sociedade
& natureza

DOI: 10.14393/SN-v32-2020-45694

Received: 29 October 2018 | Accepted: 29 August 2019

Water sustainability of the Guamá river basin, Eastern Amazonia/Brazil

Nívia Cristina Vieira Rocha[1]
Aline Maria Meiguins de Lima[2]

Keywords
Indicators
Watershed
Management

Abstract

The Guamá River basin covers 19 municipalities located in northeastern Pará, with great diversity of land use forms and the highest population density of the state. In this research, its water sustainability was evaluated, based on the hydrological, environmental, social and management aspects, in its 8 sub-basins. The hydrological indicator showed a medium behavior for the sub-basins; the environmental highlighted the fragility of the resilient vegetal cover; the social performance presented the worst performance; and the management pointed out the need for institutional strengthening. The Guamá river basin in general obtained an intermediate sustainability index, but the partial results indicated that for measures geared to the strategic planning and management, to minimize pressures on the remaining vegetation, enhancing institutional capacity and improving the quality of life of the population and resources, with the intention of enhancing the sustainability of the basin.

---

[1] Universidade Federal do Pará, Belém, Pará, Brasil. niviavieira.ciamb@gmail.com
[2] Universidade Federal do Pará, Belém, Pará, Brasil. ameiguins@gmail.com

INTRODUCTION

Significant demographic growth has led to a greater demand for water resources to meet the needs of both the population and the industry, but changes in vegetation cover lead, in the medium to long term, to altered water potential (PRATES; BACHA, 2011). This highlights the need for institutional and technological advances for the recovery and protection of water systems, as well as new perspectives for preventive, integrated and adaptive management (MARQUES, 2017).

The per capita consumption of water increases as society's income improves, and this resource is used for various purposes directly related to regional, national and international economies. The most common and frequent are domestic, irrigation, industrial and hydroelectric uses, which demand the proper management of this resource (RIBEIRO; PIZZO, 2011).

From the 1980s onwards, the modernization of water management models incorporated the concept of sustainability, stressing the importance of environmental and water management through public development policies (CARVALHO, 2014). Maintaining water sustainability is of paramount importance, as this takes into account quantitative and qualitative availability aligned to a balanced access, within the uses and requirements of each river basin (TRINDADE; SCHEIBE, 2019). Water sustainability implies maintaining a dynamic balance between water supply and demand so that water sources are used at rates that are equal or below their resilience (SOOD; RITTER, 2011).

Suitable instruments for assessing the efficiency of water and environmental systems are among the ways to subsidize water resource management, promoting sustainable development (CARVALHO et al., 2011). Therefore, the development of a water sustainability index allows a multidisciplinary analysis of various aspects of integration of various parameters (VIEIRA; STUDART, 2009).

Although various environmental aspects of sustainability and water scarcity indices are available, they are not designed to assess river basins, to consider the integration among their various components. In this context, the International Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) initiated and supported the research and development of indices accordingly to the development strategy of each place where they are applied (CORTÉS et al., 2012).

The creation of water sustainability indicators is based on the principles of supply control by management and monitoring of availability, according to FAO (2017), and this premise is associated with the perception of sustainable consumption and control of water scarcity and pollution.

The methods to evaluate these indicators vary according to the proposed objectives, involving concepts such as sustainability, vulnerability, ecological footprint, and social and environmental parameters (SULLIVAN et al., 2003; BÖHRINGER; JOCHEM, 2007; BLANC et al., 2008; EMERSON et al., 2010). In general, they use statistical concepts such as arithmetic average through standardization, equally weighted average, weight distribution based on statistical analysis, and consultations of experts (WELSCH et al., 2005; NARDO et al., 2008; RICKWOOD; CARR, 2009). Selecting the best method depends on the characteristics of the model and the parameters adopted (JUWANA et al., 2012).

Among the hydrological performance indices (more focused on the evaluation of water availability based on hydrometeorological factors), the Standardized Precipitation Index; Palmer Drought Index; Precipitation Anomaly Index; and Aggregate Drought Index stand out (KEYANTASH; DRACUP, 2004; BLAIN; BRUNINI, 2007; SOUSA et al., 2010; FARO et al., 2019).

There are also indices involving biophysical and socioeconomic parameters, such as the Integrated Water Resources Management Index; Water Sustainability Index; Potential Water Resources Degradation Index; and Water Quality Index (SULLIVAN, 2002; XU et al., 2002; BOYACIOGLU, 2007; CHAVES; ALIPAZ, 2007; TEJADA-GUIBERT et al., 2015; FERREIRA et al., 2016; SILVA et al., 2017).

Composite indices (WILLET et al., 2019) are built by aggregating indicators, and their results are useful for decision-makers because large amounts of information can be condensed into more manageable and comparable values for better application and representativeness.

According to the Habitat Conservation Trust Fund – HTCF (2003), watershed sustainability indicators must meet some basic criteria to be useful. They must be available and easily accessible, understandable, reliable, relevant and integrative. The application of a water sustainability index that addresses different socioeconomic and environmental responses is useful to verify the level of sustainability of watersheds, allowing the collection of a set of indicators, besides enabling the elaboration of instruments capable of identifying obstacles that hinder management (CHAVES; ALIPAZ, 2007).

In this context, the Guamá river basin, located in the Hydrographic Region of the Atlantic Coast, in the northeast of the state of Pará - Brazil, comprises 19 municipalities in the domain of the Amazon biome within the area of influence of the so-called “Amazon Deforestation Arch”, which has been subjected to an accelerated deforestation process in recent years (RIVERO et al., 2009; SILVA et al., 2013; BARROSO et al., 2015).

Relevant analyses of the Guamá river basin in the context of waters of northeastern Pará have indicated the need for a perception of the composition and structure of its landscape (BEZERRA et al., 2011; SANTOS et al., 2016), as well as the need to collect relevant information for the analysis of the quality of life of the population of this area, so as to adopt actions aimed at its management.

The objective of this research was to apply a water sustainability index adapted from Chaves and Alipaz (2007) to the Guamá river basin. The spatial analysis of the landscape was associated with surface runoff parameters to compose the hydroenvironmental axis, and aspects related to the population's quality of life and focused on the institutional capacity of the municipalities to form the social and management axis.

