# SPATIAL DISTRIBUTION OF RIVER BASIN SUSTAINABILITY INDICATORS IN TRANSITION REGION OF NORTHEASTERN BRAZIL

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**Abstract.** Sustainability indicators were applied in river basins of a state in Northeastern Brazil, aiming to outline and support effectively sustainable actions of water resources management. Twelve indices and three indicators of Sustainability focused on socioeconomic, hydrological and institutional issues were calculated for six hydrographic regions, quantitatively and qualitatively. Partial scales for all indices related the calculated values to levels of performance (Very High, High, Medium, Low, and Very Low). Posteriorly the indices were grouped in global scales, constructed with levels of water sustainability for all indicators. The results have shown an overall intermediate performance in the assessed river basins, indicating the need to adopt priority measures in the hydrological dimension, especially in relation to groundwater; attention to primary sanitation, with regard to public supply; reduction in water demand and waste; implementation of management tools; consolidation and support to river basin committees. The spatialization of water sustainability indicators enabled a clearer perception and an unmistakable assessment of each river basin surveyed.
**Keywords:** *water resources, decision-making, indicators, sustainability, river basin*

## Introduction

The imbalance between water availability and demand causes its scarcity, which has become one of the most pressing problems in the world (Peterson and Schoengold, 2008). This situation may worsen due to population growth, global climate change and deterioration of water quality (Qu et al., 2013). Demand for water is expected to increase by more than 40% by 2050. By 2025, about 1.8 billion people will live in countries or regions where water is scarce, and two-thirds of the earth may live in a condition where the supply of clean water does not meet its demand (UN, 2015; Ross, 2017).

In Brazil, water demand has grown significantly in the last decades due to the economic development process, the increase of population clusters and the quantification, increasingly grounded, of environmental needs (Carvalho and Curi, 2013). Although Brazil has an abundance of water, it is poorly distributed in relation to the demographic density of the country, with 80% of the water being in the Amazon region and a severe scarcity existing in the Northeastern region (ONU, 2007). However, in addition to misdistribution, Brazil faces more severe issues, such as permanent contamination and waste of the remaining clean water (Bragatto et al., 2012).


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According to Oelkers et al. (2011), one of the key solutions to this global water crisis is better management of this valuable natural resource. The literature reports that, as the complexity of issues related to water resources has increased, there have been extensive studies to combine the concept of sustainability with water management matters (Loucks e Gladwell, 1999; Loucks et al., 2000; Starkl and Brunner, 2004; Mays, 2006; Policy Research Initiative, 2007). An integrated view of water is essential because it can add social, economic, environmental and institutional aspects to all management processes (Juwana et al., 2010), contributing to understand the evolution of the water system and its influences, that is, the achievement of a sustainable management of water resources (Sun et al., 2016).

According to the OECD (2003, p. 19), "water is the perfect example of a sustainable development challenge – encompassing environmental, economic and social dimensions." The sustainable management of water resources, therefore, implies not only the indefinite continuation of physically and biologically stable systems, but also concern for the other dimensions of sustainable development, such as the economic efficiency of water use, the equitable distribution of the costs and benefits of water resource developments and participatory approaches to policy-making and decision-taking (Ioris et al., 2008).

Sustainability indicators have become relevant tools for the integrated planning and management of water resources (Hooper, 2010). Very useful in decision-making, they enable the simplification of information on complex phenomena and the identification of primary demands (Barros and Silva, 2012). The adoption of indicators to assess and monitor progress towards sustainable development is highly recommended by scientists (Moldan et al., 2012; Cornescu and Adam, 2014; Bolcárová and Kološta, 2015), policy developers (UN, 2007), financial institutions (OECD, 2014; WWAP, 2003), governments (OSE, 2008), business sector (WBCSD, 2000) and nongovernmental organizations (WWF, 2010), as they are means to assess the level of satisfaction of several criteria, helping to translate abstract concepts into measurable parameters (Lee and Huang, 2007).

In Brazil, several authors have used indicators to analyze and propose suggestions aimed at enabling water management in an integrated and sustainable method in river basins (He et al., 2000; Pompermayer et al., 2007; Chaves and Alipaz, 2007; Ioris et al., 2008, Vieira and Studart, 2009; Magalhães Júnior, 2010; Carvalho et al., 2011; Maynard et al., 2017), fact also occurs in river basins in several countries, according to studies carried out by UNESCO (2008), Ioris et al. (2008), Catano et al. (2009), Cortés et al. (2012), Pellicer-Martínez and Martínez-Paz (2016).

Currently, society is seeking a broader debate on sustainable development in terms of rational use and valuation of natural resources. Therefore, discussing aspects related to water management in river basins by using indices and indicators in order to enable a more integrated and sustainable water management brings relevant contributions to the current scenario.

This article it is proposed to a holistic assessment of river basins through indicators that measure how water management is progressing in the perspective of sustainability in a strategic region of Brazil, located between the semiarid Northeastern region and the Amazon region.

As a background, specifically regarding water resources in Maranhão, the area used to perform this study, Dias (2018) points out that there is a notable gap in literature on water resource management, which presents an unfavorable framework regarding the


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implementation of management instruments. There are no studies that address the issue of water sustainability in the State of Maranhão.

Thus, this study also intends to help fill a specific gap in the Northeastern part of Brazil, where there is little literature related to integrated management of water resources aiming at the sustainability of river basins.

Taking into consideration these arguments and the relevance of this issue in the context of water management and sustainability, this article aims to diagnose, through indicators, the water sustainability of river basins in the State of Maranhão, in Northeastern Brazil, and to substantiate the decision-making process for the integrated management of water resources.

## Materials and methods

### *Characterization of the study area*

The study was conducted in the State of Maranhão, which is located in the Northeastern part of Brazil, between the coordinates of 02° to 10° south latitude and 44° to 48° west longitude. Covering an area of 331,935,507 km², Maranhão has approximately 7 million inhabitants, being the fourth most populous state in Northeastern Brazil (IBGE, 2017).

It is located in a transition area between the Amazon (wet) and Northeastern (semiarid) regions, favoring great annual rainfall contrasts. The portion of Legal Amazon in Maranhão covers an area equivalent to 80% of the territorial area of the State, about 264,000 km². The region of transition between the Amazon and Cerrado biomes is characterized by a high diversity of ecosystems and biodiversity. (Silva et al., 2016).

The State of Maranhão is divided into twelve hydrographic regions, of which six were selected for this research: Parnaíba, Tocantins, Gurupi, Munim, Mearim and Itapecuru (*Fig. 1*).

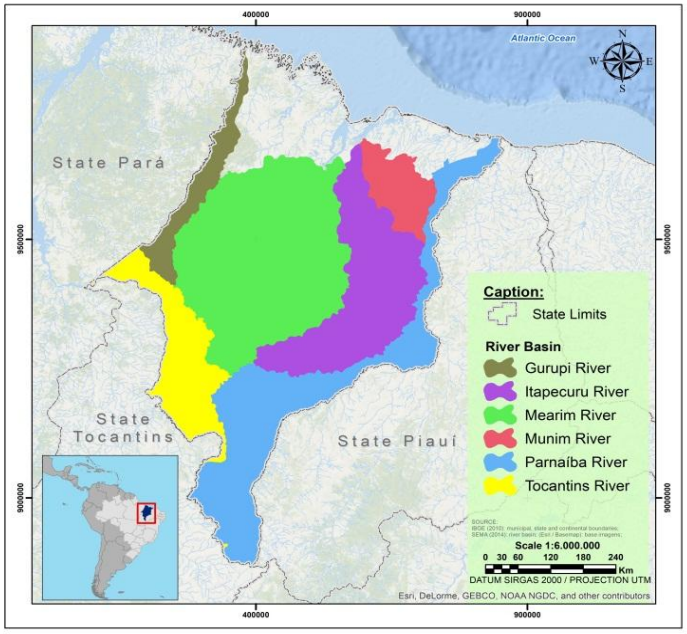


***Figure 1.*** *Geographical location of the river basins researched*


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*Frame 1* shows some demographic characteristics of the river basins studied.

***Frame 1.*** *Demographic characteristics of the river basins studied in this research. (Source: IBGE, Censo Demográfico, 2010; NUGEO/UEMA, 2011)*

| Basin | Area (km²) | Population | % over the State area | Population density in the basin (inhabitant/km²) | No. of cities in the basin |
|---|---|---|---|---|---|
| Tocantins River | 30,665.15 | 498,105 | 9.24% | 16.24 | 23 |
| Parnaíba River | 66,449.09 | 717,723 | 20.02% | 10.80 | 39 |
| Gurupi River | 15,953.91 | 178,302 | 4.81% | 11.18 | 12 |
| Mearim River | 99,058.69 | 1,681,307 | 29.84% | 16.97 | 83 |
| Munim River | 15,918.04 | 320,001 | 4.79% | 20.10 | 27 |
| Itapecuru River | 53,216.84 | 1,019,398 | 16.03% | 19.16 | 57 |

### *Selecting indicators and setting indices*

The selection process was initially based on an extensive bibliographical research on indices and indicators applied to water resources, aiming at meeting the need to evaluate water sustainability conditions in the basins of Maranhão.

Based on the information required to compose each indice and indicator and the information available in the river basins studied, we have decided to use the methodology elaborated by Vieira (1999) and modified by Campos et al. (2014). Thus, based on these authors, we have chosen to apply the following indicators:

(a) Indicator of Potentiality, Availability and Demand (IPAD), to assess information regarding potentiality and availability of the water from the river basin, as well as the capacity to meet demands; (b) Indicator on Water Resources Management (IWRM), to reflect how entities are implementing it and instruments of the water resources policy; and (c) Water Use Efficiency Indicator (WUEI), to inform the conditions of environmental sanitation in the river basin and the level of efficiency of public utilities in the distribution of the captured water. These sustainability indicators were applied at the river basin level, which is the water resources management unit. Chaves and Alipaz (2007) highlight that this consideration is important, since the assessment of water resource sustainability cannot be limited by jurisdictional boundaries.

