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Sustainability index in the municipal district of the Marapanim river watershed (Pará/Brazil)

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Abstract

Objective: The present study applies the water sustainability index to municipal seats belonging to the Marapanim river basin, aiming to assess the management of these cities through Pressure-State-Response (PSR) indicators.
Methodology: The applied water sustainability index, derived from Chaves and Alipaz (2007), proposes key indicators (Hydrology, Environment, Life, and Policy), structured and evaluated according to the Pressure-State-Response matrix.
Relevance: The Indicators of Pressure-State-Response, formulated by the Organization for Economic Cooperation and Development (OECD), have a great potential for application in the management of water resources and construction of policies for resolving conflicts over water use.
Results: The municipal offices of Castanhal, Igarapé-Açu, Marapanim, and Terra Alta obtained a sustainability index of 0.40; 0.50; 0.44; 0.54 and 0.5 respectively (Regular), and São Francisco do Pará achieved a result of 0.54 (Good). Despite being in the same watershed, each had its particular response in the PSR matrix, with weaknesses in common, especially in hydrologic and environmental indicators.
Theoretical contributions: The principal contribution is to support the formulation of public policies capable of representing reality the reality of the watersheds associated with more effective action recovery, conservation, and preservation of priority areas.
Management contributions: The contribution lies in the integration of various indicators (hydrological, environmental, policy, and life) that represent the needs of each water territory, supporting the decision-making of public managers.

Keywords: Indicators. Management. Water resources. Water territory. Uses of water.

Índice de sustentabilidade nas sedes municipais da bacia hidrográfica do rio Marapanim (Pará/Brasil)

Resumo

Objetivo: O presente estudo aplica o índice de sustentabilidade hídrica às sedes municipais pertencentes à bacia hidrográfica do rio Marapanim, visando avaliar a gestão dessas cidades por meio dos indicadores de Pressão-Estado-Resposta (PER).
Metodologia: O índice de sustentabilidade hídrica aplicado, derivado da metodologia de Chaves e Alipaz (2007), propõe indicadores-chave (Hidrológico, Ambiental, Social e Político), que foram estruturados e avaliados segundo a matriz de Pressão-Estado-Resposta.
Relevância: Os indicadores de Pressão-Estado-Resposta, formulados pela Organização para Cooperação e Desenvolvimento Econômico (OCDE), têm elevado potencial de aplicação na gestão de recursos hídricos e na construção de políticas voltadas para resolução de conflitos associados ao uso das águas.

Resultados: As sedes municipais de Castanhal, Igarapé-Açu, Marapanim e Terra Alta obtiveram o índice de sustentabilidade 0,40; 0,50; 0,44; 0,54 e 0,5 respectivamente (Regular) e São Francisco do Pará alcançou um resultado de 0,54 (Bom). Apesar de estarem na mesma bacia hidrográfica, cada uma teve sua particularidade em relação à matriz de PER, com fragilidades em comum, principalmente nos indicadores hidrológico e ambiental.
Contribuições teóricas: No apoio à formulação de políticas públicas, que representem a realidade das bacias hidrográficas associadas, possibilitando ações mais efetivas para sua recuperação, conservação e preservação de áreas prioritárias.
Contribuições para a gestão: Na avaliação integrada de vários indicadores (hidrológico, ambiental, político e social), o que possibilita uma visão mais direcionada das necessidades de cada território hídrico, orientando a tomada de decisão dos gestores públicos.

Palavras-chave: Indicadores. Gerenciamento. Recursos hídricos. Território hídrico. Usos da água.

Índice de sostenibilidad en la sede municipal de la cuenca hidrográfica del río Marapanim (Pará/Brasil)

Resumen
Objetivo: Este estudio aplica el índice de sostenibilidad hídrica a cabeceras municipales pertenecientes a la cuenca hidrográfica del río Marapanim, con el objetivo de evaluar la gestión de estas ciudades a través de indicadores Presión-Estado-Respuesta (PER).
Metodología: El índice de sostenibilidad hídrica aplicado, derivado de la metodología de Chaves y Alipaz (2007), propone indicadores clave (Hidrológico, Ambiental, Social y Político) que fueron estructurados y evaluados de acuerdo a la matriz Presión-Estado-Respuesta.
Relevancia: Los indicadores Presión-Estado-Respuesta, formulados por la Organización para la Cooperación y el Desarrollo Económicos (OCDE), tienen un alto potencial de aplicación en la gestión de los recursos hídricos y en la construcción de políticas orientadas a resolver conflictos asociados al uso de aguas.
Resultados: Las oficinas municipales de Castanhal, Igarapé-Açu, Marapanim y Terra Alta obtuvieron un índice de sostenibilidad de 0,40; 0,50; 0,44; 0,54 y 0,5 respectivamente (Regular) y São Francisco do Pará lograron un resultado de 0,54 (Bueno). A pesar de estar en la misma cuenca, cada uno tenía su particularidad con relación a la matriz PER, con debilidades comunes, especialmente en los indicadores hidrológicos y ambientales.
Aportes teóricos: Apoyar la formulación de políticas públicas que representen la realidad de las cuencas hidrográficas asociadas, posibilitando acciones más efectivas para su recuperación, conservación y preservación de áreas prioritarias.
Aportes a la gestión: En la evaluación integrada de diversos indicadores (hidrológico, ambiental, político y social), que posibilita una visión más focalizada de las necesidades de cada territorio hídrico, orientando la toma de decisiones de los gestores públicos.

Palabras clave: Indicadores. Gestión. Recursos hídricos. Territorio de agua. Usos del agua.

Introduction

In the Amazon region, as regards the environmental and economic sustainability, the gradual increase in the natural resources exploitation, revealed through the annual rates of deforestation of native forest, occasioned several problems and environmental impacts, reflecting the development model adopted in the 1970s (Pereira et al, 2016; Gorayeb et al., 2009). Among these problems, the expansion of cities associated with the impacts on water quality, leads to a scenario that generates social and economic issues, where the conflict over water use becomes recurrent for its multiplicity and several purposes (Poleto, 2014).