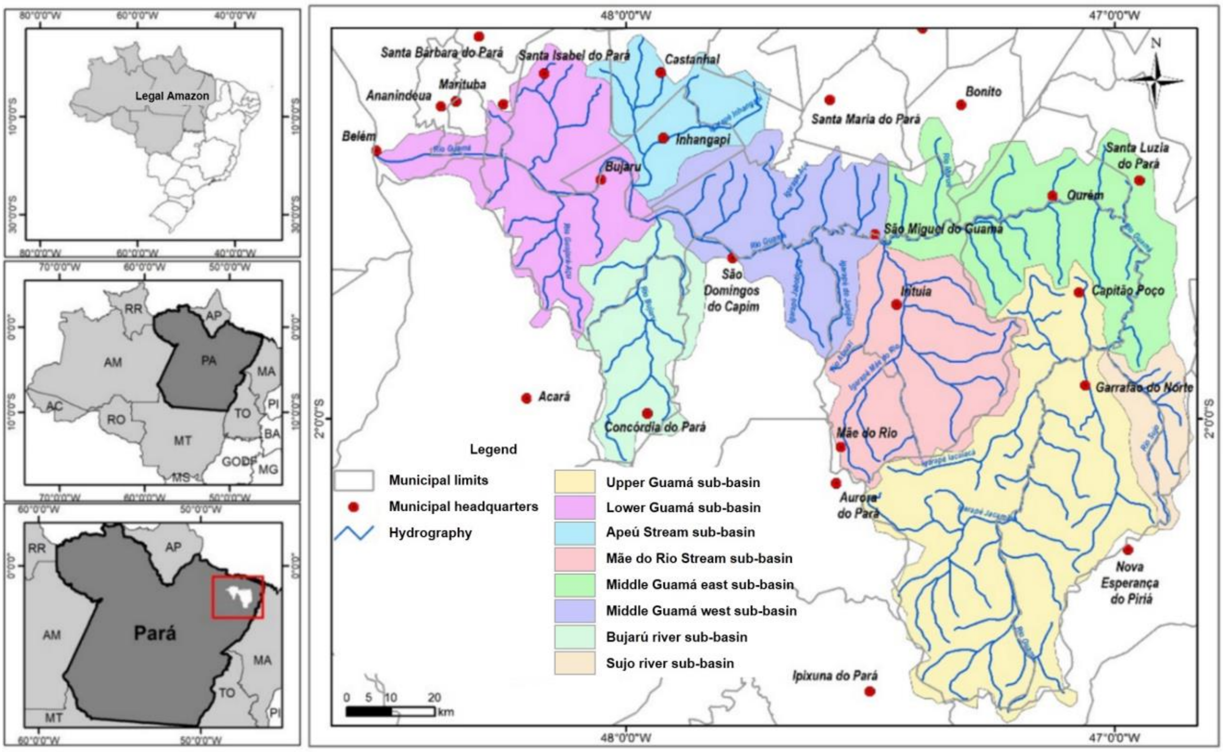
The results of the study aimed at obtaining a set of specific indicators for the Guamá river basin (and the municipalities that compose it), as well as enabling the elaboration of tools to identify the obstacles to water management in the area that can contribute to the planning of land use and occupation from the perspective of the Amazonian water territory, according to Becker (2009) and Aragón (2018).

MATERIAL AND METHODS

Study Area

The Guamá river basin is located in the northeast of the state of Pará and covers an area of about 11,870 km², representing 1% of the area of the state (Figure 1).

Figure 1 - Location of the study area.



Source: Hydroenvironmental Studies and Modeling Lab (LEMHA), 2018. Org.: The author, 2018.

The river basin is inserted in the Hydrographic Region of the Atlantic Coast - Northeast, according to Resolution 04/2008 of the Water Resources Council of the state of

Pará. The Guamá river basin is a large area formed by 19 municipalities with intense economic activity centered in industry, mining, commerce and agriculture. They are: Capitão Poço, Garrafão do Norte, Irituia, São Miguel do Guamá, Bujarú, Santa Luzia do Pará, Concórdia do Pará, Santa Izabel do Pará, Inhangapi, Castanhal, São Domingos do Capim, Ourém, Mãe do Rio, Belém, Acará, Bonito, Benevides, Marituba and Ananindeua, with a total of nearly 2,700,000 inhabitants according to the last census (BRASIL, 2010).

Water sustainability assessment

The calculation of the Water Sustainability Index (WSI) for the Guamá river basin was an adaptation (for the condition of State) of the methodology applied by Chaves and Alipaz (2007), which takes into account hydrological (H), environmental (E), social (S) and management (M) aspects, because the sustainability of a basin is a dynamic process.

For the application of the index in large basins such as Guamá, it is more feasible to divide the basin into sub-basins and calculate its total value in a weighted way.

Thus, the Guamá river basin was divided into eight sub-basins for analysis, namely: Lower Guamá, Apeú Stream, Bujarú River, Middle Guamá west sector, Middle Guamá east sector, Mãe do Rio Stream, Sujo River, and Upper Guamá, delimited according to the river flow system and considering the main river and its tributaries.

To analyze the environmental variable (E), a land use and land cover map was created, defining eight classes adapted according to the IBGE Land Use Manual (BRASIL, 2013): vegetated area, agriculture, occupation areas, uncovered soil, pasture, water bodies, unobserved areas, and others.

The map was generated through the supervised classification method for multispectral images based on the Maximum Likelihood (MaxVer) classifier, performed pixel by pixel, using the ENVI software in orthorectified satellite images of the RapidEye system (high resolution, in a total of 43 scenes, dated 6/29/2011, 7/28/2011, 8/4/2011, 10/23/2011, 7/31/2012, 8/2/2012, 9/13/2012, 10/24 / 2012, 01/08/2013, 04/09/2013, 17/08/2014 and 25/11/2014, which contain five spectral bands, obtained through the Geo Catalog of the Ministry of the Environment (MMA); the selected scenes presented better conditions related to the lower cloudiness index, which favors the analysis and classification of targets), which allowed the analysis of the landscape and the quantification of areas that have forest cover (ratio between total area of each sub-basin and the forested area). Results were validated through field surveys.

Regarding the hydrological variable (H), the hydrological curve number - CN model was used. This model is designed to estimate the surface runoff dynamics in sub-basins, according to the analysis of land use and land cover types. Soil Conservation Service (SCS) procedures, adapted by Calzavara and Fernandez (2015) for Brazilian conditions, were adopted. Precipitation values were obtained from data collected by 11 rainfall stations located in the area of direct influence of the Guamá river basin (series from 1985 to 2015), available from the National Water Agency (ANA) Hydro 1.2 software. These values were spatialized according to the Thiessen Polygon method, which assigned a weighting factor to the precipitated totals in each rain gauge to their respective area of influence (CORREIA; RIBEIRO; BAPTISTA, 2015).

Information on social issues of the municipalities that compose the sub-basins was used in the analysis of the social variable (S), taking into account institutional, political and socioeconomic aspects linked to the population, that directly affect the management of water resources. They included the municipal human development index (MHDI), municipal Gini Index (BRASIL, 2010), water consumption index, and total water supply index per municipality according to the National Sanitation Information System - NSIS (BRASIL, 2016). These data were also investigated from information provided by municipal secretariats and the state government.

After obtaining the variables, arithmetic averages were used to calculate the social indicator for each municipality (Equation 1). This indicator contributed to compare and analyse the municipalities. Then, the weighted average was used so that the social indicators of each municipality were spatialized in their respective sub-basins, i.e. the area of each municipality within the sub-basins was considered (Equation 2). Thus, a social indicator was obtained for each sub-basin and used to determine the WSI, where: S_{mi} = social indicator per municipality; S_i = variables analyzed; n = number of variables; S = social indicator in the sub-basin; A_i = area of the municipality within the sub-basin (ha); A = total area of the sub-basin (ha).

$$S_{mi} = \frac{\sum S_i}{n} \qquad (1)$$

$$S = \frac{\sum_{i=1}^{n} A_i S_{mi}}{A} \qquad (2)$$

Finally, the analysis of the management variable (M) assumed arithmetic and weighted averages, likewise in the previous variable, and referred to characteristics that influence the environmental management capacity of the municipalities that are part of the sub-basins (Table 1). They correspond to 13 attributes collected from the databases of IBGE, SNIS, Green Municipalities Program, and websites of the City Halls. Weights from 0 to 1 were assigned to each sub-basin, so that the management conditions of the municipalities could be analyzed and compared, where 0 indicates bad conditions and 1 good conditions.

