Evaluation of sustainability in the use of water within the Amazon deforestation area: a case study in Rondon do Pará, Pará State, Brazil

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ABSTRACT. The use of water in a hydrographic basin within the Amazon deforestation area is evaluated as a case study for the municipality of Rondon do Pará, State of Pará, Brazil. Current investigation takes into account the hydrographic basin as a system, following the Pressure/State/Response concept model, and aims at an analysis of the system's sustainability. Results show that the use of water within the context of the system under analysis tends towards non-sustainability. Economic growth, especially triggered by the expansion of extensive cattle-raising and industrial activities, has worsened the situation. These conditions do not represent local reality since the above-mentioned activities have produced only scanty employment. Further, the municipality is striving with problems concerning the supply of drinking water, deficiency in sewage treatment and especially the deterioration of surface water resources.

Keywords: PSR, WQI, management and planning of water resources, river Ararandeua.

Avaliação da sustentabilidade do uso da água no arco do desmatamento da Amazônia: estudo de caso de Rondon do Pará, Estado do Pará, Brasil

RESUMO. O trabalho apresenta uma avaliação do uso da água em uma bacia hidrográfica inserida no "arco do desmatamento" da Amazônia, considerando um estudo de caso no município de Rondon do Pará, Estado do Pará, Brasil. O estudo considerou a bacia hidrográfica como um sistema, tendo seus indicadores socioeconômicos e ambientais agrupados, de acordo com o modelo conceitual Pressão/Estado/Resposta, visando uma análise de sustentabilidade do sistema. O resultado mostrou que o uso da água no sistema em estudo caminha para a insustentabilidade. Tal situação vem agravando-se com o crescimento econômico, principalmente impulsionado pela expansão da pecuária extensiva e atividade industrial, o qual não reflete a realidade local, já que essas atividades têm gerado poucos postos de trabalho. Além disso, o município convive com problemas no abastecimento de água potável, deficiência no tratamento de esgotos, e principalmente a degradação dos recursos hídricos superficiais.

Palavras-chave: PER, IQA, gestão e planejamento de recursos hídricos, rio Ararandeua.

Introduction

According to Rivero et al. (2009), deforestation in the Brazilian Amazon is directly related to cattle-raising, large-scale agriculture and slash-and-burn agriculture, although the former is the most relevant. The activities' direct and indirect impacts are causing serious consequences and modification in the water cycle through a limitation of its use and with deep damage to the social and economical aspects of the Amazon region.

Fearnside (2006) states that such scenario has continually worsened since 1991, with the constant loss of environmental service such as the maintenance of biodiversity and water and carbon stock cycling which avoid degradations of greenhouse effects.

When quantitative implications on water resources are taken into consideration, Davidson et al. (2012) insist that the expansion of agriculture and climate variability have become important disruptive agents within the Amazon basin. In fact, recent studies have revealed possible changes in regional rainfall standards, river water discharge, water cycles in the southern and eastern regions of the Amazon basin.

According to Borges and Júnior (2012) in their studies on the implication on water quality, the quality of water resources is highly influenced by the type of soil use and occupation. Modifications in the chemical, physical and biological characteristics of any natural and environment effects have repercussions directly or indirectly on

the fauna and flora and, consequently, on human beings. Mudian et al. (2012) comment that human activities associated with agriculture, industrialization and urbanization trigger the degradation of water quality.

Current research evaluates the sustainability of use of water in Rondon do Pará, a town and municipality within the hydrographic basin of the river Ararandeua (HBRA), under control of the federal government of Brazil (with sources in the State of Maranhão, Brazil) and within the Amazon deforestation region.