According to Grostein (2001) this is a recurrent pattern in Brazil, where the disorderly urbanization tied to the lack of sanitation presents a component of unsustainability, which notoriously affects the quality of water resources. And no different, the same is observed in the Marapanim river watershed, located in the state of Pará, inserted in the mesoregion of northeast Pará, which according to Andrade et al. (2018) is considered the in the Amazon colonization, therefore, it presents a very anthropized landscape.

Obregón (2013) states that these relations between territorial occupation and the increased demand for water embrace the concept of hydrologic territory, which corresponds to the space where the water is a key part, as it uses availability (quantity and quality), appropriation and accessibility, and it is indispensable for maintaining social relations and protective activities, articulating tension and conflict situations, according the distinguished modalities of water use.

It is fundamental that the integration of water space with cities take place, so that they recognize themselves belonging to its territory. And one of the ways, is by the adequate planning from the watershed connection, which according to Ribeiro (2016) it is the key unit for water resources management and environmental planning, with its municipal districts.

In order to associate this relationship between cities and water systems, sustainability indicators are adopted, which according to Sousa et al. (2018) aims to feature the urban environment, displaying sustainability or lack of it. Maynard et al. (2017) and Sousa et al. (2018) state that the application of a sustainability index, embracing different socioeconomic and environmental aspects and responses, seeks to analyze the existing local demands, intending to subsidize general information that helps in decision-making by public managers.

According to Rocha et al. (2020) the indexes and indicators are good tools with the purpose of presenting trends and providing an efficient response to the executed actions, with potential to assist in the decision-making process and participatory management as they allow the understanding of reality through monitoring and management of natural resources in time and space; as an example, the proposal by Chaves and Alipaz (2007) is mentioned, which discusses the Water Sustainability Index (WSI) and derivative works, such as Cortés et al. (2012), Juwana et al. (2012), Chandniha et al. (2014), Mititelu-Ionuş (2017), Maiolo and Pantusa (2019), Ferreira et al. (2020) and, Rocha et al. (2020).

The Pressure-State-Response (PSR) indicators were elaborated by the Organization for Economic Cooperation and Development (OECD) based on the SR model (Stress-Response, created by Anthony Friend and David Rapport in 1979, through Statistic Canada), according to Felinto et al. (2018). Its applicability and potential for integration with multiple variables, turn it into an easy replication mechanism in the process of water resource management, guiding the construction of public politics and conflict resolution in watersheds. Thus, the aim of this study is to assess the management process of Castanhal, Igarapé-Açu, Marapanim, São Francisco do Pará and Terra Alta municipal seats, belonging to the

Marapanim River Watershed, through the water sustainability index with Pressure-State-Response indicators (PSR).

Sustainability indicators

The economic indicators were created during World War II in order to measure the used production with the conflict, and later indexes such as GNP (Gross Domestic Product) were added to the economic management of countries as a way to measure their wealth. Although, this index alone could not assess the national welfare of the population, since it should take into account other agents besides the economy, such as social and environmental factors (Malheiros et al., 2013; Pott and Estrela, 2017).

In 1987, the World Commission on Environment and Development published the Bruntland report, bringing for the first time the concept of sustainable development (Neamtu, 2012; Kemerich et al., 2014). In 1992, the United Nations Conference on Environment and Development (also known as Rio 92 or Earth Summit), established it as a global goal, and highlighting the following documents: the Rio Declaration, Agenda 21, the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity; that advocate the use of sustainability indicators (Malheiros et al., 2013).

Silva et al. (2014) points out that the concepts of indexes and indicators are occasionally used superficially; however, this difference can be undone when the index is characterized as a final added value that has a meaning and, for its composition calculation procedures, several indicators can be adopted. For Maynard et al. (2017) the indexes are perceived as the result of a set of parameters associated to each other by a pre-established relation, which generates a single value through statistics, analytical formulation or mathematical calculus.

Kemerich et al. (2014) and Felinto et al. (2018) also admit an indicator as a parameter that has the ability to describe a state or a phenomena response that occurs in an environment, representing a form of perception of reality. There are countless indicators used to measure sustainability, according to Cammarrota and Pierantoni (2005), Juwana et al. (2012), Tischer et al. (2015), Ferreira et al. (2020) and Yu et al. (2020) the following indicators can be highlighted: Pressure-State-Response (PSR), Driving Force-Pressure-State-Response (DPSR), Driving Force-Pressure-State-Impact-Response (DPSR), the Barometer of Sustainability (BS), the Dashboard of Sustainability (DS), and the Ecological Footprint as the most used for sustainability assessment tools.

The PSR, that has its origins associated to researches linked to the Organization for Economic Cooperation and Development (OECD), had an immediate application in several management segments bounded to environmental politics, deriving new forms of application in order to distinguish even more its component activities. Thus, emerged the Driving Force-Pressure-State-Response (DPSR) and Driving Force-Pressure-State-Impact-Response (DPSR) adapted by the UN Environment Programme (UNEP) and the European Environment Agency (EEA) (Cammarrota and Pierantoni, 2005; Tischer et al., 2015; Lima et al., 2017).

It is also important to highlight that the water sustainability index (WSI) use the same base as PSR, DPSIR and other indicators, however, within the watershed territorial outline, as used in the researches of Chaves and Alipaz, (2007), Juwana et al. (2012), Silva et al. (2014), Araújo et al. (2019), Ferreira et al. (2020) and Rocha et al. (2020). Maynard et al. (2017) state that the water resources sustainability requires meeting the needs of multiple water uses, such as domestic use, irrigation, industrial use, recreation and power generation, in addition to the economic development, which depends, at the same time, on environmental protection actions and the improvement of social conditions. Juwana et al. (2012) point out ways for water sustainability which include the importance of the water infrastructure, environmental quality, economy and finances, institutions and society, human health and welfare, as well as planning and technology.