To calculate the WSI from indicators that fit the evaluated aspects (H, E, S, M), each one of them was divided into five scale scores (0; 0.25; 0.50; 0.75 and 1) to simplify the estimate, where 0 represents the worst conditions and 1 the best conditions (Table 2).

Table 1. Parameters for the evaluation of municipal management.

Classification = Weigth/Variables				
$\leq 10\% = 0$	$10\% < G \leq 20\% = 0.25$	$20\% < G \leq 30\% = 0.5$	$30\% < G \leq 50\% = 0.75$	$> 50\% = 1$
- Degree of Coverage according to the Rural Environmental Registry (RER)				

Individual = 1	*Associated = 0.5*	*Absent = 0*
- Environment Secretariat		

High Impact = 1	*Low Impact = 0,5*	*No = 0*
- Performs Environmental Licensing		

Existent = 1	*Non-existent = 0*
- Environmental Legislation -	Municipal Environment Council

Yes = 1	*No = 0*
- Participation in the Green Municipalities Program - Environmental management information by internet - Realization of environmental education actions in the municipality - Existence of Land-Use Planning	- It has Basic Sanitation Plan - It has Sanitation Policy - It has qualification for environmental management - It has Municipal Fund of the Environment

Org.: The Author, 2018

Table 2. Variables for the application of the WSI.

Indicator	**Parameters of state defined in this proposal**	**Level defined in this proposal**	p_w
Hydrological	Flow potential from the hydrological curve number - CN model	≤ 0.1	0.00
		$0.1 < H \leq 0.25$	0.25
		$0.25 < H \leq 0.50$	0.50
		$0.50 < H \leq 0.75$	0.75
		> 0.75	1.00
Environmental	% total area of the basin and area occupied by forest cover	$\leq 5\%$	0.00
		$5\% < E \leq 15\%$	0.25
		$15\% < E \leq 30\%$	0.50
		$30\% < E \leq 45\%$	0.75
		$E > 45\%$	1.00
Social	Based on the MHDI, Gini index, and Sanitation Index according to the National Sanitation Information System - NSIS.	≤ 0.5	0.00
		$0.5 < S \leq 0.6$	0.25
		$0.6 < S \leq 0.75$	0.50
		$0.75 < S \leq 0.9$	0.75
		> 0.9	1.00
Management	Institutional capacity of the basin: level of organization of the environmental management system	$\leq 10\%$	0.00
		$10\% < M \leq 20\%$	0.25
		$20\% < M \leq 30\%$	0.50
		$30\% < M \leq 50\%$	0.75
		$> 50\%$	1.00

Org.: The Author, 2018

The WSI corresponds to the sum of variables, according to each parameter considered, divided by the total number of variables adopted (Equation 3). All indicators have the same weight since none of the variables is considered more important than the others, but rather complementary for the sustainability of the basin. They were: hydrological (p_{wH}), environmental (p_{we}), social (p_{wS}), and management (p_{wm}) aspects, rated from 0 to 1 (0 indicates poor conditions and 1 indicates optimal conditions). The expression ni represents the variables considered (Table 2). After obtaining the results, they were classified for each sub-basin according to Table 3. With the analysis of the resulting sustainability indices for each sub-basin, a weighted average in relation to the area was applied to obtain the WSI of the entire Guamá river basin.

$$ISH = \sum p_{wi} / \sum n_i \tag{3}$$

Equally weighted analysis facilitates structuring the dimensions of the indicators, assuming that they have intrinsic characteristics with water management, are measurable, approachable and comparable, so that redundancy effects among the selected variables are reduced (CARVALHO et al., 2013). The analysis allows the integration of heterogeneous criteria and options simultaneously, as for example in the assessment of water sustainability. These factors are highlighted by Flores-Alsina et al. (2010) in the assessment of the water quality index and by Chuang et al. (2018) in the evaluation of hydroenvironmental indicators in coastal systems.

Table 3. Classification of WSI values.

ISH (0.00 – 1.00)	Performance
≤ 0.20	Bad/unsustainable
0.21 to 0.40	Poor/potentially unsustainable
0.41 to 0.60	Medium/intermediate
0.61 – 0.80	Good/potentially sustainable
≥ 0.81	Very good/sustainable

Source: Adapted from Carvalho et al. (2011).

Complementarily, aiming at an integrated analysis, the results were presented in cartographic format and using cluster analysis. The clustering methodology is a multivariate statistical analysis that enables the identification of groups with homogeneous characteristics (k-means), considering mathematical calculations of proximity (similarity) to all pairs of objects and between each object and subgroups. such that the distances between the members of a subgroup are minimal and distances between subgroups are maximum (YOSHIMITANAKA et al., 2015). Results are presented as groupings and heatmaps, where each cell corresponds to the position occupied by the value of a given variable in a unit of analysis.

RESULTS AND DISCUSSION

Environmental indicator

The analysis of the land use and occupation map allowed the identification of the percentage of areas with vegetation (Table 4), and this result identified which sub-basins had the best and worst representativeness in terms of environmental indicator.

It was observed that the sub-basins that presented the best conservation stage, with the occurrence of vegetated areas, were Lower Guamá (57.87%) and Bujarú River (55.51%). In turn, the ones with the largest presence of altered areas were Mãe do Rio Stream (24.07%) and Upper Guamá (29.08%).

It is noteworthy that the largest concentration of altered areas was associated with municipalities that have characteristics focused on agribusiness, with small and medium producers that meet the needs of the state and large producers that serve the rest of Brazil and the foreign market (REBELLO et al., 2011).

The results obtained are in agreement with what Watrin et al. (2009) highlight to the northeast region of Pará, with pasture being the dominant pattern of land use. The same was observed by Pereira et al. (2015) for the Apeú Stream basin, and by Nascimento and Fernandes (2017) for a sub-basin of Upper Guamá.

Table 4. Area corresponding to vegetation cover in the sub-basins analyzed.

Sub-basin	Area of the sub-basin (ha)	Total vegetation area (ha)	Total vegetation area (%)
Upper Guamá	331,639.30	96,444.02	29.08
Apeú Stream	74,737.99	29,318.04	39.23
Sub- basin of Médio Guamá Oeste	142,137.30	53,676.70	37.76
Lower Guamá	163,960.76	94,885.30	57.87
Mãe do Rio Stream	155,244.52	37,359.57	24.07
Middle Guamá east	191,134.49	66,943.62	35.02
Bujarú river	99,019.23	54,964.38	55.51
Sujo river	46,012.53	17,046.30	37.05
Total	1,203,886.12	450,637.93	37.43

Org.: The Author, 2018.

Vegetation cover is of fundamental importance for the functioning of several processes that occur in an ecosystem, such as infiltration or runoff processes, energy balance, maintenance of weather conditions, among others. Changes in vegetation cover caused by deforestation or implementation of agricultural activities can lead to several negative environmental impacts, such as river siltation, soil compaction, triggering of erosive processes, among others (SILVA et al., 2017).

Hydrological indicator

Runoff values were obtained for each sub-basin analyzed through the Curve Number method (Table 5). The runoff of the sub-basins varied between 28 and 33% of the incident precipitation values, and the sub-basin that presented the highest result was the Bujarú River, and the one with the lowest value was the Upper Guamá.

