Quality Analyses		
Gregoire and Clausen (2011) – United States		
Parameters	Rain	Green roof
Ammoniacal Nitrogen (mg / L)	0.101	0.023
Nitrate + Nitrite (mg / L)	0.265	0.369
Total Nitrogen (mg / L)	0.510	0.490
Total Phosphorus (mg / L)	0.007	0.043
Orthophosphate (mg / L)	0.004	0.025

The work of Ferrans et al. (2018) in Colombia seeks to understand the variables that alter the results of water quality parameters obtained from the drained water from the green roof. For this, twelve green roof modules were set up, located at the top of the University of Los Andes in Bogota, which is 2640 m high. Nearby are areas for service, commerce, and residency. In total, information based on twelve rain events was collected for water quality analysis. Table 8 presents the mean values for each water quality parameter analyzed.

Table 8 Drained water quality analysis of a green roof Ferrans et al. (2018)

Green Roof Drained Water Quality Analyses		
Ferrans et al. (2018) - Colombia		
Parameters	Rain	Green Roof
Color (uH)	4.330	34.460
Turbidity (UNT)	6.810	18.740
pH	6.510	8.220
Nitrite (mg / L)	0.020	0.100
Nitrate (mg / L)	1.830	9.240
Ammoniacal Nitrogen (mg / L)	0.620	0.500

Total Phosphorus (mg / L)	0.080	4.060
Orthophosphate (mg / L)	0.360	-
Total Coliforms (MPN)	750	150000

The international studies presented here contributed to the elaboration of the experiment since it was possible to understand how the experimental procedures were developed, the necessary analysis required, and a general idea of the nature of the obtained results (Teemusk and Mander 2011, Gregoire and Clausen 2011, Ferrans et al. 2018).

3. Materials and Methods

This part of the study describes the water quality parameters for the use of water in sanitary. Besides, the section includes a description of the steps of the experimental procedure.

3.1. Description of water quality parameters for use in sanitary and irrigation

Water quality can be described via parameters that translate the main physical, chemical, and biological characteristics of the water examined (Manjare 2010, Pradeep 2011, Gupta 2017). This work investigates the most relevant parameters for water use in a green roof system based on technical documents and international references described in the previous sections (NBR 15527 2019, Ministério da Saúde 2011, CONAMA 357 2005, EMBRAPA 2010, USEPA 2012), Teemusk and Mander 2011, Gregoire and Clausen 2011, Ferrans et al. 2018). The parameters were selected for the end-use phase water in sanitary. The water quality parameters examined in this study include color; turbidity; pH; ammoniacal nitrogen; nitrite; nitrate; orthophosphate; total coliforms and thermotolerant coliforms. This study disregards the analysis parameters of water alkalinity and hardness as there is no reference value in the documents presented above as a basis for comparison. Figure 1 outlines and separates these parameters into physical, chemical, and biological for the analysis of the quality of rainwater.

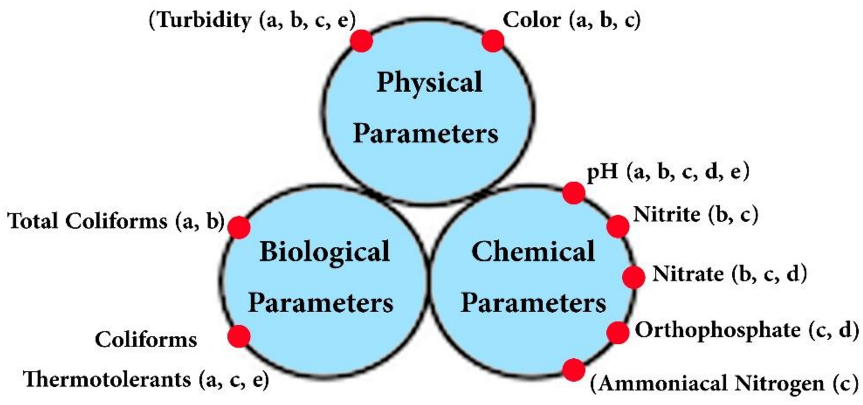

Fig 1. Schematic of the analyzed parameters for rainwater (a - NBR 15527 (2019), b - Ordinance 2914 (2011), c - CONAMA 357 (2005), d - EMBRAPA (2010) and e - USEPA (2012)).

3.2. Experimental procedure

The experiment is carried out at the Experimental Centre for Environmental Sanitation of UFRJ (CESA / UFRJ), which is a teaching research and extension laboratory, reporting to the Department of Water Resources and Environment in Brazil (Drhima) of the Polytechnic School (POLI- UFRJ). The experimental bench was built in 2013 for activities related to permeable pavements and green roofs. Information regarding the construction of the experimental bench and the construction of the green roof was taken from the previous research group work of Garrido Neto (2012, 2016), Pontes (2013), and Bruno (2016). At this level of the analysis, part of the work of Garrido Neto (2012) consisted of the design of the experimental green roof bench design. Pontes (2013) carried out the construction of experimental benches for testing permeable floors and green roofs. Bruno (2016) and Garrido Neto (2016) performed the construction and assembly of the green roof on one of the experimental benches. Garrido Neto (2012) and Silva (2018) studied the green roof as a compensatory technique in urban drainage, evaluating the water retention by the system and the reduction of peak flow. Busch (2017) analyzed the contribution of plant interception and evapotranspiration to this bromeliad green-roofed bench.

The green roof was first assembled in November 2015 by a group of students. The module is 202 cm long and 89 cm wide, with an overall area of 1.80 m^2. The module is tapped for the control of water output, which goes through a gutter and is carried to the rain box (Garrido Neto 2012). In August 2018, the green roof was rebuilt and the bromeliads were rearranged, as shown in Figure 2 (Silva, 2020). Bromeliads are typical of the tropical and subtropical areas of the Americas; this plant is used here since it is adaptable, requires little maintenance, and resists intense solar radiation, which are necessary elements for the local climate of Rio de Janeiro (Garrido Neto 2016).

Fig. 2 Experimental prototype - Green roof with bromeliads August (Silva 2020)

Experimenting necessitates incorporating the existing green roof bench and some additional materials to collect the samples of water drained by the green roof. The following materials were required: two 1m long hoses, two 5L gallons, and sterile vials. The hoses were placed in the side drains of the prototype and carried the water to the gallons, making it possible to collect water from the green roof during rain events. The sterile vials were used to transport the samples to the LEMA-UFRJ (Environmental Engineering Laboratory. Figure 3 illustrates the complementary structure to the experimental bench (taps, hoses, and gallons). Also, an open-air bucket was placed for rain collection, without interference from other surfaces.

Fig. 3 Rainwater collection structure (Welp Sá 2020)

After evaluating the quality of water collected from the green roof experimental bench, the results are contrasted with recommendations made in existing standards, as well as with the similar experiments performed by other authors. The health assurance of the water user is required; as a result, the analysis of the biological parameters of thermotolerant coliforms and total coliforms is necessary. The analysis of chemical parameters is important because the green roof is a living system that receives nutrients through fertilization and other organisms that inhabit the site (Welp Sá 2020). Nitrogen and phosphorus parameters were chosen because they are the main organic loads found in this medium and are related to the development of plants and algae. Finally, the physical parameters are related to aesthetics and user comfort. Although high values of color and turbidity do not pose a health risk to the user, ignorance on the part of the user would classify the water as "bad". In addition, if water with a high color remains in contact with a surface (such as toilets) for a long time, stains may occur on these surfaces. With the completion of the assembly, it was possible to start the experiment. The experimental procedure was divided into 5 phases, as illustrated in Figure 4.