Rocha et. al (2020) highlight that the WSI aims to maintain a dynamic balance between water supply and demand, so that the water resources are used at rates equal to or lower than its resilience, and also emphasizes its interdisciplinarity, as it deals with several parameters in the hydrological, environmental, social and political area. Therefore, Kemerich et al. (2014) underline that sustainability is a process of change, constant improvement and structural transformation that must include the participation of the population as a whole. In this case, it is necessary to consider an expressive amount of data that communicate with the many different types of plans, both at local, regional, national and international spheres, indicating the states and trends of natural resources socioeconomic variables (Maynard et al., 2017).

Juwana et. al (2012) point up that the indicators analysis in multiple scales aims to subside public planning activities and the social politics formulation in different government spheres, enabling the monitoring of population life conditions and well-being by the government and civil society. In addition, when the democratization of information favors the increase of popular participation in the formulation of public politics, the indicators become instruments for management control and assessment of its efficiency and efficacy (Teixeira et al., 2015). Finally, it is essential to understand the process of sustainability indicators, as their existence becomes a vital tool in helping society’s decision-taking, and therefore reach sustainability.

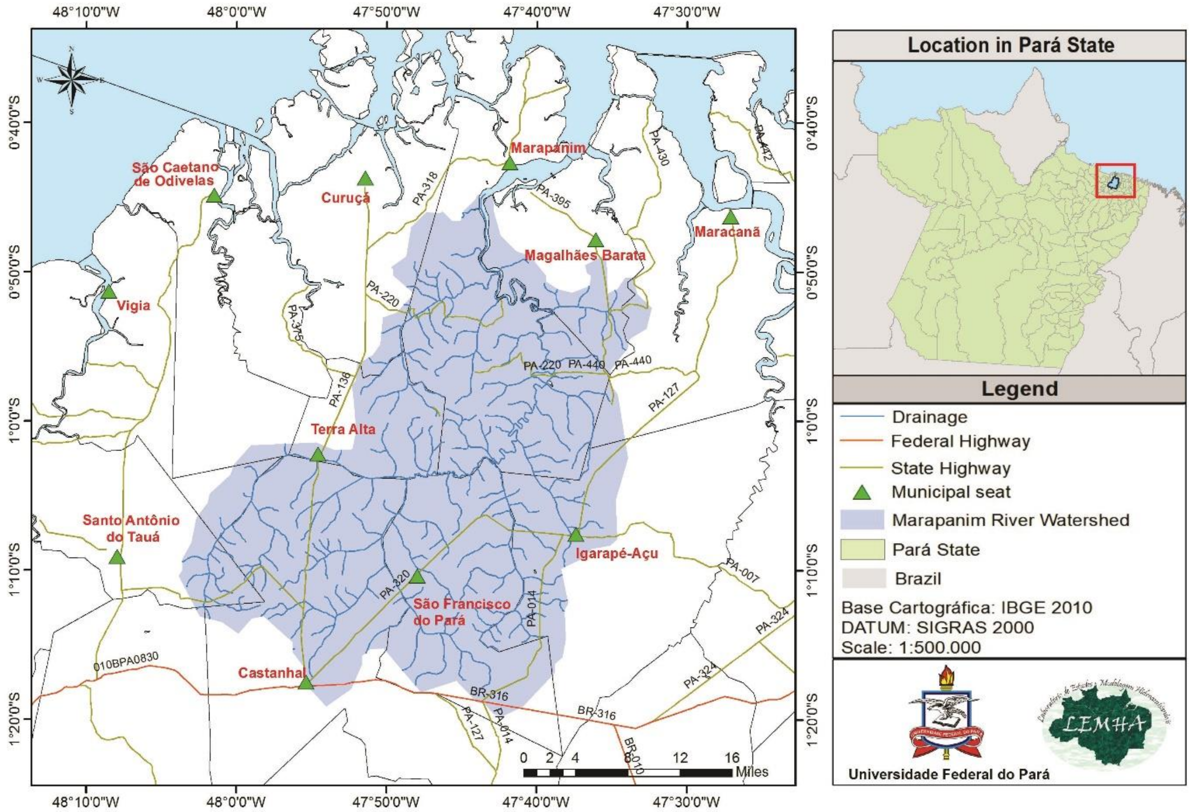
Methodology

Study area

The study area are the municipal seats of Castanhal, Igarapé-Açu, Marapanim, São Francisco do Pará and Terra Alta that are inserted in the Marapanim river watershed (Figure 1) in the Pará state, in the Eastern Northeast Atlantic Hydrographic Macro Region, Atlantic Coast Hydrographic Sub-Region.

Figure 1

Location of the marapanim river hydrographic basin.



Source: Elaborated by the authors (2020).

The municipal seats' hydrography presents direct influence on Marapanim river which is the main watercourse in the Marapanim river watershed. Its main spring is located northeast of Castanhal municipality to the river mouth in Marapanim bay, with a total length of 127,80 km and its main tributaries are the rivers and Maú Paramaú (Teixeira, 2015; Santos et al., 2019).

The São Francisco do Pará municipality has as its main watercourse the right arm of Marapanim river which has Igarapé Açu stream as direct affluent located next to the municipal seat of Igarapé-Açu. In contrast, the Terra Alta municipality has its urban outline delimited by the left arm of Marapanim river, in the south, originating many bathhouses in the city (FAPESPA, 2016a). The municipal seat of Castanhal is characterized as an agricultural warehouse, being the most important market center in the region (Rodrigues and Vieira, 2017). On the other hand, the municipalities of Igarapé-Açu, Marapanim, São Francisco and Terra Alta present an economic organization focused on agriculture, livestock, extractivism and artisanal fishing (Miranda, 2012; FAPESPA, 2016a; Alves et al., 2018).

Water Sustainability Index (WSI)

The water sustainability index of watersheds was applied in each municipal seat inserted in the Marapanim River basin, using an adaptation from the methodology applied by Chaves and Alipaz (2007), that propose key indicators composed in 4 groups: Hydrology (H), Environment (E), Life (L) and Policy (P); structured in a Pressure-State-Response (PSR) matrix, as shown in Table 1. Each key indicator represents an estimate that can vary from 0 (zero) to 1 (one), being divided in a scale of 0; 0.25; 0.5; 0.75; and 1, where 0 (zero) means bad conditions and 1 (one) means good conditions. The river basin sustainability index (WSI) was obtained by Equation 1.

$$WSI = \frac{(H+E+L+P)}{4} \qquad (1)$$

Table 1

Hydrology, environment, life and policy indicators.