The process of choosing indicators also considered whether they meet the four criteria of sustainability: social, economic, environmental and institutional, as described by Pires et al. (2017). In this evaluation, the three indicators IPAD, IWRM and WUEI meet most sustainability criteria. Thus, the chosen indicators can be applied to reliably diagnose the sustainable use and water management in selected river basins. In addition, they are interesting tools that allow us to see some of the multiple aspects of water management and use from specific angles.

The following criteria were taken into consideration to define the indices constituting each indicator: (a) relevance (ability to translate the phenomenon); (b) local adherence (ability to capture the phenomenon produced or that can be transformed at the local level); (c) availability (coverage and timeliness of data); and (d) ability to allow time comparisons (Campos et al., 2014).

*Frame 2* shows the indices selected for each indicator.


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***Frame 2.*** *Indicators and their respective indices selected for this research. (Based on Campos et al., 2014)*

| Indicator | Indice | Description |
|---|---|---|
| **IPAD** Indicator of Potentiality, Availability and Demand | Activation of Potentialities **(IAP)** | Relation between availability and potentiality |
| | Use of Potentialities **(IUP)** | Relation between demand and potentiality |
| | Use of Availabilities **(IUA)** | Relation between demand and availability |
| **IWRM** Indicator on Water Resources Management | River Basins Committees **(IRBC)** | Existence and scope of operations |
| | Grant **(GI)** | Level of implementation of the grant |
| | Collection **(CI)** | Level of implementation of the collection |
| **WUEI** Water Use Efficiency Indicator | Households Supplied by Wells **(IHSW)** | Percentage of households supplied by wells in relation to the total number of households |
| | Households Supplied by a Water Supply System **(IHSWSS)** | Percentage of households supplied by a water supply system in relation to the total number of households |
| | Sewer Connections **(ISW)** | Percentage of households with a sewage network or a septic tank in relation to the total number of households |
| | Sewage Treatment **(IST)** | Percentage of households with sewage treatment in relation to the total number of households |
| | Solid Waste Treatment **(ISWT)** | Percentage of households with waste collection in relation to the total number of households |
| | Water Loss in the Network **(IWLN)** | Average percentage of physical losses (leaks) and billed losses (illegal connections) |

## *Data collection and calculation of indices*

The information used in this study was obtained by bibliographic research. To determine the IPAD, the values of availabilities, potentialities and surface water demands were obtained from the most recent report prepared by the Geoenvironmental Nucleus of the State University of Maranhão (NUGEO, 2010), entitled "Estimation of demand and water availability of river basins in Maranhão". The determination of demands by river basin has taken into consideration human supply (urban and rural), industry, irrigation and livestock (*Frame 3*).

***Frame 3.*** *Potentialities, availabilities, and surface water demands, by river basin, in the State of Maranhão. (Source: NUGEO, 2010)*

| Basin | Potentialities ($h^3$/year) | Availabilities ($h^3$/year) | Demands ($h^3$/year) |
|---|---|---|---|
| Parnaíba River | 3828.41 | 1475.17 | 288.38 |
| Munim River | 4098.95 | 269.8 | 66.44 |
| Itapecuru River | 6599.97 | 1112.55 | 306.64 |
| Tocantins River | 11692.44 | 2412.15 | 432.4 |
| Mearim River | 13971.85 | 665.21 | 290.47 |
| Gurupi River | 5970.17 | 1263.94 | 27.62 |


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Information on availability, potentialities and underground water demands were based on data from Brasil (2009) and Santos (2010). In the calculation of the water demands, we have considered human supply (urban and rural), industry, irrigation, livestock, agricultural production and environmental demands (*Frame 4*).

***Frame 4.*** *Potentialities, availabilities, and underground water demands, by river basin, in the State of Maranhão. (Source: Brasil, 2009; Santos, 2010)*

| **Basin** | **Potentialities ($h^3$/year)** | **Availabilities ($h^3$/year)** | **Demands ($h^3$/year)** |
|---|---|---|---|
| Parnaíba River | 9030 | 1107.92 | 2076.08 |
| Munim River | 3120 | 183.85 | 220.87 |
| Itapecuru River | 1550 | 219.54 | 267.68 |
| Tocantins River | 500 | 81.11 | 150.08 |
| Mearim River | 3490 | 639.16 | 656.18 |
| Gurupi River | 2510 | 90.85 | 299.72 |

The data necessary for the calculations of the indices composing the WUEI were obtained on the platforms of the Brazilian Institute of Geography and Statistics (IBGE, 2010) and the National Information System on Sanitation (Sistema Nacional de Informações Sobre Saneamento - SNIS) for the reference year of 2010.

Data on total households, households supplied by wells, households supplied by a water supply system, households supplied by a sewage network or septic tank, households with sewage treatment, households with waste collection and information on water losses in the supply network were gathered by municipality (see *Appendix*). The final indice, by river basin, was calculated from the average among municipalities that compose the basin.

Currently SNIS has the most comprehensive data on the sanitation sector in Brazil, constituting the largest and most important information tool on water services, collection and treatment of sewage since 1995, as well as solid waste management since 2002 (SNIS, 2015). Thus, the information in this study is very relevant regarding the reliability of its data.

Information on Grant, Collection and Committees required to compose the IWRM was obtained from the Superintendency of Water Resources of the State Department of Environment and Natural Resources of Maranhão (SEMA), the agency responsible for water resources management in Maranhão.

### *Partial scales*

According to *Frame 2*, the indices constituting IPAD are the following: IAP, IUP and IUA. These indices show that regions with IUA > 1 are under situations of exhaustion of availability (Fernandes, 2002).

Vieira (1999) states that due to natural physical limitations, the maximum IUP value would be equal to 0.8. Thus, IUP values > 0.7 would indicate a critical situation of use of water resources in a river basin.

The IAP indice, on the other hand, would represent the level of efficiency of the water resources of a basin, being larger as they are closer to 1 (Fernandes, 2002).


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Thus, the partial scale for all indices relates the calculated values to levels of performance (Very High, High, Medium, Low, and Very Low). For example, a IUA value greater than 1, a IUP value greater than 0.7 and a IAP value closer to 0 were related to "Very Low" performance levels; a IUA and a IUP equal to zero and a IAP closer to 1 are related to "Very High" performance levels.

These indices were calculated by river basin considering superficial and underground waters, which allows us to observe the relations of the demands with availabilities and potentialities. Vieira and Gondim Filho (2006) strongly recommend that these indicators are spatially implemented in terms of surface and ground potentiality.

The indices that make up the IWRM (IRBC, GI, CI) are subjective and determined from the analysis of their application to the hydrographic basin being studied. The partial scales for these indices are qualitative (*Frame 5*).

For the indices that make up the WUEI (IHSW, IHSWSS, ISW, IST, ISWT, IWLN), the partial scales (also from Very High to Very Low) are related to percentages ranging from 0 to 100%. For example, an indice with a value equal to 60% is classified as "Medium", while another with a value equal to 25% is considered "Low". These indices were calculated for all the cities that compose the river basins.

***Frame 5.*** *Partial scales for IWRM indices. (Source: Campos et al., 2014)*

| LEVEL | DESCRIPTION |
|---|---|
| **Indice of River Basins Committees (IRBC)** | |
| Very High | The committee is well articulated and has a high rate of problem solving in the basin |
| High | The committee has been operating for a few years and has a mean rate of problem solving in the basin |
| Medium | The committee has been recently set up and has a low rate of problem solving in the basin |
| Low | The committee has been proposed by law and is being set up |
| Very Low | There is no action for creating a committee in the basin |
| **Grant Indice (GI)** | |
| Very High | The grant has been implemented, it is very well supervised and there is a high reduction in water consumption |
| High | The grant has been implemented and the level of inspection and reduction in water consumption is medium |
| Medium | The grant has been implemented and the level of inspection and reduction in water consumption is low |
| Low | The grant has been proposed by law and is being implemented |
| Very Low | There is no action for deploying a grant in the basin |
| **Collection Indice (CI)** | |
| Very High | The collection has been implemented, a high amount is being collected and there is a high level of development in the basin |
| High | The collection has been implemented, a significant amount is being collected and there is a good level of development in the basin |
| Medium | The collection has been recently implemented and involves a deficit |
| Low | The collection has been proposed by law and is being implemented |
| Very Low | There is no action for deploying a collection in the basin |

### *Global scales*

When the indices are grouped, global scales are constructed with levels of water sustainability for all indicators in order to allow a better understanding of the value obtained for each indicator. The levels of the scales are qualitative, varying according to


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the values obtained when grouping the indices. This grouping can occur by considering the average of the indices (IPAD) and (WUEI), or by joining the management instruments (IWRM) (*Frame 6*).

After obtaining the indicators and respective level of water sustainability for each basin surveyed, the indicators IPAD, IWRM and WUEI were spatially distributed. For the development of maps, we used ArcGIS 10.3 software (ESRI, 2011), a GIS (Geographic Information System) tool that allows the manipulation of geospatial, matrix and vector databases.

