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# Study of the feasibility of use of rainwater in concrete plants: path for sustainable buildings

# Estudo da viabilidade do uso de água pluvial em concreteiras: caminho para construções sustentáveis

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## ABSTRACT

Water is an essential natural resource for life on Earth. Currently, one of the biggest problems affecting humanity is the scarcity of this resource, widely used by the entire population. In this perspective, ensuring the sustainability of water means ensuring its responsible use, reuse and care in maintaining its purity. Therefore, the use of rainwater is seen as one of the ecological and sustainable means to avoid a possible scarcity of a natural resource. What motivated the preparation of this work was the study on the feasibility of using rainwater to be used in concreting processes without compromising its resistance. For this, the parameters for using the samples collected at predetermined points were determined; physical-chemical analyzes of the collected water were carried out; the concrete specimens were made with potable and rainwater and compression tests were carried out to analyze the resistance of the specimens. The values obtained from the tests and trials carried out on the two samples of rainwater collected, the parameters evaluated in this study obtained through the tests already mentioned, were satisfactory and fit the standards established by the ABNT NBR 15900 standard for the use of water of the rain on the concrete kneading.

**Keywords**: Rainwater, technical feasibility, concrete.

## 1 INTRODUCTION

Water is a natural resource essential for life on Earth. Currently, one of the biggest problems affecting humanity is the scarcity of this precious resource that is widely used by the entire world population, despite its unequal distribution. According to Boff (2012), it is necessary to urgently curb the growing scarcity of water caused by its misuse. To ensure the sustainability of water is to guarantee its responsible use, its reuse and the care in maintaining its purity against contamination. Although 75% of the Earth is made up of water, 97% of this water cannot be consumed or used for most of the processes that demand water resources, because it has a high content of sodium chloride and its treatment has a high cost, which makes its use difficult. One of the most used strategies to avoid water shortages, due to its economic viability and ease of use, is the use of cisterns. These are reservoirs that capture rainwater, which is stored and used for domestic and industrial uses, such as cleaning vehicles and machinery, cleaning services at the construction site, flushing toilets and urinals, curing, and making concrete.

This research sought to demonstrate that rainwater storage represents a great contribution to the preservation of the environment, and can be easily used for the demand of concrete plants in various processes and activities, leading to sustainability and possible cost reduction. After establishing the importance of rainwater harvesting, the following questions were raised: what is the best method and what is the feasible use for this resource in the concrete plant area? Does the use of rainwater harvesting cause any change in concrete strength?

Given the problem presented and the concern with the planet's sustainability, professionals in the construction sector need to adapt their projects prioritizing the rational and conscious use of water, and the creation of strategies to capture and use this resource.

## 2 THEORETICAL FRAMEWORK

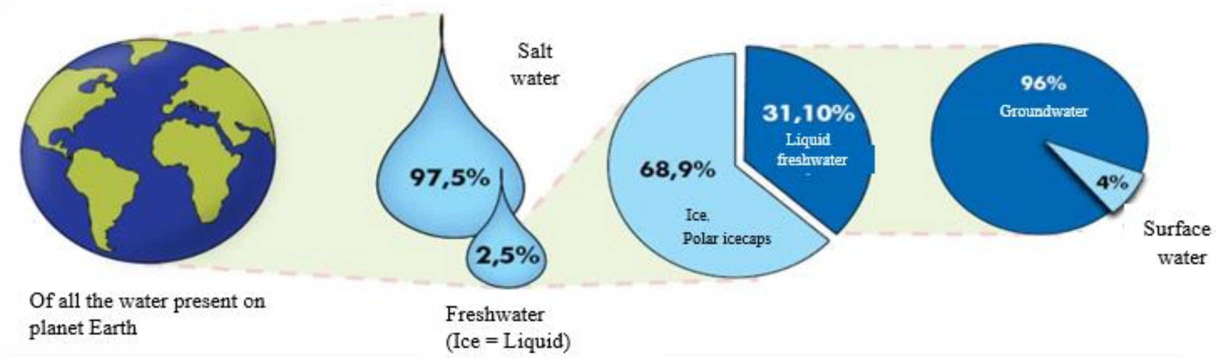
In the following topics the fundamental theoretical references for the development of this research will be presented.

### 2.1 HYDRIC RESOURCES

Water is a natural resource essential for the survival and development of all species on Earth. It is an abundant element on the planet, representing 75% of it. Despite this large amount of existing water, only 2.5% is freshwater, of which almost 96% is underground, i.e., only a minimum part of this entire resource is available easily and suitable for consumption.

Besides the low availability of drinking water, as shown in Figure 1, there are other factors that are directly contributing to the scarcity of this resource on the planet.