Indicators	Parameters		
	Pressure	**State**	**Response**
Hydrology	% Variation in the urban water service index in the period 2013 to 2017	% Urban Water Service Index - 2017	Evolution in water use efficiency in the municipal seats in the period of 2013 to 2017
	% Variation in the sewage service index in the period 2013 to 2017	% Sewage Service Index (2017)	Evolution in sewage treatment and disposal in the municipal seats, in the period of 2013 to 2017
Environment	Environment Pressure Index (EPI): period from 1999 to 2017	% Area of Natural Vegetation Remaining in Municipal Seats in 2017	Evolution in protected areas (Reservations and Good Management Practices) in the watershed between 1999 to 2017
Life	Variation in the IDH-Income per capita, in the period from 2000 to 2010	Municipal Human Development Index (MHDI) (2010)	MHDI Evolution (2018)
Policy	Variation in the Municipal Human Development Index-Education (2010)	Institutional and legal capacity in Integrated Water Resources Management in the Watershed (2019)	Evolution in the expenses on integrated management of Water Resources in the basin (2017 to 2019)

Source: Adapted from Chaves and Alipaz (2007).

Chaves and Alipaz (2007) state that besides considering that all indicators have the same weight, its recognized that it can vary from basin to basin, and it must be chosen by consensus between both interested parts, therefore, using the same weight, it avoids the distortion of results and enable the mutual respect between different segments and interested parts.

Hydrology indicators

According to Dias (2018) the hydrology indicators can be divided in 2 groups. The first is related to quantitative indicators, that usually are based on the biophysical system information. The second one is related to a qualitative evaluation, more connected to water management aspects. In this paper adaptations were made about the hydrology indicators.

The Marapanim river watershed does not have water quality or quantity monitoring, which would enable its hydrological behavior to be defined. For this reason, it was necessary to look for elements that would enable the assessment of water availability and demand parameters, and not compromise the adopted method and reflect the local reality. The variables that could best translate this reading (of pressure on the system) would be the ones associated with basic sanitation conditions, with the demand indicated by the consumption of supply water and dilution of sewage.

Originally, Chaves and Alipaz (2007) used the country's per capita availability to calculate the hydrological sub-indicator of quantity. Due to the lack of data, the urban supply service index values of the National Sanitation Information System (SNIS) were adapted, but the same level and weight for the data was maintained.

The second hydrological indicator to be considered is water quality. Chavez and Alipaz (2007) originally used the biochemical oxygen demand (BOD) which is correlated with other water quality parameters, such as dissolved oxygen, turbidity, pollutant concentration and others. In the study proposed by Maynard et al. (2017), they replace the biochemical oxygen demand by the Water Quality Index (WQI), which stands out for bringing together in a single value several water quality parameters.

CONAMA resolution n. 357/2005, that states the classification of water bodies and establishes conditions and standards for effluent discharge, considers that the quality of river water must meet these specifications, and when the city presents a low level of sewage collection and treatment, it is possibly because effluents are being discharged directly into the rivers. Thus, releasing effluent without proper treatment into the water body compromises water quality in urban areas, impacting the population's health, in addition to interfering in the water uses at the river downstream, such as human supply, bathing, irrigation, among others.

Considering the lack of data related to the water quality index, this paper the IQA by the Sanitary Sewage Index was replaced by the Sewage Service Index, which will be used in the municipalities of Castanhal, Marapanim, Terra Alta, São Francisco do Pará and Igarapé-Açu. This will be according to the methodology proposed by Lopes et al. (2016), which determines a Sanitary Sewage Service Performance Index (IDSES) for the city of Campina Grande, Paraíba. The selected indicators were the population connected to the sewage collection network (IQS_1) and sewage treatment (IQS_2), which are calculated from equations

2 and 3, respectively, and expressed in %. With the found values, the arithmetic mean between the results will be made and classified according to Table 2.

$$IQS_1 = \frac{Population\ assisted\ by\ sewage\ service}{Total\ population}\ x\ 100 \quad (2)$$

$$IQS_2 = \frac{Treated\ sewage\ volume}{Generated\ sewage\ volume}\ x\ 100 \quad (3)$$

For the water use efficiency calculation, it was considered the water loss index (WLI) in the distribution of the water system. With the results of WLI (%) the classification of Mayard et al. (2017) adapted from Tsutiya (2006) was used, classifying the Water Loss in Distribution Networks in:

- P < 25%: the water supply system is classified as "good", with an adapted score to the WSI equivalent to 1.0.
- 25 ≤ P < 40%: the water supply system is classified as "regular" and receives a score equal to 0.5 for the WSI calculation.
- P ≥ 40%: the water supply system is classified as "poor" and receives a minimum score of 0.0.

Table 2

IDSES classification

Assigned values for IDSES (%) Lopes et al. (2016)	Classification Lopes et al. (2016)	Classification Chaves and Alipaz (2007)
0 - 25	Very poor	0.00
26 - 40	Poor	0.25
41 - 55	Regular	0.50
56 - 75	Good	0.75
76 - 100	Excellent	1.00

Source: Chaves and Alipaz (2007) and Lopes et al. (2016).

For the calculation of sewage treatment evolution, it was considered the Sewage Collection and Treatment Index. It is noteworthy that the used data to find the hydrologic indicator results were provided by SNIS. In Table 3 are presented the adaptation to the hydrologic indicator and its respective weights.

