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**Environment**

# Management of the Total Water Footprint and its environmental sustainability in the Camaratuba river sub-basin, located in the state of Paraíba

## Gestão da Pegada Hídrica Total e sua sustentabilidade ambiental na sub-bacia do rio Camaratuba localizada no Estado da Paraíba

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## ABSTRACT

The water footprint study, as an indicator that measures consumption patterns over time and space, requires ongoing research, making it a topic of great relevance for natural resource management, since water is a strategic natural resource of great interest to various sectors of society. Thus the main objective of this research is to determine the total water footprint to analyze the level of scarcity, water appropriation and pollution to highlight environmental sustainability in the Camaratuba River Sub-basin located on the coast of Paraíba, for the reference year 2023. In order to calculate the total water footprint in the geographical region indicated, it was required to determine the blue, green and gray components of the main multiple uses of water in different sectors of the region studied. With regard to methodological aspects, this research can be classified as qualitative-quantitative, exploratory and descriptive, because it includes data collection from master plan, mathematical models, as well as a case study. Based on the analysis of the results obtained, it was possible to identify that the irrigation sector accounts for 74.68% of the total water footprint of the sub-basin studied, while basic sanitation requires 19.28% of the available water, meaning that these sectors represent the largest water footprints when compared to the other sectors analyzed. Taking the results as a whole, it can be inferred that the sub-basin studied, for the year 2023, presents a sustainable environmental pattern when analyzed on an annual time scale, since the level of scarcity is 37.90%, the level of water appropriation is 47.18%, the pollution level is 70.04%, and they did not exceed the critical environmental value of 100.00% established as the standard. However, mapping these levels and their environmental sustainability in the Camaratuba River sub-basin in Paraíba will guide public managers in their decision-making and consequently promote actions to strengthen the National Water Resources Management System, whose main goal is to achieve sustainable governance.

**Keywords:** Consumption; Scarcity; Pollution; Virtual water; Sustainability

## RESUMO

O estudo da pegada hídrica, por ser um indicador que mensura o padrão de consumo no tempo e no espaço, vem demandando ainda pesquisas contínuas, tornando uma temática de grande relevância para gestão dos recursos naturais, já que água é um recurso natural estratégico e de grande interesse de vários setores da sociedade. Assim o objetivo principal desta pesquisa é determinar a pegada hídrica total para analisar o nível de escassez, de apropriação da água e de poluição a fim evidenciar a sustentabilidade ambiental na Sub-bacia do Rio Camaratuba localizada no litoral paraibano, para o ano de 2023. Para calcular a pegada hídrica total na região geográfica indicada foi necessário determinar as componentes azul, verde e cinza dos principais usos múltiplos da água em diferentes setores da região estudada. Com relação aos aspectos metodológicos essa pesquisa pode ser classificada como quali-quantitativa, de caráter exploratório e descritiva, pela razão de contemplar coletas de dados a partir de plano diretor, modelos matemáticos, como também, um estudo de caso. A partir da análise dos resultados obtidos, foi possível identificar que o setor da irrigação possui um consumo hídrico de 74,68% da pegada hídrica total da sub-bacia estudada, enquanto o saneamento básico requer um consumo de 19,28% da água disponível, ou seja, esses setores representam as maiores pegadas hídricas quando comparados com os demais setores analisados. Englobando ainda os resultados, pode-se inferir que a sub-bacia estudada, para o ano de 2023, apresenta padrão ambiental sustentável quando analisada numa escala de tempo anual, já que o nível de escassez é de 37,90%, o nível de apropriação da água é de 47,18%, o nível de poluição é de 70,04% e não ultrapassaram o valor crítico ambiental de 100,00% estabelecido como padrão. Contudo, com esse mapeamento destes níveis e de sua sustentabilidade ambiental na sub-bacia do Rio Camaratuba/PB, norteará o gestor público numa possível tomada de decisão e promoverá consequentemente ações no fortalecimento do Sistema Nacional de Gerenciamento de Recursos Hídricos que tem como meta principal a busca por uma governança sustentável.


**Palavras-chave:** Consumo; Escassez; Poluição; Água virtual; Sustentabilidade

## 1 INTRODUCTION

In recent years, with the increase in population and progress in industrial and food production, there has been a growing demand for natural resources, which has compromised their sustainability, especially water resources. Despite the numerous efforts made on this subject, such as the published works of the Brazil Water Program in 2024, it is still necessary to carry out continuous theoretical and reflective studies on the impacts and harmful effects of the global climate crisis. So the use of indicators is one of the mathematically simplified and effective techniques for mapping the evolution of these problems, and can even help in the search for short-term actions that can alleviate the problem of water scarcity and excessive consumption.

According to Ferreira (2014), there are several factors that affect the reduction of water availability, among which we can mention: natural effects (high evaporation rates resulting from elevated temperatures), human activities, environmental degradation, pollution and demand. This connection of factors highlights the urgency of sustainable approaches to efficient water management. Understanding these elements is essential for developing effective strategies aimed at the preservation and responsible use of this vital resource.

In order to understand the consumption and distribution of fresh water, an indicator called the water footprint was created. This method was developed to quantify water consumption patterns and their sustainability based on human activities in different sectors of society. The water footprint concept was developed by researcher Hoekstra in 2002 (Hoekstra, 2003). According to Hoekstra *et al.* (2011), the water footprint can be defined as a comprehensive indicator that considers the traditional measure of appropriation, as well as levels of scarcity, i.e. an indicator for measuring anthropogenic pressure on water resources, which also considers the water that was used in the production of a consumer good, for example, the amount of water to produce 1 kg of meat, this is known as virtual water.

The Water Footprint is based on the measurement of virtual water proposed by Allan (1998), which considers all the water used in a production process, including both direct and indirect consumption by consumers and producers. As well as revealing the consumption of the water source, this multidimensional approach also covers the volumes of pollution generated and the amount of water needed to dilute it.

Albuquerque (2013) defines the three basic components used to determine the total water footprint, by type of use: the blue footprint, which is defined as the consumptive volumes of freshwater withdrawn from rivers and lakes; the green footprint, which corresponds to the volumes of water resulting from the soil water balance; and the gray footprint, which considers the volumes of effluents (domestic and industrial sewage, among others) from human activities.

Calculating the total water footprint of a river basin is essential, given the complexity of water resource management, as it allows for a detailed analysis of the various elements of the sector. This makes it possible to understand the impact of consumption patterns on the availability of water for individuals and local ecosystems. Estimating the total water footprint is strategic and necessary because it enables a more comprehensive assessment of water impacts, promoting the proper management of natural resources in the long term and raising awareness of sustainable consumption.

Based on this context, any analysis of the levels of water footprint reduction and unsustainability in a river basin directly influences the development of efficient management aimed at minimizing the vulnerability of water systems.

In the study conducted by Vieira *et al.* (2022), the total water footprint of the Taperoá River sub-basin, located in the state of Paraíba, was analyzed and determined, and they concluded that the level of environmental sustainability, on an annual basis, is classified as satisfactory since it did not exceed the critical environmental value.

To this end, the following problem was posed: How can the total water footprint show the levels of scarcity, appropriation and pollution in determining environmental (water) sustainability in the Camaratuba River sub-basin located in the state of Paraíba?

The general aim of this research was to calculate the total water footprint in the year 2023 as an instrument for measuring the level of scarcity, appropriation and pollution in order to understand the magnitude of sustainability in the Camaratuba River sub-basin located in the state of Paraíba.

The scientific contribution of this study lies in the recognition of the total water footprint as a multidimensional indicator to show the water commitment in meeting the demands of the different sectors highlighted in this study.

## 2 THEORETICAL BACKGROUND

Considering that the subject is relatively recent at the academic and scientific level, the following research was used as a basis for the theoretical foundation of this work, starting with the basic work of Hoekstra *et al.* (2011), who prepared a manual with the aim of standardizing the assessment of the water footprint, in which they define the objectives and scopes of the assessment, namely: accounting, sustainability and the formulation of water footprint responses.

Silva *et al.* (2013) reviewed several studies on the accounting of the total water footprint with a view to assessing the environmental impacts of the production of consumer goods and agricultural products, and found that there is a consensus that the water footprint method is capable of monitoring anthropogenic pressures on the environment. Noteworthy is the work of Zhang *et al.* (2011), who conducted a territorial assessment of the water footprint in Beijing, China, showing that the total water footprint can reach 4,498.4x106 m3. year-1, of which 51% of this water footprint comes from virtual water.

According to Higazy *et al.* (2024), they highlight the consolidation of the water footprint concept as an essential tool for water management and discuss the interdependence between countries through virtual water trade, proposing integrations between economic and environmental indicators. This research comprehensively examined Qatar's water consumption patterns, both nationally and internationally, at the sectoral level (agricultural, industrial, and urban sectors) between 2010 and 2021.