Figure 1 - Distribution of water on planet earth

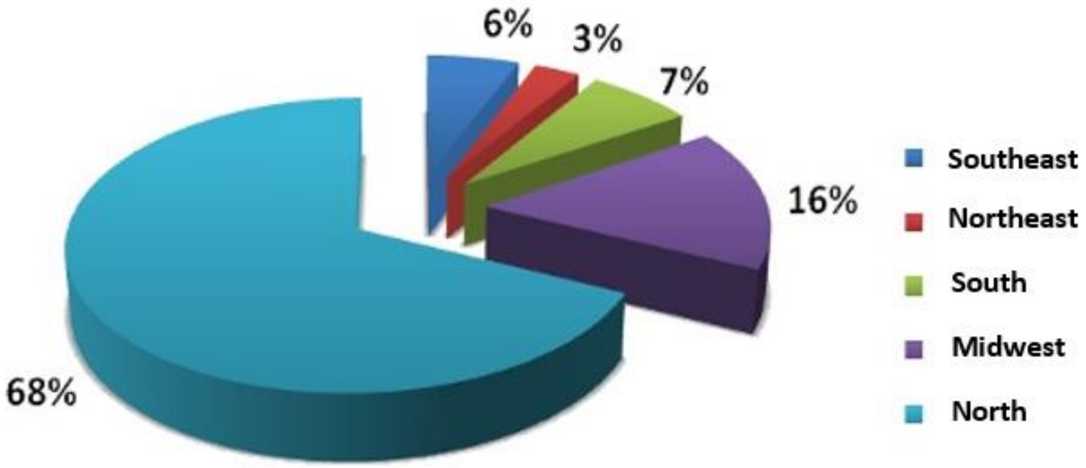


Source: MMA-SRHU, 2007.

## 2.2 SITUATION IN BRAZIL

Brazil has a privileged location in relation to the availability of water resources, however, water reserves are disproportionately distributed in its territory. According to 2016 data from the Brazilian Chemistry Congress, illustrated in Figure 2, the northern region is the most favored by water resources in its location. One of the largest river basins in the world is located in the Amazon, but it has a lower population density compared to the other regions.

Figure 2 - Water distribution by regions



Source: CBQ, 2016.

The Northeast and Southeast regions suffer from greater droughts and water shortages due to their higher population density. The reuse of water can generate environmental, economic and social benefits for the population where it is inserted, being a sustainable option for increasing the supply of water.

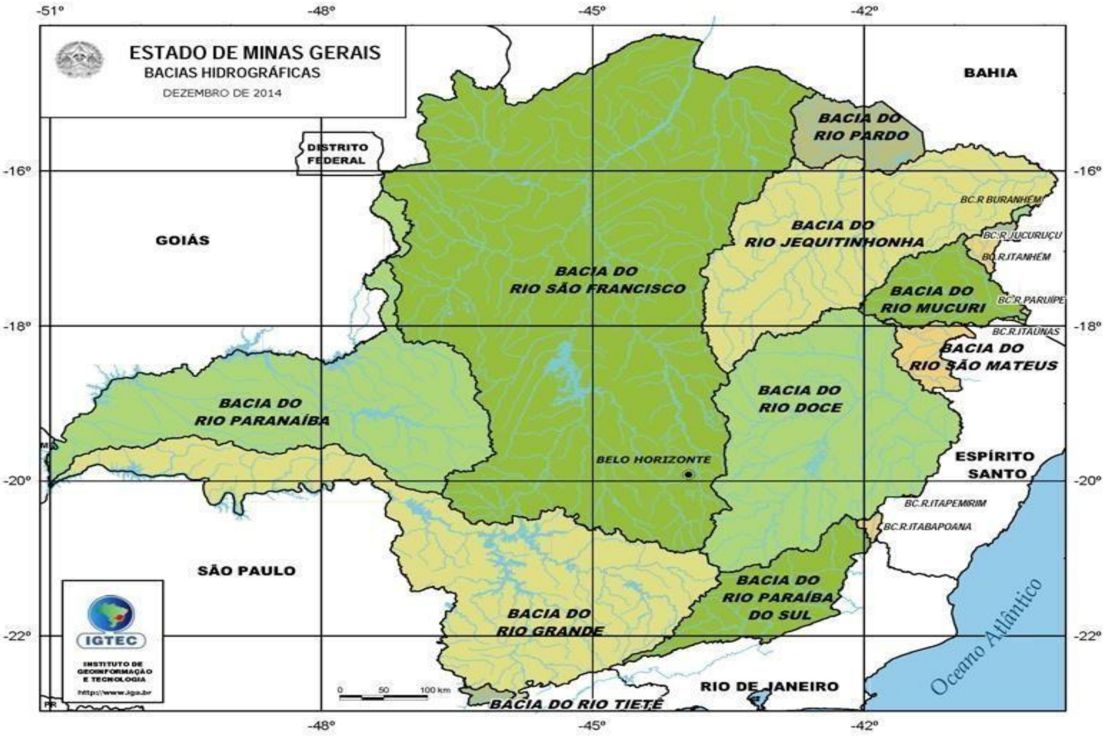
### 2.2.1 Situation in Minas Gerais State

Minas Gerais is of fundamental importance for the supply of water and successively for the supply of electric power in Brazil. In its territory are born some of the main hydrographic basins of Brazil.

> "The state of Minas Gerais has become known as the Brazilian 'water box', in a reference to the relevance of its watersheds. It is a producer of water in its 58.6 million hectares. The main basins that make up the state's hydrographic network are the Doce, Grande, Jequitinhonha, Mucuri, Paraíba do Sul, Paranaíba, Pardo and São Francisco rivers. (MG.GOV,BR, 2019, p.1)

Figure 3 shows the distribution of the Hydrographic Basins in the state of Minas Gerais:

Figure 3 - Mapping of Hydrographic Basins located in Minas Gerais



Source: IGTEC - Institute of Geoinformation and Technology (Portuguese acronym), 2014.