Table 3

Hydrologic indicator

	Parameter	Level	Score	Database
PRESSURE	% Variation in the urban water service index 2013 - 2017	0 - 25	0.00	Municipal Seat - SNIS (2019)
		26 - 40	0.25	
		41 - 55	0.50	
		56 - 75	0.75	
		76 - 100	1.00	
	% Variation in the sewage service index in the period 2013 - 2017	0 - 25	0.00	Municipal Seat - SNIS (2019)
		26 - 40	0.25	
		41 - 55	0.50	
		56 - 75	0.75	
		76 - 100	1.00	
STATE	**Parameter**	**Level**	**Score**	**Database**
	% Urban Water Service Index (2017)	0 - 25	0.00	Municipal Seatl - SNIS (2019)
		26 - 40	0.25	
		41 - 55	0.50	
		56 - 75	0.75	
		76 - 100	1.00	
	% Sewage Services Index (2017)	0 - 25	0.00	Municipal Seatl - SNIS (2019)
		26 - 40	0.25	
		41 - 55	0.50	
		56 - 75	0.75	
		76 - 100	1.00	
RESPONSE	**Parameter**	**Level**	**Score**	**Database**
	Evolution in water use efficiency in the municipal seats in the period of 2013 - 2017	Very Poor	0.00	Municipal Seatl - SNIS (2019)
		Poor	0.25	
		Regular	0.50	
		Good	0.75	
		Excellent	1.00	
	Evolution in sewage treatment and disposal in the municipal seats, in the period of 2013 - 2017	Very Poor	0.00	Municipal Seat - SNIS (2019)
		Poor	0.25	
		Regular	0.50	
		Good	0.75	
		Excellent	1.00	

Source: Adapted from Chaves and Alipaz (2007) and Lopes et al. (2016).

Environmental indicators

To calculate the Pressure, State and Response indicators, data from satellite images from Landsat 7 and 8 were used, based on the analysis of the Normalized Difference Vegetation Index (NDVI) (Huete et al., 2002; Ahmed et al., 2017), treated by Google Earth Engine code, in the year 1999 and 2017 and data from the Brazilian National Institute of Geography and Statistics (IBGE). In the calculation, bands 3 and 4 (Landsat 7) in 1999 and bands 4 and 5 (Landsat 8) in 2017 were used. Equation 4 represents the adopted formulation, which consists in the use of red and near infrared bands. Where IVP is the reflectance value of the near Infrared band; and V represents the reflectance value of the band in red.

$$NDVI = \frac{(IVP-V)}{(IVP+V)} \quad (4)$$

Green and healthy vegetation shows contrast between the visible region, especially the red and near infrared, and the greater this contrast, the greater the vigor of the vegetation in the area. Thus, in areas occupied by denser vegetation they tend to have NDVI values close to 1, ranging on a scale from -1 to 1 (Ahmed et al., 2017). For values close to zero or negative, it is consequently characterized as areas with few or no occurrences of chlorophyll, which can be classified as areas with buildings and/or exposed soil.

To find the value of the Environment Pressure Index (EPI) the percentage of urbanized area in the chosen municipal seats was adopted, plus the percentage of the urban population in the municipal seat (equation 5).

$$EPI = \frac{\%\, urbanized\ area + \%\, municipal\ seat's\ urban\ population}{2} \quad (5)$$

Regarding the evolution in protected areas (Reservations and Good Management Practices), in the response parameter, the difference in percentage between the amount of green area from 1999 to 2017 was considered, analyzed from the NDVI, treated by Google Earth Engine code. On Table 4 the adaptations of the environmental indicators and their respective weights are shown.

Table 4

Environmental indicators

	Parameter	Level	Score	Database
PRESSURE	Environment Pressure Index (EPI): from 1999 to 2017 (%)	EPI > 20	0.00	Municipality - Landsat 7 (1999); Landsat 8 (2017); IBGE (2019)
		10 < EPI ≤ 20	0.25	
		5 < EPI ≤ 10	0.50	
		0 < EPI ≤ 5	0.75	
		EPI ≤ 0	1.00	
	Parameter	**Level**	**Score**	**Database**
STATE	% Area of Natural Vegetation Remaining in Municipal Seats in 2017	Av < 5	0.00	Municipality - Landsat 7 (1999); Landsat 8 (2017);
		5 ≤ Av < 10	0.25	
		10 ≤ Av < 25	0.50	
		25 ≤ Av < 40	0.75	
		Av ≥ 40	1.00	
	Parameter	**Level**	**Score**	**Database**
RESPONSE	Evolution in protected areas (Reservations and Good Management Practices) (%)	$\Delta < -10$	0.00	Municipality - Landsat 7 (1999); Landsat 8 (2017)
		$-10 \leq \Delta < 0$	0.25	
		$0 \leq \Delta < 10$	0.50	
		$10 \leq \Delta < 20$	0.75	
		$\Delta \geq 20$	1.00	

Source: Adapted from Chaves and Alipaz (2007).

Life indicators

Chaves and Alipaz (2007) and UNESCO (2008) used the GDP per capita to calculate the Pressure parameter. However, for this study, the adaptation used by Maynard et al. (2017)

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was chosen, which uses the HDI - Income. Regarding the State and Response parameters, the value for the year 2010 and % of the variation of the Municipal Human Development Index (MHDI) of each municipality will be selected, respectively. The data necessary for the calculation were obtained from the Atlas of Human Development in Brazil. In Table 5, the social indicators and their respective weights are presented.

Table 5

Life indicator

	Parameter	Level	Score	Database
PRESSURE	Variation in the HDI - Per capita income, in the period from 2000 to 2010 (%)	Δ < -20	0.00	Municipality - Brazilian Human Development Atlas
		-20 ≤ Δ < -10	0.25	
		-10 ≤ Δ < 0	0.50	
		0 ≤ Δ < +10	0.75	
		Δ ≥ +10	1.00	
STATE	**Parameter**	**Level**	**Score**	**Database**
	MHDI	IDH < 0,5	0.00	Municipality - Brazilian Human Development Atlas
		0,5 ≤ IDH < 0,6	0.25	
		0,6 ≤ IDH < 0,75	0.50	
		0,75 ≤ IDH < 0,9	0.75	
		IDH ≥ 0,9	1.00	
RESPONSE	**Parameter**	**Level**	**Score**	**Database**
	Variation in the MHDI (%)	Δ < -10	0.00	Municipality - Brazilian Human Development Atlas
		-10 ≤ Δ < 0	0.25	
		0 ≤ Δ< 10	0.50	
		10 ≤ Δ < 20	0.75	
		Δ ≥ 20	1.00	

Source: Adapted from Chaves and Alipaz (2007).