Demeke *et al.* (2024) further analyze the spatiotemporal water footprint of cotton production, demonstrating how climatic and technological variations affect water sustainability and water use efficiency. They observed that the unsustainable use of blue water in cotton cultivation increased from 59.3 $km^3$/year to 70.9 $km^3$/year between 1972-1976 and 2014-2018, with 71.1% of unsustainable water traded virtually. The United States, Pakistan, and India accounted for more than 60% of this unsustainable virtual water trade.

Demir and Muratoglu (2025) reviewed the concept of water footprint in the irrigated agriculture sector, integrating volumetric and Life Cycle Assessment (LCA) approaches, identifying key methodological challenges, and distinguishing between water components (green, blue, and gray), considering effective precipitation and standardizing calculations across spatial scales. They noted that the integration of hydrological models to support water footprint methods shows promise for improving accuracy. However, it is important to note that although the water footprint methodology provides valuable information for sustainable water management, its practical application requires careful consideration of regional contexts and limitations.

Vieira *et al.* (2022) conducted an analysis of the total water footprint in the Taperoá River sub-basin, located in the state of Paraíba. Thus, the level of environmental sustainability was determined on an annual and monthly basis, and it was concluded that, in the year analyzed, the sub-basin is sustainable on an annual basis, but on a monthly basis it becomes unsustainable between June and November.

In 2014, the Brazil Water Program (PAB) published a study on the sustainability of the water footprint in the seven river basins covered by the program. In the calculation, recommendations were made for future research that proposes re-evaluating the calculation of the water footprint and its sustainability, as new data is collected and made available to assess the possible water scarcity scenarios that could occur in the river basins analyzed.

However, in order to calculate the total water footprint in a river basin, it is necessary to consider the sum of the estimates of all the blue, green and gray components of the main water users in the different sectors of society. In this case, the sectors that will be considered in this research are: livestock, water supply, agriculture and sanitation. As shown in Chart 1, which lists the main formulas suggested by the PAB (Água Brasil Program, 2014) for determining the water footprint in a given river basin.

Chart 1 – Possible equations for calculating the total water Footprint

| Water Users | Supply | Agriculture | Livestock | Sanitation |
|---|---|---|---|---|
| Components of the Water Footprint (WF) | $PH_{verde} = \frac{DCHverde}{Y}$ | $PH_{verde} = \frac{DCHverde}{Y}$ | NA | NA |
| | $PH_{azul} = \frac{CAazul}{Y}$ | $PH_{azul} = \frac{CAazul}{Y}$ | $PH_{azul} = \frac{CAazul}{Y}$ | NA |
| | $PH_{cinza} = \frac{\left(\frac{L}{Cmax\text{-}Cnat}\right)}{Y}$ | $PH_{cinza} = \frac{\left(\frac{L}{Cmax\text{-}Cnat}\right)}{Y}$ | $PH_{cinza} = \frac{\left(\frac{L}{Cmax\text{-}Cnat}\right)}{Y}$ | $PH_{cinza} = \frac{\left(\frac{L}{Cmax\text{-}Cnat}\right)}{Y}$ |
| Total Water Footprint (TWF) | $\sum(PH_{verde}, PH_{azul}, PH_{cinza})$ | $\sum(PH_{verde}, PH_{azul}, PH_{cinza})$ | $\sum(PH_{azul}, PH_{cinza})$ | $PH_{cinza}$ |
| Sustainability Analysis | $EA_{verde} = \frac{\sum PHverde(x,t)}{DAverde(x,t)}$ | $EA_{verde} = \frac{\sum PHverde(x,t)}{DAverde(x,t)}$ | NA | NA |
| | $EA_{azul} = \frac{\sum PHazul\,(x,t)}{DAazul\,(x,t)}$ | $EA_{azul} = \frac{\sum PHazul\,(x,t)}{DAazul\,(x,t)}$ | $EA_{azul} = \frac{\sum PHazul(x,t)}{DAazul(x,t)}$ | NA |
| | $NPA(x,t) = \frac{\sum PHcinza(x,t)}{Qatual(x,t)}$ | $NPA(x,t) = \frac{\sum PHcinza(x,t)}{Qatual(x,t)}$ | $NPA(x,t) = \frac{\sum PHcinza(x,t)}{Qatual(x,t)}$ | $NPA(x,t) = \frac{\sum PHcinza(x,t)}{Qatual(x,t)}$ |
| Water Footprint of the Basin or Sub-Basin (PHB) | $PHB = PHT_{abastecimento} + PHT_{pecuária} + PHT_{agricultura} + PHT_{saneamento}$ | | | |

Legend: DHC= Crop water demand, Y= Productivity, CA= Water consumption, L= Pollution load, Cmax= Maximum cafterntration acceptable under legislation, Cnat= Pollutant cafterntration under natural conditions, EA= Water scarcity, DA= Water availability, NPA= Water pollution level, Qatual= Current monthly flow, NA= Not applicable

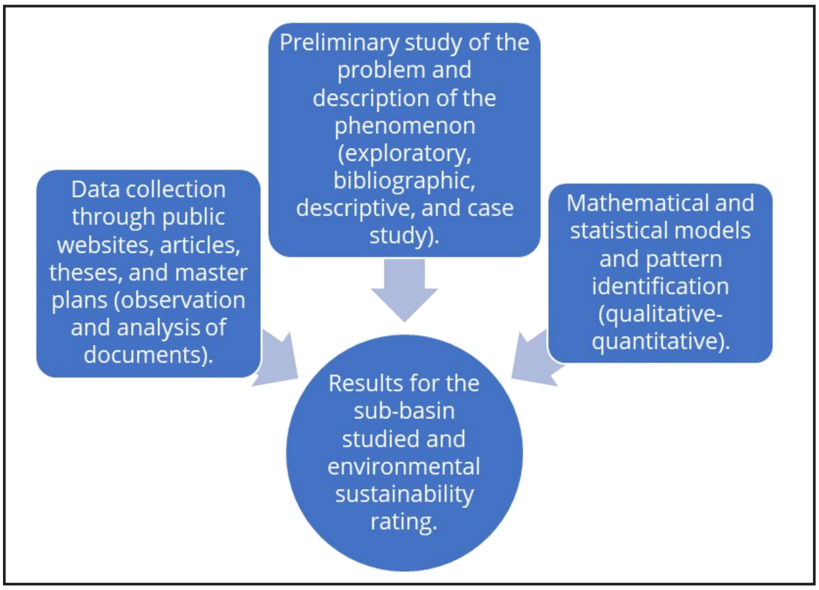
Source: Adapted from Programa Água Brasil (PAB) (2014). Water Footprint of River Basins. Initiative of the National Water Agency, Banco do Brasil Foundation and WWF-Brazil

## 3 METHODOLOGY

The research was carried out using the deductive method. This option is justified because the chosen method allows the researcher to carry out a comprehensive analysis up to explaining specific points. The material documented and collected (water resources master plan for the sub-basin studied), as well as the respective analyses of the results, will lead to knowledge of the magnitude of environmental (water) sustainability in the geographical region studied.

According to Mezzaroba and Monteiro (2004, p. 65), the deductive method is based on considering “true and unquestionable” arguments, and these arguments are defined in such a way that the conclusion can be developed formally. The term ‘formal’ is used because the results obtained through the method come through strict logical operations applied to the basic propositions. In essence, the deductive method involves a systematic application of logic to arrive at bases that are derived from premises. The flowchart (Figure 1) below highlights the main research methods and techniques used to determine environmental sustainability in the sub-basin studied.