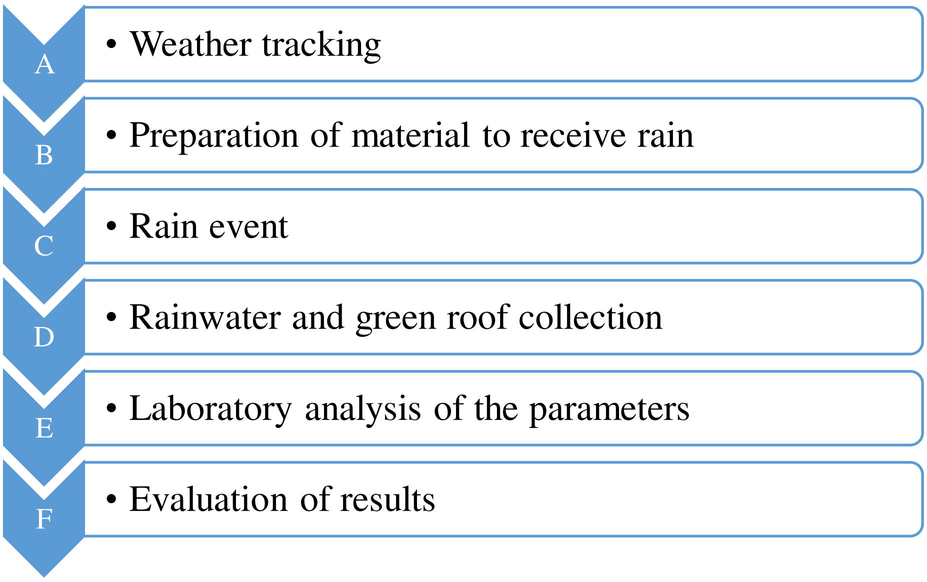

Fig. 4 Experimental Procedure Steps (Welp Sá 2020)

Cleaning up a reservoir using the gallons and the bucket was performed before the occurrence of the rain event to reduce the external impurities contained inside and thus reduce the external interference with the obtained results as much as possible (Welp Sá 2020). As presented in Figure 4, it was necessary to follow the weather forecast (Phase A) and, on the day before the rain, the trip to CESA to clean the reservoirs (Phase B). Given the rain event (Phase C), the samples of the gallons (with water from the green roof) and the bucket (with rainwater) were collected, composing Phase D. This collection was performed with sterile bottles supplied by LEMA-UFRJ and consisted of Phase D of the procedure. In Phase E, the bottles were delivered to the laboratory for analysis. The parameters analyzed in the laboratory (LEMA-UFRJ) were color, turbidity, pH, nitrite, nitrate, ammonia nitrogen, orthophosphate, total coliforms, and coliforms. thermotolerant. The description of the methods used in this work to analyze the physical-chemical parameters of the collected samples is illustrated in Table 9.

Table 9. Description of the parameters and methods (Welp Sá 2020)

Parameters	Method
Color (uH)	8025 – Platinum -Cobalt Standard Method - HACH
Turbidity (UNT)	8237 – Attenuated Radiation Method – direct reading - HACH
pH	4.500 pH – B – Colorimetric - SMEWW – 20º Edition
Nitrite (mg / L)	4.500 NO^2 – B – Colorimetric - SMEWW – 20º Edition
Nitrate (mg / L)	8171 – Cadium Reduction Method - HACH
Ammoniacal Nitrogen (mg / L)	4.500 NH_3 – F – Indophenol - SMEWW – 20º Edition
Orthophosphate (mg / L)	4.500 P – E – Ascorbic acid - SMEWW – 20º Edition
Total Coliforms (MPN)	9.223 – Enzymatic – COLILERT/SOVEREIGN - SMEWW – 20º Edition

With the results, it was possible to make a comparison with the standards and bibliographical studies already presented.

4. Results and Discussions

In the analysis carried, four samples of rainwater were collected by using an open-air bucket and four samples of the green roof were collected by using two 5L gallons. To avoid contamination of the samples at the time of collection, high-density autoclavable plastic bottles, supplied by the sterile laboratory, with a capacity of 500ml were used, as can be seen in figure 5.

Fig. 5 Rainwater and green roof samples, respectively (Welp Sá 2020).

The first collection took place on the 5th of April. This collection aimed to verify if the whole experimental procedure was correct and if modifications were necessary. The following collections occurred on February 13, 18, and 19 the following year, the month with the highest rainfall in the city of Rio de Janeiro. A statistical analysis of the sample amplitude of the parameters of each type of sample was performed using the Excel program. The arithmetic mean, the maximum value, the minimum value, the median, and standard deviation were calculated, based on a sample amplitude since the samples do not represent all rain events in the period. Table 10 presents the results of minimum, maximum and average values found for the analyzed parameters, where the sample of the rain is contrasted with water collected from the green roof (Welp Sá 2020).

Table 10. Drained water quality analysis: sample of the rain *vs* green roof (Welp Sá 2020)

Green Roof Drained Water Quality Analyses Rio de Janeiro, Brazil - 2019						
	Values Obtained - Rain			Values Obtained - Green Roof		
Parameters	minimum	maximum	average	minimum	maximum	average
Color - Platinum-Cobalt Scale (PtCo)	0.00	7.00	3.75	289.00	521.00	383.75
Formazina Turbidity Unit (FTU)	0.00	5.00	2.50	32.00	91.00	51.75
pH	5.41	6.96	5.99	6.24	6.88	6.62
Nitrite (mg/L)	0.01	0.01	0.01	0.03	0.05	0.04
Nitrate (mg/L)	0.90	1.20	1.08	1.30	6.10	2.63
Ammoniacal Nitrogen (mg/L)	0.12	0.24	0.16	0.09	0.09	0.09
Orthophosphate (mg/L)	0.10	0.91	0.49	7.50	14.30	10.88
Total Coliforms (NMP/100mL)	15.00	43.00	26.00	24000.00	24000.00	24000.00
Thermotolerant Coliforms (NMP/100mL)	0.00	0.00	0.00	0.00	0.00	0.00

The first observation that one realizes from Table 10 is that the results for color and turbidity are much higher in the water collected from the green roof, contrasted with that collected via rainwater, which may be justified by the soil particles carrying through water percolation. In terms of pH, the rain was more acidic on average in the green roof, contrasted with directly collected rain, though it should be pointed out that the maximum acidity was less in the green roof water. In all collections, there was an increase in nitrite and nitrate concentration for the green roof, and a reduction of ammonia concentration, when contrasted with the collected rainwater. This may indicate that on the green roof the nitrification process is in more advanced stages. However, the difference between the values is small and no conclusions can be drawn. Orthophosphate in the green roof sample is significantly higher, indicating that it is a very common element in the system and that through water percolation. Finally, the green roof presented very high concentrations of total coliforms, indicating the presence of these bacteria in the system. However, the water from the green roof did not present thermotolerant coliforms indicating that there was no fecal contamination from warm-blooded organisms. For rainwater, small amounts of total coliforms were found. One possibility for this event is the fact that this collection is carried out within a sewage treatment plant, which may cause slight interference with the results obtained (Welp Sá 2020). All collections were made with intense rainfall, ranging from 20 mm to 60 mm. Light and medium rainfall did not provide enough water for laboratory measurements. The most intense rainfall was in Collection 4, with approximately 56 mm and the weakest rain was the third collection with approximately 23 mm. Less intense rainfall showed slightly higher values of color and turbidity, but without significant difference. The increase in nitrite and nitrate concentration was also more significant in less intense rainfall, but this difference was also low. For orthophosphate, it was possible to notice that with the increase in rain intensity, there is a higher phosphorus leaching. This was the largest relationship between rainfall intensity and the results obtained. In terms of coliforms, rainfall intensity did not have a major impact (Welp Sá 2020).

4.1. Comparison between experimental results and technical document recommendations

The first comparison performed in this work was between the average values obtained for each green roof water parameter, with the existing standards and technical documents described previously. To facilitate this comparison, three tables (physical, chemical, and biological parameters) were set up with all the limits of each reference, as seen in Table 11, Table 12, and Table 13, respectively (Welp Sá 2020). In addition, a color scale was used to verify the adequacy of the results to the limits suggested in the standards and technical documents. The black color indicates that the results are following the existing standards and recommendations presented. The *white* color indicates that the result for the parameter was analyzed and approved by some standards and failed by others. And the grey color indicates that the result is not appropriate to the existing standards and technical documents studied. Table 11 presents the experimental results and technical document recommendations based on the physical parameters of water quality.