Policy indicators

According to Chaves and Alipaz (2007) and UNESCO (2008), the use of the Education Development Index aims to measure the educational level of the population, the positive values of the MHDI-Education correlate the population's ability and willingness to involve in watershed management, putting more pressure on decisions (Table 6). The data obtained were collected from the Atlas of Human Development in Brazil, available on the Brazilian Federal Government’s Transparency Portal and through surveys carried out with the responsible public institutions in all municipal offices (Table 7). Regarding the Response parameter, the UNESCO (2008) methodology was used, according to equation 6.

$$\triangle = \frac{investiments\ in\ the\ current\ period\ (2019) + investiments\ in\ the\ previous\ period\ (2018)}{investiments\ in\ the\ previous\ period\ (2018)} x(100) \qquad (6)$$

Table 6

Parameters for the evaluation of municipalities management

Variables	Classification	Weight
Environmental Legislation	Existent	1
	Inexistent	0
Secretary of Environment	Individual	1
	Associated	0.5
	Inexistent	0
Municipal Council for the Environment	Existent	1
	Inexistent	0
Access to Environmental Management Information via Internet	Yes	1
	No	0
Performance of Environmental Education Actions in the Municipality	Yes	1
	No	0
Possession of Municipal Director Plan	Yes	1
	No	0
Existence of Municipal Director Plan	Yes	1
	No	0
Existence of Municipal Sanitation Policy	Yes	1
	No	0

Source: adapted from Rocha et al. (2020).

Table 7

Policy indicators

	Parameter	Level	Score	Database
PRESSURE	Variation of HDI-Education in the period of 2000 - 2010 (%)	Δ < -20	0.00	Municipality - Brazilian Human Development Atlas
		-10 ≤ Δ< -20	0.25	
		-20 ≤ Δ< 0	0.50	
		0 ≤ Δ< +10	0.75	
		Δ ≥ +10	1.00	
STATE	**Parameter**	**Level**	**Score**	**Database**
	Legal and institutional capacity for Integrated Water Management (IWM) of the municipality	Very poor	0.00	Municipalities' City Halls
		Poor	0.25	
		Regular	0.50	
		Good	0.75	
		Excellent	1.00	
RESPONSE	**Parameter**	**Level**	**Score**	**Database**
	Evolution of expenses on Integrated Water Management (IWM) in the municipality (%)	Δ < -10	0.00	Municipality - Brazilian Federal Government's Transparency Portal
		-10 ≤ Δ < 0	0.25	
		0 ≤ Δ< 10	0.50	
		10 ≤ Δ < 20	0.75	
		Δ ≥ 20	1.00	

Source: Adapted from Chaves and Alipaz (2007).

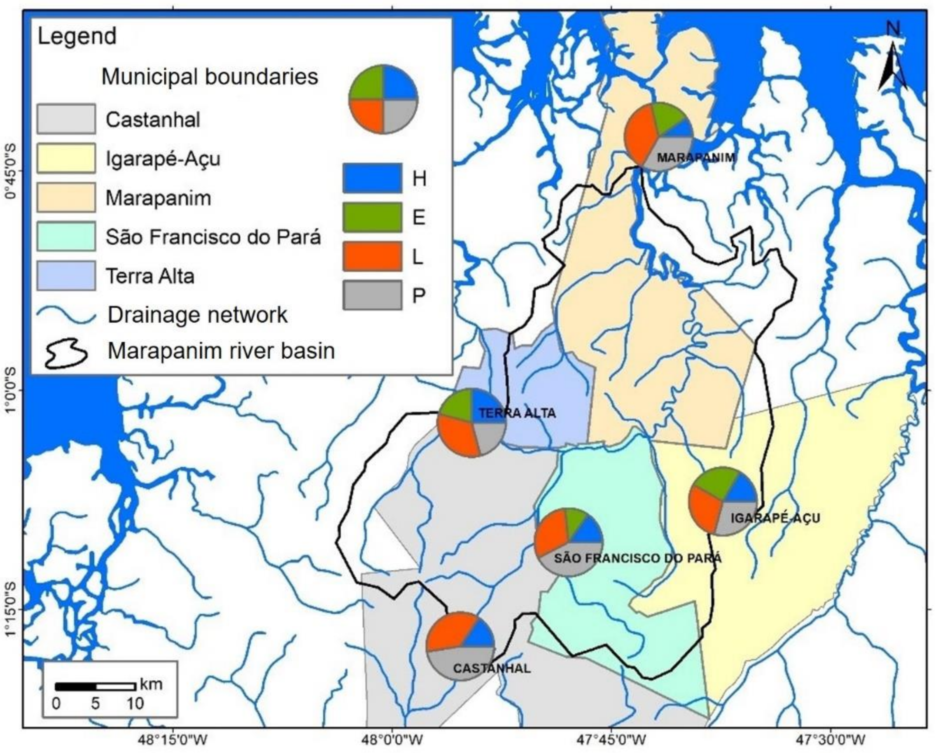
Results and discussion

Based on the surveys carried out and the products obtained from water demand and land use, the weights of each of the Hydrology (Table 3), Environment (Table 4), Life (Table

5) and Policy (Table 7) indicators were defined and used to calculate the PER indicator for the municipal seats of Castanhal, Igarapé-Açu, Marapanim, São Francisco and Terra Alta. The scores for each PER were found using the HELP arithmetic mean, by equation 1, resulting in the Sustainability Index for each city. The municipal seats of Castanhal, Igarapé-Açu, Marapanim and Terra Alta obtained a sustainability index of 0.40; 0.50; 0.44; 0.54 and 0.50 respectively, which represents a regular value. The city of San Francisco achieved a result of 0.54, classified as a good index, as shown in Figure 2.