Due to the characteristics of its relief, and other aspects, the state presents thermodynamic conditions that result in different rainfall regimes within its territory.

> The rainy season in Minas Gerais, as in the entire Southeastern Region, occurs between the months of October and March, but the first rain showers usually occur in the second half of September, evidencing the decline of the dry season (INSTITUTO NACIONAL DE METEOROLOGIA – INMET, 2017, p. 1).

Urban development, lack of sanitation, and the various types of pollution that affect rivers and their effluents in Brazil and in the world cause heavy rainfall to cause serious problems, such as flooding, landslides, infectious diseases, and flooding, among others.

## 2.3 CONSEQUENCES OF WATER SHORTAGE

As a result of the water crisis, several consequences can be observed in our country and in the world.

> Today more than one billion people - that's one in seven of the world's inhabitants - lack adequate access to safe drinking water. More than 40% of the planet's population will soon live in regions increasingly affected by water stress (JACOBI, 2016, p. 1).

According to data from Projeto Brasil das Águas:

> – One sixth of the world's population - more than one billion people - lack access to safe drinking water;
> – 40% of the planet's inhabitants (2.9 billion - the 2013 population estimate was 7.3 billion) do not have access to basic sanitation services;
> – About 6,000 children die every day from diseases linked to unsafe water and poor sanitation and hygiene; - According to the UN, by 2025, if current consumption patterns continue, two out of every three people in the world will experience moderate or severe water shortages (PROJETO BRASIL DAS ÁGUAS, 2013, p. 1).

Considering the aforementioned texts, water scarcity is imminent, causing a series of consequences such as: reduction in the production of food and raw materials for industries, which will probably impact the economy; significant impact on the supply of electricity, which will trigger social and industrial crises and irreversible damage to the environment, among others.

## 2.4 RAINWATER CHARACTERISTICS

As a consequence of increasing environmental degradation, we contemplate a decrease in the availability of water and a change in its quality.  The quality of rainwater can change according to several items, such as: atmospheric pollution, contact of the water in the runoff, i.e., cleaning of the catchment surface, maintenance of the screen or filtration method, and storage (JUSSARA, 2016).

The quality of rainwater deteriorates when it passes over a catchment surface that may have contaminants, leaves or fecal droppings, chemical infectants can dissolve during precipitation and leach into the components of the rainwater system, and poor quality storage. It is very important that users understand the potential hazards and risks of neglecting rainwater harvesting (HAN, 2012).

## 2.5 ALTERNATIVES FOR SOLVING THE WATER SCARCITY PROBLEM

Nowadays, it is extremely important to raise the issue of water, especially the possible lack of it. Because there is a limited amount of drinkable water available in nature, on the other hand, about 97.61% of the planet's total water comes from ocean waters, i.e., not drinkable.

> According to Aldo (2015): the greed for the "blue gold" is such that, in the last 50 years, more than 500 conflicts had water as the main motive. "Even so, the fundamental issue is not the quantity of water: for now, we consume only 12% of the available liquid. The problem is the misuse of this resource. This, indeed, can further aggravate the supply crisis. (Aldo, 2015, p.1).