Table 11 Experimental results and technical document recommendations - physical parameters (Welp Sá 2020)

Water Quality - Physical Parameters		
Technical Documents	Color (mgPt/L)	Turbidity (FTU)
NBR 15527/2007	15	20.5
Ordinance 2914/2011	15	15.8
CONAMA 357/2005 - Freshwater - Class 1	True color	74.5
CONAMA 357/2005 - Freshwater - Class 2	75	167.3
CONAMA 357/2005 - Freshwater – Classes 3 and 4	75	167.3
EMBRAPA	-	-
USEPA	-	15.8
Collected Results	383.75	51.75
Adequacy		

The color-related parameter on the green roof was above all recommended limits. This indicates the need for a filtration process. Filtration will also help reduce turbidity, which has only been approved under the criteria of CONAMA 357 (2005). From Table 12, the pH of (6.62) is adequate in all cases, which is close to the specified limit of (6.0). It is noteworthy that the turbidity parameter was measured in the Formazina Turbidity Unit (FTU) by LEMA-UFRJ and in the existing standards and technical documents the unit found is Nephelometric Turbidity Units (NTU) (Welp Sá 2020). For this, the units were converted using Eq. (1) (Jordão and Volschan 2005).

$$FTU = 1{,}5454 \text{ x } UNT + 12{,}712 \quad (1)$$

Table 12 Experimental results and recommendations of the technical documents - chemical parameters (Welp Sá 2020)

Water Quality - Chemical Parameters					
Technical Documents	pH	Ammoniacal Nitrogen (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Orthophosphate (mg/L)
NBR 15527/2007	Between 6,0 and 8,0	-	-	-	-
Ordinance 2914/2011	Between 6,0 and 9,5	1.5	1	10	-
CONAMA 357/2005 - Freshwater - Class 1	-	3.7	1	10	0.02
CONAMA 357/2005 - Freshwater - Class 2	-	3.7	1	10	0.03
CONAMA 357/2005 - Freshwater – Classes 3 and 4	-	13.3	1	10	0.05
EMBRAPA	Between 6,0 and 8,5	5	-	10	2
USEPA	Between 6,0 and 9,0	-	-	-	-
Collected Results	6,62	0.09	0.04	2.63	10.88
Adequacy					

Nitrite, nitrate, and ammonia nitrogen concentrations also met all recommendations of CONAMA 357 (2005), as shown in Table 12. The concentration of orthophosphate was much higher, by two orders of magnitude relative to the recommendations indicated by CONAMA 357 (2005), and one order of magnitude for the recommendations of EMBRAPA (2010) (Welp Sá 2020). NBR 15527 (2019), which deals with the use of rainwater from urban roofs, is the closest standard to the reality of green roof projects and does not present any restriction for this parameter. In fact, the high phosphorus concentrations make the environment more conducive to the eutrophication process, however, this process is more related to rivers and lakes. For the use of water in buildings, this phenomenon is not a problem (Welp Sá 2020).

Table 13 Experimental results and recommendations of the technical documents - biological parameters (Welp Sá 2020)

Water Quality - Biological Parameters		
Technical Documents	Total Coliforms (NMP/100mL)	Thermotolerant Coliforms (NMP/100mL)
NBR 15527/2007	0	0
Ordinance 2914/2011	0	0
CONAMA 357/2005 - Freshwater - Class 1	-	200
CONAMA 357/2005 - Freshwater - Class 2	-	1000
CONAMA 357/2005 - Freshwater – Classes 3 and 4	-	2500
EMBRAPA	-	-
USEPA	-	0
Collected Results	24000	0
Adequacy		

Finally, as can be seen in Table 13, the total coliforms in the green roof samples were always higher than 24000 NMP/100ml, and therefore above that recommended by NBR 15527 (2019). As a result, it is necessary to introduce a disinfection process to ensure the health of the user of the collected water. Thermotolerant coliforms were absent in all collections, however since green roofs are an environment where living beings live and fecal contamination may occur, the disinfection process would already be necessary (Welp Sá 2020).

4.2. Comparison between experimental results and international references

The second comparison made in this research was with international publications. The comparison between the results is presented in Figures 6 - 13. A comparison is presented for the parameters of color, turbidity, PH, nitrite, ammoniacal nitrogen, nitrate, orthophosphate, and total coliforms. The graphs have then represented the value of each of these parameters on the Y-axis and the correlated authors on the X-axis. As presented in Figure 6, for the color parameter, the result was higher than that reported in Ferrans et al. (2018).

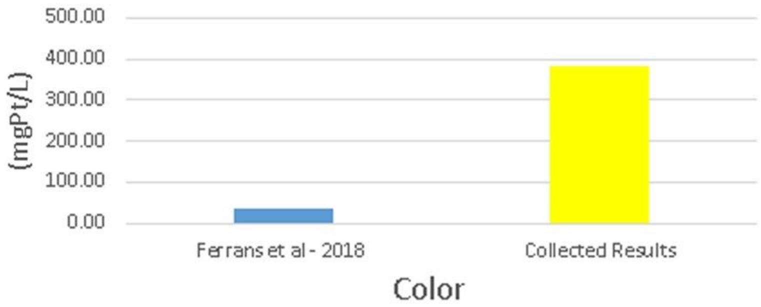

Fig. 6 Color parameters (Welp Sá 2020)

For turbidity, the results of Ferrans et al. (2018) are in the same order of magnitude as the result presented in this paper, appearing to be a behavioral pattern of the green roof system, as presented in Figure 7.

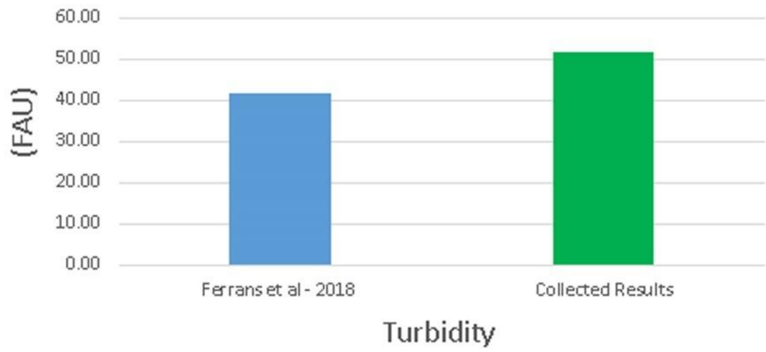

Fig. 7 Turbidity parameters (Welp Sá 2020)

The experiments of Teemusk and Mander (2011) and Ferrans et al. (2018) found values close to 8.0 for pH, as presented in Figure 8. This difference may be related to the substrate and fertilizers used in Brazil. However, according to Ferrans et al. (2018) and Teemusk and Mander (2011), the pH parameter increased when passing through water, and also appears to be a behavioral pattern of the green roof system.

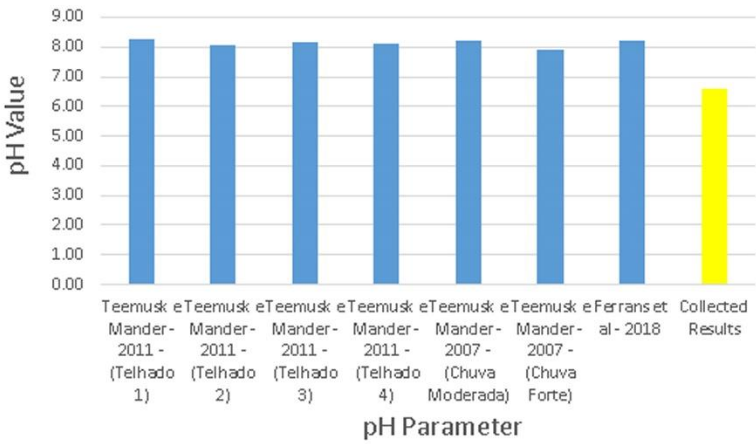

Fig. 8 PH parameters (Welp Sá 2020)

For nitrite and ammonia nitrogen, the concentration values found in this work were close to those found by the other authors, as presented in Figure 9 and Figure 10 respectively (Welp Sá 2020).