Figure 2

Sustainability index results for each municipal seat



Municipality	Hydrology (H)	Environmental (E)	Life (L)	Policy (P)	WSI	Chaves and Alipaz (2007) classification
Castanhal	0.25	0.00	0.58	0.75	**0.40**	Regular
Igarapé-Açu	0.33	0.50	0.58	0.58	**0.50**	Regular
Marapanim	0.17	0.33	0.67	0.58	**0.44**	Regular
São Francisco do Pará	0.33	0.25	0.67	0.92	**0.54**	Good
Terra Alta	0.50	0.42	0.67	0.42	**0.50**	Regular

Source: Elaborated by the authors (2019).

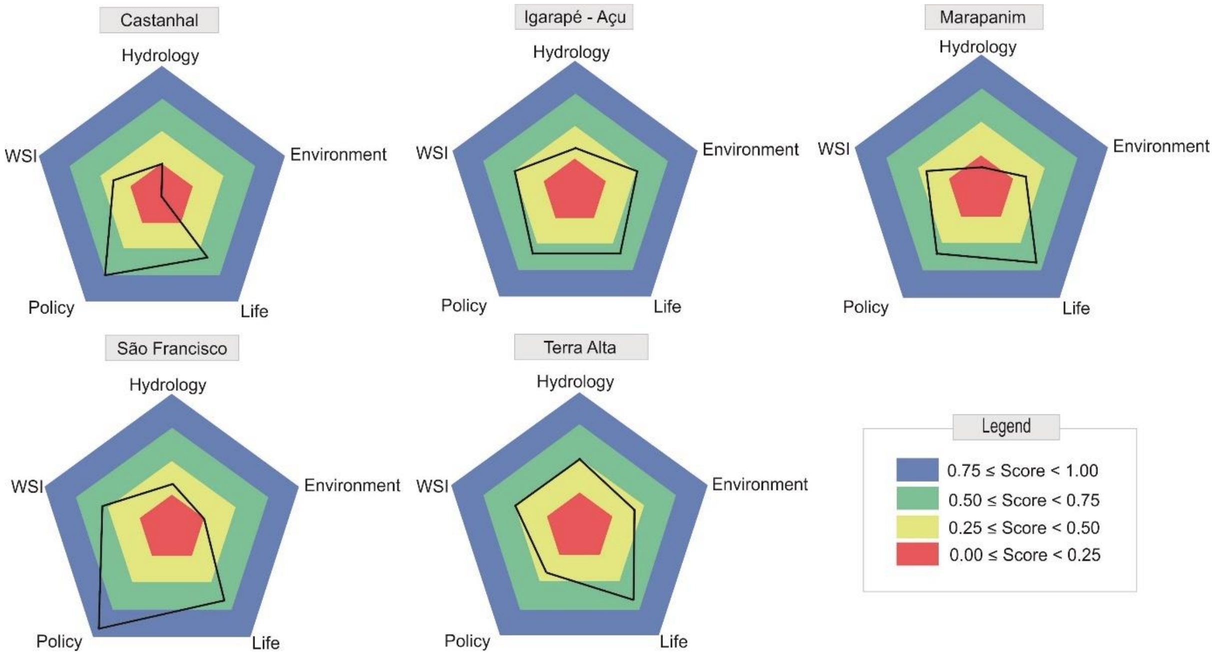
It is noteworthy that despite the São Francisco do Pará seat getting a good rating, compared to other headquarters, it presents the same problems. The only point that differs is the political indicator (Figure 2), showing that at least there is the intention, but there is no implementation, which ends up compensating for the lack of response from other indicators.

Regarding the context of the Marapanim river basin area, the municipality of Castanhal, for being located at the head of the basin area, ends up pressing an expansion of land use as a whole in the region, being an inductor of pressure in the smaller municipalities.

Figure 3 illustrates the association between municipal seats and the score of each indicator, with colors according to the methodological classification developed by Maynard et al. (2017). Among the analyzed indicators, the qualitative hydrological sub-indicator (Table 3), which uses data from the collection, treatment and coverage index of sanitary sewage in the urban area, was the one with the greatest weakness in all PER indicators of each headquarters, confirming a common scenario in the State of Pará, where sewage service rate is less than 10% (Brasil, 2017).

Figure 3

Graphic representation of the WSI results



Source: Elaborated by the authors (2019).

The lack of support from city halls and concessionaires for sewage collection and treatment makes the population look for alternatives through individual solutions, such as construction of septic tanks, cesspits or direct sewage connections to canals or rivers. According to Tischer (2017), the use of septic tanks in urban centers can cause soil contamination and especially harm water quality, as they are close to groundwater.

In addition, the untreated disposal of sewage directly into water bodies has several negative consequences for society, which directly impact the health of the population, causing the increase of various diseases, such as fecal-oral diseases (Costa and Guilhoto, 2014). And this problem is evident in the hospitalizations rates for feco-oral transmission in the state of Pará, which showed an increase of 9.8% in 2016 compared to 2015 (IBGE, 2019).

It is important to highlight that in the quantitative hydrological sub-indicator regarding pressure and status, which uses the water supply service data available by the SNIS, these may contain inconsistencies due to the calculation of the population served adopted by the providers, leading many municipalities to have a service rate equal to or even greater than 100% (Brasil, 2014). This ends up masking the results for the sustainability index of each municipal seat, as it does not represent on a real scale the service provided to the water supply system (SAA).

When the water supply and demand relation is compatible and presents a good management of water resources, there is evidence of a diversification of uses, and consequently the reduction of conflicts (Campos and Fracalanza, 2010). However, when there is poor management of water resources, the distribution of water ends up being harmed, demonstrating a low level of water supply in urban areas, as occurs in Castanhal and Marapanim.

For Razzolini and Günther (2008), the deficit in the distribution of drinking water conditions a risk factor and contributes to effects on health, which can favor the increase in the incidence of waterborne diseases, as both water collection and its transport and storage, if necessary, may be inadequately performed. Another point to be considered, and which directly interferes with the coverage of water supply, is the water supply system loss index, in which all headquarters presented critical values, with exception of Terra Alta, which obtained the best result.

Tsutiya (2006) and Heller and Padua (2013) state that high water losses occur mainly due to the deterioration of older water transport and distribution systems that do not have adequate maintenance and recovery, contributing to low institutional and management capacity of systems; in addition to the extension of the networks to the systems' peripheral areas and, consequently, the low water coverage index.