Figure 1 – Research stages



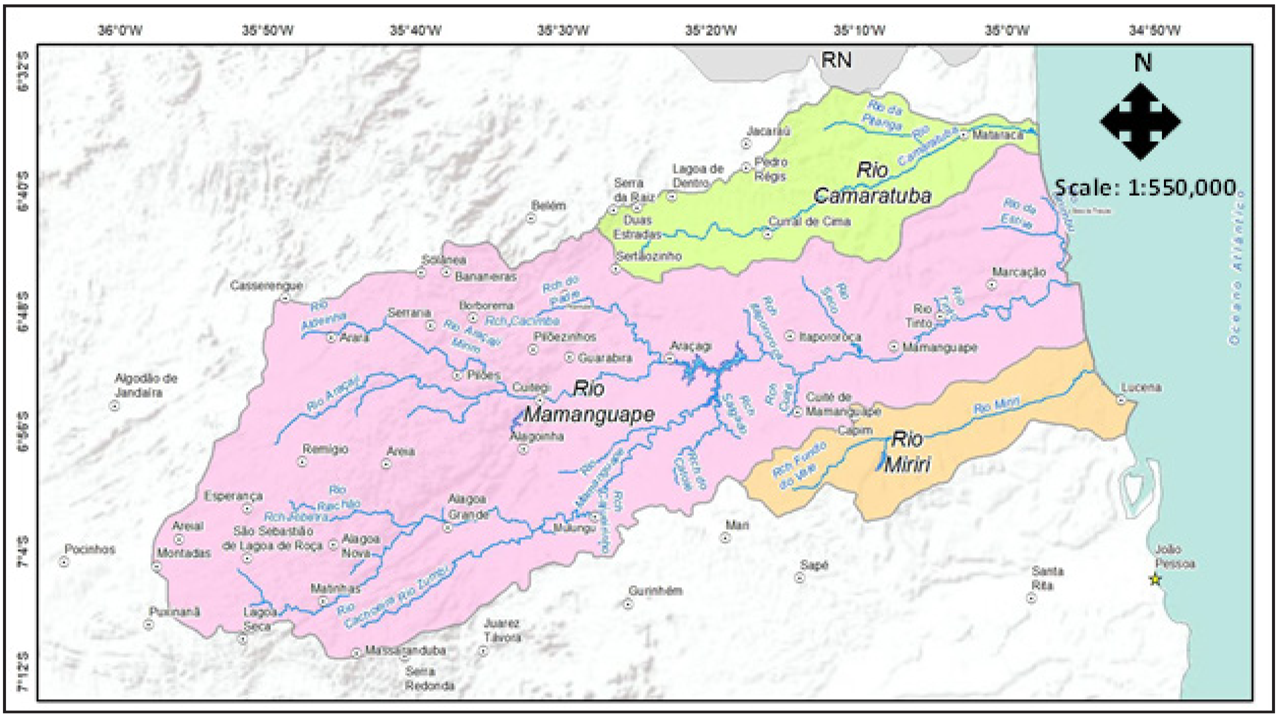

Source: Adapted own authorship (2025)

### 3.1 Characterization of the area studied

The Camaratuba River sub-basin (Figure 2) is located in the far east of the state of Paraíba, covering an area of around 635.6 km², and is situated at Geographical Coordinates Latitudes 6º32’49” and 6º46’2” South and Longitudes 34º57’49” and 35º27’59” West of Greenwich. The study area belongs to three micro-regions of the state of Paraíba, comprising Agreste da Borborema, Brejo, and Piemonte da Borborema. Its main river is the Camaratuba River, and it is bordered to the south by the Mamanguape

River sub-basin, to the east by the Atlantic Ocean, to the west by the Curimataú River sub-basin, and to the north by the Guajú and Curimataú River sub-basins.

Figure 2 – Camaratuba River Sub-basin/PB




Legend: Camaratuba River sub-basin/PB, Mamanguape River sub-basin/PB, and Miriri River sub-basin
Source: AESA (2021). Includes scale and north orientation

The relief has altitudes of no more than 200 m. The climate is classified as Aw'i hot and humid, with fall and winter rains according to the Köeppen classification (AESA, 2022). In order to carry out the calculations, the percentages of the area of the cities that are geographically located in the sub-basin and had water withdrawal permits in force in 2023 were taken into account. Therefore, the following cities were selected as the basis for the calculation: Baía da Traição, Curral de Cima, Duas Estradas, Jacaraú, Lagoa de Dentro, Mamanguape, Mataraca, Pedro Régis, Rio Tinto, Serra da Raíz and Sertãozinho. With regard to the region's economy, it stands out for its production of sugarcane. According to the IBGE (2023), the population of Mataraca, the main municipality, is 7,407 inhabitants, while that of Baía da Traição is 8,012 inhabitants, including indigenous and non-indigenous people.

### 3.2 Data collection

The instruments used to collect data to understand and determine the total water footprint and its sustainability are: articles, books, websites, documents such as the Paraíba State Water Resources Plan (AESA, 2021) and the Coastal Basin Master Plan (AESA, 2022), estimates provided by the Brazilian Institute of Geography and Statistics (IBGE, 2023), among others. Initially, a bibliographic and exploratory research was carried out to understand the concepts of water footprint and collect the necessary data related to quantitative and qualitative variables (hydroclimatic, types of crops, per capita consumption, population, cisterns, water sources, sanitary standards, number of animals per species, type of livestock feed, among others), being the capacity of the cisterns in each city was obtained from the website of the Brazilian Semiarid Articulation (ASA Brasil, 2023) and the main mathematical methods available, as shown in Table 1, which allow the level of environmental sustainability of the Camaratuba-PB hydrographic sub-basin to be determined through the indicators of scarcity, water appropriation, and pollution.

It is important to note that in order to project the operating scenario data for the year 2023, the moving average method was used to estimate the population of each municipality belonging to the sub-basin studied. In addition, data were collected from the Brazilian Institute of Geography and Statistics (IBGE, 2023) to estimate the population and types of crops per cultivated area in each municipality, from the National Health Information System (SNIS, 2023) to measure the effluent load generated in the sub-basin studied, and from the Water and Sewage Company of Paraíba (CAGEPA, 2023) to provide consumption data.

Specifically, the following factors were taken into account: the population in 2023, the per capita quota (liters/inhabitant/day), the average sewage flow (m³/year), the average standard sewage concentration (kg/m³), the pollutant load of untreated sewage (kg/year), the average natural concentration (kg/m³), and the maximum permitted concentration (kg/m³) were taken into account. Based on these variables, it is possible to determine the volume of untreated sewage discharged into rivers. It was also necessary to use the municipality's per capita water consumption and the percentage of the population that does not have access to a sewage system. With this data, it was possible to obtain the gray water footprint corresponding to the sanitation sector of each city. In addition to the aforementioned data, the average per capita consumption per individual (IN022) and the distribution loss index (IN049) were also used, which are fundamental data for determining the water footprint for human consumption.

It is important to note that average per capita consumption represents the daily average of water used per person to meet their domestic, commercial, public and industrial demands. In addition, the distribution loss index was taken into account, reflecting the amount of water lost along the distribution network before it reaches consumers in the cities supplied. This process also involved comparisons based on the technical coefficient by population group, allowing a comparative analysis with the cities selected in the Camaratuba River sub-basin and projecting the population for the year 2023.

To calculate the livestock sector, data were collected on the number of cattle per municipality, the average weight of each species, and the average consumption of water and silage. Based on this information, it was possible to calculate the blue water footprint related to animal desiccation and also the green water footprint, which refers to the amount planted to meet the consumption demands for feeding the herds.

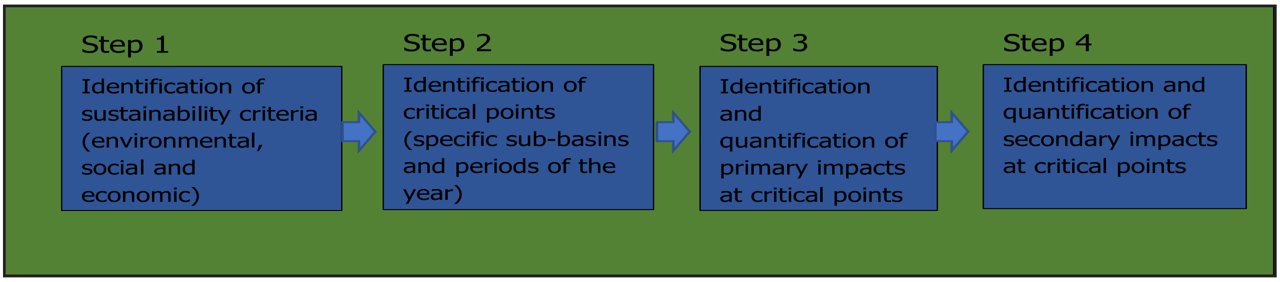
Natural flows were estimated using the SMap.Net Rainfall-Flow model, based on the drainage area of 42% of the total area of the sub-basin studied, the average monthly precipitation for the year 2023 (mm), the average monthly evapotranspiration (mm), with an average activated base flow of 0.137 m³/s and a field capacity of 41.30% (AESA, 2021).

### 3.3 Analysis and determination of environmental sustainability

In order to understand the magnitude of environmental sustainability based on the total water footprint in the Camaratuba/PB river sub-basin, it was necessary to follow four phases, the first of which began by defining the objective and scope of the assessment. The study area was considered to be the Camaratuba River sub-basin, and the total water footprint was determined considering a scenario for the year 2023, based on multiple water users for the supply, livestock, irrigation and basic sanitation sectors. The second phase is the accounting of the water footprint. The cities that the sub-basin studied supplies and those that generate domestic effluents were considered. Based on these cities, data was collected and the different components of the water footprint (blue, green and gray) were quantified, using the methodologies proposed by Hoekstra et al. (2011), cited in Table 1 and available in the Water Footprint Manual.

Once the accounting phase is over, the third stage is the assessment of sustainability from an environmental perspective. Sustainability in a river basin will be quantified considering the primary and secondary impacts based on the definition of its critical points, as shown in Figure 3. The levels of scarcity, water appropriation and pollution were quantified, culminating in knowledge of the magnitude of environmental sustainability.