Rondon do Pará is a town and a municipality to which converge the social, economical, administrative, political, environmental and territorial characteristics of the hydrographic basin of the river Ararandeua (HBRA). The municipality is experiencing deep economical changes since the agricultural and cattle-breeding activities are on the increase and overshadowing the timber and mineral extraction activities. Direct and indirect impacts are consequently being felt within the social and environmental levels since growth in cattle raising means an increase in activities in the local abattoirs, most of which without any sanitary planning. Untreated-wastes are dumped in the waters of the HBRA, already deteriorated by decades of former activities (sediment deposition caused by the destruction of riparian vegetation and by mineral extraction).
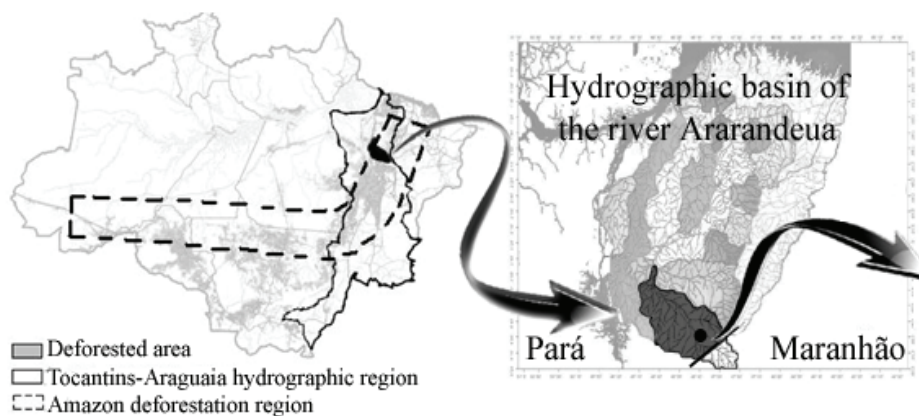

Figure 1. Analyzed area (SEMA/PA, 2008, GOOGLE, 2009, edited).

Material and methods

Hydric system's characterization and sustainability

The hydrographic basin is the territorial unit for the management and planning of Water Resources in Brazil (Lei 9433/97). Management planning requires a systemic view in which design is relevant towards long term efficiency. Besides being a physical system, HBRA should be considered a complex system with special social and economical characteristics for human well-being.

The comprehension of the hydrographical basin as a water system comprises the identification of the following basic features:

- **Elements in the system**: living beings, from the simplest to the most complex, are elements, each with its own importance and relevance. Abiotic elements, such as rocks, water and others, integrate the system. According to Perilla et al. (2010), human beings are a subsystem (each considered to be an element too in the case of current analysis) that requires conditions and resources, namely water, in sufficient quality and quantity to develop their productive activities. However, in this context it is very important to emphasize that human beings are special elements within the hydric system since they have the capacity of modify it.

- **Interactivity among the elements**: The food chain among living beings is a type of interactivity in which exchanges in matter and energy, from primary producers to decomposers, may be identified. In the case of abiotic factors, dependence interactivities, such as fish and water habitat or vegetation and oxygen in the air and in the water, may also be identified.

- **External environment**: neighboring hydrographical basins.

- **The system's aim**: The system provides equilibrium to the several elements which belong to it, or rather, it provides means so that it performs its function within the system. Within the research context, equilibrium is related to the sustainable development of the water system. In fact, the evaluation of the use of water in a hydrographical basin boils down to an analysis of its sustainability or non-sustainability. Bossel (1999) states that sustainability implies a time dimension since non-sustainability rarely suggests an immediate existential foreseeing. The author also reports that the evaluation the sustainability of dynamic systems requires three basic information categories for analysis: data on stocks to be analyzed, modification rates of the system and useful information for evaluation.

Information is obtained by the exploration of the variable of the systems and their derivates in indexes and indicators of sustainability.

According to Bodini (2012), indexes are holistic measures that reveal the relationship between internal processes and the performance of the systems as a whole. Siche et al. (2007) remarks that indexes or indicators function as warning signs on the situation of the system evaluated. In fact, they are static rates, or portraits of the present. Shields et al. (2002) state that indexes represent the state of a system or of a phenomenon, including interactivity among the elements. Scipioni et al. (2009) emphasize that the use of adequate indexes and indicators is essential for sustainable development since it is the basis for analysis and evaluation, backs decision taking and helps communication among society as a whole.

According to Levrel et al. (2009), many national and international organizations develop sustainability indexes among which may be mentioned the highly relevant interactivity indicators which permit the linking of human activities, ecological dynamics and social objectives. Pérez-Foguet and Garriga (2011) report that several indicators are cited in the literature, especially those foregrounded on the concept of the cause and effect relationships.

The Organization for Economical Cooperation and Development (OECD) was a pioneering movement for the development of environmental indicators to measure a system's sustainability, with a specific program starting as from 1990. The program comprises the principle that indicators do not stand alone since the most useful are always a function of their aims. The set of indicators is systemized on the conceptual model Pressure/State/Response model (PSR) developed by the OECD.

Pressure indicators characterize pressures on environmental systems; State indicators present the quality of the environment in a specific space at a determined period. It may show the environment's susceptibility to certain pressures. Response indicators show the answers given by society, such as attenuating measures for the solution of environmental issues.