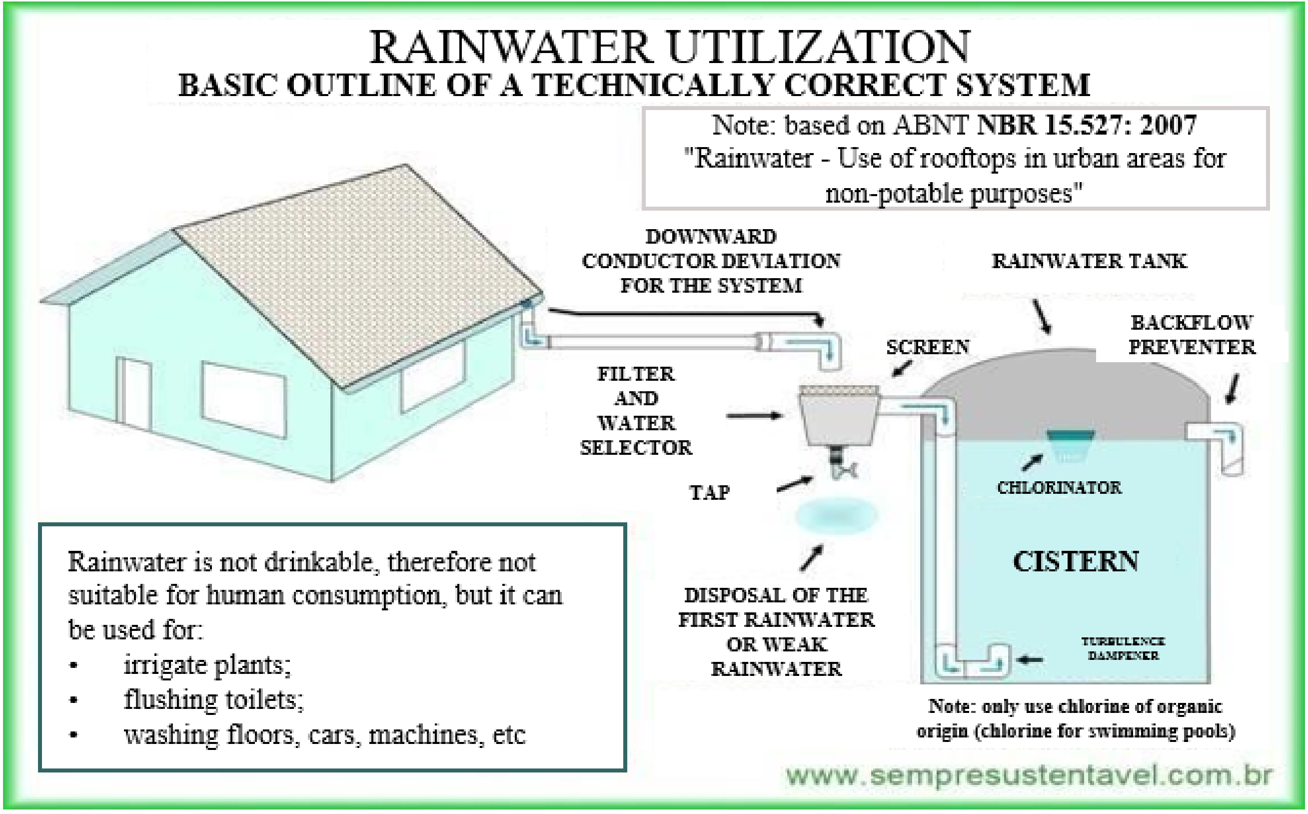
### 2.5.1 Rainwater Utilization

The use of rainwater emerges as a promising, ecological and sustainable way to avoid a possible shortage of this natural resource.

> According to Thomas (2010): water shortage is one of the serious global problems that can affect the survival of human beings. The disorderly use, waste and growing demand are factors that contribute to intensify the scarcity of drinking water on the planet (THOMAS, 2010, p. 7).

According to Ferreira (2018): the use of rainwater has become an alternative in the urban area for private homes and businesses not only in the environmental sense, but also economically. The use of treated water for garden irrigation purposes or even for cleaning the external areas of residences can be replaced by stored rainwater. In industries, the use of rainwater for cleaning purposes and even in the production system, as long as it is not used for food purposes, is an interesting alternative, especially when the company uses water supplied by a concessionaire, which implies high monthly costs. Although in many situations the storage system does not have a large volumetric capacity and the rainwater supply source does not have an exact periodicity, water harvesting is interesting when well planned and taking into account the average daily consumption and the temporal variability of rainfall occurrence. One of the solutions adopted to avoid water shortage in the world is the use of rainwater, which can be done through the capture system shown in Figure 4.

Figure 4 - Rainwater Harvesting Model



Source: sempresustentável.com site, 2019.

To realize a complete system for capturing and using rainwater, the following equipment is used:

- Collecting Basin (roof): works as a rainwater catchment;
- Gutters and collectors: collects the water that comes from the roof;
- Coarse filter: retains solid residues, such as branches, leaves, and other coarse impurities;
- Sand filters: retains most of the contaminants present in the raw water;
- Deironing filter: removes iron and manganese present in the water;
- First Water Separator: abstracts the first rain;
- Disinfection unit: ensures the sanitary security of a rainwater utilization system, chlorine, ozone or ultraviolet radiation can be used;
- Reservoir (cistern): to accumulate rainwater. The reservoir must be closed to prevent dirt and sunlight from entering;
- Pressurization System: pumps and a safety and automation system to send the stored water to the supply boxes;

- Secondary feed boxes or elevated reservoir
- Use network: exclusive and independent piping for the use of the reserved water. It cannot be mixed with the distribution water.
- Verification of the water quality (acid rain);
- Water treatment, if necessary (SUSTENTARQUI, 2015, p. 1).

### 2.6 Legislation pertaining to rainwater reuse in concrete

The normative parameters present in Brazilian legislation guide the use of rainwater. Among them, the following norms can be cited:

**ABNT NBR 15527:2007** - Rainwater - Use of rooftops in urban areas for non-potable purposes - This norm establishes the practical application on the use of rainwater in urban areas for non-potable purposes;

**ABNT NBR 10844:1989** - Building Installations for Rainwater - This norm establishes the necessary requirements for the projects of rainwater drainage installations, in order to guarantee acceptable levels of functionality, safety, hygiene, comfort, durability and economy.

The following normative standards are required for the concrete to be made correctly and efficiently:

**ABNT NBR 15900-1:2009** - Water for concrete mixing - This Standard (all parts) specifies the requirements for water to be considered suitable for concrete preparation and describes the sampling procedures, as well as the methods for its evaluation.

**ABNT NBR 7212:2012** - Execution of concrete batched in central - This standard establishes the requirements for the execution of concrete and includes the operations of storage of materials, batching, mixing, transport, receipt, quality control and inspection, including criteria for acceptance and rejection of the internal control of the concrete plant.

### 2.7 Concrete in construction

Concrete is the most used material in civil construction and its composition is basically a mixture of at least one binder, in this case cement, coarse aggregates (stones), fine aggregates (sand), water, additives and additions (silica fume).