***Frame 6.*** *Global scale for the indicators used in this research. (Adapted from Campos et al., 2014)*

| **LEVEL** | **IPAD and WUEI**<br>**Average (%)** | **IWRM**<br>**Joint Indices (J)** |
|---|---|---|
| Very High | $80 \leq M$ | Committee, grant and collection in full operation in the basin, generating a high reduction in demand |
| High | $60 \leq M < 80$ | Committee, grant and collection operating for a few years, generating little reduction in demand |
| Medium | $40 \leq M < 60$ | Committee, grant and collection (one or more) recently implemented, but with operational problems |
| Low | $20 \leq M < 40$ | Committee, grant and collection (one or more) proposed by law, in the process of installation |
| Very Low | $M < 20$ | There is no action to apply a committee, a grant and a collection in the basin (one or more) |

## Results

### *Indicator on water resources management - IWRM*

The assessment of the performance indicator for the water resources management system can be observed in *Table 1*.

***Table 1.*** *Classification of the indices composing IWRM*

| **Basin** | **Indice of River Basins Committees (IRBC)** | **Grant indice (GI)** | **Collection indice (CI)** |
|---|---|---|---|
| Parnaíba River | Very Low | Medium | Very Low |
| Munim River | Medium | Medium | Very Low |
| Itapecuru River | Very Low | Medium | Very Low |
| Tocantins River | Very Low | Medium | Very Low |
| Mearim River | Medium | Medium | Very Low |
| Gurupi River | Very Low | Medium | Very Low |

### *Water use efficiency indicator – WUEI*

*Table 2* shows classification of the indices composing WUEI.


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***Table 2.*** *Classification of the indices composing WUEI*

| BASIN | Indices | | | | | |
|---|---|---|---|---|---|---|
| | **IHSW** | **IHSWSS** | **ISW** | **IST** | **ISWT** | **IWLN** |
| Mearim River | 11.67 | 13.08 | 47.64 | 16.73 | 15.22 | 50.30 |
| | **VL** | **VL** | **M** | **VL** | **VL** | **M** |
| Itapecuru River | 9.53 | 14.06 | 14.67 | 7.77 | 6.90 | 55.72 |
| | **VL** | **VL** | **VL** | **VL** | **VL** | **M** |
| Parnaíba River | 14.48 | 73.92 | 17.01 | 9.72 | 8.53 | 48.69 |
| | **VL** | **A** | **VL** | **VL** | **VL** | **M** |
| Tocantins River | 11.85 | 18.45 | 20.76 | 10.22 | 14.64 | 30.15 |
| | **VL** | **VL** | **L** | **VL** | **VL** | **L** |
| Munim River | 15.40 | 9.82 | 13.50 | 5.25 | 4.19 | 67.59 |
| | **VL** | **VL** | **VL** | **VL** | **VL** | **A** |
| Gurupi River | 17.94 | 16.95 | 28.31 | 11.50 | 12.91 | 26.14 |
| | **VL** | **VL** | **L** | **VL** | **VL** | **L** |

Indices: IHSW - Indice of Households Supplied by Wells; IHSWSS - Indice of Households Supplied by a Water Supply System; ISW - Indice of Sewer Connections; IST - Indice of Sewage Treatment; ISWT - Solid Waste Treatment; IWLN - Indice of Water Loss in the Network. Classification: (VH), Very High; (H), High; (M), Medium; (L), Low; (VL), Very Low

### *Indicator of potentiality, availability and demand – IPAD*

The application of sustainability indices for this indicator has shown the low utilization of existing water resources in all river basins surveyed (*Table 3*).

***Table 3.*** *Classification of the indices composing IPAD*

| BASIN | SURFACE | | | UNDERGROUND | | |
|---|---|---|---|---|---|---|
| | **IAP** | **IUP** | **IUA** | **IAP** | **IUP** | **IUA** |
| Parnaíba River | 0.39 | 0.08 | 0.20 | 0.12 | 0.23 | 1.87 |
| | **L** | **VH** | **H** | **VL** | **H** | **VL** |
| Munim River | 0.07 | 0.02 | 0.25 | 0.06 | 0.07 | 1.20 |
| | **VL** | **VH** | **H** | **VL** | **VH** | **VL** |
| Itapecuru River | 0.17 | 0.05 | 0.28 | 0.14 | 0.17 | 1.22 |
| | **VL** | **VH** | **H** | **VL** | **VH** | **VL** |
| Tocantins River | 0.21 | 0.04 | 0.18 | 0.16 | 0.30 | 1.85 |
| | **L** | **VH** | **VH** | **VL** | **H** | **VL** |
| Mearim River | 0.05 | 0.02 | 0.44 | 0.18 | 0.19 | 1.03 |
| | **VL** | **VH** | **M** | **VL** | **VH** | **VL** |
| Gurupi River | 0.21 | 0.00 | 0.02 | 0.04 | 0.12 | 3.30 |
| | **L** | **VH** | **VH** | **VL** | **VH** | **VL** |

Indices: IAP - Indice of Activation of Potentialities; IUP - Indice of Use of Potentialities; IUA - Indice of Use of Availabilities. Classification: (VH), Very High; (H), High; (M), Medium; (L), Low; (VL), Very Low


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### *Water sustainability*

The assessment of the sustainability indicators used in this research is described in *Table 4*.

***Table 4.*** *Classification of water sustainability indicators*

| BASIN | IWRM | WUEI | IPAD | |
|---|---|---|---|---|
| | | | sur | und |
| Mearim River | M | L | H | L |
| Itapecuru River | M | L | VH | M |
| Parnaíba River | M | L | VH | M |
| Tocantins River | M | VL | VH | L |
| Munim River | M | L | VH | M |
| Gurupi River | M | L | VH | VL |

Indicators: IWRM - Indicator on Water Resources Management; WUEI - Water Use Efficiency Indicator; IPAD - Indicator of Potentiality, Availability and Demand; sur - surface; und - underground. Classification: (VH), Very High; (H), High; (M), Medium; (L), Low; (VL), Very Low

All basins of the state showed a "Medium" level of sustainability for IWRM (*Fig. 2*).

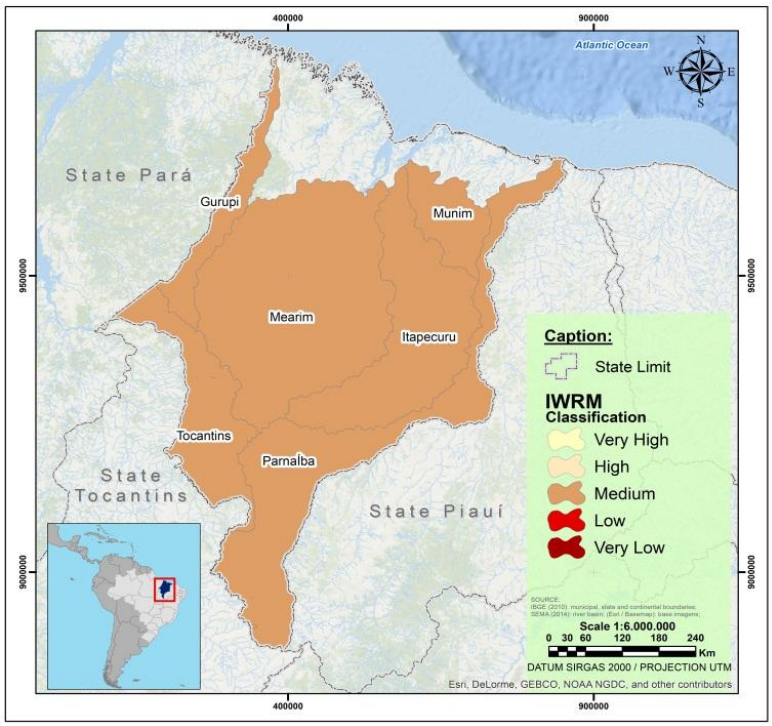


***Figure 2.*** *Spatial distribution of IWRM*

The WUEI showed a sustainability level ranging from "very low" to "low" in the state river basins (*Fig. 3*).


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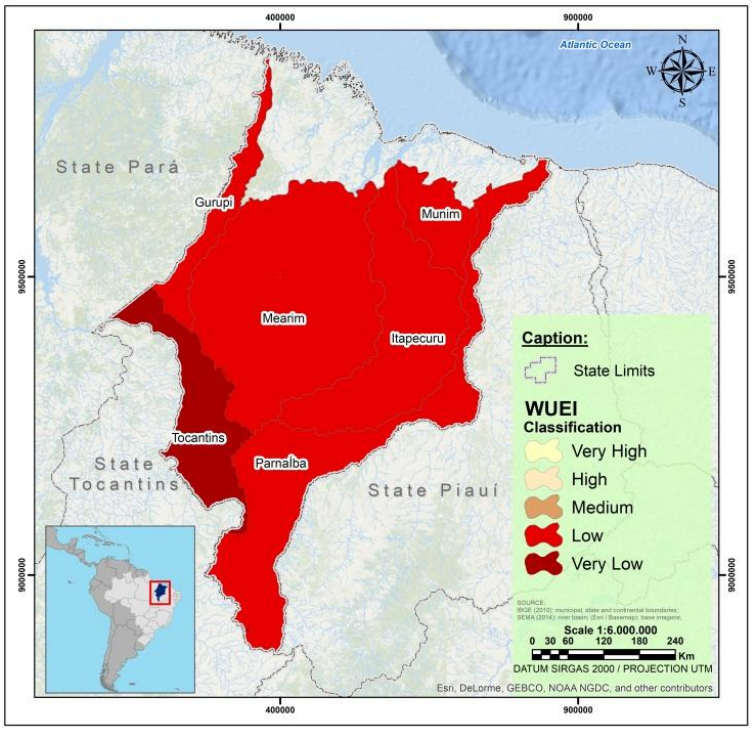


***Figure 3.*** *Spatial distribution of WUEI*

On the global scale, for surface water the IPAD showed a sustainability level ranging from "Very High" to "High" (*Fig. 4*), depicting surplus availabilities in relation to demands and indicating that water resources are not fully available in the basins studied.