According to Guimarães and Magrini (2008), the systemic formulation of indicators for hydrographic basins with sources and well-defined elaboration procedures provides an information system that foregrounds their use in administration plans for hydrographical basins.

Technical procedures

Current research, developed by field study and document analysis, was based on the General Theory of Systems and on Sustainable Development comprising the reading and analysis of books, journals, documents, maps, photos, manuscripts and personal interviews. Figure 2 shows a methodological flowchart with research stages.
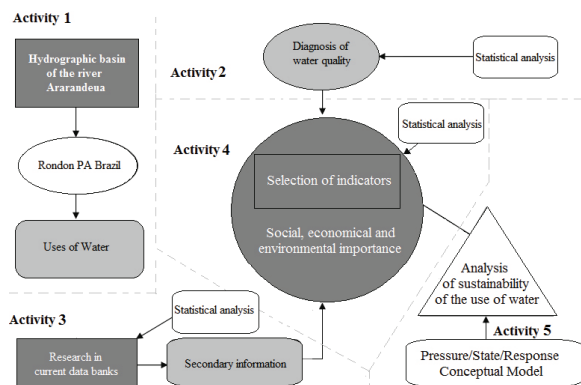

Figure 2. Flowchart with research stages.

Research stages

- **Investigation of the area's general aspects**: The area comprising the Ararandeua hydrographic basin with intense human activities was identified. The historical and cultural aspects on the process of soil occupation and the diverse use of water could be found in documents kept at the administrative premise of the municipality of Rondon do Pará.

- **Diagnosis of water quality**: Data on water quality (IQA_{CETESB}), comprising 2008 and 2009 (dry and rainy period, respectively), at the most sensitive places with regard to pollution and contamination were used.

- **Social and economical diagnosis**: Data banks provided demographic information of the

municipality, data on the production of its main economical activities, data on health and on sanitary infrastructure. Social and economical indexes were thus defined from the information above.

- **Selection of social, economical and environmental indexes**: several indexes were selected from the literature and foregrounded on criteria of relevance, conceptual basis, accessibility and trustworthiness, so that the proposed aims could be achieved (Table 1).

Table 1. Sustainability indexes on the use of water collected in Rondon do Pará.

Aspects of sustainability	Indexes
Social	Rate of population growth
	Rate of urbanization
	Demographic density
	Municipal Human Development Index
	Percentage of population with tap water in the home
	Percentage of population without sewage system in the home
Economical	Agricultural and cattle-raising production
	Gross Internal Product per capita
	Policies against waste of water
Environmental	Proportion of treated sewage
	Degradation of riparian vegetation
	Water quality index

- **Evaluation of the sustainability of water use:** after the above-mentioned selection, the most representative indexes were systemically analyzed from the social-economical and social-environmental aspects by means of a performance scale which standardizes the indexes' measurement units. Whereas a control-type scale was used featuring equal intervals ('very bad'; 'bad'; 'fair'; 'good'; 'very good'), the conceptual model employed in current research was that used by the OECD (Pressure/State/Response). Figure 3 shows how the indexes were grouped.

Figure 3. Pressure/State/Response Indexes.

Pressure indexes scores were directly proportional to their degradation potential, or rather, the highest score is given to the worst Pressure index result. In the case of State and Response indexes, score were distributed differently as Table 2 shows: scores were directly proportionate to the quality of results, or rather, the highest scores were given to the best results in State and Response indexes.

Table 2. Evaluation scores for the hydric system.

Evaluation of indexes for the system	Pressure Index	State Index	Response Index
Very bad	5	1	1
Bad	4	2	2
Fair	3	3	3
Good	2	4	4
Very good	1	5	5

Results and discussion

Social and economical analysis

GIP per capita

BIP per capita consists of the regional richness divided by the number of inhabitants. It depends on economical activities which, in turn, depend on natural resources. Since water resource is the focus of current research, in systemic terms the index is one of the economical factors in human life quality and reflects interactivities with the element water. Although GIP per capita does not necessarily show social improvement because of income concentration, it is a good indicator of Rondon do Pará's economical conditions.

According to SEPOF/PA (2007), mean income increased 99.49% from 1997 to 2004. A financial analysis of the index as evidence of water use shows that results are excellent although they largely depend on agricultural, cattle-raising and industrial activities which concentrate most of the GIP, or rather, from 59.88% in 1997 to 67.68% in 2004.