There are several concrete mixes, which depend on what will be built and where it will be applied. In the case of a foundation, the concrete mix is 5 18-liter cans of sand, 6 18-liter cans and half an 18-liter can of stone (coarse aggregate), and 1 18-liter can and a half of water for each bag of cement. If the concrete will be used in floors, walls or pillars for example, the concrete mixes will be different. The concrete must follow a standard in the choice of its products to achieve a satisfactory result. Besides the care taken in its production, good quality cement, clean stones and sand must be used: without clay, mud, organic materials and grains that can crumble, moisten the stones when exposed to a lot of sunlight, and use clean water, without suspended materials and in the right quantity: the excess decreases resistance and the lack of water creates holes in the mixture, and the fact that we use water from rainwater collection (Appendix A) has brought an economic and sustainable option, which may provide increased monthly profit for concrete plants, reducing the water bill at certain times of the year. Water is also used in other processes such as concrete curing. (Caio, 2014).

> According to Diniz (2012): curing is one of the main steps in the execution of concrete and has a direct participation in the development of the hydration process of the cement paste, sealing the concrete, keeping the mixing water inside, avoiding shrinkage and the transport of substances that may interfere in hydration (DINIZ, 2012, p. 1).

The curing process could easily be carried out with rainwater. Civil construction demands a lot of water in its processes and one of the best examples is the curing of concrete. As curing comprises a series of procedures that aim to maintain cement hydration, using rainwater is therefore one of the most efficient options for construction. These practices adopted together have the potential not only to make the construction more sustainable, but also to generate greater savings in the project. To prove all that we have said, just check the cost of using tap water on the site and draw a comparison (Ralph, 2018).

## 3 METHODOLOGY

This research, qualitative and quantitative in nature, was developed through three main components: literature survey, qualitative and quantitative approaches. Regarding its nature, this work was characterized as an applied research, which, according to Gil (2010), is aimed at the acquisition of knowledge with a view to application in a specific situation, in the case of this work, the use of rainwater catchment in various sectors of the construction industry.

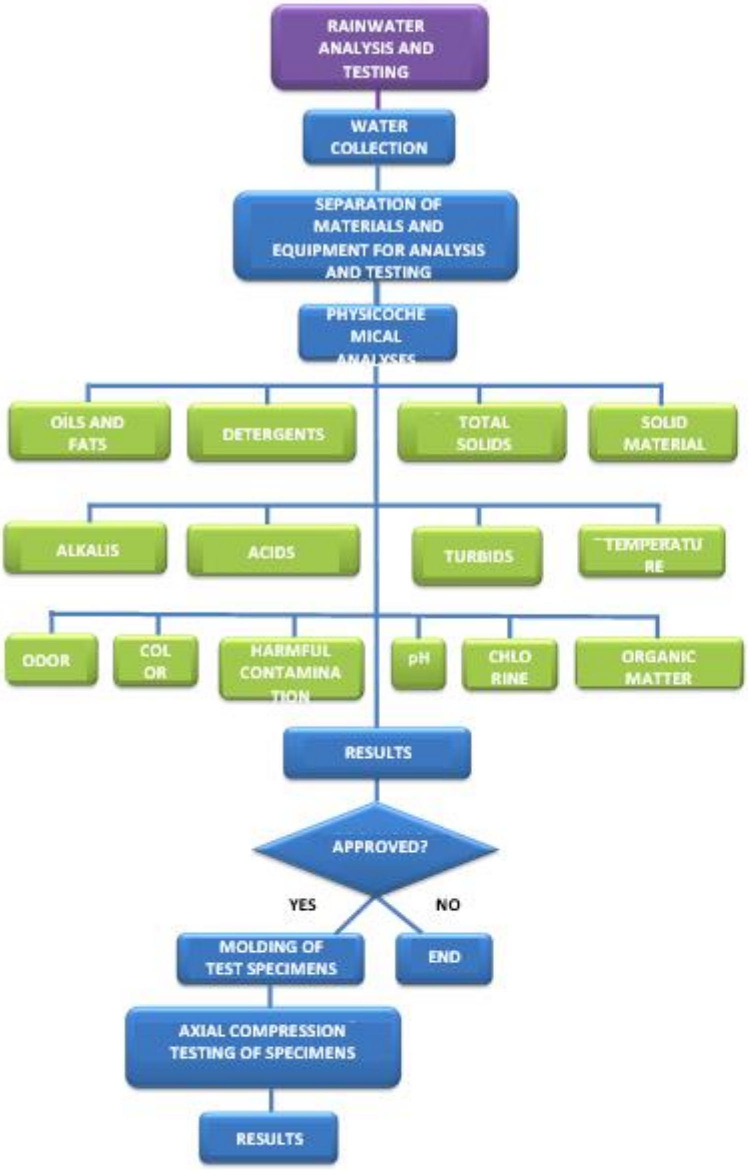
According to the proposed objectives, this research started with an exploratory research, because, according to Lakatos and Marconi (2011), this constitutes the first stage of all scientific research. According to Gil (2008), exploratory research aims to enable greater knowledge of the problem and is intended to build hypotheses for it. The hypothesis presented for this research project aimed to provide sustainability and cost reduction in concrete plants by using rainwater in their processes. As for the technical procedures, bibliographic and experimental researches were carried out, which allowed the selection of variables that influenced the object of study (GIL, 2008).

Water samples were collected in the region of Itabira. Then, the characterization of this material was carried out, which makes the research a quantitative approach. In a quantitative research, the data are quantified, that is, they are expressed in numbers, and can be classified (SILVA, 2014). In the case of this investigative work, laboratory tests were performed, being, at first, the physical-chemical tests.