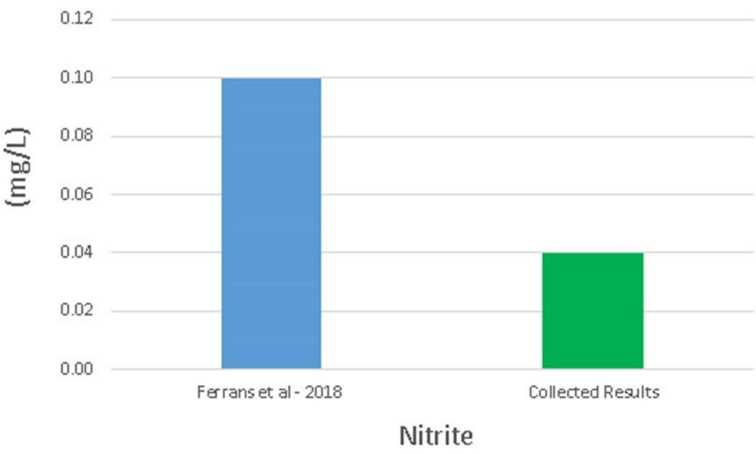

Fig. 9 Nitrite parameters (Welp Sá 2020)

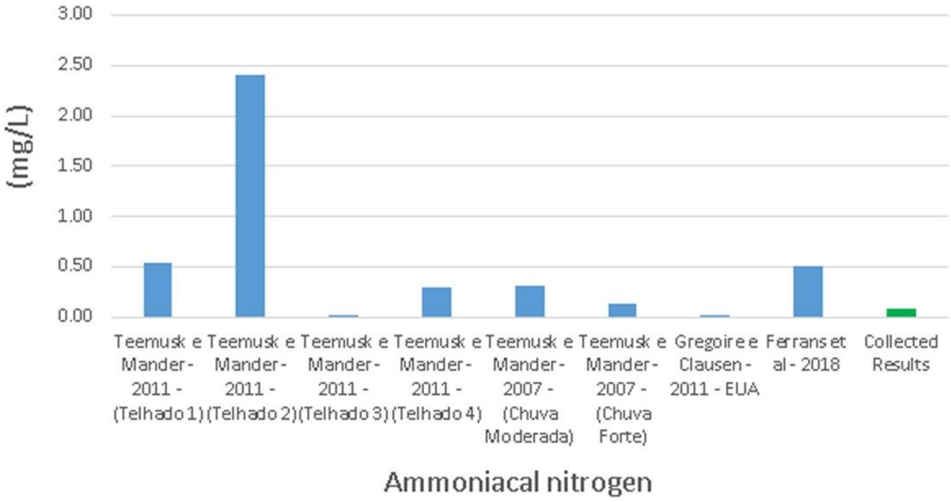

Fig. 10 Ammoniacal nitrogen parameters (Welp Sá 2020)

For nitrate concentrations, the work of Ferrans et al. (2018) presented concentrations much higher than those found in this paper, as indicated in Figure 11.

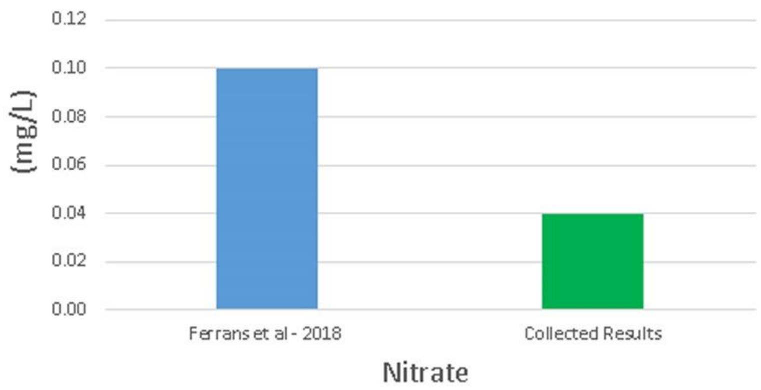

Fig. 11 Nitrate parameters (Welp Sá 2020)

For orthophosphate, the values are much higher than the concentrations obtained by Teemusk and Mander (2011) and Gregoire and Clausen (2011), as presented in Figure 12. As well as the result for pH, this difference may be related to the substrate and fertilizers used in Brazil.

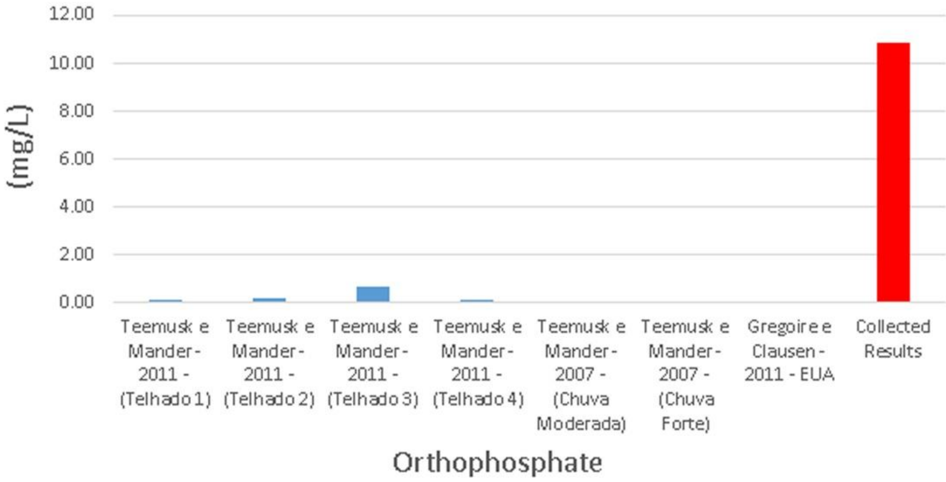

Fig. 12 Orthophosphate parameters (Welp Sá 2020)

For the total coliforms, the values were always higher than 1000NMP/100 ml, reaching up to 150000 NMP/100 ml in the work of Ferrans et al. (2018), as presented in Figure 13. For the present work, the values were higher than 24000 NMP/100ml, however, the most accurate analysis would use more reagent than available in the laboratory. However, these results are already sufficient to indicate the need for the introduction of a disinfection step, to enable the safe use of water. In this work, no thermotolerant coliforms were found in the water samples, nor were they found in the reference works. The need for a disinfection process in the green roof system with water use in buildings is reinforced to prevent risks to people (Welp Sá 2020).