The Guamá river basin is basically composed of five dominant soil types, namely, Yellow Latosols, Concretionary Latosols, Fluvic Latosols, Quartzarenic Neosols, and Red-Yellow Argisols. Yellow Latosols occupy most of the basin, 84.91% of the land.

Yellow Latosol is characterized as deep, porous and with high texture, as well as a moderate infiltration rate, resistance and tolerance to erosion, contributing to the median runoff values in all sub-basins. These conditions favor soil fertility, because the smaller the runoff, the smaller the drag of the finer particle size of the soil (FEITOSA et al., 2010).

The performance shown in Table 5 indicates that the best basin framework, according to the physical-water parameters, of dominant soil type is between Groups A and B, which are classified as (SARTORI et al., 2015): Group A - soils with low runoff and high infiltration, very deep (> 2.0m), with high permeability and low erodibility; Group B - less permeable soils with higher potential to generate runoff, consisting mainly of moderately deep to deep soils. These characteristics make it possible to understand the runoff dynamics in the basin. Consequently, the assessment of water yield potential is also important to the planning of measures for conservation of soil and water characteristics and reduction of siltation processes and risks of floods (MUÑOZ-ROBLES et al., 2011).

Table 5. Mean superficial runoff of sub-basins.

Sub-basin	Precipitation (annual accumulation) (mm)	Runoff (mm)	Runoff from precipitation (%)
Bujarú river	2,462.78	814.12	33.06
Lower Guamá	2,642.59	767.70	29.05
Apeú Stream	2,425.84	733.17	30.22
Middle Guamá west	2,331.86	680.46	29.18
Mãe do Rio Stream	2,392.43	683.74	28.58
Middle Guamá east	2,224.02	668.42	30.05
Sujo river	2,179.63	610.62	28.01
Upper Guamá	2,066.94	578.39	27.98

Org.: The author, 2018.

Social indicator

Parameters related to the municipalities of the Guamá river basin, such as the municipal human development index, the Gini index and two indices of the National Sanitation Information System related to water supply and consumption were used in the analysis of the social indicator. The weighted average values per municipality were the basis to determine the social indicators of the sub-basins, taking into account the areas of the municipalities in relation to their respective sub-basins (Table 6).

Table 6. Social indicators of sub-basins.

Sub-basin	Social indicator
Mãe do Rio Stream	0.66
Middle Guamá West	0.57
Alto Guamá	0.57
Sujo river	0.56
Lower Guamá	0.55
Bujarú river	0.51
Apeú Stream	0.49
Middle Guamá East	0.48

*There is no information regarding the index.
Source: Brasil (2010); Brasil (2016). Org.: The author, 2018.

It was observed that the sub-basin that was most prominent in relation to this indicator was Mãe do Rio Stream, with a value of 0.66. This basin is composed by the municipalities of Capitão Poço, São Domingos do Capim, Irituia and Mãe do Rio, which stand out mainly in relation to the water supply.

The least prominent sub-basin was the Middle Guamá east sector, with a value of 0.48, composed by the municipalities of Bonito, Capitão Poço, Irituia, Ourém, Santa Luzia do Pará and São Miguel do Guamá, two of which did not present information about two of the indices analyzed (Bonito and São Miguel do Guamá).

Management indicator

The analysis of management of the municipalities was based on the mean values obtained by assigning weight to the 13 variables analyzed (Table 1) regarding the presence or degree of coverage of: environmental legislation, municipal council environment, environmental licensing, Environment Secretariat, Rural Environmental Registry (RER), Green Municipalities Program, environmental management via internet, environmental education in the municipality, municipal land-use planning, basic sanitation plan, sanitation policy, environmental management and Municipal Fund of the Environment. Based on these variables, a value was generated for the management indicator for each municipality and then weighted for the sub-basin area (Table 7).

Table 7. Management indicators of sub-basins.

Sub-basin	Management indicator
Apeú Stream	0.62
Bujarú river	0.56
Middle Guamá West	0.53
Middle Guamá East	0.42
Lower Guamá	0.40
Mãe do Rio Stream	0.37
Upper Guamá	0.29
Sujo river	0.26

Org.: The author, 2018.

The Guamá river basin is heterogeneously composed of 19 municipalities that present different percentages in area (contained in the basin) of different representativeness: Acará (0.80%); Ananindeua (0.15%); Belém (0.96%); Benevides (0.51%); Bonito (0.65%); Bujaru (7.96%); Capitão Poço (21.59%); Castanhal (3.82%); Concordia do Pará (5.40%); Garrafão do Norte (13.92%); Inhangapi (3.87%); Irituia

(11.15%); Mãe do Rio (3.38%); Marituba (0.28%); Ourem (3.45%); Santa Izabel do Pará (4.78%); Santa Luzia do Pará (5.48%), São Domingos do Capim (3.83%); and São Miguel do Guamá (8%). Of these, 14 present their municipal headquarters within the basin area. As management indicators refer to the political actions in the municipality as a whole, it was decided to attribute equal weights because it is understood that, once consolidated, management actions will have consequences distributed throughout the territory.

The procedure adopted follows the premise discussed by Carvalho (2014) in stating that the integrity of watersheds must encompass a systemic understanding of sustainability, with water being understood as a whole in spatial relationships, with integrated environmental planning of watersheds associated with territorial planning.

The sub-basin with the highest value for this indicator was the Apeú stream, which comprises the municipalities of Castanhal and Santa Izabel do Pará that obtained values above 0.50, and Inhangapi had a low management indicator. The sub-basins of the Sujo River and the upper Guamá River had the lowest values. This is because both municipalities had indicators below 0.40, indicating that they need more immediate actions to strengthen environmental management.