## 4 MATERIAL E MÉTODOS

The flowchart shown in figure 5 illustrates all the analyses performed to verify the usability of rainwater in concrete pouring, whose steps will be detailed in later items.

Figure 5- Demonstration scheme of the rainwater analysis used in this study.



Source: The authors, 2022.

## 4.1 WATER COLLECTION

The rainwater was collected directly from the gutter at two predetermined points in the city of Itabira / Minas Gerais. One of the samples was collected from a residence in the Bethânia neighborhood and the other in the João XXII neighborhood. Sterilized bottles were used so that no contamination could occur. According to NBR15900-1, the water collected for analysis fits the classification of item 3.5 - Natural surface water, rainwater catchment water and industrial wastewater. This water may be suitable for use in concrete; however, it requires previous physical-chemical tests. The collected material that was not immediately used was stabilized and cooled in an appropriate place for later use.

## 4.2 ANALYSES AND TESTS

The samples were sent to the chemical laboratory of the University of the State of Minas Gerais - João Monlevade Unit, where physical-chemical tests were performed for Chlorides, Alkalis, Total Solids, Hydrogen Potential (pH), Temperature, Turbidity, to evaluate the quality of the water in the samples, making sure that they are suitable for use in concrete mixing.

## 4.3 MATERIALS

For this present study, the following materials were used: Rain catchment water; Phenolphthalein; Methylorange indicator; Bromocresol green/methyl red indicator mixture; Sulfuric acid solution; Sodium thiosulfate solution; Silver nitrate standard solution; Indicator solution of potassium chromate K2CrO4; Sodium hydroxide; Sodium chloride; Potassium Chloroplatinate standard solution; Absorbent paper; Buffer solutions of known pH; Medium sand; Gravel 1 and Cement CP II E - 32.

## 4.4 PHYSICOCHEMICAL ANALYSES

NBR 15900-1 (2009) is the standard that defines the requirements, evaluations, and analyses of water for concrete mixing. Such parameters are presented in Table 1.

Table 1 - Requirements and test procedures for preliminary inspection of water intended for concrete mixing

| Parameter | Requirement | Test Procedure |
|---|---|---|
| Oils and fats | No more than visible traces | ABNT NBR 15900-3 |
| Detergents | Any foam should disappear in 2 minutes | |
| Color | The color should be compared qualitatively with drinking water and should be light yellow to colorless, except for water classified under 3.3 | |
| Solid Material | Maximum 50 000 mg/L | For water from sources classified in item 3.3, use the methodology in Annex A or ABNT NBR 15900-3. For the other types of water the ABNT NBR 15900-3 Project applies. |
| Odor | Water from sources classified under item 3.3 shall be odorless, except for a faint cement odor and, where slag is present, a faint hydrogen sulfide odor after the addition of hydrochloric acid | ABNT NBR 15900-3 |
| | Water from other sources should be odorless and free of hydrogen sulfide odor, after the addition of hydrochloric acid | |
| Acids | pH ≥ 5 | |
| Organic Matter | The water color should be clearer or equal to that of the standard solution after the addition of NaOH | |

Source: ABNT NBR 15900-1, 2009.

According to the standard, among the most important points to be analyzed in the water to be used in the concrete mixing process are the following chemical properties described in Table 1.

Table 1: Chemical tests

| Determination | Method |
|---|---|
| Chlorides | ABNT NBR 15900-6 |
| Alkalis | ABNT NBR 15900-9 |
| Total Solids | ABNT NBR 15900-3 |
| Hydrogen Potential | ABNT NBR 15900-3 |
| Temperature | ABNT NBR 15900-3 |
| Turbidity | ABNT NBR 15900-3 |

Source: ABNT NBR 15900-1, 2009.

### 4.4.1 Chlorides

The chloride content of the rainwater should not exceed the maximum limits established in Table 2, to avoid possible subsequent pathological manifestations.

Table 2: Maximum chloride content in kneading water

| End Use | Maximum chloride content mg/L | Test procedure |
|---|---|---|
| Prestressed concrete or grout | 500 | ABNT NBR 15900-6 |
| Reinforced concrete | 1000 | |
| Simple concrete (without reinforcement) | 4500 | |

Source: ABNT NBR 15900-1, 2009.

### 4.4.2 Alkalis

If potentially alkali reactive aggregates are used in concrete, the water should be tested for alkali content according to ABNT NBR 15900-9 (2009). The alkaline equivalent of sodium oxide should not exceed 1500 mg/L.

### 4.4.3 Total solids

Total solids are determined by checking the mass of the residue of a water sample after evaporation and drying to constant weight at (103-105) °C. Dissolved solids represent the amount of substances solubilized in water, which can change its physical and chemical properties.

### 4.4.4 Hydrogen potential (pH)

For use in concrete mixing it is recommended to use water with a pH between 6.0 and 8.0 or at most 9.0, without a salty taste. It is generally satisfactory to use potable water for mixing.

### 4.4.5 Temperature

The temperature is one of the factors that affect the reaction kinetics in cement hydration, therefore a temperature of up to 30 ºC must be measured, which is stipulated by the standard.

### 4.4.6 Turbidity

Turbidity represents the amount of light reflected by the suspended particles. Thus, the greater the intensity of scattered light, the greater the turbidity of the sample analyzed.