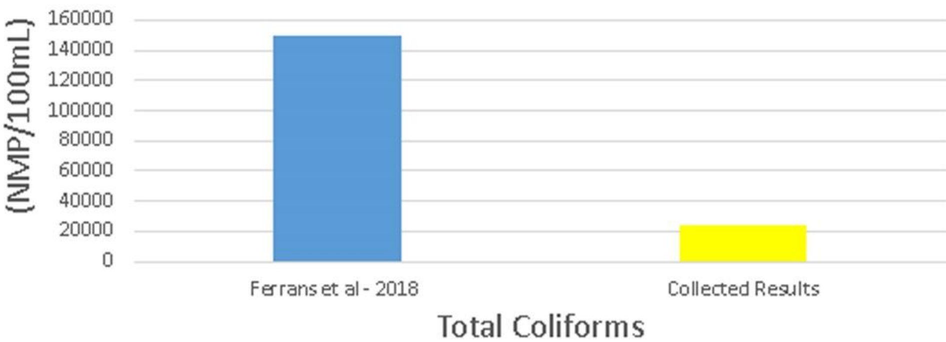

Fig. 13 Total coliforms parameters (Welp Sá 2020)

A summary of the results obtained in the research with the results of other authors is presented in Table 14. According to Ferrans et al., there needs to be more research conducted to understand the quality of water drained from a green roof

Table 14 Summary of the results obtained in the research with the results of other authors (Welp Sá 2020)

Water Quality Parameters	Comparison
Color (uH)	Intermediate values, however, with a lot of discrepancy between them
Turbidity (UNT)	Values close to the results of other authors
pH	Value below all the results of other authors, however still close to them

Nitrite (mg / L)	Values close to the results of other authors
Nitrate (mg / L)	Intermediate values, however, with a lot of discrepancy between them
Ammoniacal Nitrogen (mg / L)	Values close to the results of other authors
Orthophosphate (mg / L)	Values higher than the results of other authors
Total Coliforms (MPN)	Intermediate values, however, with a lot of discrepancy between them

The results discussed above highlight the potential of using a green roof system as a water treatment alternative. This is specifically relevant when the water use application imposes less stringent requirements on the water quality as indicated by the standards available. In terms of color and turbidity results indicate that the water collected from the green roof can be utilized for irrigation without treatment, while chemical parameters seem to indicate the need for treatment for sanitary. Biological parameters, on the other hand, reveals the need for the disinfection process. Generally, the technical standard that best suits the use of green roofs in buildings in Brazil is NBR 15527 (2019), because it refers to rainwater utilization in urban building coverage.

At the international research level, the works of Teemusk and Mander (2011) and Gregoire and Clausen (2011) were limited to chemical parameters of nitrogen and phosphorus, heavy metals, and pH. The work of Ferrans et al. (2018) also showed an interest in the physical and biological parameters of green roof water quality, which are therefore the most comprehensive.

5. Conclusions

With the lack of water resources being experienced worldwide, rainwater harvesting systems appear as an alternative to mitigate current and future water recycling challenges. Green roofs offer a great alternative for water treatment. This study examined the quality of water collected from green roofs through the use of various legislations, ordinances, and manuals that are dealing with water quality standards. Based on such observations, filtration and disinfection processes are therefore required in the green roof system for the sanitary use of rainwater. A practical experimental study on a green roof prototype located at the Experimental Center for Environmental Sanitation (Centro Educacional de Saneamento Ambiental - CESA) of the (UFRJ) was conducted, to cover gaps in standards of green roofs water quality. The aim of this work is therefore to encourage the calibration of water quality parameters collected from a green roof and inspire its use as a sustainable measure in buildings for the collection and treatment of rainwater.

It can be concluded from the results that a filtration and disinfection process is required in the green roof system for the use of the rainwater. Other water treatment processes may be required depending on the purpose of the water. The results, in line with those of other international publications serve as a basis for the future elaboration of standards regarding the use of rainwater in buildings from the use of green roofs. It needs to be highlighted that for the proper use of rainwater in buildings, the purpose of water use should be defined. That is, each use of water may imply greater or lesser restrictions related to water quality, and therefore will imply different levels of treatment, to guarantee the quality of the system and the health of the user.

Several limitations exist for the experiment analysis conducted. There was some unforeseen rain in the weather forecast, which was therefore lost as the containers were not placed to collect water. The opposite also occurred: the containers were cleaned, but the expected rain did not happen. There were a large number of variables that change the values obtained for water quality in green roofs. The main variables are green roof type, slope, vegetation type, substrate type, substrate thickness, fertilizer use, green roof drainage, rainfall intensity, previous rainfall, green roof age, maintenance performed, and the sources of pollution around the green roof. All of these need to be analyzed in future works. This work also disregarded addressing water alkalinity and hardness parameters for the reasons described above. Hence, future studies may seek reference values in international standards for the analysis of these parameters, given the great importance of calcium and magnesium indices for rainwater use. As a suggestion, it is possible to vary the roof's construction characteristics (substrate material and thickness, slope, vegetation type, and thickness) and change the system used (complete system, modular and pre-cultivated blanket), allowing the comparison between each system and every constructive feature of green roofs. Another possibility is the variation of rainfall intensity and variation of soil moisture. Finally, a suggestion for the continuity of the research could be reinforced by comparing the bench-scale model using different types of plants and taking samples of real (operational) green roofs in some of the buildings. Such discoveries can establish guidelines for the application of green roofs in different climatic zones and the suitability of different types of plants. This work, I believe, is suitable for a magazine of local interest.

Declarations

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Conflicts of interest/Competing interests

The authors have no conflict of interest to declare.

Availability of data and material

The data used is available if requested when applicable.

Code availability

Not applicable

Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Thomas Schatzmayr Welp Sá and Elaine Garrido Vazquez. The first draft of the manuscript was written by Thomas Schatzmayr Welp Sá and Elaine Garrido Vazquez and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

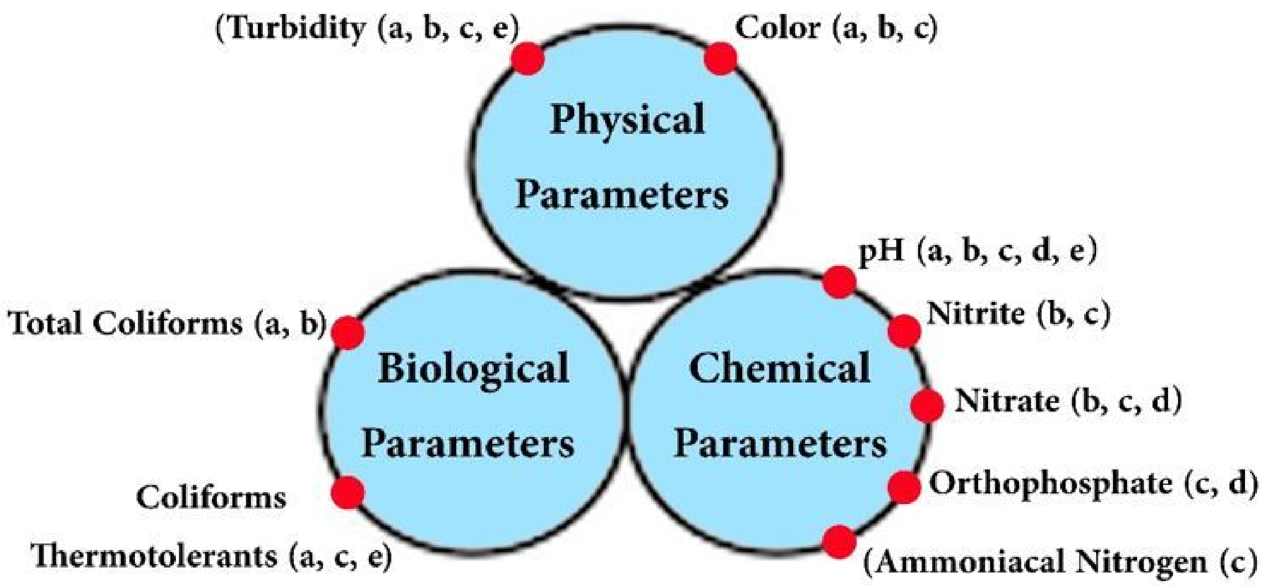

Figure 1

Schematic of the analyzed parameters for rainwater (a - NBR 15527 (2019), b - Ordinance 2914 (2011), c - CONAMA 357 (2005), d - EMBRAPA (2010) and e - USEPA (2012)).