***Figure 4.*** *Spatial distribution of IPAD, for surface water*


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The global scale of IPAD for groundwater showed sustainability levels varying from "very low" to "low" and "medium" (*Fig. 5*), due to demands higher than the available water resources, which means that the potential of the basins is not fully activated. Despite these results, the indissociability of surface and underground waters should be noted, as well as the importance of groundwater in maintaining the flow of the Maranhão rivers that have perennial characteristics.

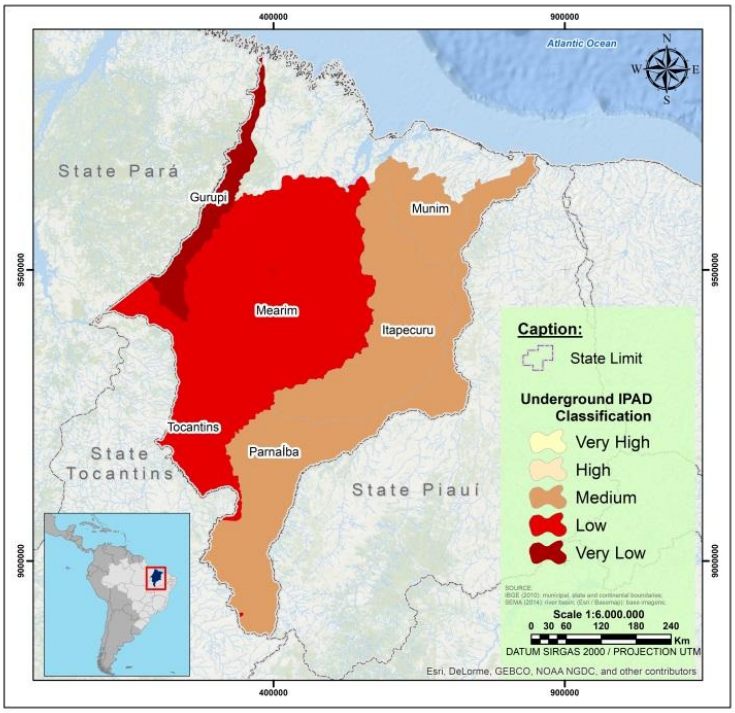


***Figure 5.*** *Spatial distribution of IPAD, for groundwater*

## Discussion

About IWRM, the grant indice had a "medium" level in all basins in Maranhão because this instrument is implemented, but it has a low level of inspection and reduction in water consumption. The collection indice has shown a "very low" level in all basins because the collection for the use of water is only established in the state policy of water resources (Brazilian Law no. 8.149/2004). The effective implementation of this instrument would require legal regulation, but there is still no state action in this regard in any of the basins studied in this research. The indice of river basins committees has shown a "very low" level for the Parnaíba, Tocantins, Itapecuru and Gurupi river basins, since none of these has a committee; and a "medium" level for the Mearim and Munim river basins, because they are the only ones that have a recently installed committee, but both have a low rate of problem solving.

Despite the average level of sustainability obtained in the IWRM, the shallow institutionalization of management instruments (grant with problems in implementation undergoing a bureaucratic process, poor inspection, collection for the use of nonexistent water) is clear.

Only two committees have been created so far in the state, which have little or no economic and political sustainability, indicating the existence of issues and fragilities in


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their effective performance and resulting in the low performance of these organizations. The river basin committees which are members of the National System of Water Resources Management play a relevant role in water management. The effective performance of these entities implies in the democratization of water resources management and in sharing the power to decide. This requires effort from the public authorities to share power, and effort from users and civil society to share responsibilities.

The IHSW and IHSWSS indices, which make up the water use efficiency indicator, were "very low", indicating little coverage of water supply (including by wells).

According to a diagnosis carried out by the National Information System on Sanitation - SNIS, approximately 83% of the Brazilian population is served by a water supply system (Brazil, 2016). Although it appears to be a positive percentage, 17% do not have access to this basic utility, which represents more than 35 million people, mainly concentrated in the Northern and Northeastern regions of the country (Araújo et al., 2016).

Almost all basins studied have shown "very low" ISW and IST levels, except for the Tocantins and Gurupi river basins, whose ISW was "low". These data show a poor service of collection and sewage treatment. In the calculation of IST, for example, we have observed that in some cities there were no data available on sewage treatment or, when this type of treatment did not occur in the region being studied, the percentage was equal to zero. It should be noted that the National Plan for Basic Sanitation (Plano Nacional de Saneamento Básico - PLANSAB) considers as an appropriate sanitary sewage service not only the presence of a sewage collection and treatment network, but also the use of a septic tank. This fact may have contributed to increasing the level of the ISC indicator, since it also considers the households served by septic tank, the main type of treatment adopted in the cities of Maranhão.

It is important to note that the percentage of cities in Maranhão that has appropriate systems of sewage treatment, with effective removal of organic load, is minimal. Most cities only implement sewage removal in urban regions, with in natura discharge in surface waters, or preliminary treatment, facts that may have contributed to the low level obtained in the IST indicator. According to ANA (2017), the lowest levels of organic load removal from sewage are found especially in the Northern and Northeastern regions of the country. Of the 5,570 cities, 70% remove at most 30% of the organic load generated.

The ISWT indicator also reached a "very low" level in all the basins surveyed, indicating a deficiency in solid waste collection services. The collection of waste in general is not a guarantee that this waste will receive proper treatment, because despite the goal of closing all dumps in Brazil by 2014 as established by the National Policy on Solid Waste, Brazilian Law no. 12.305/2010, Maranhão is now the second State of Brazil with the largest number of dumps, totaling 250 in operation that are responsible for receiving daily almost three thousand tons of waste (ABRELPE, 2017).

The inappropriate disposal of solid waste has become a worldwide issue and can cause damages to the environment, particularly water pollution. This type of pollution can change the characteristics of the aquatic environment through leachate percolation associated to rainwater and springs in the waste disposal sites (Pires et al., 2016).

As for the IWLN indice, which measures the percentage of physical and billed losses, the level shown in the Mearim, Itapecuru and Parnaíba river basins was "medium". In the Tocantins and Gurupi river basins it was "low" and in the Munim


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river basin it was “high”, above 60%. Elevated levels of loss in water distribution systems have been reported in Northeastern Brazil, including in Maranhão, reaching 60% and 70% (Maranhão, 2014; Araújo et al., 2016).

Except for the basins with low indices, the others are above the national average, which is 37.57% (Brazil, 2016). In addition, all the basins assessed are above the level of water loss considered acceptable by Cambrainha and Fontana (2015), which is 10%.

A survey released by IBNET (International Benchmarking Network for Water and Sanitation Utilities) showed that, in terms of water loss, Brazil ranks 20th in a ranking of 43 countries (Instituto Trata Brasil, 2015). According to the institute, around 6.5 billion cubic meters of treated water were lost in Brazil in 2013, which amounts to a financial loss of 8.015 billion Reais.

The elevated level of loss of water resources observed in this research indicates the fragility and precariousness of the sanitation system and of the companies that operate water supply services in the regions studied. This also results in many problems, not only economic and social, but mainly environmental, since this loss increases the need for exploration of surface and underground sources of water (Morais et al., 2010).

The the low degree of sustainability of WUEI revealed alarming sanitation conditions, such as low coverage of supply by public utilities, poor or non-existent sewage collection and treatment, incipient waste collection and significant losses of water in the distribution network, which reflects the current reality of Maranhão although the data and information refer to 2010.

As for the IPAD, the Indice of Use of Availabilities - IUA for surface waters ranges from 0.02 to 0.028 and 0.44, resulting in “Very High”, “High” and “Medium” levels, respectively. A “Medium” level of sustainability was observed in the Mearim river basin, being the greatest demand considered for irrigation. The “High” level was observed in the Itapecuru river basin, in which the higher demand is mainly used for urban supply. The “Very High” level was seen for the Gurupi river basin, which presents demands for multiple uses, such as urban and rural supply, industry, irrigation and livestock. The assessment of this indicator revealed surplus availabilities in relation to demands, meaning there is no unmet demand.

The indice of use of underground availability evidences demands higher than availability, which results in a “Very Low” level of sustainability in all basins analyzed. Therefore, there is a situation of exhaustion of availability, with repressed demands in all basins, which would imply the need to increase supply by drilling more wells or adopting other measures such as demand rationalization. Currently, the situation is even more critical as demand has been growing mainly for urban supply, industrial use and irrigation.

Specifically, with respect to groundwater, Costa (1994) already observed that its availability was, in general, lower than the total demand in most regions of Northeastern Brazil. Vieira and Gondim Filho (2006), using potentiality, availability and demand indicators in river basins in Northeastern Brazil, classified the groundwater of the Itapecuru, Mearim and Tocantins basins as little sustainable due to the high demands in these regions. Recent articles show that groundwater resources are under increasing pressure in developing regions and in other regions that are more crucial to economic development (Mukherjee et al., 2015; Watto and Mugera, 2015).

The “Very High” IUP levels for surface waters and the “Very High” and “High” IUP levels for underground waters indicates a comfortable situation regarding the use of potentiality of water resources in all basins.


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The IAP indice, on the other hand, showed that water resources are not efficiently available in all basins, especially in relation to groundwater, for which the level obtained in all the basins was "Very Low". As for surface water, the IAP levels ranged from "Very Low" to "Low", meaning that the basins potential is not fully activated.

Relevant information was observed in this research by assessing the IPAD for 2010. On the other hand, it is necessary to calculate such indice with updated data to allow comparisons and to obtain a more current picture on the balance of demand, availability and potentialities of the river basins in the State of Maranhão.