Fighting and controlling losses is a fundamental issue in scenarios where there is, for example: scarcity and conflicts over use; high volumes of unbilled water, compromising health and regulatory environments, in which indicators that portray water losses are among the most valued for performance assessment (Heller and Pádua, 2013).

In the analysis of environmental indicators, all municipal seats showed critical values for the Pressure indicator, which indicates urban expansion without adequate environmental planning. As the State and Response indicators regarding the percentage of green area in the urban perimeter in 2017 and the percentage of vegetation during 1999 and 2017, the cities showed different scores. Igarapé-Açu and Terra Alta show the areas with the highest values, followed by São Francisco, Marapanim and Castanhal with a much lower area of coverage. It is worth mentioning that the city of Castanhal was the only city that presented a critical score in all PER indicators, indicating the strong urbanization during the period from 1999 to 2017.

According to Isernhagen et al. (2009) in developing countries, population growth and disorderly expansion of cities lead to several conflicts, mainly over land use, resulting in the search and use of spaces that could become parks or other types of green areas. In addition, the absence of afforestation in cities reflects the worsening of the environmental issue, because as cities expand and over-appropriate natural resources, they transform its natural space, reducing the quality of life of the local population (Moreira and Vitorino, 2017).

However, when cities have green areas, tree-lined lanes and squares, significant gains are made in the urban environment, especially in regards to reducing air pollution, minimizing temperatures, lumnic and acoustic comfort, in addition to promoting physical and psychological well-being of human beings, acting, consequently, in their quality of life (Costa and Ferreira, 2009).

The social indicators that analyze the MDHI - Income and the MDHI, were the ones that presented the best results in all municipal seats, showing that there was progress in the 2000s compared to 2010. However, the analysis of the MDHI - Income and MDHI is done every decade and for not providing updated data, they end up influencing the final result of the sustainability index. But, despite the lack of current data, the IDHM is important because it fills an important gap in the universe of social welfare indicators adapted to the Brazilian context and represents an established reference and widely adopted at different technical, managerial and strategic levels, helping to guide the municipality's public policies (Figueiredo Filho et al., 2013).

It is worth mentioning that the calculation of the MDHI is a methodological adaptation of the global HDI at municipal level, made by UNDP, IPEA and João Pinheiro Foundation, and both add the dimensions of health, education and income, which allows knowing the reality of human development in the Brazilian territory, facilitating the comparison between locations (UNDP, 2013).

In the Political indicators, the Pressure indicator that analyzes the variation of the MDHI - Education, presented an excellent score in all municipal seats, indicating a significant improvement in the education indexes for the period from 2000 to 2010. For Cortés et al. (2012), when education indicators are low, they will hinder the active, informed and responsible participation of citizens (society engagement) in integrated water resources management and sustainable development initiatives. Lira and Cândido (2013) emphasize that the population engagement is important, regarding the projects and laws of the city halls, which can guarantee the sustainability of the services provided. In other words, with a more educated population, it can become an active agent when it comes to demanding the public policies necessary for its quality of life.

Regarding the Institutional and Legal Capacity of the seats, all obtained critical values, with exception of São Francisco, which was the only city to present a basic sanitation plan (in 2014) and municipal basic sanitation policy (in 2013). However, through visits to the city hall and through data collection from the SNIS, there is no collection and treatment of sewage generated by households, which proves that there is no concrete application of the law.

Regarding the investments made by the municipal offices in the areas of sanitation, environment and water resources, in the period from January 2018 to January 2019, São Francisco presented a 20% increase in the collection for these areas, followed by Castanhal and Igarapé-Açu; Marapanim and Terra Alta were the only locations that had a regression in their investments (Brasil, 2020).

Ferreira et al. (2020) obtained a similar pattern for the Moju River watershed and Rocha et al. (2020) for the Guamá River hydrographic basin, compatible with the development framework observed for the municipalities in the northeast of Pará. It is important to emphasize that the creation of laws and public policies aimed at protecting water resources, the environment and the stimulation for the regulation of basic sanitation services does not guarantee their applicability, generally caused by lack of management and inspection by the competent public institutions. Thus, for the positive evolution of the indicators in the municipal seats, it is suggested that first the elaboration and execution of the municipal master plan be carried out, which has as its objective the urban environmental development, aiming at greater insertion of green areas such as parks, woods and squares in the cities, in addition to investments in environmental education programs in schools, aimed at reducing socio-spatial inequalities and ensuring an improvement in the population's quality of life and achieving sustainability.

The basic sanitation plan must also be done in conjunction with the director plan, which aims to promote the universalization of basic sanitation services, based on the guidelines of the National Basic Sanitation Policy (National Law n. 11.445/2007) and thus reduce the deficits in the collection and treatment of sanitary sewage, the levels of losses in water distribution and improved service in water supply.

Conclusion

Based on the data analysis from each municipal seat, using the WSI calculation, all cities were classified as regular in terms of sustainability, with the exception of São Francisco, which presented a good index. Although Castanhal, Igarapé-Açu, Marapanim, São Francisco and Terra Alta are located in the same hydrographic basin, each one has its particularity in relation to the PER indicators, and also presented common weaknesses, mainly in the hydrological and environmental indicators.

It is worth mentioning that the lack of data is one of the main difficulties for monitoring, as it ends up compromising the real seats' demand, which influences the commitment of public policies, especially for areas that cover hydrological and environmental indicators, directly reflecting on management problems water resources, such as the deficit of water supply, distribution losses, lack of micro and macro-metering of the network, in addition to not having any type of treatment for the sewage generated, which may compromise the availability of this water resource.

It is important to invest in quali-quantitative water and hydrometeorological monitoring, in order to be able to anticipate the problems linked to water crises, as it has been occurring continuously in the country. And associated with this, the strengthening of the performance indicators construction that better assess water demand and availability relations.

Thus, the application of the sustainability index from the Pressure-State-Response model enables an integrated approach and assessment of hydrological, environmental, political and social indicators, allowing a more focused view of the needs of each territory, and thus it helps to guide the decision-making of managers.

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