Figure 2

Experimental prototype - Green roof with bromeliads August (Silva 2020)

Figure 3

Rainwater collection structure (Welp Sá 2020)

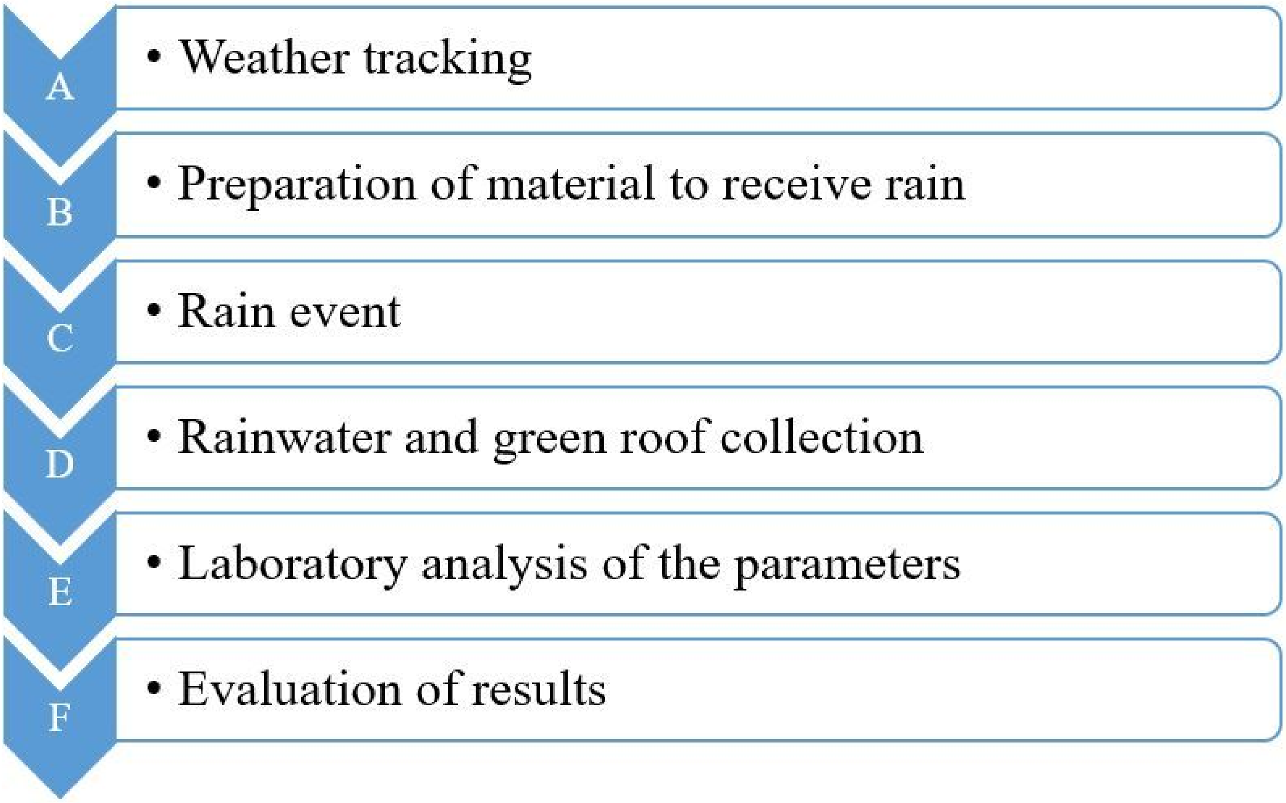

Figure 4

Experimental Procedure Steps (Welp Sá 2020)

Figure 5

Rainwater and green roof samples, respectively (Welp Sá 2020).

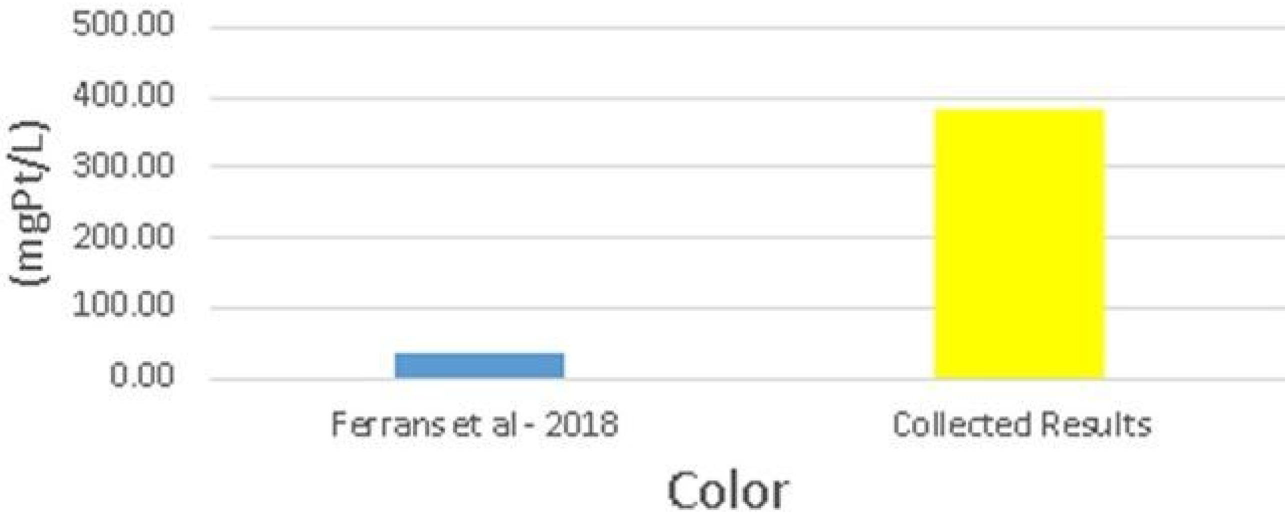

Figure 6

Color parameters (Welp Sá 2020)

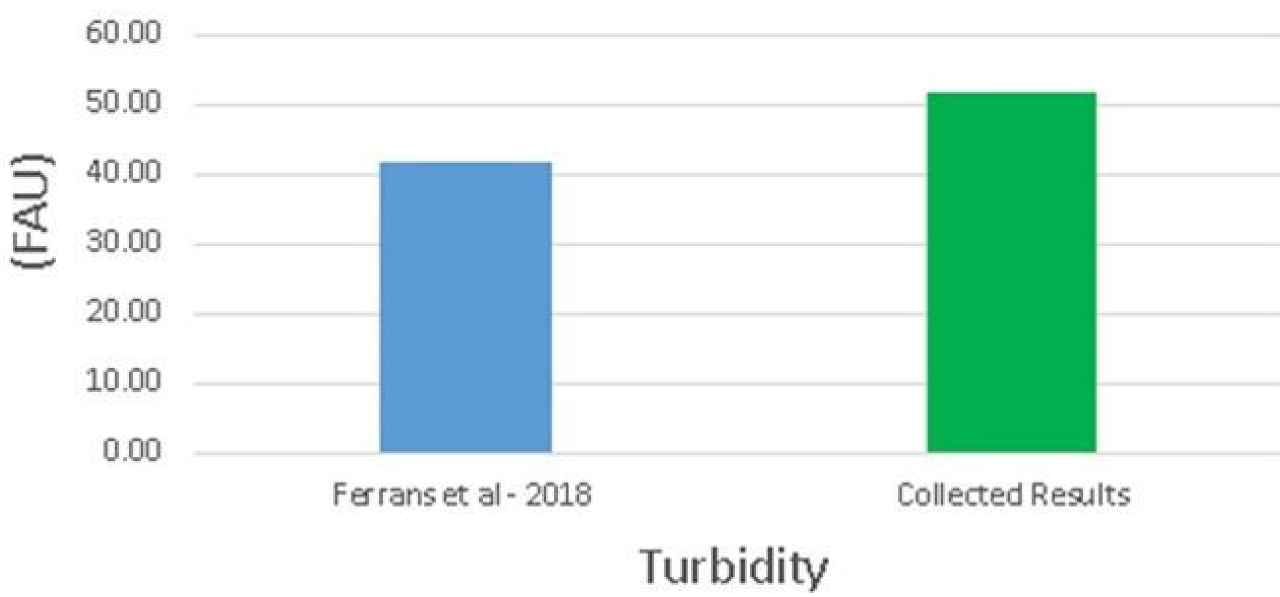

Figure 7

Turbidity parameters (Welp Sá 2020)