Currently, in the case of surface water, it is already possible to identify conflicts over the use of water in some regions of Maranhão, especially in times of water scarcity. In the Parnaíba river basin, for example, conflicts in the southern region of the State are related to the use of water for irrigation. In the Mearim river basin, in addition to demands for irrigation, there is a growing use of water for intensive and semi-intensive fish farming, associated with illegal abstractions and effluent releases without the authorization from the water resources management authority. In this basin there are also problems with floods, especially in the Pindaré and Grajaú rivers, two important tributaries of the Mearim river. In the Itapecuru river basin, the demand for urban supply stands out because the Italuís system, which supplies a large part of the metropolitan region of São Luís, the state capital, will have its uptake flow doubled by the end of 2018. In addition, deforestation, silting and irregular sand extraction are some of the main environmental problems found in the course of the main river. In recent years, the Tocantins river basin has undergone droughts and significant reductions in the level of the main river and its tributaries, compromising the basin's sustainability, multiple uses of water and also the production of energy, as the basin houses the hydroelectric power plant of Estreito, which has an installed rated capacity of 1,087 MW.

Concerning groundwater, particularly in the metropolitan region of São Luís, there are reports of wells with high levels of salinization. In 2013, there were a total of 462 records of deep wells, distributed by several municipalities of the State (Cunha et al., 2013). Currently, there are more than 11,000 wells drilled (CPRM, 2018), which may indicate a scenario of overexploitation of the aquifers in Maranhão.

## Conclusion

This study presents the application of a methodology that uses river basin sustainability indicators, bringing a contribution to the related literature, in particular to water resources management in terms of diagnosis of sustainability and support to planning and decision making. Sustainability indicators were used in the context of river basins, analyzing surface and underground waters when possible, since water resources are part of an integrated whole that has great relevance in the constitution of life and in a balanced ecosystem.

The application of the methodology to the basins of the state of Maranhão, located in Northeastern Brazil, determined sustainability with an overall intermediate performance in the river basins assessed in this research. These basins require priority measures in the hydrological dimension, especially for underground waters; attention to basic sanitation, including with regard to public supply; reduction of demands and waste; in addition to proper sewage collection and treatment. The results also highlighted the need to improve the state water management system, with actions oriented to the


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implementation and consolidation of the water resources policy instruments and promotion and support to river basin committees.

The spatialization of the indicators enables a clearer view of the water sustainability of the basins in Maranhão, so that all concepts regarding the performance of the water management structure, efficient use of available water as well as potentialities, availability and water demands could be unequivocally considered.

The application of this methodology may be a model for the assessment of other river basins, especially with conditions similar to the ones evaluated in this study. This tool, provided it is regularly applied, can provide an appropriate description of the evolution of basin conditions in terms of sustainability, assisting different stakeholders and water managers in the planning, decision-making and implementation of local strategies for sustainable development. Authors such as Corrêa and Teixeira (2006) recommend that sustainability indicators are annually applied to observe their evolution and to evaluate the effectiveness of the actions proposed from the surveys of the previous period.

Carvalho et al. (2011) have shown that the adoption of an average value as a measure to build the sustainability indice may be an area of weakness, which may represent a fragility in this study. Another difficulty found when conducting this research was the scarce availability of data in most of the state river basins, a fact that prevented the inclusion of other basins in this analysis and limited the assessment of more indicators.

However, we may conclude that these results were satisfactory and are applicable in regions with scarce data. Consideration was given to variables that fulfill the main components of sustainability, with social, economic, hydro-environmental and institutional characteristics, despite their incommensurability and the complexity of grouping information from indicators of such diverse nature, in particular in places where data availability is scarce. In addition, the aspects of the indicators used here allowed the joint and separate analysis of each dimension. This allows a unique look at the most critical issues of each basin, so as to act correctively and/or preventively to solve the main negative items.

The bottlenecks and limitations identified in this study represent a window of opportunity to improve the current situation in the basins, but it requires a more efficient coordination between the different institutions involved in water resources management.

In this specific application in river basins in the Northeastern part of Brazil, the results are particularly relevant, since there is a considerable gap in the literature on the integrated management of water resources for this region, and especially in the state of Maranhão, which can support more sustainable management actions.

As for future studies, it is recommended that researches shall be carried out on the potentialities, availabilities as well as superficial and underground water demands, by river basin, portraying the current reality of water resources in the State. It is also recommended that other studies shall be carried out to address the issue of water sustainability indicators at the site, including a greater number of indicators that consider other water sustainability criteria.

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## APPENDIX

***Annex 1.*** *Data used for the calculation of WUEI indices by municipality of River basin Mearim, State of Maranhão*

| Municipality | Total number of households | % households supplied by wells | % households supplied by a water supply system | % households with a sewage network or a septic tank | % households with sewage treatment | % households with waste collection | Average percentage of physical losses water in the network |
|---|---|---|---|---|---|---|---|
| Açailândia | 27,473 | 20.28 | 76.55 | 95.95 | 43.02 | 86.98 | 60.19 |
| Altamira do Maranhão | 2,632 | 30.01 | 51.13 | 76.75 | 0 | 17.04 | 51.23 |
| Alto Alegre do Pindaré | 7,282 | 23.05 | 76.79 | 78.97 | 28.44 | 25.39 | 68.7 |
| Amarante do Maranhão | 9,267 | 39.05 | 57.45 | 58.25 | 18.31 | 33.19 | 55.02 |
| Anajatuba | 6,503 | 46.71 | 42.77 | 59.16 | 19.15 | 14.01 | 55.71 |
| Araguanã | 3,051 | 62.3 | 37.05 | 81.02 | 0 | 46.39 | 64.51 |
| Arame | 6,961 | 58.44 | 38.37 | 51.02 | 15.49 | 41.02 | 7.6 |
| Arari | 6,915 | 25.76 | 66.8 | 71 | 17.41 | 45.2 | 11 |
| Bacabal | 26,215 | 15.11 | 81.15 | 76.37 | 68.98 | 65.71 | 48.64 |
| Bacabeira | 3,660 | 19.2 | 72.54 | 69.8 | 69.55 | 39.93 | 79.04 |
| Barra do Corda | 21,597 | 31.76 | 58.53 | 65.45 | 45.11 | 50.71 | 68.34 |


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| Municipality | Total number of households | % households supplied by wells | % households supplied by a water supply system | % households with a sewage network or a septic tank | % households with sewage treatment | % households with waste collection | Average percentage of physical losses water in the network |
|---|---|---|---|---|---|---|---|
| Bela Vista do Maranhão | 2,979 | 29.31 | 69.39 | 84.69 | 41 | 22.58 | 0 |
| Bernardo do Mearim | 1,496 | 59.93 | 38.24 | 66.01 | 6.98 | 40.59 | 86.88 |
| Bom Jardim | 9,610 | 36.46 | 58.79 | 75.82 | 51.12 | 27.14 | 74.14 |
| Bom Jesus das Selvas | 6,220 | 52.74 | 43.19 | 53.33 | 35.8 | 24.1 | 67.86 |
| Bom Lugar | 3,514 | 67.71 | 29.05 | 59.51 | 43.09 | 14.89 | 0 |
| Brejo de Areia | 1,276 | 55.66 | 41.24 | 52.26 | 11.22 | 3.44 | 0 |
| Buriticupu | 14,968 | 19.03 | 76.75 | 82.54 | 0 | 27.72 | 86.01 |
| Buritirana | 3,778 | 16.82 | 82.77 | 87.59 | 7.12 | 34.29 | 2.86 |
| Cajapió | 2,594 | 73.65 | 25.31 | 67.07 | 8.97 | 0.76 | 82 |
| Cajari | 4,306 | 75.22 | 16.85 | 52.14 | 21.1 | 11.67 | 91.17 |
| Capinzal do Norte | 2,884 | 31.61 | 66.72 | 59.54 | 44.63 | 24.49 | 0 |
| Centro Novo do Maranhão | 3,951 | 79.42 | 10.45 | 66.02 | 22.43 | 8.08 | 0 |
| Conceição do Lago Açú | 3,336 | 32.04 | 61.52 | 41.04 | 11.05 | 20.96 | 61.91 |
| Dom Pedro | 6,208 | 16.8 | 76.59 | 75.44 | 0 | 69.06 | 62.4 |
| Esperantinópolis | 4,806 | 25.34 | 70.39 | 67.81 | 15.18 | 53.26 | 69.81 |
| Fernando Falcão | 1,883 | 68.16 | 15.53 | 30.61 | 33.13 | 3.88 | 0 |
| Formosa da Serra Negra | 3,884 | 60.21 | 34.59 | 38.32 | 18.02 | 2598 | 0 |
| Governador Newton Bello | 2,831 | 63.91 | 34.84 | 65.48 | 11.3 | 22.22 | 56.18 |
| Grajaú | 14,913 | 23.06 | 72.3 | 63.49 | 39.01 | 58.59 | 9.46 |
| Igarapé do Meio | 3,022 | 29.91 | 64.5 | 49.65 | 14.32 | 3.01 | 0 |
| Igarapé Grande | 2,853 | 38.84 | 60.73 | 62.1 | 10.37 | 62.2 | 66.68 |
| Itaipava do Grajaú | 3,293 | 20.75 | 70.41 | 55.46 | 0 | 24.33 | 0 |
| Jenipapo dos Vieiras | 3,636 | 61.8 | 31.59 | 51.81 | 0 | 6.16 | 20.73 |
| João Lisboa | 5,407 | 15.27 | 84.13 | 92.42 | 31.7 | 53.58 | 72.45 |
| Joselândia | 3,913 | 19.08 | 77.34 | 58.98 | 12.39 | 17.81 | 53.43 |
| Lago da Pedra | 11,463 | 77.38 | 18.62 | 84.37 | 5.4 | 73.25 | 62.69 |
| Lago do Junco | 2,594 | 86.84 | 11.59 | 50.85 | 12.35 | 17.85 | 79.38 |
| Lago dos Rodrigues | 2,060 | 69.21 | 28.88 | 74.59 | 0 | 43.54 | 0 |
| Lago Verde | 3,684 | 46.78 | 47.5 | 48.19 | 9.33 | 18.75 | 78.55 |
| Lagoa Grande do Maranhão | 2,407 | 33.09 | 52.36 | 65.03 | 3.47 | 37.85 | 0 |
| Lima Campos | 3,185 | 34.61 | 61.72 | 67.67 | 7.06 | 53.55 | 65.23 |
| Marajá do Sena | 1,759 | 90.47 | 7.28 | 20.62 | 2 | 7.45 | 0 |
| Matinha | 5,579 | 62.68 | 37.15 | 88.9 | 13.9 | 27.22 | 74.5 |
| Matões do Norte | 2,519 | 23.82 | 45.32 | 33.35 | 10.7 | 16.99 | 81.44 |
| Miranda do Norte | 5,196 | 17.73 | 76.85 | 51.83 | 5.44 | 55.57 | 61.74 |
| Monção | 7,470 | 48.44 | 37.4 | 55.25 | 15.76 | 1.62 | 88.59 |
| Montes Altos | 2,381 | 37.69 | 61.42 | 59.23 | 6.32 | 48.48 | 48.91 |
| Olho D'água das Cunhãs | 4,857 | 55.91 | 39.19 | 64.31 | 31.4 | 18.07 | 91.14 |
| Olinda Nova do Maranhão | 3,264 | 44.54 | 52.9 | 48.2 | 8.22 | 26.26 | 0 |
| Paulo Ramos | 4,746 | 66.76 | 27.89 | 65.16 | 5.69 | 38.41 | 89.77 |
| Pedreiras | 10,630 | 16.83 | 78.79 | 59.18 | 9.13 | 66.3 | 72.43 |
| Pedro do Rosário | 5,294 | 94.78 | 3.71 | 75.69 | 5.06 | 13.5 | 0 |
| Penalva | 7,889 | 57.44 | 38.14 | 71.56 | 14.65 | 8.47 | 69.63 |
| Peritoró | 5,593 | 47.32 | 51.55 | 40.94 | 4.31 | 17.66 | 73.42 |
| Pindaré-Mirim | 7,750 | 6.25 | 92.38 | 76.66 | 6.38 | 53.35 | 61.53 |
| Pio XII | 5,399 | 26.09 | 60.02 | 63.4 | 31.49 | 34.9 | 50 |
| Poção de Pedras | 5,309 | 72.49 | 26.76 | 64.2 | 7.22 | 38.07 | 73.61 |
| Presidente Dutra | 11,923 | 2.17 | 95.99 | 83.81 | 13.11 | 59.37 | 58.84 |
| Santa Filomena do Maranhão | 1,753 | 12.26 | 82.3 | 15.18 | 0 | 0.97 | 73.17 |
| Santa Inês | 20,264 | 4.52 | 93.9 | 78.75 | 58.77 | 77.33 | 65.09 |
| Santa Luzia | 17,466 | 48.62 | 44.21 | 50.36 | 44.36 | 9.67 | 69.53 |