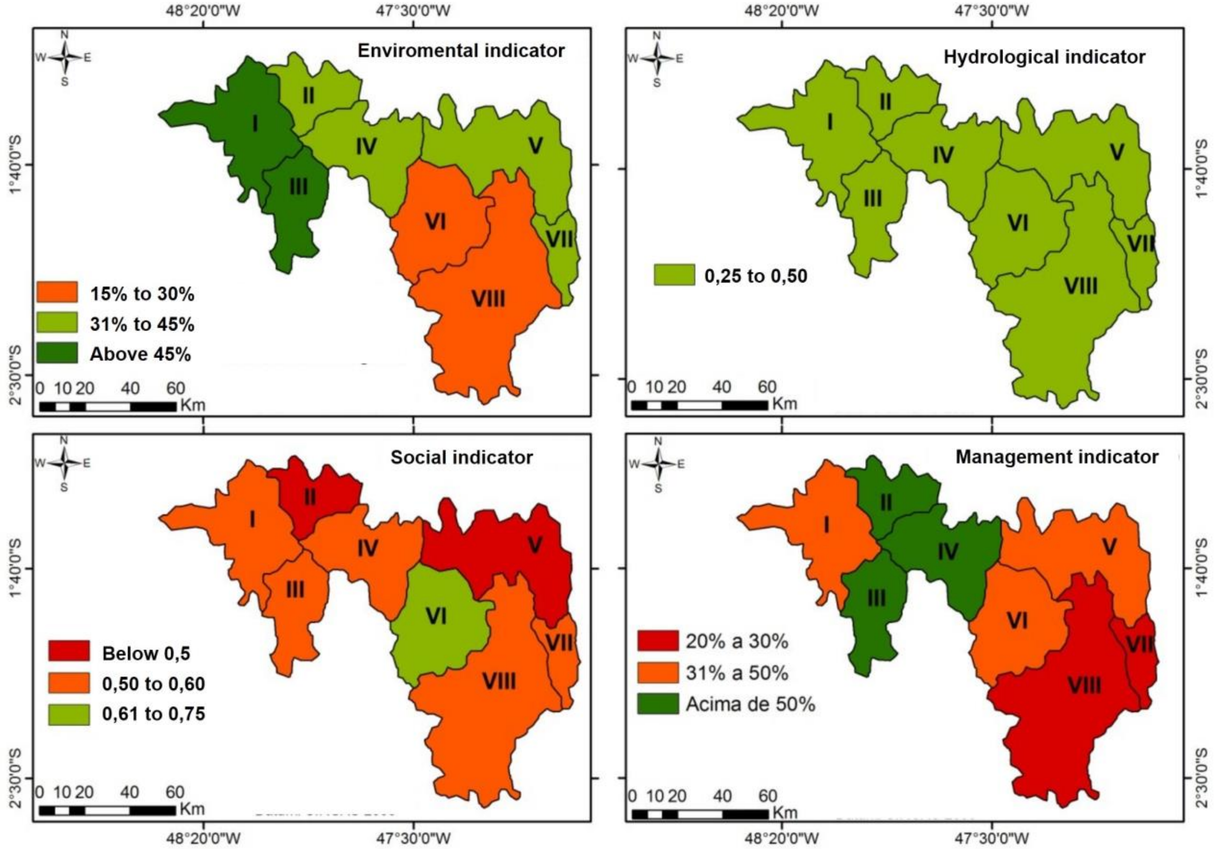
Water sustainability index

Water sustainability was initially calculated per sub-basin, and the results were framed according to each indicator: hydrological, environmental, social and management (Figure 2). Figure 3 represents the treatment given to the indicator categories using the clustering methodology. Relationships observed spatially or by cluster indicate existing similarities and factors of greater intervention. The basin can be viewed in 3 major segments: Upper Guamá – Sujo river - Mãe do Rio stream; Middle Guamá – Apeú Stream; Bujarú River - Lower Guamá.

The social (S) and management (M) indicators are the most responsible for the fragilities observed, mainly pressing the Upper Guamá, Apeú Stream and Mãe do Rio Stream sub-basins. The WSI is the global average of the four indicators and this indicator analysis allowed obtaining the water sustainability indices of each sub-basin and their respective performances (Table 8). The analysis resulted in a value of 0.54.

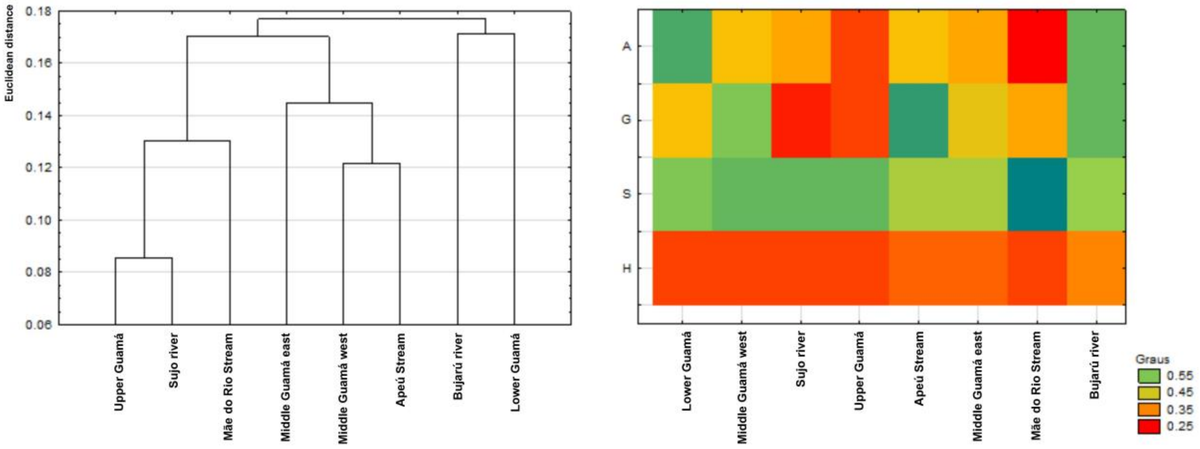
Maynard et al. (2017) obtained a value of 0.66 for the Japaratuba river basin (SE), with the weakest indicators being the hydrological and management ones. Silva (2017) obtained a value of 0.53 for the Piranhas-Açu sub-basin (RN), also identifying that, in general, the indicators related to socioeconomic and management aspects make a considerable contribution to the maintenance of intermediate sustainability.

Figure 2 - Water sustainability index based on environmental, hydrological, social and management indicators for the sub-basins: I- Lower Guamá; II- Apeú Stream; III- Bujarú River; IV- Middle Guamá west sector; V- Middle Guamá east sector; VI- Mãe do Rio Stream; VII- Rio Sujo; VIII- Upper Guamá.



Org.: The author, 2018.

Figure 3. (a) Result of analysis by hierarchical clustering. (b) Representation of the cluster analysis through color matrices - Heatmaps.



(a) (b)

Org.: The author, 2018.

Table 8. Water sustainability indices of the sub-basins.

Sub-basin	ISH	Performance
Lower Guamá	0.63	Good/potentially sustainable
Apeú Stream	0.56	Medium/Intermediate
Bujarú River	0.69	Good/potentially sustainable
Middle Guamá Oeste	0.63	Good/potentially sustainable
Mãe do Rio Stream	0.56	Medium/Intermediate
Middle Guamá East	0.50	Medium/Intermediate
Sujo River	0.50	Medium/Intermediate
Upper Guamá	0.44	Medium/Intermediate

Org.: The author, 2018.

Juwana et al. (2012) presented a review of water sustainability indicators and highlighted the influence that the “management” component may have on the others, where unfavorable conditions in the “hydrological” and “environmental” axes may have their impacts reduced with better management conditions of water resources.

The values of the social indicator showed the need to seek alternatives that contribute to the improvement of the indices analyzed, to obtain circumstances that favor an ideal quality of life and assurance of quality basic services for the population. Environmental management is of fundamental importance for the organization of municipalities and, consequently, of sub-basins. Investing in actions focused on this criterion represents a beneficial strategy for the maintenance of sub-basins, in addition to strengthening and conserving the interdependent relationships that occur in their territories (MARTINS et al., 2010).

The global average obtained for the basin showed its situation in relation to water sustainability, urging for the establishment of water management programs capable of enhancing the scenario presented, through more responsible actions by management regulators and other sectors of society. Water sustainability suggests the conditions necessary for basins to have conditions to replenish resources, compatible with the existing demand, always aiming at a consumption that is equal to or lower than their recovery capacity (TAMASAUSKAS et al., 2016).

The indicators analyzed demonstrated that the process of use and occupation of the territory of the Guamá river basin has a high potential to interfere with water sustainability, since they exert a positive or negative influence on it. Where the evolutionary dynamics of a landscape are understood by its historical processes at different time scales and according to the predominant environmental characteristics, both aspects contribute to the establishment of a local distribution pattern (VIEIRA et al., 2007).