Figure 3 – Steps to understanding the state of environmental sustainability in a geographical region




Source: Adapted from Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, M. M. (2011). Water Footprint Assessment Handbook: Setting the Global Standard. Portuguese translation

Finally, after feedback from the analysis, it was possible to map the sustainability situation from the total water footprint in the sub-basin analyzed, considering the environmental aspect in the year 2023. To implement all data, statistical/mathematical models, and prepare tables and graphs, the Excel spreadsheet program was used.

## 4 RESULTS AND DISCUSSIONS

After collecting data from the cities that make up the Camaratuba River sub-basin in Paraíba, defining the variables and their relationships with the mathematical models proposed below, the results are presented by sector for the 2023 operating scenario.

### 4.1 Estimating the water footprint of urban and rural supply

In Table 1, the Blue Water Footprint (BWF) varied significantly between municipalities, mainly reflecting population size, even though water supply systems were inefficient due to distribution losses. It can be observed that the city of Mamanguape, with the largest population (23,942 inhabitants), has a disproportionately high BWF (1.154 million m³/year), indicating that its higher per capita consumption (95 L/inhabitant/day) and high loss rate (39%) are critical factors.

Table 1 – Water footprint of human supply by municipality

| Municipality | Percentage of the municipality's area | Projected population | (In022) - Cons. average per capita water consumption (liter/ inhab.day) | (In049) - Distribution losses index (%) | Blue water demand (m³/year) |
|---|---|---|---|---|---|
| Baía da Traição | (13.1%) | 1,257 | 87.00 | 0.36 | 54,286 |
| Curral de Cima | (71.4%) | 3,635 | 87.00 | 0.36 | 156,984 |
| Duas Estradas | (96.0% ) | 3,314 | 87.00 | 0.37 | 144,173 |
| Jacaraú | (40.5%) | 5,573 | 87.00 | 0.36 | 240,680 |
| Lagoa de Dentro | (65.9%) | 5,050 | 87.00 | 0.36 | 218,093 |
| Mamanguape | (52.1%) | 23,942 | 95.00 | 0.39 | 1,153,963 |
| Mataraca | (21.6%) | 2,026 | 87.00 | 0.36 | 87,496 |
| Pedro Régis | (78.2%) | 5,221 | 87.00 | 0.36 | 225,478 |
| Rio Tinto | (14.3%) | 3,384 | 87.00 | 0.36 | 146,144 |
| Serra da Raíz | (42.6%) | 1,263 | 87.00 | 0.37 | 54,946 |
| Sertãozinho | (75.6% ) | 4,066 | 87.00 | 0.36 | 175,598 |

Note: Master Plan for the Coastal Basins (AESA, 2022)
Source: Research data (2024)

Analyzing Table 2 below, the water stored in cisterns (9,116 m³/year) is insignificant when compared to the Blue Water Footprint (BWF) of the municipalities, which totals more than 2.6 million m³/year. Almost all of the available water (98%) is concentrated in 16m³ cisterns, with the municipalities of Duas Estradas, Jacaraú, and Lagoa de Dentro being the largest consumers. It is important to note that consumption via the supply system is the dominant pressure on water resources, while the cistern program is a crucial social technology for water security in the rural area of the sub-basin studied, even though it represents a minimal fraction of total blue water use.

Table 2 – Water footprint from social technologies (cisterns)

| Municipality | Water demand cisterns 16m³ | | Cistern water demand 52m³ | |
|---|---|---|---|---|
| | Quantity per municipality | Blue water demand (m³/year) | Quantity per municipality | Blue water demand (m³/year) |
| Baía da Traição | 0 | 0 | 0 | 0 |
| Curral de Cima | 4 | 64 | 0 | 0 |
| Duas Estradas | 115 | 1840 | 1 | 52 |
| Jacaraú | 133 | 2128 | 0 | 0 |
| Lagoa de Dentro | 150 | 2400 | 1 | 52 |
| Mamanguape | 48 | 768 | 0 | 0 |
| Mataraca | 0 | 0 | 0 | 0 |
| Pedro Régis | 2 | 32 | 0 | 0 |
| Rio Tinto | 1 | 16 | 0 | 0 |
| Serra da Raíz | 70 | 1120 | 1 | 52 |
| Sertãozinho | 37 | 592 | 0 | 0 |
| Total | 560 | 8960 | 3 | 156 |

Note: Articulation of the Brazilian Semi-Arid (ASA, 2023)
Source: Research data (2024)

Thus, adding up the blue water values for the municipalities in Tables 1 and 2, we obtain a total water footprint for the supply sector of 2.67 million m³/year for the sub-basin studied.

## 4.2 Estimating the water footprint in sanitation

Looking at Table 3, the Gray Water Footprint (GWF) shows extremely high values, exceeding the Blue Water Footprint (BWF) of each municipality by dozens of times, indicating the volume of water needed to dilute the pollutant load of untreated domestic sewage. It is worth noting that the municipality of Mamanguape, with the largest population, has the highest GWF (32.6 million m³/year), confirming the strong correlation between population size and domestic wastewater generation.

Table 3 – Sanitation's water footprint

| Municipality | Percentage of the municipality's area | Projected population (2023) | Grey water demand (m³/year) |
|---|---|---|---|
| Baía da Traição | (13.1%) | 1,257 | 1,568,193 |
| Curral de Cima | (71.4%) | 3,635 | 4,534,910 |
| Duas Estradas | (96.0% ) | 3,314 | 4,134,441 |
| Jacaraú | (40.5%) | 5,573 | 6,952,697 |
| Lagoa de Dentro | (65,9%) | 5,050 | 6,300,219 |
| Mamanguape | (52.1%) | 23,942 | 32,615,875 |
| Mataraca | (21.6%) | 2,026 | 2,527,573 |
| Pedro Régis | (78.2%) | 5,221 | 6,513,553 |
| Rio Tinto | (14,3%) | 3,384 | 4,221,770 |
| Serra da Raíz | (42.6%) | 1,263 | 1,575,678 |
| Sertãozinho | (75.6% ) | 4,066 | 5,072,612 |

Source: Research data (2024)

To this end, the Gray Water Footprint (GWF) of the region studied reaches a figure of 77.02 million m³/year, which is the equivalent volume needed to dilute domestic effluent pollution, which is directly influenced by the size of the population of each municipality, this being the predominant factor. The result is mainly driven by the city of Mamanguape, which alone accounts for more than 40% of the total, due to its significantly larger population. The underlying factor that explains the magnitude of these values is the absence or inefficiency of sewage treatment, which means that the organic load generated by the population needs to be diluted in a huge volume of water available in water bodies.

### 4.3 Estimating the water footprint of irrigated agriculture

To determine the water footprint for the irrigated agriculture sector, it is important to highlight that two components were considered. The first component is the green water footprint, which considers the absorption of water from regional crops available in the soil due to effective precipitation, and the second is the blue water footprint, which deals with the water needed to be withdrawn from a given source for the irrigation of these crops. Table 4 below shows the agricultural planning with the respective crop coefficients for the most prevalent permanent and temporary crops in the region. The water consumption of sugarcane stands out, as it is higher when compared to the others.

Table 4 – Crop cultivation coefficient

| Cultures | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mango | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Bay coconut | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| Guava | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Banana | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Peanuts (in shell) | 0 | 0.65 | 0.68 | 0.75 | 0.58 | 0 | 0 | 0.65 | 0.68 | 0.75 | 0.58 | 0 |
| Sweet potatoes | 0 | 0.5 | 0.8 | 1.2 | 0.75 | 0 | 0 | 0.5 | 0.8 | 1.2 | 0.75 | 0 |
| Cassava | 0 | 0.4 | 0.98 | 0.69 | 0 | 0 | 0 | 0.4 | 0.98 | 0.69 | 0 | 0 |
| Corn | 0 | 0.7 | 1.1 | 0.95 | 0.95 | 0 | 0 | 0.7 | 1.1 | 0.95 | 0.95 | 0 |
| Sugarcane | 0 | 0.4 | 1.25 | 1.25 | 0.75 | 0 | 0 | 0.4 | 1.25 | 1.25 | 0.75 | 0 |
| Beans | 0.7 | 1.1 | 0.9 | 0 | 0 | 0 | 0 | 0.7 | 1.1 | 0.9 | 0 | 0 |
| Bean | 0.7 | 1.1 | 0.9 | 0 | 0 | 0 | 0 | 0.7 | 1.1 | 0.9 | 0 | 0 |
| Watermelon | 0 | 0 | 0 | 0.67 | 0.91 | 0.98 | 0.82 | 0 | 0.67 | 0.91 | 0.98 | 0.82 |
| Orange | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| Avocado | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Papaya | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Passion fruit | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Lemon | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Cashew | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |

Note: Gomes, H. P. (1999). *Engenharia de irrigação: hidráulica dos sistemas pressurizados, aspersão e gotejamento.3. ed. Campina Grande: UFPB, 412 p
Source: Research data (2024)

The average monthly evaporation data was collected from the National Institute of Meteorology (2020) for the climatological station located in the state capital João Pessoa/PB, where coefficients were used for the monthly analysis, as shown in Table 5. The highest evaporimetric rates correspond to the October-December and January-March quarters, respectively. Based on evaporation and precipitation data, clear water variability can be identified in the geographical region studied, with a period of marked deficit. It should be noted that from August to December, evaporation consistently exceeds precipitation, creating severe climatic water stress, which is particularly critical between October and December.