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| Municipality | Total number of households | % households supplied by wells | % households supplied by a water supply system | % households with a sewage network or a septic tank | % households with sewage treatment | % households with waste collection | Average percentage of physical losses water in the network |
|---|---|---|---|---|---|---|---|
| Santa Rita | 7.887 | 46.53 | 51.45 | 62.85 | 22.47 | 17.37 | 69.37 |
| Santo Antônio dos Lopes | 3,708 | 44.49 | 51.05 | 52.87 | 32.25 | 38.24 | 73.1 |
| São Francisco do Brejão | 2,672 | 24.97 | 73.93 | 81.69 | 11.78 | 63.08 | 18.28 |
| São João Batista | 5,069 | 50.51 | 20.91 | 71.92 | 0 | 7.46 | 98.06 |
| São João do Carú | 2,615 | 54.19 | 39.85 | 71.96 | 0 | 24.76 | 0 |
| São José dos Basílios | 1,870 | 35.92 | 59.66 | 46.49 | 3.09 | 13.34 | 79.57 |
| São Luís Gonzaga do Maranhão | 5,236 | 54.74 | 34.57 | 47.08 | 17.03 | 13.43 | 96.4 |
| São Mateus do Maranhão | 9,818 | 41.44 | 55.56 | 78.08 | 12.28 | 60.14 | 67.82 |
| São Raimundo do Doca Bezerra | 1,397 | 26.82 | 46.35 | 59.35 | 2.75 | 42.18 | 0 |
| São Roberto | 1,317 | 39.3 | 60.14 | 46.73 | 0 | 41.37 | 0 |
| São Vicente Férrer | 5,131 | 76.29 | 20.65 | 54.49 | 17.03 | 12.06 | 74.34 |
| Satubinha | 2,491 | 33.33 | 65.27 | 53.44 | 21 | 13.95 | 82.49 |
| Senador La Rocque | 4,530 | 9.14 | 90.4 | 74.2 | 12.86 | 41.02 | 76.62 |
| Sítio Novo | 4,097 | 49.76 | 41.02 | 45.08 | 8.9 | 41.49 | 0 |
| Trizidela do Vale | 5,101 | 13.55 | 80.29 | 70.08 | 6.97 | 68.6 | 73.6 |
| Tufilândia | 1,373 | 38.99 | 59 | 50.03 | 33 | 1.34 | 8.46 |
| Tuntum | 10,440 | 16.01 | 77.24 | 74.13 | 11.78 | 60.43 | 73.4 |
| Viana | 12,347 | 58.28 | 31.78 | 78.97 | 13.2 | 34.13 | 14.23 |
| Vitória do Mearim | 7,547 | 15.59 | 81.56 | 89.32 | 10.77 | 35.83 | 93.92 |
| Vitorino Freire | 8,222 | 57.92 | 40.64 | 80.24 | 8.05 | 40.64 | 80.73 |
| Zé Doca | 11,887 | 48.96 | 48.48 | 71.96 | 9.56 | 48.76 | 71.39 |

***Annex 2.*** *Data used for the calculation of WUEI indices by municipality of River basin Itapecuru, State of Maranhão*

| Municipality | Total number of households | % households supplied by wells | % households supplied by a water supply system | % households with a sewage network or a septic tank | % households with sewage treatment | % households with waste collection | Average percentage of physical losses water in the network |
|---|---|---|---|---|---|---|---|
| Aldeias Altas | 5,795 | 67.64 | 24.74 | 35.63 | 4.7 | 19.2 | 83.2 |
| Alto Alegre do Maranhão | 7,282 | 26.6 | 72.08 | 77.64 | 33.21 | 47.82 | 75.51 |
| Arari | 6,915 | 25.76 | 66.8 | 71 | 17.41 | 45.2 | 20 |
| Axixá | 2,542 | 57.3 | 38.45 | 53.8 | 12 | 11.02 | 54.63 |
| Bacabal | 26,215 | 15.11 | 81.15 | 76.37 | 68.98 | 65.71 | 48.64 |
| Bacabeira | 3,660 | 19.2 | 72.54 | 69.8 | 69.55 | 39.93 | 79.04 |
| Buriti Bravo | 5,702 | 28.86 | 61.81 | 51.66 | 0 | 16.46 | 73.34 |
| Cantanhede | 4,713 | 25.96 | 67.63 | 56.21 | 10.03 | 31.63 | 38.75 |
| Capinzal do Norte | 2,884 | 31.61 | 66.72 | 59.54 | 44.63 | 24.49 | 0 |
| Caxias | 40,172 | 21.18 | 75.41 | 65.12 | 47.21 | 55.41 | 60.28 |
| Codó | 29,594 | 28.89 | 69.8 | 60.89 | 34.76 | 64.78 | 33.05 |
| Colinas | 9,855 | 42.27 | 51.01 | 60.43 | 31.27 | 30.56 | 82.89 |
| Coroatá | 15,930 | 23.62 | 72.4 | 57.89 | 7.2 | 50.36 | 73.6 |
| Dom Pedro | 6,208 | 16.8 | 76.59 | 75.44 | 0 | 69.06 | 62.4 |
| Fernando Falcão | 1,883 | 68.16 | 15.53 | 30.61 | 33.13 | 3.88 | 0 |
| Formosa da Serra Negra | 3,884 | 60.21 | 34.59 | 38.32 | 18.02 | 25.98 | 0 |
| Fortuna | 3,926 | 10.46 | 68.69 | 84.55 | 4.34 | 42.11 | 72.69 |
| Gonçalves Dias | 4,558 | 34.34 | 61.9 | 52.12 | 12.11 | 37.13 | 66.08 |
| Governador Archer | 2,582 | 15.02 | 84.31 | 70.88 | 8.32 | 55.68 | 30.34 |
| Governador Eugênio Barros | 4,093 | 18.22 | 79.73 | 57.3 | 0 | 29.16 | 91 |
| Governador Luiz Rocha | 1,891 | 6.37 | 91.65 | 56.3 | 6 | 4.3 | 81.4 |