The evolutionary dynamics from the perspective of sustainability of the Guamá river basin has several historical landmarks, such as the construction of the Belém-Brasília highway (BR 010), responsible for the emergence of dozens of towns, villages and cities, particularly those in the NE region of the state (TAVARES, 2008). Given this context, land use forms have marked northeastern Pará by a process of de-characterization due to deforestation. The percentage of change due to anthropism in the region has reached almost 25%, concomitant to the growth of logistic services and natural resources exploitation services such as logging, slashand-burn agriculture, and livestock, forming a mosaic of different degrees of plant succession, agricultural crops and pasture areas (CORDEIRO et al., 2017).

Regarding the use of the Guamá river basin, it covers part of the municipalities of the Metropolitan Region of Belém, with the headwaters of its sub-basins having the axis of the BR-360, that connects Pará to Maranhão, and of the BR-010, that makes the connection with the southeast of the state, as water divisors. Thus, their urban centers have the ability to polarize and influence a significant number of smaller cities and articulate relationships of all kinds, with the presence of medium-sized urban centers that make up the metropolitan area (TRINDADE Jr, 2011).

Land use in the Guamá basin faces future prospects of water sustainability for the region, with a high degree of urbanization, concentration of economic activities accompanied by growing poverty and persistent social problems (access to health, education, housing and basic sanitation) necessary for a large portion of the population (SILVA; SILVA, 2008).

FINAL CONSIDERATIONS

The WSI was more representative in the sub-basins where there was a higher runoff, higher concentration of vegetated areas, significant quality of life, and strengthened management. Thus, the results obtained indicated that the lower Guamá sub-basins (0.63), the Middle Guamá west sector (0.63), and the Bujarú river (0.69) had good sustainability conditions. The sub-basins of the Upper Guamá (0.44), Mãe do Rio Stream (0.56), Sujo River (0.50), Middle Guamá east sector (0.50), and Apeú Stream (0.56) had an intermediate performance. Thus, the water sustainability of the Guamá river basin was intermediate, with a value of 0.54.

It was observed that the research carried out in the basin-scale allowed the joint analysis of hydrological, environmental, social and management aspects. Considering the context of the Guamá river basin, measures are needed for strategic planning linked to its management, where managers and other sectors of society must work more efficiently to minimize pressures on remnant vegetation so as to strengthen institutional capacity and improve the quality of resources and livelihoods of the population, to enhance the sustainability of the basin as a whole.

ACKNOWLEDGEMENTS

To the Coordination for Improvement of Higher Education Personnel (CAPES) and the National Council for Scientific and Technological Development (CNPq) for the funding given for the development of the research.

REFERENCES

ARAGÓN, L. E. A dimensão internacional da

Amazônia: um aporte para sua interpretação. **R. NERA**, n. 42, p. 14-33, 2018.

BARROSO, D. F. R.; FIGUEIREDO, R. O.; PIRES, C. S.; COSTA, F. F. Avaliação da sustentabilidade ambiental de sistemas agropecuários em microbacias do nordeste paraense a partir de parâmetros físico-químicos. **R. do Instituto Histórico e Geográfico do Pará**, v. 2, n. 2, p. 56-68, 2015. https://doi.org/10.17553/2359-0831/ihgp.v2n2p56-68

BECKER, B. **Amazônia**: geopolítica na virada do III milênio. Rio de Janeiro: Garamond, 2009, 168 p.

BEZERRA, C. G.; SANTOS, A. R.; PIROVANI, D. B.; PIMENTEL, L. B.; EUGENIO, F. C. Estudo da fragmentação florestal e ecologia da paisagem na sub-bacia hidrográfica do córrego horizonte, Alegre, ES. **Espaço & Geografia**, v. 14, n. 2, p. 257-277, 2011.

BLAIN, G. C.; BRUNINI, O. Análise comparativa dos Índices de Seca de Palmer, Palmer Adaptado e Índice Padronizado de Precipitação no estado de São Paulo. **R. B. de Meteorologia**, v. 22, n. 1, p. 105-111, 2007. https://doi.org/10.1590/S0102-77862007000100011

BLANC, I.; FRIOT, D.; MARGNI, M.; JOLLIET, O. Towards a New Index for Environmental Sustainability Based on a DALY Weighting Approach. **Sustainable Development**, v. 16, p. 251-260, 2008. https://doi.org/10.1002/sd.376

BÖHRINGER, C.; JOCHEM, P. E. P. Measuring the immeasurable - A survey of sustainability indices. **Ecological Economics**, v. 63, p. 1-8, 2007. https://doi.org/10.1016/j.ecolecon.2007.03.008

BOYACIOGLU, H. Dvelopment of a Water Quality Index Based on a European Classification Scheme. **Water**, v. 33, p. 101-106, 2007. http://dx.doi.org/10.4314/wsa.v33i1.47882

BRASIL. Instituto Brasileiro de Geografia e Estatística (IBGE). **Censo demográfico 2010**. Disponível em: <http://www.ibge.gov.br/home/>. Acesso em: 09 de Setembro de 2015.

BRASIL. Instituto Brasileiro de Geografia e Estatística (IBGE). **Manual técnico de uso da terra**: manuais técnicos em geociências. Brasília, DF: Instituto Brasileiro de Geografia e Estatística – IBGE, 2013. 171 p.

BRASIL. Sistema nacional de informações sobre o saneamento (SNIS). **Séries históricas.** 2016. Disponível em: <http://www.snis.gov.br/>. Acesso em: 28 de setembro de 2017.

CABRAL, S. L.; CAMPOS, J. N. B.; SILVEIRA, C. S.; PEREIRA, J. M. R. O Intervalo de tempo para uma máxima previsiblidade da precipitação sobre o semiárido brasileiro. **R. B. de Meteorologia**, v. 31, n. 2, p. 1-9, 2016. https://doi.org/10.1590/0102-778631220130034

CALZAVARA, S. F.; FERNANDEZ, O. V. Q. Uso e ocupação do solo e número de curva (CN) na bacia hidrográfica do córrego Matilde Cuê, Marechal Cândido Rondon (PR). **Geoingá**, v. 7, n. 1, p. 185-209, 2015.

CARVALHO, J. R. M.; CURI, W. F.; CURI, R. C. Uso da análise multicritério na construção de um índice de sustentabilidade hidroambiental: estudo em municípios paraibanos. **R. B. de Gestão e Desenvolvimento Regional**, v. 9, n. 2, p. 3-26, 2013.

CARVALHO, J. R. M.; CURI, W. F.; CARVALHO, E. K. M. A.; CURI, R. C. Proposta e validação de indicadores hidroambientais para bacias hidrográficas: estudo de caso na sub-bacia do alto curso do Rio Paraíba, PB. **Sociedade & Natureza**, v. 23, n. 2, p. 295-310, 2011.

CARVALHO, R. G. As bacias hidrográficas enquanto unidades de planejamento e zoneamento ambiental no Brasil. **Caderno Prudentino de Geografia**, n. 36, p. 26-43, 2014.