Municipal Human Development Index – HDI-M

HDI-M index aggregates several important types of information (income, schooling, childhood, habitation and longevity) since it reveals the level of a population's life quality and human development. The human being's interactivity with the element water within the system are a good indicator of the state of the human element. HDI-M does not demonstrate the same growth as that of the GIP per capita. In fact, there was an evolution of only 22.3% in the pre- and post-cattle-raising periods (respectively 1991 and 2000), with an increase from 0.560 to 0.685 (IBGE, 2000), or rather, a fair indicator of the use of water within the system.

The social aspect of the human element within the system under analysis is the result of interactions with the hydric environment, such as water use in the sanitation context. This fact is highly relevant to decrease poverty rates and to protect environment and human health. On the other hand, lack of the above increases the occurrences of diseases associated with bad water quality and the potential contamination of water bodies, with subsequent quality degradation in the system as a whole. Pressure factors are related mainly to the "percentage of the population with adequate sewage system in their homes". If this is the local pressure index, "access to water with quality" indicates the local response of the administration to the situation.

Percentage of the population without a proper sewage system and Percentage of the population with tap water in the home

Whereas the 'percentage of the population without a proper sewage system' indicates a potential degradation factor of quality in water resources, 'the percentage of the population with tap water in the home' is an indicator of access to fresh drinking water. These indexes respectively represent pressures and responses of the human element within the system under analysis through its interactivity with the hydric medium or water use.

According to the IBGE (2000), the percentage of the population with no type of adequate sewage decreased from 30 to 25.90% between 1991 and 2000 – a rather fair result when compared to water use. Results for access to drinking water are very good, with an increase from 75.50 to 92.84% of the whole population in Rondon do Pará.

Social and environmental analysis

Index of Water Quality – IWQ

IWQ is an indicator which diagnoses the quality of water in hydric bodies. In systemic terms it reflects the pressures by the human element mainly through sewerage.

The river Ararandeua and its affluent Rio das Pebas, within the municipality of Rondon do Pará, receive water from the soil surface of pastureland of the local plantations. Whereas the river Ararandeua also receives waste discharges from the urban rain drainage system, the dairy industries and sand and stone extraction plants, the Rio das Pebas receives effluent discharges from a dairy industry and an abattoir. During the dry season the Rio das Pebas showed better results than the river Ararandeua. Contrastingly, the situation is inverted during the rainy period, probably due to the riparian vegetation on the banks of the river Ararandeua in the town

area provided with a natural protection against the leaching process. Further, discharge increase in the river Ararandeua attenuates the issue where a greater capacity of self-cleansing occurs. Although some stretches (areas within the plantations) of the Rio das Pebas lack riparian vegetation, the river receives a smaller discharge of industrial effluents and no urban sewage wastes.

Taking twon of Rondon do Pará as a reference, indexes of the two rivers under analysis showed fair results upstream, or rather, A02 = 39.51; P01 = 48.15 during the dry period and A02 = 48.23;

P01 = 46.66 during the rainy period, as shown by Figures 4 and 5.

'Growth of agricultural and cattle-raising production', 'population growth' and 'demographic density' are pressure factors impacting the quantity of available resources. Coupled to 'degradation of riparian vegetation', they limit the use of the water resource through quality degradation. Results on the river Ararandeua and Pebas show a decrease of 42.54 and 44.70 respectively during the dry and rainy seasons, rated as fair by the IWQ scale (from 0 to 100).
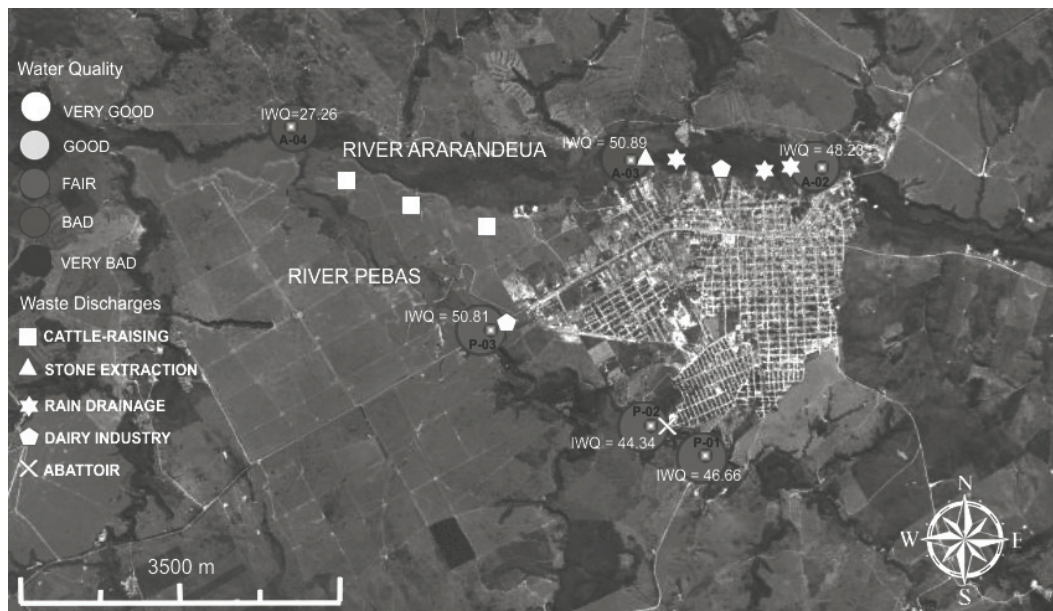