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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Graça Aranha | 1,696 | 2.24 | 96.99 | 83.11 | 17.34 | 44.47 | 79.56 |
| Itapecuru Mirim | 15,710 | 37.56 | 58.52 | 63.79 | 15.24 | 34.1 | 58.43 |
| Jatobá | 2,139 | 8.71 | 89.45 | 99.61 | 0 | 3.68 | 81.56 |
| Lagoa do Mato | 2,687 | 26.04 | 65.9 | 50.72 | 1.98 | 15 | 5.29 |
| Lima Campos | 3,185 | 34.61 | 61.72 | 67.67 | 7.06 | 53.55 | 65.23 |
| Loreto | 2,669 | 33.14 | 61.47 | 66.57 | 3.44 | 45.18 | 73.79 |
| Matões | 7,598 | 50.42 | 46.62 | 55.4 | 4.47 | 13.12 | 0 |
| Matões do Norte | 2,519 | 23.82 | 45.32 | 33.35 | 10.7 | 16.99 | 81.44 |
| Mirador | 4,894 | 8.05 | 86.67 | 74.84 | 11 | 55.02 | 59.97 |
| Miranda do Norte | 5,196 | 17.73 | 76.85 | 51.83 | 5.44 | 55.57 | 61.74 |
| Paraibano | 5,291 | 12.25 | 82.67 | 69.25 | 5.91 | 61.72 | 65.63 |
| Parnarama | 8,654 | 42.91 | 53.17 | 51.89 | 0 | 22.42 | 20 |
| Passagem Franca | 4,562 | 12.83 | 85.08 | 52.95 | 7.54 | 32.3 | 0 |
| Pastos Bons | 4,694 | 20.48 | 76.59 | 68.26 | 14.65 | 50.91 | 18.94 |
| Peritoró | 5,593 | 47.32 | 51.55 | 40.94 | 4.31 | 17.66 | 73.42 |
| Pirapemas | 4,157 | 38.08 | 54.68 | 56.76 | 9.3 | 22.84 | 80.92 |
| Presidente Juscelino | 2,495 | 70.87 | 23.94 | 43.18 | 4.87 | 8.09 | 83.01 |
| Rosário | 9,448 | 28.22 | 64.07 | 71.15 | 19.07 | 49.23 | 56.65 |
| Sambaíba | 1,370 | 55.31 | 40.79 | 48.05 | 12.37 | 3.14 | 88.52 |
| Santa Rita | 7,887 | 46.53 | 51.45 | 62.85 | 22.47 | 17.37 | 69.37 |
| Santo Antônio dos Lopes | 3,708 | 44.49 | 51.05 | 52.87 | 32.25 | 38.24 | 73.1 |
| São Domingos do Azeitão | 1,679 | 38.58 | 57.33 | 79.04 | 9.44 | 49.84 | 46.6 |
| São Domingos do Maranhão | 8,853 | 26.53 | 65.06 | 74.81 | 13.2 | 32.9 | 79.46 |
| São Félix de Balsas | 1,213 | 85.31 | 10.16 | 46.46 | 5.87 | 10.93 | 91 |
| São Francisco do Maranhão | 3,289 | 51.58 | 39.24 | 22.62 | 0.87 | 15.62 | 43.81 |
| São João do Soter | 4,268 | 46.48 | 50.14 | 37.15 | 1.23 | 1.94 | 15.38 |
| São João dos Patos | 7,007 | 12.95 | 84.42 | 77.28 | 7.26 | 56.35 | 65.36 |
| São Luís Gonzaga do Maranhão | 5,236 | 54.74 | 34.57 | 47.08 | 17.03 | 13.43 | 96.4 |
| São Mateus do Maranhão | 9,818 | 41.44 | 55.56 | 78.08 | 12.28 | 60.14 | 67.82 |
| São Raimundo das Mangabeiras | 4,443 | 32.37 | 61.87 | 47.11 | 14.09 | 50.06 | 49.24 |
| Senador Alexandre Costa | 2,573 | 91.26 | 6.65 | 62.48 | 13.54 | 23.33 | 0 |
| Sucupira do Norte | 2,696 | 24.07 | 62.91 | 63.69 | 0 | 19.08 | 92 |
| Timbiras | 6,549 | 44.28 | 41.02 | 47.73 | 8.51 | 13.11 | 58.76 |
| Timon | 40,477 | 11.76 | 85.55 | 80.01 | 48.93 | 71.1 | 43.98 |
| Tuntum | 10,440 | 16.01 | 77.24 | 74.13 | 11.78 | 60.43 | 73.4 |
| Turiaçu | 7,784 | 83.09 | 12.93 | 65.81 | 5.87 | 15.1 | 15.8 |
| Vargem Grande | 11,100 | 48.39 | 37.43 | 41.96 | 14 | 14.7 | 69.13 |

***Annex 3.*** *Data used for the calculation of WUEI indices by municipality of River basin Parnaíba, State of Maranhão*

| **Municipality** | **Total number of households** | **% households supplied by wells** | **% households supplied by a water supply system** | **% households with a sewage network or a septic tank** | **% households with sewage treatment** | **% households with waste collection** | **Average percentage of physical losses water in the network** |
|---|---|---|---|---|---|---|---|
| Água Doce do Maranhão | 2,730 | 71.45 | 26.72 | 60.47 | 3.97 | 16.11 | 0 |
| Alto Parnaíba | 2,647 | 37.9 | 59.16 | 31.69 | 12.22 | 33.2 | 29.09 |
| Anapurus | 3,328 | 37.32 | 57.69 | 50.31 | 5.88 | 12.9 | 68.19 |
| Araioses | 10,241 | 82.89 | 12.47 | 58.98 | 7.39 | 11.49 | 81.31 |
| Balsas | 21,310 | 32.57 | 65.47 | 75.37 | 43.2 | 73.95 | 28.69 |
| Barão de Grajaú | 4,735 | 22.75 | 66.38 | 46.79 | 0 | 41.51 | 79.9 |
| Barreirinhas | 12,162 | 72.16 | 21.27 | 77.99 | 15.43 | 19.17 | 71.43 |
| Benedito Leite | 1,424 | 15.4 | 70.01 | 51.19 | 1.54 | 41.67 | 74.21 |
| Brejo | 7,953 | 51.7 | 40.73 | 26.18 | 0 | 3.47 | 91.67 |


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| Municipality | Total number of households | % households supplied by wells | % households supplied by a water supply system | % households with a sewage network or a septic tank | % households with sewage treatment | % households with waste collection | Average percentage of physical losses water in the network |
|---|---|---|---|---|---|---|---|
| Buriti | 6,044 | 66.7 | 22.84 | 26.24 | 13.74 | 8.38 | 80.64 |
| Caxias | 40,172 | 21.18 | 75.41 | 65.12 | 47.21 | 55.41 | 60.28 |
| Coelho Neto | 11,110 | 20 | 72.15 | 79.03 | 4.21 | 48.13 | 85.52 |
| Duque Bacelar | 2,387 | 53.57 | 45.72 | 39.12 | 11.65 | 12.23 | 73.51 |
| Feira Nova do Maranhão | 1,988 | 80.2 | 18.62 | 46.7 | 0 | 27.64 | 0 |
| Fortaleza dos Nogueiras | 2,851 | 48.29 | 44.98 | 49.57 | 9.11 | 46.6 | 53.78 |
| Lagoa do Mato | 2,687 | 26.04 | 65.9 | 50.72 | 1.98 | 15 | 5.29 |
| Loreto | 2,669 | 33.14 | 61.47 | 66.57 | 3.44 | 45.18 | 73.79 |
| Magalhães de Almeida | 4,033 | 16.3 | 77.21 | 66.76 | 18.12 | 41.29 | 74.89 |
| Matões | 7,598 | 50.42 | 46.62 | 55.4 | 4.47 | 13.12 | 0 |
| Milagres do Maranhão | 1,800 | 51.97 | 40.79 | 32.76 | 10.54 | 10.75 | 0 |
| Nova Colinas | 1,186 | 40.49 | 50.08 | 50.79 | 12.2 | 29.08 | 13 |
| Nova Iorque | 1,202 | 40.56 | 55.44 | 46.26 | 0 | 26.68 | 67.05 |
| Parnarama | 8,654 | 42.91 | 53.17 | 51.89 | 0 | 22.42 | 20 |
| Passagem Franca | 4,562 | 12.83 | 85.08 | 52.95 | 7.54 | 32.3 | 0 |
| Pastos Bons | 4,694 | 20.48 | 76.59 | 68.26 | 14.65 | 50.91 | 18.94 |
| Riachão | 5,277 | 46.77 | 51.98 | 55.05 | 16 | 43.46 | 68.3 |
| Sambaíba | 1,370 | 55.31 | 40.79 | 48.05 | 12.37 | 3.14 | 88.52 |
| Santa Quitéria do Maranhão | 6,364 | 57.57 | 41.17 | 45.71 | 6.73 | 26.92 | 71.9 |
| Santana do Maranhão | 2,500 | 9.85 | 89.71 | 56.26 | 23.4 | 5.94 | 0 |
| São Bernardo | 6,289 | 53.19 | 37.31 | 57.56 | 12.66 | 25.69 | 49.07 |
| São Domingos do Azeitão | 1,679 | 38.58 | 57.33 | 79.04 | 9.44 | 49.84 | 46.6 |
| São Félix de Balsas | 1,213 | 85.31 | 10.16 | 46.46 | 5.87 | 10.93 | 91 |
| São Francisco do Maranhão | 3,289 | 51.58 | 39.24 | 22.62 | 0.87 | 15.62 | 43.81 |
| São João dos Patos | 7,007 | 12.95 | 84.42 | 77.28 | 7.26 | 56.35 | 65.36 |
| São Raimundo das Mangabeiras | 4,443 | 32.37 | 61.87 | 47.11 | 14.09 | 50.06 | 49.24 |
| Sucupira do Riachão | 1,213 | 22.97 | 72.83 | 56.26 | 9.45 | 0.07 | 42.18 |
| Tasso Fragoso | 1,935 | 35.77 | 62.19 | 55.13 | 13.04 | 55.13 | 59.97 |
| Timon | 40,477 | 11.76 | 85.55 | 80.01 | 71.1 | 71.1 | 43.98 |
| Tutóia | 11,344 | 66.54 | 27.64 | 53.86 | 20.65 | 14.92 | 27.7 |