CHAVES, H. M. L.; ALIPAZ, S. M. F. An integrated indicator based on basin hydrology, environment, life, and policy: the watershed sustainability index. **Water Resources Management**, v. 21, n. 5, p. 883-895, 2007. http://dx.doi.org/10.1007/s11269-006-9107-2

CHUANG, Y. H.; YU, R. F.; CHEN, W. Y.; CHEN, H. W.; SU, Y. T. Sustainable planning for a coastal wetland system with an integrated ANP and DPSIR model for conflict resolution. **Wetlands, Ecology and Management**, v. 26, n. 6, p. 1015-

1036, 2018. http://dx.doi.org/10.1007/s11273-018-9627-6

CORDEIRO, I. M. C. C.; RANGEL-VASCONCELOS, L. G. T.; SCHWARTZ, G.; OLIVEIRA, F. A. **Nordeste Paraense**: panorama geral e uso sustentável das florestas secundárias. Belém: Embrapa Amazônia Oriental, 2017, p. 19 - 58.

CORREIA, E. F. G.; RIBEIRO, G. P.; BAPTISTA, A. C. Modelagem hidrológica da bacia hidrográfica do rio Bengalas, Nova Friburgo, RJ, utilizando o potencial de geotecnologias na definição de áreas de risco à inundação. **R. B. de Cartografia**, v. 67, n. 6, p. 1183-1202, 2015.

CORTÉS, A. E.; OYARZÚN, R.; KRETSCHMER, N.; CHAVES, H.; SOTO, G.; SOTO, M.; AMÉZAGA, J.; OYARZÚN, J.; RÖTTING, T.; SEÑORET, M.; MATURANA, H. Application of the Watershed Sustainability Index to the Elqui river basin, North-Central Chile. **Obras y Proyectos**, v. 12, p. 57-69, 2012. http://dx.doi.org/10.4067/S0718-28132012000200005

EMERSON, J.; ESTY, D. C.; LEVY, M. A.; KIM, C. H.; MARA, V.; SHERBININ, A.; SREBOTNJAK T. **2010 Environmental Performance Index**. New Haven: Yale Center for Environmental Law and Policy, 2010, 87 p.

FAO. **Water for Sustainable Food and Agriculture**: a report produced for the G20 Presidency of Germany Rome: Food and Agriculture Organization of the United Nations, 2017, 33 p.

FARO, G. T. C.; GARCIA, J. I. B.; OLIVEIRA, C. P. M.; RAMOS, M. R. S. Application of indices for water resource systems stress assessment. **B. J. of Water Resources**, v. 24, e7, 2019. https://doi.org/10.1590/2318-0331.241920180106

FEITOSA, A.; FECHINE, J. A. L.; FERREIRA, C. W. S.; ARAÚJO, M. S. B. Modelagem dinâmica de escoamento superficial influenciando a susceptibilidade à erosão dos solos num município do semi-árido de Pernambuco. **R. B. de Geomorfologia**, v. 11, n. 2, p. 75-82, 2010. http://dx.doi.org/10.20502/rbg.v11i2.154

FERREIRA, A. V.; SÁNCHEZ-ROMÁN, R. M.; GONZÁLEZ, A. M. G. O. Temporal dynamic modeling for the assessment of water availability and its effects on sustainability of water resources at Boi Branco Sub-basin, SP, Brazil. **Athens J. of Sciences**, v. 3, n. 2, p. 137-154, 2016. https://doi.org/10.30958/ajs.3-2-4

FLORES-ALSINA, X.; GALLEGO, A.; FEIJOO, G.; RODRIGUEZ-RODA, I. Multiple-objective evaluation of wastewater treatment plant control alternatives. **J. of Environmental Management**, v. 91, p. 1193-1201, 2010. https://doi.org/10.1016/j.jenvman.2010.01.009

HTCF. **Mission creek sustainable watershed indicators workbook.** British Columbia: Habitat Conservation Trust Fund, 2003, 24 p.

JUWANA, I.; MUTTIL, N.; PERERA, B. J. C. Indicator-based Water Sustainability Assessment - a review. **Science of the Total Environment**, v. 438, p. 357-371, 2012. https://doi.org/10.1016/j.scitotenv.2012.08.093

KEYANTASH, J. A.; DRACUP, J. A. An aggregate drought index: assessing drought severity based on fluctuations in the hydrologic cycle and surface water storage. **Water Resources Research**, v. 40, W09304, 2004. https://doi.org/10.1029/2003WR002610

MARQUES, R. V. Recursos hídricos no Brasil: um panorama histórico e institucional. **R. Tecnologia & Cultura**, v. 19, n. 29, p. 15-23, 2017.

MARTINS, A. A.; SOUZA, C. S. M.; FERREIRA, R. S.; SICILIANO, A. A importância da gestão ambiental com foco na sustentabilidade ambiental. **Avesso do Avesso**, v. 8, n. 8, p. 1-16, 2010.

MAYNARD, I. F. N.; CRUZ, M. A. S.; GOMES, L. J. Applying a sustainability index to the Japaratuba river wathershed in Sergipe State. **Ambiente & Sociedade**, v. 20, n. 2, p. 201-220, 2017. https://doi.org/10.1590/1809-4422asoc0057r1v2022017

MUÑOZ-ROBLES, C.; REID, N.; TIGHE, M.; BRIGGS, S. V.; WILSON, B. Soil hydrological and erosional responses in patches andinter-patches in vegetation states in semiarid Australia. **Geoderma**, v. 160, p. 524–534, 2011.

https://doi.org/10.1016/j.geoderma.2010.10.024

NARDO, M.; SAISANA, M.; SALTELLI, A.; TARANTOLA, T.; HOFFMAN, A.; GIOVANNINI, E. **Handbook on Constructing Composite Indicators** - Methodology and User Guide. Paris, France: OECD Publications, 2008, 162 p.

NASCIMENTO, T. V.; FERNANDES, L. L. Mapeamento de uso e ocupação do solo em uma pequena bacia hidrográfica da Amazônia. **Ciência e Natura**, v. 39, n. 1, p. 170-178, 2017.

PEREIRA, B. W. F.; MACIEL, M. N. M.; OLIVEIRA, F. A.; SILVA, H. A. S.; BRAGA, T. G. M.; FIGUEIREDO, D. B. Estrutura da paisagem da bacia hidrográfica do rio Peixe-Boi com base na fragmentação da vegetação. **R. de Ciências Agrárias**, v. 58, n. 2, p. 159-167, 2015.

PRATES, R. C.; BACHA, C. J. C. Os processos de desenvolvimento e desmatamento da Amazônia. **Economia e Sociedade**, v. 20, n. 3, p. 601-636, 2011. https://doi.org/10.1590/S0104-06182011000300006

REBELLO, F. K.; SANTOS, M. A. S.; HOMMA, A. K. O. Modernização da agricultura nos municípios do nordeste paraense: determinantes e hierarquização no ano de 2006. **R. de Economia e Agronegócio**, v. 9, n. 2, p. 209-232, 2011.

RIBEIRO, C. R.; PIZZO, H. S. Avaliação da sustentabilidade hídrica de Juiz de Fora/MG. **Mercator**, v. 10, n. 21, p. 171-188, 2011. https://doi.org/10.4215/RM2011.1021.0012

RICKWOOD, C. J.; CARR, G. M. Development and Sensitivity Analysis of a Global Drinking Water Quality Index. **Environmental Monitoring and Assessment**, v. 156, n. 1-4, p. 73-90, 2009. https://doi.org/10.1007/s10661-008-0464-6

RIVERO, S.; ALMEIDA, O.; ÁVILA, S.; OLIVEIRA, W. Pecuária e desmatamento: uma análise das principais causas diretas do desmatamento na Amazônia. **Nova Economia**, v.19, n. 1, p. 41-66, 2009. https://doi.org/10.1590/S0103-63512009000100003

SANTOS, L. S.; MARTORANO, L. G.; BATALHA, S. S. A.; PONTES, A. N.; SILVA, O. M.; WATRIN, O. S.; GUTIERREZ, C. B. B. Imagens orbitais e termografia infravermelho na avaliação da temperatura de superfície em diferentes usos e cobertura do solo na floresta nacional do Tapajós e seu entorno-PA. **R. B. de Geografia Física**, v. 9, n. 4, p. 1234-1253, 2016.