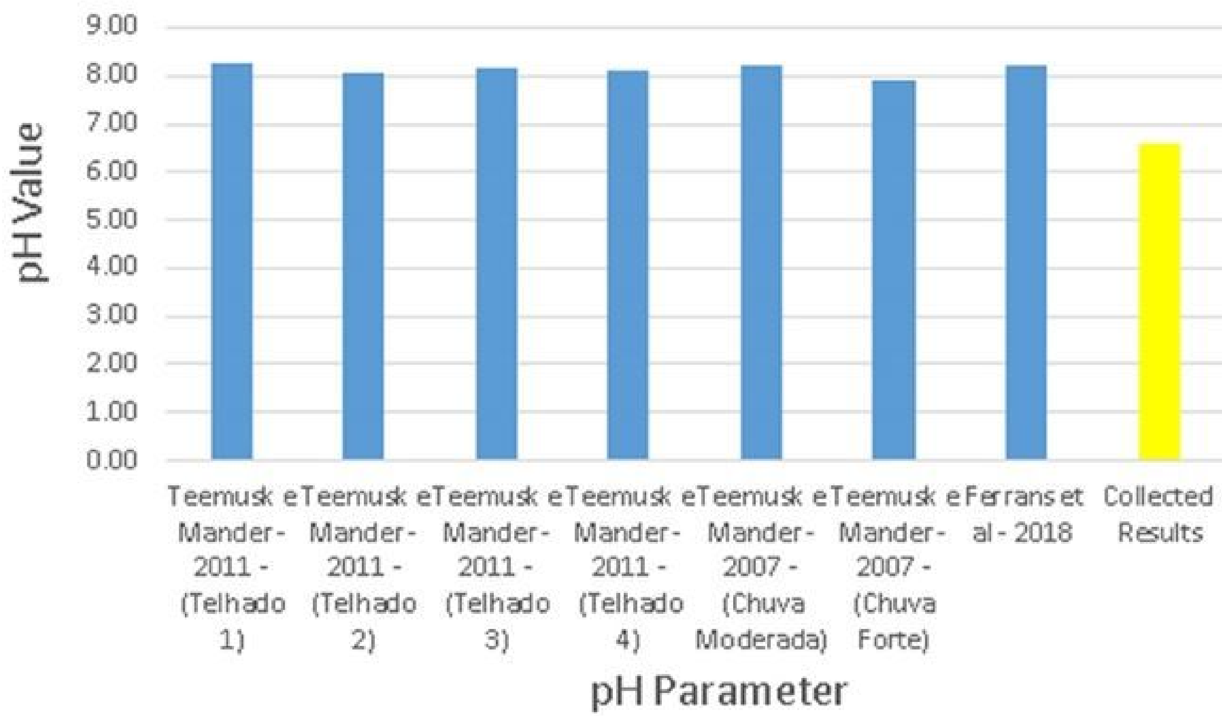

Figure 8

PH parameters (Welp Sá 2020)

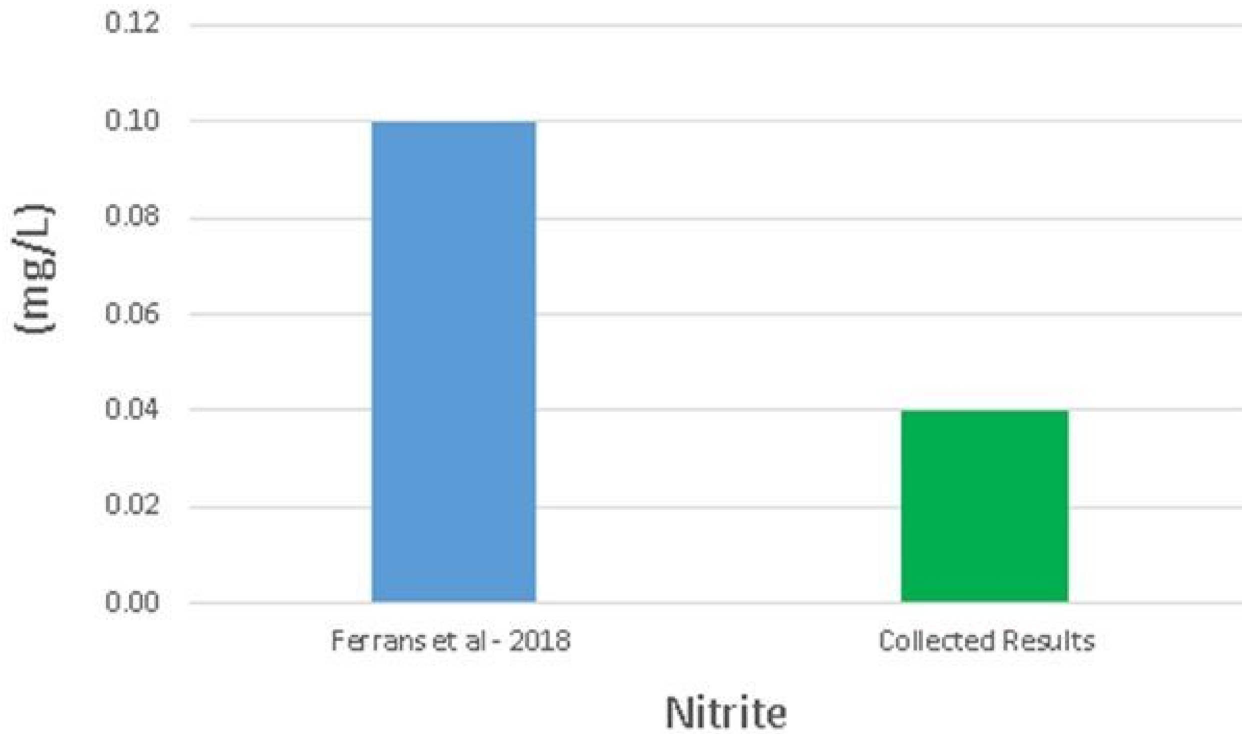

Figure 9

Nitrite parameters (Welp Sá 2020)

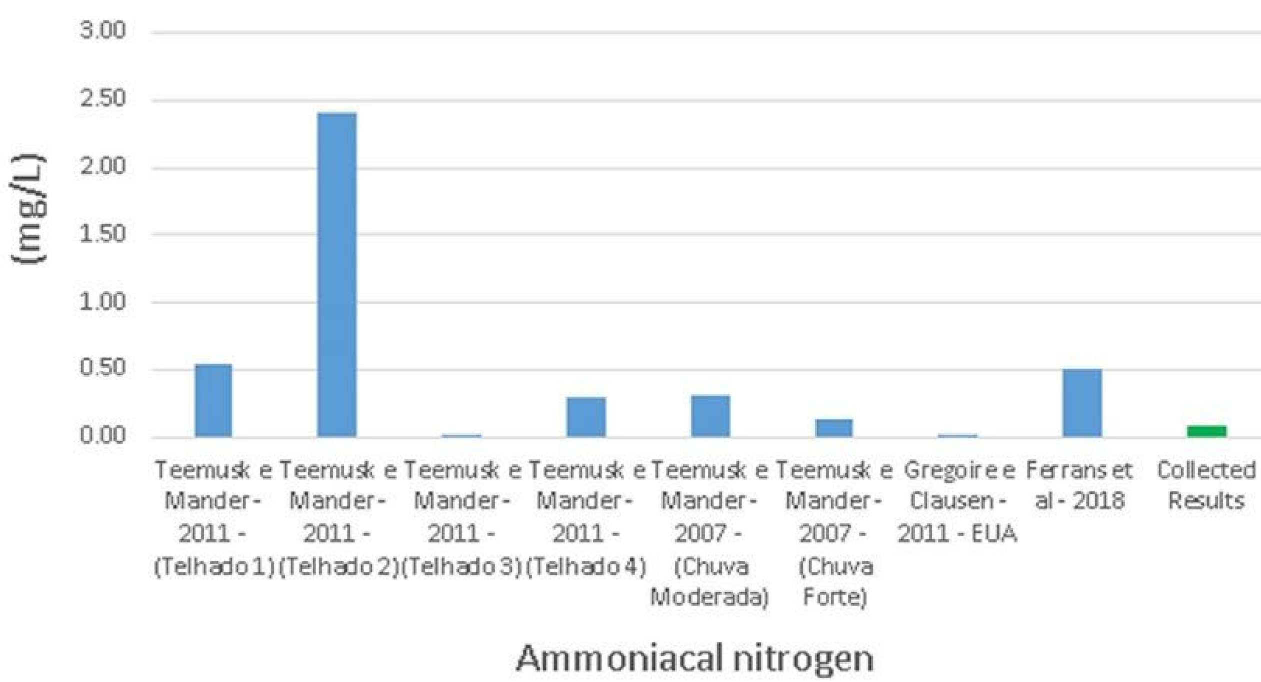

Figure 10

Ammoniacal nitrogen parameters (Welp Sá 2020)