***Annex 4.*** *Data used for the calculation of WUEI indices by municipality of River basin Tocantins, State of Maranhão*

| Municipality | Total number of households | % households supplied by wells | % households supplied by a water supply system | % households with a sewage network or a septic tank | % households with sewage treatment | % households with waste collection | Average percentage of physical losses water in the network |
|---|---|---|---|---|---|---|---|
| Açailândia | 27,473 | 20.28 | 76.55 | 95.95 | 43.02 | 86.98 | 60.19 |
| Buritirana | 3,778 | 16.82 | 82.77 | 87.59 | 7.12 | 34.29 | 2.86 |
| Campestre do Maranhão | 3,529 | 8.13 | 91.44 | 89.4 | 6.31 | 68.43 | 0 |
| Carolina | 6,284 | 24.2 | 68.31 | 55.83 | 16.98 | 53.43 | 51 |
| Cidelândia | 3,515 | 19.2 | 80.19 | 84.62 | 0 | 45.89 | 53.6 |
| Davinópolis | 3,326 | 38.85 | 60.6 | 69.83 | 0 | 27.99 | 75.66 |
| Estreito | 9,117 | 22.52 | 76.17 | 61.4 | 11.6 | 70.77 | 0 |
| Feira Nova do Maranhão | 1,988 | 80.2 | 18.62 | 46.7 | 0 | 27.64 | 0 |
| Governador Edison Lobão | 4,243 | 18.67 | 80.12 | 80.07 | 17.09 | 67.67 | 0 |
| Igarapé Grande | 2,853 | 38.84 | 60.73 | 62.1 | 10.37 | 62.2 | 66.68 |
| Imperatriz | 68,537 | 6.32 | 93.29 | 67.83 | 56.34 | 89.22 | 71.59 |
| João Lisboa | 5,407 | 15.27 | 84.13 | 92.42 | 31.7 | 53.58 | 72.45 |


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| Municipality | Total number of households | % households supplied by wells | % households supplied by a water supply system | % households with a sewage network or a septic tank | % households with sewage treatment | % households with waste collection | Average percentage of physical losses water in the network |
|---|---|---|---|---|---|---|---|
| Lajeado Novo | 1,825 | 36.12 | 56.77 | 48.79 | 6.74 | 44.77 | 0 |
| Montes Altos | 2,381 | 37.69 | 61.42 | 59.23 | 6.32 | 48.48 | 48.91 |
| Porto Franco | 5,638 | 20.23 | 79.71 | 90.11 | 13.21 | 78.49 | 27.26 |
| Riachão | 5,277 | 46.77 | 51.98 | 55.05 | 16 | 43.46 | 68.3 |
| Ribamar Fiquene | 1,899 | 39.28 | 59.13 | 73.32 | 12 | 59.28 | 0 |
| São Francisco do Brejão | 2,672 | 24.97 | 73.93 | 81.69 | 11.78 | 63.08 | 18.28 |
| São João do Paraíso | 2,876 | 37.42 | 58.11 | 56.57 | 14.71 | 42.88 | 9.09 |
| São Pedro da Água Branca | 3,017 | 24.47 | 72.84 | 87.38 | 9.43 | 57.46 | 81.37 |
| São Pedro dos Crentes | 1,105 | 45.65 | 54.17 | 55.84 | 7.52 | 50.31 | 0 |
| Senador La Rocque | 4,530 | 9.14 | 90.4 | 74.2 | 12.86 | 41.02 | 76.62 |
| Serrano do Maranhão | 2,734 | 53.35 | 31.98 | 75.84 | 7 | 1.07 | 0 |
| Sítio Novo | 4.097 | 49.76 | 41.02 | 45.08 | 3.65 | 41.49 | 0 |
| Vila Nova dos Martírios | 2.728 | 17.76 | 75.3 | 90.7 | 0 | 71.51 | 0 |

***Annex 5.*** *Data used for the calculation of WUEI indices by municipality of River basin Munim, State of Maranhão*

| Municipality | Total number of households | % households supplied by wells | % households supplied by a water supply system | % households with a sewage network or a septic tank | % households with sewage treatment | % households with waste collection | Average percentage of physical losses water in the network |
|---|---|---|---|---|---|---|---|
| Afonso Cunha | 1,301 | 51.53 | 42.04 | 46.18 | 11.53 | 50.25 | 83.2 |
| Aldeias Altas | 5,795 | 67.64 | 24.74 | 35.63 | 4.7 | 19.2 | 83.2 |
| Anapurus | 3,328 | 37.32 | 57.69 | 50.31 | 5.88 | 12.9 | 68.19 |
| Axixá | 2,542 | 57.3 | 38.45 | 53.8 | 12 | 11.02 | 54.63 |
| Belágua | 1,263 | 40.71 | 41.64 | 58.67 | 0 | 0.12 | 25 |
| Brejo | 7,953 | 51.7 | 40.73 | 26.18 | 0 | 3.47 | 91.67 |
| Buriti | 6,044 | 66.7 | 22.84 | 26.24 | 13.74 | 8.38 | 80.64 |
| Cachoeira Grande | 1,763 | 78.87 | 10.75 | 40.11 | 5.67 | 5.96 | 60 |
| Caxias | 40,172 | 21.18 | 75.41 | 65.12 | 47.21 | 55.41 | 60.28 |
| Chapadinha | 17,658 | 45.74 | 40.14 | 71.77 | 16.87 | 30.52 | 52.35 |
| Codó | 29,594 | 28.89 | 69.8 | 60.89 | 34.76 | 64.78 | 33.05 |
| Coelho Neto | 11,110 | 20 | 72.15 | 79.03 | 4.21 | 48.13 | 85.52 |
| Duque Bacelar | 2,387 | 53.57 | 45.72 | 39.12 | 11.65 | 12.23 | 73.51 |
| Icatu | 5,782 | 81.46 | 14.68 | 51.66 | 17 | 11.6 | 70.58 |
| Itapecuru Mirim | 15,710 | 37.56 | 58.52 | 63.79 | 15.24 | 34.1 | 58.43 |
| Mata Roma | 3,537 | 19.81 | 76.12 | 65.96 | 12.23 | 14.94 | 71.56 |
| Milagres do Maranhão | 1,800 | 51.97 | 40.79 | 32.76 | 10.54 | 10.75 | 0 |
| Morros | 3,774 | 46.94 | 33.42 | 44.58 | 7.32 | 19.79 | 78.75 |
| Nina Rodrigues | 2,541 | 75 | 22.56 | 75.56 | 13.17 | 13.43 | 73.9 |
| Presidente Juscelino | 2,495 | 70.87 | 23.94 | 43.18 | 4.87 | 8.09 | 83.01 |
| Presidente Vargas | 2,514 | 85.8 | 6.47 | 31.57 | 0 | 4.2 | 97 |
| Santa Quitéria do Maranhão | 6,364 | 57.57 | 41.17 | 45.71 | 6.73 | 26.92 | 71.9 |
| Santa Rita | 7,887 | 46.53 | 51.45 | 62.85 | 22.47 | 17.37 | 69.37 |
| São Benedito do Rio Preto | 3,918 | 62.17 | 31.1 | 77.57 | 0 | 3.68 | 97 |
| Timbiras | 6,549 | 44.28 | 41.02 | 47.73 | 8.51 | 13.11 | 58.76 |
| Urbano Santos | 5,324 | 55.72 | 26.8 | 59.12 | 6 | 13.49 | 74.35 |
| Vargem Grande | 11,100 | 48.39 | 37.43 | 41.96 | 14 | 14.7 | 69.13 |


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***Annex 6.*** *Data used for the calculation of WUEI indices by municipality of River basin Gurupi, State of Maranhão*

| Municipality | Total number of households | % households supplied by wells | % households supplied by a water supply system | % households with a sewage network or a septic tank | % households with sewage treatment | % households with waste collection | Average percentage of physical losses water in the network |
|---|---|---|---|---|---|---|---|
| Açailândia | 27,473 | 20.28 | 76.55 | 95.95 | 43.02 | 86.98 | 60.19 |
| Amapá do Maranhão | 1,504 | 19.73 | 75.05 | 90.62 | 10.12 | 22.06 | 0 |
| Boa Vista do Gurupi | 1,812 | 96.05 | 2.83 | 74.5 | 4.57 | 40.89 | 0 |
| Carutapera | 5,078 | 61.14 | 33.76 | 32.69 | 20.3 | 21.8 | 60.07 |
| Centro do Guilherme | 2,593 | 72.19 | 26.17 | 65.65 | 2.33 | 32.15 | 0 |
| Centro Novo do Maranhão | 3,951 | 79.42 | 10.45 | 66.02 | 22.43 | 8.08 | 0 |
| Cidelândia | 3,515 | 19.2 | 80.19 | 84.62 | 0 | 45.89 | 53.6 |
| Itinga do Maranhão | 6,601 | 18.93 | 78.14 | 89.5 | 13 | 68.9 | 49.57 |
| João Lisboa | 5,407 | 15.27 | 84.13 | 92.42 | 31.7 | 53.58 | 72.45 |
| Junco do Maranhão | 988 | 51.61 | 46.53 | 89.14 | 8.77 | 29.59 | 0 |
| Maracaçumé | 4,605 | 59.55 | 30.12 | 53.93 | 6.25 | 56.23 | 25.67 |
| São Francisco do Brejão | 2,672 | 24.97 | 73.93 | 81.69 | 11.78 | 63.08 | 18.28 |
| São João do Carú | 2,615 | 54.19 | 39.85 | 71.96 | 0 | 24.76 | 0 |


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