SARTORI, A.; NETO, F.; GENOVEZ, A. Classificação hidrológica de solos brasileiros para estimativa da chuva excedente com o método do serviço de conservação do solo dos Estados Unidos Parte 1: Classificação. **R. B. de Recursos Hídricos**, v. 10, n. 4, p.5-18, 2005. https://doi.org/10.21168/rbrh.v10n4.p5-18

SILVA, C. C. D.; ALBUQUERQUE FILHO, J. L.; OLIVEIRA, R. A.; LOURENÇO, R. W. Metodologia para análise do potencial de degradação dos recursos hídricos em bacias hidrográficas. **Caderno de Geografia**, v. 27, n. 50, 2017. https://doi.org/10.5752/p.2318-2962.2017v27n50p455

SILVA, D. D. C. **Aplicação do índice de sustentabilidade de bacias hidrográficas no rio Piranhas-Açu a partir dos métodos multicritério e multidecisor**. 2017. 312 f. Tese (Doutorado), Programa de Pós-Graduação em Recursos Naturais, Centro de Tecnologia e Recursos Naturais, Universidade Federal de Campina Grande, Paraíba, 2017.

SILVA, F. C.; SILVA, L. J. M. História regional e participação social nas Mesorregiões Paraenses. **Paper do NAEA**, n. 226, p. 3 - 25, 2008.

SILVA, M.; NASCIMENTO, C. P.; COUTINHO, A. C.; ALMEIDA, C. A.; VENTURIERI, A.; ESQUERDO, J. C. D. M. A transformação do espaço amazônico e seus reflexos na condição atual da cobertura e uso da terra. **Novos Cadernos NAEA**, v. 16, n. 1, p. 229-248, 2013. http://dx.doi.org/10.5801/ncn.v16i1.608

SOOD, A.; RITTER, W. F. Developing a Framework to Measure Watershed Sustainability by Using Hydrological/Water Quality Model. **J. of Water Resource and Protection**, v. 3, p. 788-804, 2011. http://dx.doi.org/10.4236/jwarp.2011.311089

SOUSA, F. A. S.; DANTAS, F. R. C.; GUEDES, R. V. S.; MACEDO, M. J. H.

Análise do Índice Padronizado de Precipitação para o estado da Paraíba, Brasil. **Ambiente & Água**: An Interdisciplinary Journal of Applied Sciences, v. 5, n. 1, p. 204-214, 2010. http://dx.doi.org/10.4136/ambi.agua.130

SULLIVAN, C. A. Calculating a Water Poverty Index. **World Developmen**t, v. 30, n. 7, p. 1195-1210, 2002. https://doi.org/10.1016/S0305-750X(02)00035-9

SULLIVAN, C. A.; MEIGH, J. R.; GIACOMELLO, A. M. The Water Poverty Index: development and application at the community scale. **United Nations Sustainable Development Journal**, v. 27, n. 3, p. 189-199, 2003. https://doi.org/10.1111/1477-8947.00054

TAMASAUSKAS, P. F. L. F.; SOUZA, L. F. P.; LIMA, A. M. M.; PIMENTEL, M. A. S.; ROCHA, E. J. P. Métodos de avaliação da influência das áreas ripárias na sustentabilidade hidrológica em bacias hidrográficas no nordeste do estado do Pará. **Caderno de Geografia**, v. 26, n. 45, p. 172-186, 2016. https://doi.org/10.5752/P.2318-2962.2016v26n45p172

TAVARES, M. G. C. A formação territorial do espaço Paraense: dos fortes à criação de municípios. **R. Acta Geográfica**, ano II, n. 3, 2008. p. 59 - 83. https://doi.org/10.5654/actageo2008.0103.0005

TEJADA-GUIBERT, J. A.; SETEGN, S. G.; STOA, R. B. Sustainable Development and Integrated Water Resources Management. In: SETEGN, S. G.; DONOSO, M. C. (Eds) **Sustainability of Integrated Water Resources Management**: Water Governance, Climate and Ecohydrology. Switzerland: Springer, p. 197-214, 2015.

TRINDADE, L. L.; SCHEIBE, L. F. Water management: constraints to and contributions of brazilian watershed Management Committees. Ambiente & Sociedade. v. 22, e02672, 2019. https://doi.org/10.1590/1809-4422asoc20160267r2vu2019l2ao

TRINDADE Jr, S - C. C. Cidades médias na Amazônia Oriental das novas centralidades à fragmentação do território. **R. B. Estudos Urbanos e Regionais**, v. 13, n. 2, 2011, p. 135 - 151. https://doi.org/10.22296/2317-1529.2011v13n2p135

VIEIRA, I. C. G.; TOLEDO, P. M. de; ALMEIDA, A. Análise das modificações da paisagem da Região Bragantina no Pará: integrando diferentes escalas de Tempo. **Ciência e Cultura**, v. 59, n. 3, p. 27-30, 2007.

VIEIRA, P. M. S.; STUDART, T. M. C. Proposta Metodológica para o Desenvolvimento de um Índice de Sustentabilidade Hidro-Ambiental de Áreas Serranas no Semiárido Brasileiro - Estudo de Caso: Maciço de Baturité, Ceará. **R. B. de Recursos Hídricos**, v. 14, n. 4, p. 125-136, 2009. https://doi.org/10.21168/rbrh.v14n4.p125-136

XU, Z. X.; JINNO, K., KAWAMURA, A.; TAKESAKI, S.; ITO, K. Sustainability analysis for yellow river water resources using the system dynamics approach. **Water Resources Management**, n. 16, p. 239-261, 2002. https://doi.org/10.1023/A:1020206826669

WATRIN, O. S.; CRUZ, C. B. M.; SHIMABUKURO, Y. E. Análise evolutiva da cobertura vegetal e do uso da terra em projetos de assentamentos na fronteira agrícola amazônica, utilizando geotecnologias. **Geografia**, v. 30, n. 1, p. 59-76. 2005.

WELSCH H. Constructing Meaningful Sustainability Indices. **Applied Research in Environmental Economics**, v. 31, p. 7-22, 2005. https://doi.org/10.1007/3-7908-1645-0_2

WILLET, J.; WETSER, K.; VREEBURG, J.; RIJNAARTS, H. H. M. Review of methods to assess sustainability of industrial water use. **Water Resources and Industry**, v. 21, 100110, 2019. https://doi.org/10.1016/j.wri.2019.100110

YOSHIMITANAKA, O.; DRUMOND JÚNIOR, M.; CRISTO, E. B.; SPEDO, S. M.; PINTO, N. R. S. Uso da análise de clusters como ferramenta de apoio à gestão no SUS. **Saúde e Sociedade**, v. 24, n. 1, p. 34-45, 2015. https://doi.org/10.1590/S0104-12902015000100003