### 4.4.7 Harmful contamination

Contaminations in concrete mixing water by substances such as sugars, phosphates, nitrates, lead and zinc can alter the setting times and strength of concrete. To approve the water for these contaminants, quantitative tests can be performed to detect sugars, phosphates, nitrates, lead and zinc, respecting the maximum limits established in Table 3. In the absence of these tests or when the limits established in Table 3 are not met, tests for initial and final setting time and compressive strength should be performed on reference samples and in parallel with the water being tested.

Table 3: Requirements for harmful substances

| **Substances** | **Maximum content (mg/L)** |
|---|---|
| Sugars | 100 |
| Phosphates, expressed as $P_2O_5$ | 100 |
| Nitrates, expressed as $NO_3^-$ | 500 |
| Lead, expressed as $Pb^{2+}$ | 100 |
| Zinc, expressed as $Zn^{2+}$ | 100 |

Source: ABNT NBR 15900-1, 2009.

### 4.5 AXIAL COMPRESSION TESTING OF SPECIMENS

After approval of the chemical analyses performed on the rainwater samples collected at locations 1 and 2, location 1 in Bethania and location 2 in João XXIII, specimens were molded using these samples as shown in Figure 9. To evaluate the compressive strength of each sample, tests were performed at 7 and 28 days of curing of the specimens, as determined by NBR 7215 (1996). According to NBR 15900, the average strength, for both ages, should reach at least 90% of the average compressive strength of specimens prepared with drinking water. Table 4 shows the mix used to make the specimens.

Table 4 - Concrete volume mix - fck = 25 Mpa

| **Mix in volume (cement/medium sand/gravel1)** | **Water/cement ratio** |
|---|---|
| 1 : 1,61 : 1,87 | 0,47 |

Source: The authors, 2021.

Figure 10 a) shows the specimens that were made and 10 b) shows the slump test in the cone trunk to determine the consistency and fluidity of concrete. The test was produced according to ABNT NBR NM 67:1996 following all the requirements established.

Figure 10 a) Fabrication of specimens and b) Shakeout test

Source: The authors, 2021.

The ruptures of the specimens were performed in the Solocap brand Electric Hydraulic Press, in the laboratory of the Universidade Federal de Itajubá- UNIFEI - Campus Itabira/MG, with which a partnership was established to perform this process.

## 6 DISCUSSION OF RESULTS

Physical-chemical analyses were performed in order to determine if the water samples collected meet the basic parameters established by the NBR 15900 standard. Table 05 presents the normative reference values and the results of the physical-chemical analyses.

Table 5: Physicochemical parameters tested in the water samples

| **Nature of Parameter** | **Parameter** | **Standard Values** | ***Values Sample 1** | ***Values Sample 2** |
|---|---|---|---|---|
| **Physics** | **Turbidity** | 40,0 uT | 1,44 uT | 3,08 uT |
| | **Total Solids** | 50,000 mg/L | 32,333 mg/L | 36,534 mg/L |
| | **Color** | Amarelo Claro a Incolor | Incolor | Incolor |
| | **Oils and Fats** | Não mais que traços visíveis | Sem traços visíveis | Sem traços visíveis |
| | **Detergent** | Qualquer espuma deve desaparecer em 2 Min | Sem presença de espuma | Sem presença de espuma |
| **Chemicals** | **Hydrogen Potential (pH)** | 6,0 a 9,0 | 6,2 | 7,01 |
| | **Temperature** | 30 °C | 21,1 °C | 27,1 °C |
| | **Chlorides** | 4500,00 mg/L | 2,49922 mg/L | 0,99969 mg/L |
| | **Total Alkalinity** | 1500,00 mg/L de $CaCO_3$ | 40 mg/L de $CaCO_3$ | 40 mg/L de $CaCO_3$ |

Source: The authors, 2021.

The maximum turbidity value established by standard is up to 40 uT. Through the tests the values 1,44 uT and 3,08uT were obtained for samples 1 and 2 respectively, complying with the ABNT NBR 15900-3 standard.For total suspended solids, the value established by the standard is up to 50,000 mg/L. Through tests the values 32.333 mg/L and 36.534 mg/L were obtained for samples 1 and 2 respectively, meeting the ABNT NBR 15900-3 standard.It was observed through visual analysis that the samples have a colorless aspect, being compatible with the NBR 15900-3 that specifies that the water should have a color between light yellow and colorless. Also by visual analysis it was noted that the samples contained no more than visible traces of oils and fats, and in the visual test for the presence of detergents it was observed that the samples did not present foam.

The maximum temperature established by the ABNT NBR 15900-3 standard is 30ºC, and samples 1 and 2 tested had values of 21.1ºC and 27.1ºC, respectively. The pre-determined value for chlorides according to the ABNT NBR 15900-6 maximum is 4500.00mg/L, samples 1 and 2 had 2.49922 mg/L and 0.99969 mg/L, respectively. Finally, the tests for total alkalinity showed a value of 40 mg of CaCO3 both, and the maximum value allowed by ABNT NBR 15900-9 is 1500.00 mg of CaCO3.

## 6.1 RUPTURE OF THE SPECIMENS

The specimens were broken on January 13 and February 3, 2021, after 7 and 28 days of the curing process, respectively. Figure 11 shows some specimens made with the two water samples collected in the city of Itabira-MG, after rupture with 28 days of curing. The bodies were broken using the Electric Hydraulic Press.