Table 5 – Average monthly evaporation at the observation post in the city of João Pessoa/PB (mm) and Average monthly rainfall observed at the Camaratuba/PB station (mm)

| **Average monthly evaporation (mm)** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Out | Nov | Dec |
| 138.9 | 124.7 | 124.6 | 104.5 | 97.2 | 84.4 | 99.3 | 120.8 | 128.8 | 153.8 | 148.8 | 149.4 |
| **Average monthly precipitation (mm)** | | | | | | | | | | | |
| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Out | Nov | Dec |
| 104.2 | 133.6 | 210.6 | 231 | 249.4 | 223.6 | 249 | 121 | 91.6 | 35 | 37 | 42 |

Note: Executive Agency for Water Management in the State of Paraíba (AESA, 2023)
Source: Research data (2024)

On the other hand, from March to July, rainfall is significantly higher than evaporation, characterizing a well-defined wet season. This pronounced seasonal pattern intensifies pressure on surface and groundwater resources during the long dry period, exacerbating the challenges posed by the high blue and green water footprints identified in previous analyses. Although rainfall volume is well defined, water availability can still be considered a limiting and seasonal factor in this region.

Once evapotranspiration was determined for each crop, the volume of green water for the agricultural sector was then calculated based on actual precipitation. However, as the green water footprint is the volume of rainwater stored in the soil, the area planted with each crop during 2023 was taken into account. Therefore, the results of the green water footprint for the various crops considered in the agricultural plan can be seen in Table 6 below:

Table 6 – Irrigation's green water footprint

| Cultures | Total (m/ year) | Planted area (m²) - estimated for the year 2023 - hydrological year 2022/2023 | Green water demand (m³/year) (2023) |
|---|---|---|---|
| Mango | 0.71 | 1,130,000 | 798,594 |
| Bay coconut | 0.68 | 9,820,000 | 6,689,580 |
| Guava | 0.66 | 200,000 | 131,144 |
| Banana | 0.81 | 2,050,000 | 1,657,876 |
| Peanuts (in shell) | 0.44 | 10,000 | 4,438 |
| Sweet potatoes | 0.49 | 3,070,000 | 1,511,085 |
| Cassava | 0.35 | 11,170,000 | 3,928,411 |
| Corn | 0.55 | 3,630,000 | 2,010,421 |
| Sugarcane | 0.52 | 273,580,000 | 141,354,682 |
| Beans | 0.38 | 7,120,000 | 2,730,235 |
| Bean | 0.38 | 2,240,000 | 858,950 |
| Watermelon | 0.41 | 360,000 | 147,343 |
| Orange | 0.68 | 600,000 | 408,732 |
| Avocado | 0.73 | 40,000 | 29,289 |
| Papaya | 0.73 | 2470000 | 1,808,583 |
| Passion fruit | 0.71 | 520000 | 367,494 |
| Lemon | 0.66 | 90000 | 59,015 |
| Cashew nuts | 0.60 | 3940000 | 2,354,780 |

Source: Research data (2024)

Considering Table 6, it is important to highlight that the Green Water Footprint (GWF) in the irrigated agriculture sector in the region is dominated by sugarcane cultivation, which alone accounts for 141.35 million m³/year, a value higher than other crops due to its vast planted area. In second place, but with a green water footprint almost 20 times smaller, is coconut (6.69 million m³/year), followed by cassava (3.93 million m³/year). Therefore, considering the crops in the region's agricultural planning, the Green Water Footprint (GWF) is approximately 164.8 million m³/year. This volume represents the rain water consumed by crops, showing that the agricultural sector is the largest consumer of water resources in the region, exceeding the Gray Water Footprint (GWF) by more than twice.

Looking now at Table 7, it is appropriate to analyze the results determined for the blue water footprint for irrigated agriculture.

Table 7 – Blue water footprint of irrigation considering the crops grown

| Cultures | Total (m/year) | Planted area (m²) - estimated for the year 2023 - hydrological year 2022/2023 | Blue water demand (m³/ year) (2023) |
|---|---|---|---|
| Mango | 0.47 | 1,130,000 | 534,987 |
| Bay coconut | 0.43 | 9,820,000 | 4,175,268 |
| Guava | 0.38 | 200,000 | 75,384 |
| Banana | 0.67 | 2,050,000 | 1,366,284 |
| Peanuts (in shell) | 0.22 | 10,000 | 2,245 |
| Sweet potatoes | 0.33 | 3,070,000 | 1,006,100 |
| Cassava | 0.17 | 11,170,000 | 1,933,147 |
| Corn | 0.38 | 3,630,000 | 1,364,299 |
| Sugarcane | 0.41 | 273,580,000 | 110,974,991 |
| Beans | 0.33 | 7,120,000 | 2,333,509 |
| Bean | 0.33 | 2,240,000 | 734,138 |
| Watermelon | 0.41 | 360,000 | 146,846 |
| Orange | 0.43 | 600,000 | 255,108 |
| Avocado | 0.52 | 40,000 | 20,868 |
| Papaya | 0.52 | 2,470,000 | 1,288,599 |
| Passion fruit | 0.47 | 520,000 | 246,189 |
| Lemon | 0.38 | 90,000 | 33,923 |
| Cashew nuts | 0.29 | 3,940,000 | 1,132,592 |

Source: Research data (2024)

Therefore, based on Table 7, the blue water required to carry out irrigated agriculture is approximately 127 million m³/year, highlighting a critical and significant pressure on the available water sources in the region studied. Sugarcane cultivation is particularly noteworthy, as it is absolutely predominant, accounting for 87% (111 million m³/year) of the total water required. This represents a volume 48 times greater than the blue water required by the urban sector, consequently highlighting a need for water security for the development of the sugarcane agroindustry, especially during periods of low rainfall. Coconut, bean, and banana crops require considerable amounts of water, but these demands are insignificant when compared to the large area of land used for sugarcane monoculture.

Table 8 shows the blue water available from underground dams by municipality, and it was observed that only the city of Mataraca has this type of social technology.

Table 8 – Underground dam's blue water footprint

| Municipality | Quantity per municipality | Blue water demand (m³/year) - 2023 |
|---|---|---|
| Baía da Traição | 0 | 0 |
| Curral de Cima | 0 | 0 |
| Duas Estradas | 0 | 0 |
| Jacaraú | 0 | 0 |
| Lagoa de Dentro | 0 | 0 |
| Mamanguape | 0 | 0 |
| Mataraca | 1 | 1000 |
| Pedro Régis | 0 | 0 |
| Rio Tinto | 0 | 0 |
| Serra da Raíz | 0 | 0 |
| Sertãozinho | 0 | 0 |

Source: Research data (2024)

To this end, considering Tables 7 and 8, the result of the blue footprint used in irrigated agriculture is 127,625,477.16 m³/year.

## 4.4 Estimating the water footprint of livestock farming

To calculate the water footprint of livestock farming, both green and blue components were considered. It is important to remember that the green footprint in this sector of livestock farming takes into account the water consumed by animals to produce food, while the blue footprint is based on water consumed by herds in the region studied. Table 9 shows the calculation of the blue footprint based on the number of heads per category.

Table 9 – Estimating the blue footprint of livestock farming by category

| Categories | Nº of heads (und) | Average weight per animal (kg) | Average average water consumption (l/day) | Blue water demand (m³/year) - 2023 |
|---|---|---|---|---|
| Cattle | 38,699 | 200 | 50 | 706,257 |
| Horses | 2,334 | 380 | 40 | 34,076 |
| Pigs | 4,702 | 161.59 | 10 | 17,162 |
| Goats | 3,425 | 50 | 8 | 10,001 |
| Sheep | 3,434 | 60 | 8 | 10,027 |
| Chickens | 1,066,881 | 2.53 | 0.2 | 77,882 |

Note: Adapted from the municipal livestock survey (IBGE, 2023)
Source: Research data (2024)

In the analysis of Table 9, the blue footprint in the livestock sector shows that the cattle category is the largest individual consumer, with a consumption of 706,257 m³/year, representing more than 80% of the sector's total. This is due to the predominance of a large herd (38,699 head) with a high daily water consumption of approximately 50 liters/day per animal. Next, but with a demand 20 times lower, are poultry, which consume an average of 0.2 liters/day, totaling a volume of 77,882 m³/year. This collective impact can be considered significant due to the size of the herd, which exceeds 1 million head, despite low individual consumption. Other herds, such as horses, pigs, sheep, and goats, have marginal requirements that are lower when compared to the overall scenario.