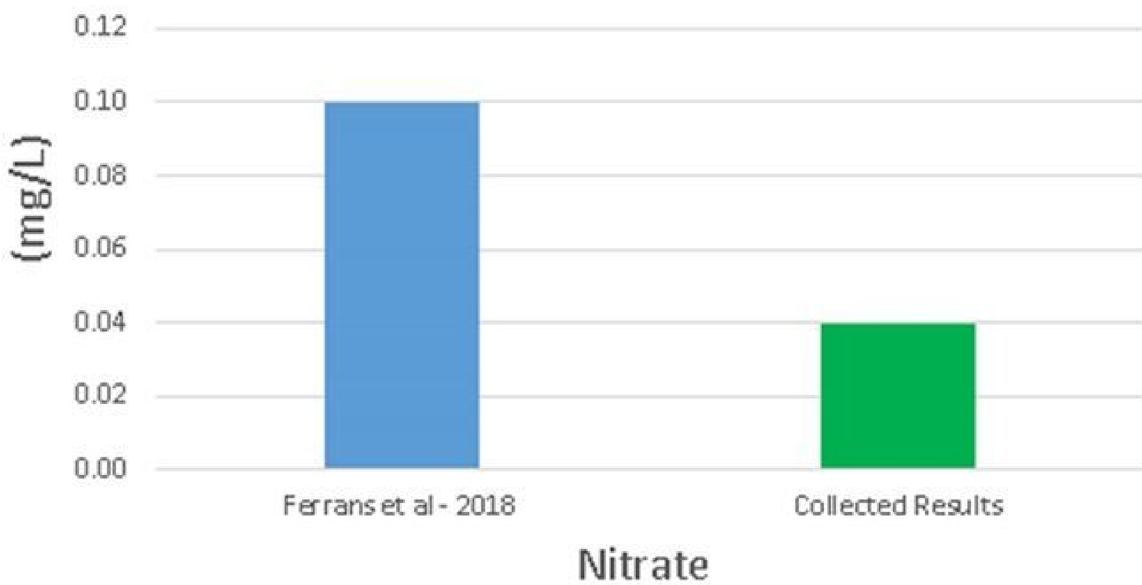

Figure 11

Nitrate parameters (Welp Sá 2020)

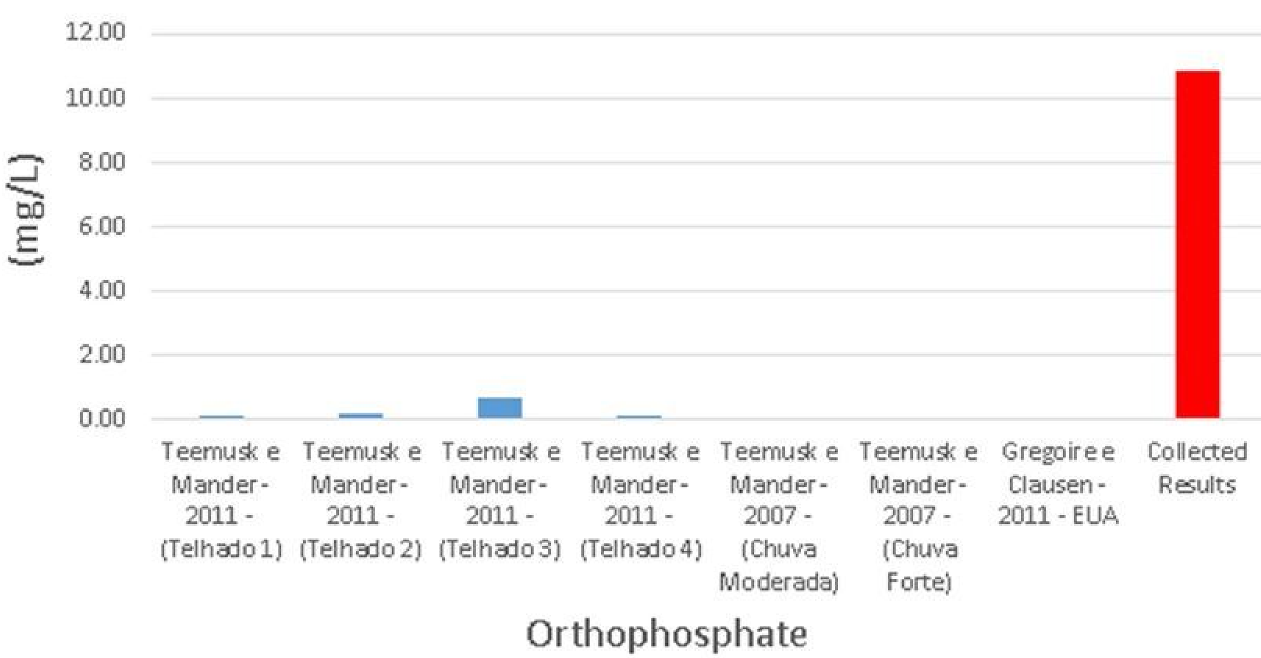

Figure 12

Orthophosphate parameters (Welp Sá 2020)

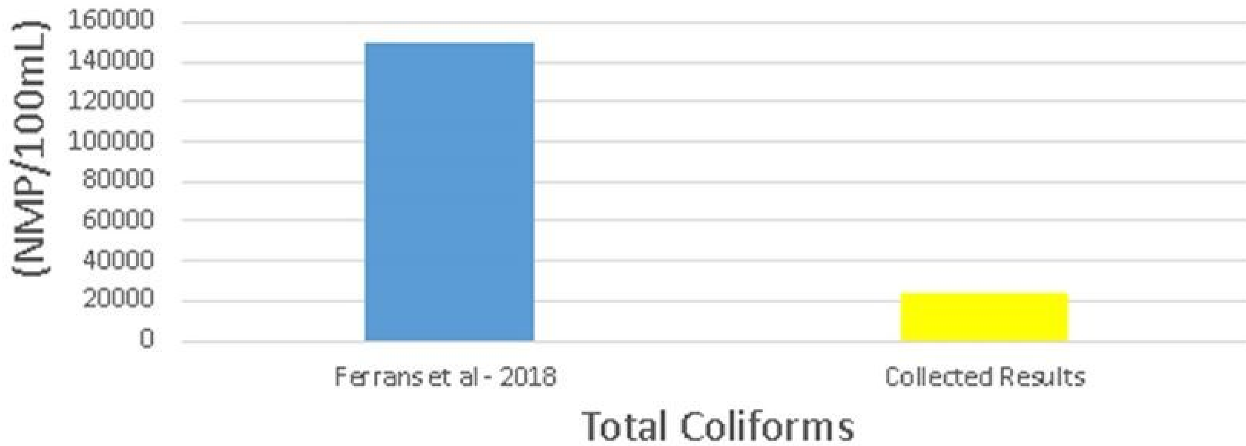

Figure 13

Total coliforms parameters (Welp Sá 2020)