Figure 11 - Post-break-in specimens

Source: The authors, 2021.

The concrete compressive strength (fc), which is given in Mpa, must be calculated according to a mathematical expression defined in NBR 5739, being necessary the maximum force reached in the loading and the diameter of the molded specimen. According to the expression shown below:

$$f_c = (F/A)$$

Each specimen is 10 centimeters in diameter and 20 centimeters high.

$$A = \pi \text{ x } r^2$$

Therefore, the Area of the base of the specimen is 78,5 cm². Therefore:

$$f_c = 10^2 \text{ x (Rupture load /78,5)}$$

Table 5 shows the calculated results after the compressive strength test.

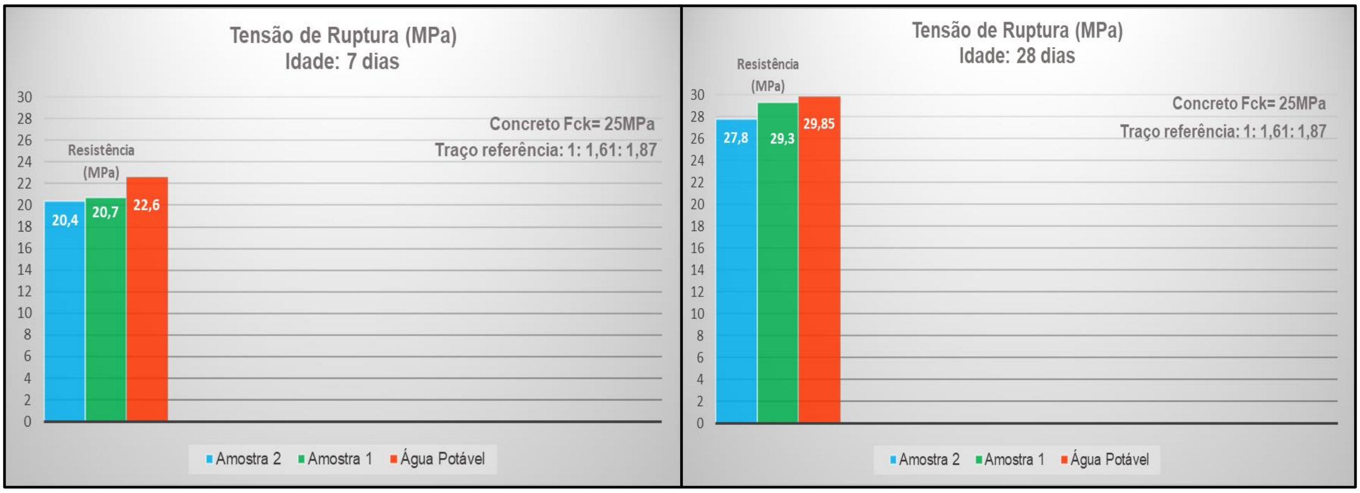
Table 6: Values of the Rupture Stress and Rupture Load obtained by means of the compressive strength test on the following specimens

| Concreto fck = 25 Mpa | | | |
|---|---|---|---|
| **Sample** | **Age** | **Rupture Stress** | **Rupture Load** |
| **Potable Water** | 7 days | 22,6 | 17,741 Kgf/cm² |
| | 28 days | 29,85 | 23,432 Kgf/cm² |
| **Rain Water - 01** | 7 days | 20,7 | 16,249 Kgf/cm² |
| | 28 days | 29,3 | 23,000 Kgf/cm² |
| **Rainwater - 02** | 7 days | 20,4 | 16,014 Kgf/cm² |
| | 28 days | 27,8 | 21,823 Kgf/cm² |

Souce: The authors, 2021.

By observing the results of the rupture of the specimens made using the two samples of rainwater, it was observed that the concrete strength would meet the average strength criterion stipulated by NBR 15900, which states that in 7 and 28 days, it should reach at least 90% of the average compressive strength of specimens prepared with drinking water. The graph shown in Figure 12 shows the strength of specimens made with drinking water compared to those made with rainwater, showing a small variation that falls within the normative limits.

Figure 12: Comparison: Strength x Age of specimens, a) 7-day and b) 28-day



Source: The authors, 2021.

## 7 FINAL CONSIDERATIONS

NBR 15900 specifies the requirements for water to be considered suitable for concrete preparation and describes the sampling procedures, as well as the methods for its evaluation.

After performing the necessary procedures for the use of rainwater samples in the preparation of concrete, the results obtained indicated that both the physical-chemical analysis and the strength tests of the specimens were satisfactory. Thus, it is possible to say that the water meets the requirements determined by the ABNT NBR15900 standard.Given the aforementioned facts it is possible to say that the water samples collected at the collection points in the city of Itabira in the month of November 2019, could be used in the concreting processes. However, it is necessary to mention that previous studies need to be conducted before the use of water for concrete making, since the region of Itabira is characterized by high gas emissions, which could decrease the pH of rainwater, and consequently, affect the strength of concrete. However, the present study shows promise, and its further research could generate considerable advances in the area of civil engineering, more precisely in the so-called sustainable civil construction. In future studies, it is suggested that the Sulfide and Sulfate parameters of the samples be studied, which are provided for in the legislation to ensure the quality of the water used for the purpose of use in reinforced concrete, thus avoiding possible corrosion of the reinforcement.

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