Next, Table 10 contains information on the trench barrens, which is a social technology designed for animal watering.

Table – 10 Blue water footprint of Barreiro Trincheiro

| **Municipality** | **Quantity per municipality** | **Blue water demand (m³/year)** |
|---|---|---|
| Baía da Traição | 2 | 1,000 |
| Curral de Cima | 0 | 0 |
| Two Roads | 12 | 6,000 |
| Jacaraú | 16 | 8,000 |
| Lagoa de Dentro | 21 | 10,500 |
| Mamanguape | 2 | 1,000 |
| Mataraca | 9 | 4,500 |
| Pedro Régis | 0 | 0 |
| Rio Tinto | 1 | 500 |
| Serra da Raíz | 4 | 2,000 |
| Sertãozinho | 1 | 500 |

Source: Research data (2024)

After adding up the categories considered and the social technology (barreiro trincheiro), the total blue water footprint of livestock farming is 889,406.04 m³/year.

Next, the estimate for calculating the green water footprint will be presented when considering total water consumption in silage production per herd. The bases for silage considered in this study were grass and corn, see Table 11.

Table 11 – Average consumption of livestock by type of silage

| Categories | Average silage consumption (kg/head/day) | Type of silage |
|---|---|---|
| Cattle | 15 | CAPIM |
| Horses | 7 | CAPIM |
| Pigs | 3.2 | CORN |
| Goats | 2.94 | CORN |
| Sheep | 2.92 | CORN |
| Chickens | 0.13 | CORN |

Note: Adapted from the Municipal Livestock Survey (IBGE-SIDRA, 2023)
Source: Research data (2024)

To calculate the volume of water in m³/year for the production of food for the livestock sector, the production of silage, animal consumption, average productivity per silage (ton/ha), total animal consumption in the two categories (ton/year) were taken into account to finally determine the area to be planted (ha). It is important to note that these calculations also took into account the average monthly evaporation of both the grass and the corn, the crop coefficient and the actual evaporation. With the projected area to be planted to feed the animals in the region studied, the green water footprint, according to Table 12, is 20,243,403 m³/year.

Table 12 – Average consumption of livestock by type of silage

| Type of silage | Cons. Of silage (ton/year) | Average productivity (ton/ha) | Area to be planted (m²/year) | Total evapotranspiration (etverde) (m/year) | Green water demand (m³/year) - 2023 |
|---|---|---|---|---|---|
| CAPIM | 217,840 | 70 | 31,120,056 | 0.4 | 12,448,023 |
| CORN | 63,451 | 35 | 18,128,790 | 0.43 | 7,795,380 |

Note: Gomes, H. P. (1999). *Engenharia de irrigação: hidráulica dos sistemas pressurizados, aspersão e gotejamento.* 3. ed. Campina Grande: UFPB, 412 p
Source: Research data (2024)

### 4.5 Estimating the total water footprint in the Camaratuba River sub-basin/PB

By calculating the water footprint for the different components of the sectors considered in this research, this allowed the authors to obtain the value of the sub-basin's total water footprint in 2023. To this end, the estimates of the blue, green and gray components of the following sectors were added together: supply, sanitation, agriculture and livestock. Table 13 shows a summary of the values obtained for each sector of each component of the water footprint, as well as the total water footprint for the Camaratuba River sub-basin, which is estimated at 394,293,417.06 m³/year.

Table 13 – Total water footprint of the Camaratuba River sub-basin/PB

| **Water sectors considered** | **Ph blue (m³/year)** | **Ph green (m³/year)** | **Ph grey (m³/year)** | **Total by sector (m³/year)** |
|---|---|---|---|---|
| Human supply | 2,666,957.51 | | | 2,666,957.51 |
| Sanitation | | | 76,017,521.18 | 76,017,521.18 |
| Irrigated agriculture | 127,625,477.16 | 166,850,652.00 | | 294,476,130.16 |
| Livestock | 889,406.04 | 20,243,403.00 | | 21,132,808.21 |
| Total water footprint by component | 131,181,840.72 | 187,094,055.00 | 76,017,521.18 | |
| Water footprint of the camaratuba river sub-basin (2023) | | | | 394,293,417.06 |

Source: Research data (2024)

Therefore, evaluating Table 13 further, it can be observed that the irrigated agriculture sector dominates approximately 75% of the Total Water Footprint (TWF) of the Camaratuba River sub-basin, while the sanitation sector alone accounts for approximately 19% of the total pressure on water resources in the region. The blue footprint of agriculture (127.6 million m³/year) is almost 50 times greater than human supply (2.6 million m³/year), highlighting critical competition for fresh water. The results indicate that the environmental sustainability of the sub-basin depends fundamentally on the management of water use in agriculture and sewage treatment.

It is clear that numerous factors have influenced the Total Water Footprint of the Camaratuba River sub-basin in Paraíba, mainly due to the cultivation of sugarcane monoculture, which requires large volumes of blue water (irrigation) even with the contribution of green water (rain), showing that the irrigated agriculture sector is the largest consumer. Another factor is the lack of effluent treatment systems that could receive the high pollutant loads generated in the geographical region studied, which also requires large volumes to dilute these domestic pollutants. In addition to these factors, we can also highlight the climatic seasonality, with a long dry season and low natural flows available in the springs, and also the livestock sector, where the size of the herds, especially cattle, contributes significantly to the sector's footprint. Finally, it is important to highlight the large actual and apparent water losses in the water distribution systems of the cities in the sub-basin studied, which complete the accounting of this consumption.

## 4.6 Analysis of environmental sustainability

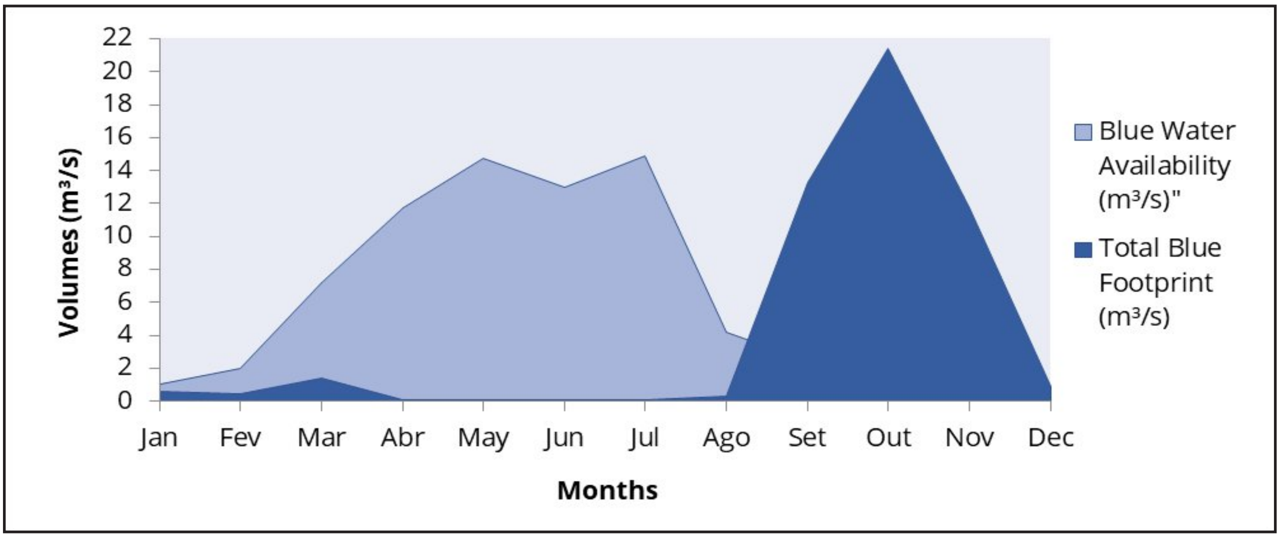
Based on the components of the water footprint of the sub-basin studied and the determination of the level of scarcity (blue), the level of water appropriation (green) and pollution (gray), this allowed the authors to infer the sustainability situation from an environmental perspective in the Camaratuba/PB sub-basin.

The following are the analyses drawing upon the results of the total blue water footprint (scarcity level), the total green water footprint (appropriation fraction) and the total gray water footprint (pollution level). It is important to note that an environmental critical point in a sub-basin is defined as a specific period in which there is a violation of the demands for blue and green water, or of the water quality standards in their natural state, this occurs when the value exceeds 100%, and it can be stated that the geographical region is unsustainable.

Therefore, the level of water scarcity was calculated, enabling the researchers to draw up a graph, as shown in Figure 4, to better illustrate the sustainability situation when considering the blue water component in the Camaratuba River sub-basin in

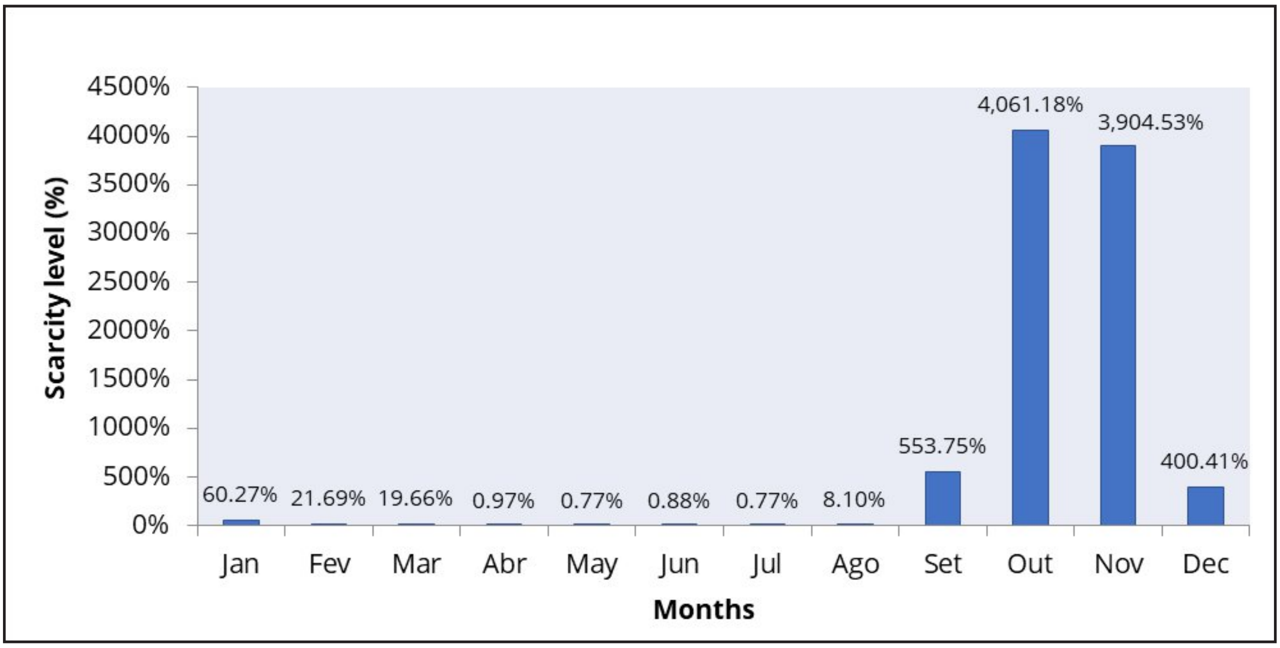
2023. It is clear that the availability of blue water is insufficient, on a monthly scale, between the months of September and December.

Figure 4 – Sustainability analysis considering the blue water footprint




Source: Research data (2024)

Figure 5 – Analysis of monthly water scarcity in the Camaratuba River/PB sub-basin



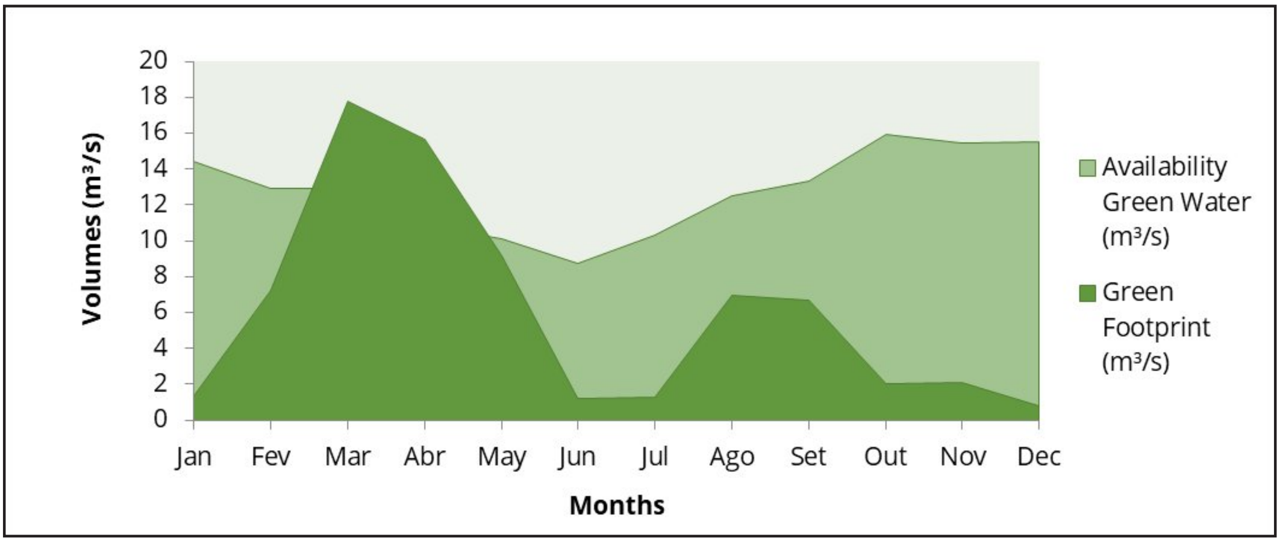

Source: Research data (2024)

According to Figure 5, these results suggest that total water consumption is unsustainable from September to December, because the blue water footprint is greater than the demand for available blue water. When the analysis moves to a global analysis on an annual scale, the level of scarcity is 70.04%, which is below the critical environmental level allowed, which cannot exceed 100%, showing that the geographical region studied is sustainable.

The lack of water in the municipalities between September and December exposes the population to periods of scarcity, requiring the use of measures to rationalize the available resources. Although there are technologies such as water tankers and social technologies for collection and storage, these are insufficient to meet the daily water needs of a population. Although there are research gaps in the analysis of the green water footprint, this research considered an analysis of the appropriation fraction that is related to the green footprint component.

The evapotranspiration of the sub-basin studied was taken into account, with 30% of this available evapotranspiration being earmarked for environmental areas and 28% for areas unsuitable for irrigated agriculture (sealed), to finally determine the availability of green water, as shown in Figure 6.

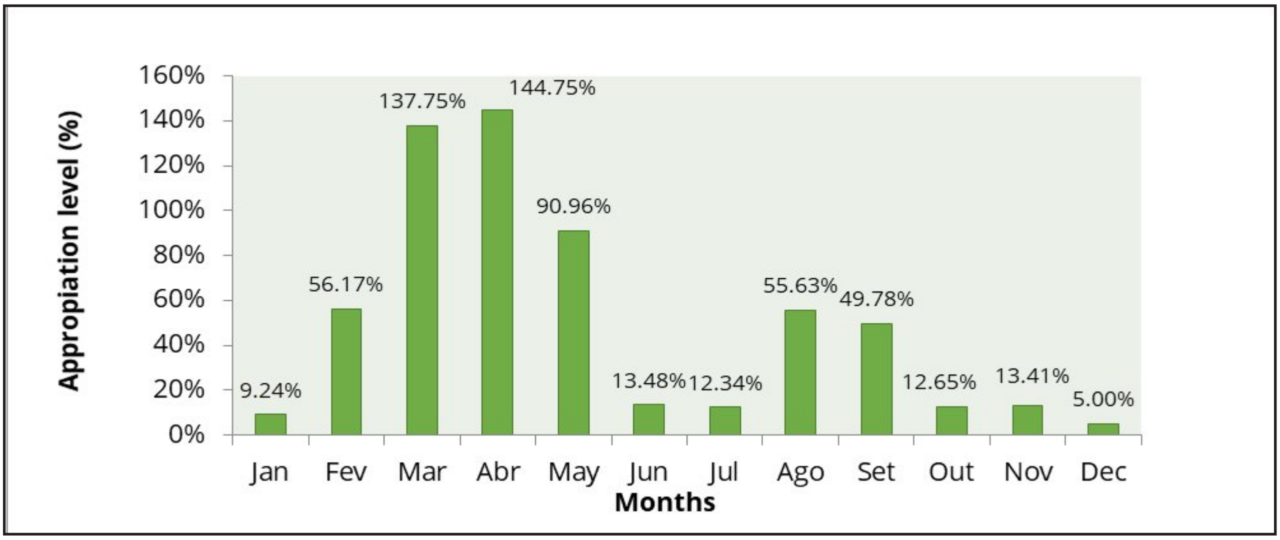
Figure 6 – Sustainability analysis considering the green water footprint




Source: Research data (2024)

From a monthly analysis, these results suggest that the sub-basin becomes unsustainable between the months of March and April, violating water availability. These figures are due to the fact that planting periods are subject to external factors such as rainfall, winds, temperature variations and other factors. It is important to highlight that the appropriation of water in the soil from rainfall is of paramount importance in accounting for the Green Water Footprint of the sub-basin studied. Figure 7 shows the monthly appropriation levels and when analyzed on an annual scale the sub-basin studied is considered sustainable, reaching a magnitude of only 47.18% in its level of green water appropriation. Note also that, in a monthly analysis, the months of October to December show low water appropriation, evidencing the level of scarcity shown in Figure 5 for the same months analyzed.

Figure 7 – Analysis of monthly water appropriation in the Camaratuba River/PB sub-basin

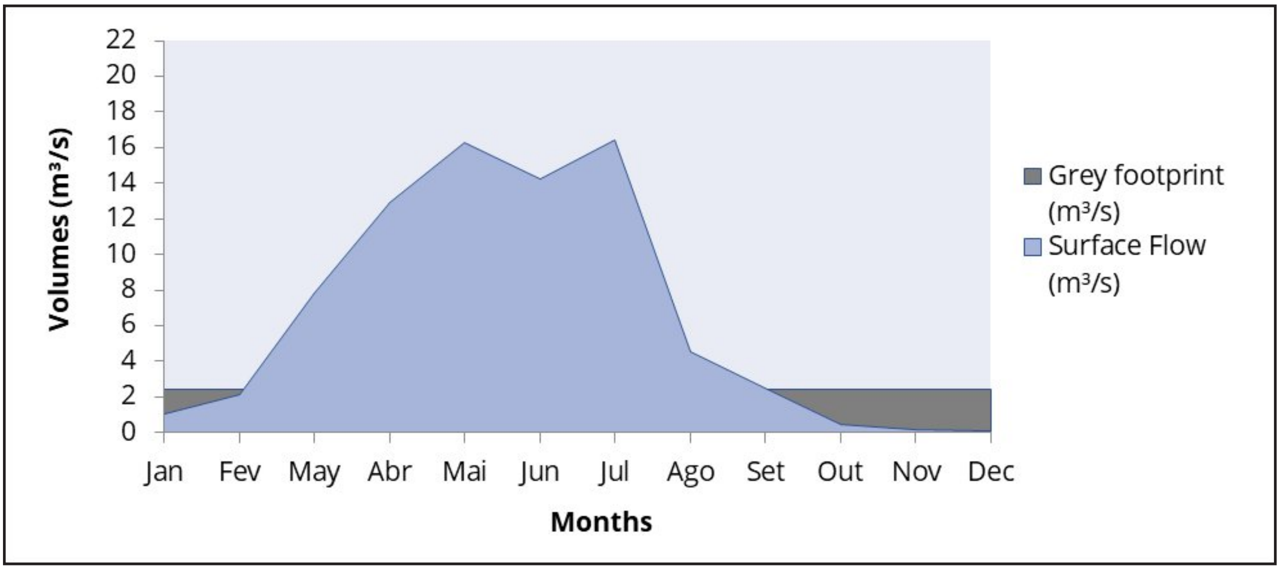



Source: Research data (2024)

Finally, the the analysis of the gray water footprint in the sub-basin studied was quantified, as shown in Figure 8.

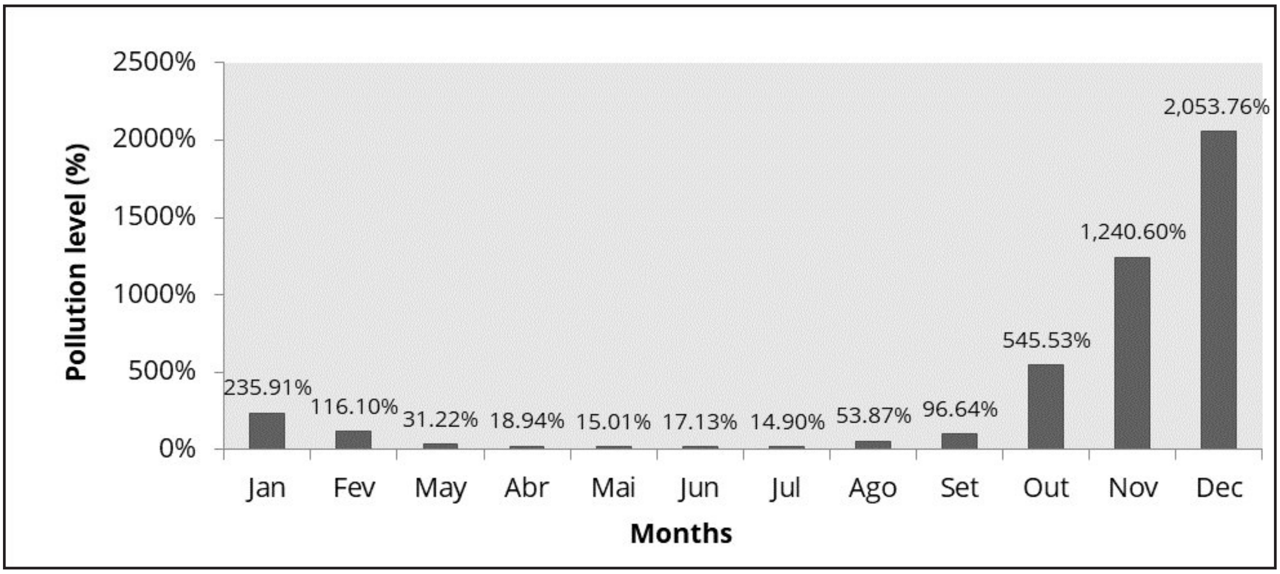
Although it is a high footprint when compared to the blue and green footprints, the results showed a good assimilation of the effluents generated in the sub-basin studied between the months of March and September, but with the other months of pollution fins. From the analysis of the gray water footprint, as shown in Figure 8, these results suggest that the available water runoff cannot assimilate the effluents generated in the months of January to February and October to December, which indicates that it has violated the critical environmental gray footprint. On a monthly scale, the level of cafterntration of organic matter generated by the population is higher than the availability of water from the springs that would dilute these harmful components. It is also important to remember that both the gray water footprint and surface runoff vary over the course of the year and may show improvements when the analysis is calculated on an annual scale.

Figure 8 – Sustainability analysis considering the gray water footprint




Source: Research data (2024)

Figure 9 – Analysis of the level of monthly pollution in the Camaratuba River/PB sub-basin




Source: Research data (2024)

In a global and annual analysis, it can be said that the sub-basin, despite the pollutant load produced, is considered sustainable since the pollutant parameters improve over time. In this case, the level of annual pollution in the Camaratuba/PB river sub-basin did not violate the environmental critical point, standing at just 37.29%, managing to assimilate the entire estimated gray footprint, which can be considered sustainable, as shown in Figure 9.

In summary, the environmental hotspots did not exceed 100% when analyzed on an annual scale, where blue and green water demands or water quality standards were not violated, making the Camaratuba/PB river sub-basin environmentally sustainable.

## 5 CONCLUSIONS

The results show that, despite being a sub-basin located in the coastal region of the state of Paraíba, the human supply, sanitation, irrigation and livestock sectors demand significant amounts of water for their activities, highlighting the urgent need for practices that promote conscious consumption and reduce total consumption. Although this is a recent approach in academia and there are still gaps to be filled, this study demonstrates the accuracy and effectiveness of applying the Water Footprint method in assessing the sustainability of the region.

Thus, it can be concluded that the Total Water Footprint of the Camaratuba River sub-basin totaled approximately 394.3 million m³ for the operating scenario in 2023, even though it showed considerable anthropogenic pressure, but within the limits of sustainability. It should also be noted that the blue footprint component was 131.2 million m³ per year, being primarily required by the irrigated agriculture sector (especially sugarcane), while the gray footprint component required approximately 76.0 million m³ per year, reflecting the volume needed to assimilate the organic load of sewage generated in the geographical region studied. The green footprint component reached 187.1 million m³ per year, highlighting the importance of rainfall, especially in rainfed agriculture, which contributes to water appropriation in the soil, indirectly putting pressure on water sources.

Thus, water footprint management contributes to a more in-depth understanding of water consumption in a geographical region, alerting us to the environmental sustainability of this vital resource, which is increasingly threatened by human pressures, making it essential to adopt preventive measures to guarantee its availability for future generations. To this end, various measures can contribute to a better sustainability scenario, including: improving the monitoring of the actual flow of rivers in the region, encouraging the registration of grants so that it is possible to assess the effective demand for water, developing public policies aimed at reducing water waste and pollution, and implementing sanitary sewage systems capable of removing pollutants from the water and returning them to the water bodies in accordance with the environmental standards established by the regulatory bodies.

However, with the mapping of the level of scarcity, the level of appropriation and pollution, we can consider that the magnitude of environmental sustainability in the Camaratuba/PB river sub-basin is sustainable, but requires care and various actions to balance consumption and water quality standards, guaranteeing the public manager efficient decision-making that promotes the strengthening of the National Water Resources Management System, whose main goal is the search for sustainable governance.

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