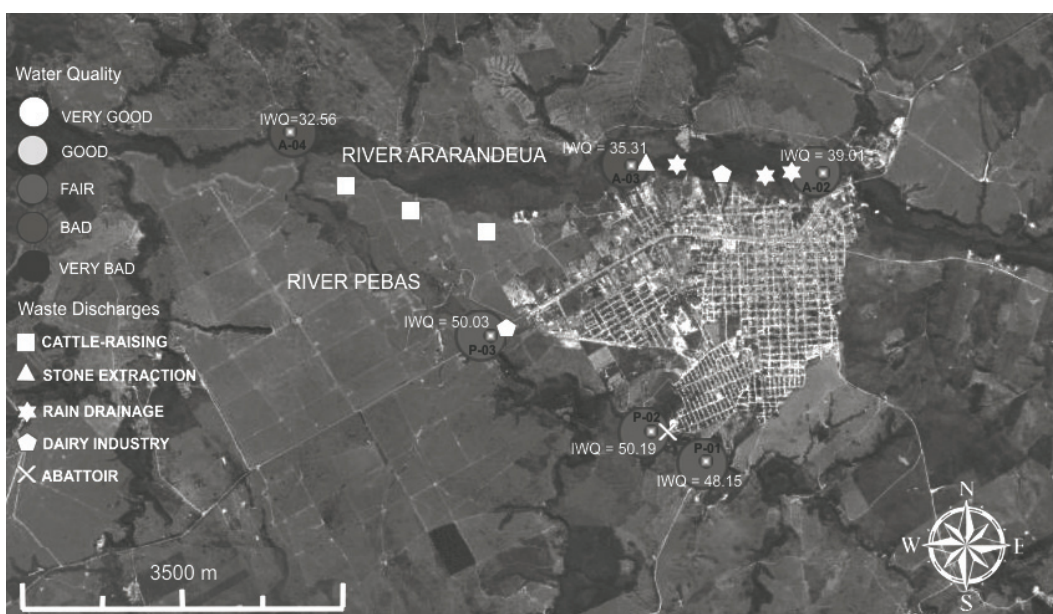**Figure 4.** IWQ during the dry season (GOOGLE, 2009, edited).

Figure 5. IWQ during the rainy season (GOOGLE, 2009, edited).

Agricultural and cattle-raising production

The manner the human element conducts the agricultural and cattle-raising production process has negative implications on the other elements, ranging from deforestation for pastureland to animal (mainly cattle) slaughtering in abattoirs. Main consequences comprise an increase in the silting of water bodies due to the removal of the vegetation covering and to pollution and contamination from liquid effluents from abattoirs and dairy plants. According to SEPOF/PA (2007), whereas in 1997 there were 153.575 heads of cattle, in 2005 the number increased to 360.598, or rather, a 134.8% growth occurred.

When cattle-raising situation in Rondon do Pará is evaluated, results are very bad. Attenuating measures against environmental impacts do not go along with production growth and social problems are rife. In fact, when contrasted to other activities in the municipality, agriculture and cattle-raising only provides few jobs. According to SEPOF/PA (2007), the latter activity demanded only 309 jobs in 1999, or rather, only 1.12% of total demand; in 2003 demand went up to 221 jobs, only 5.76% of total.

Population growth and demographic density

The system's population growth requires an increase in water demand for tap water and for other aims which directly affects the resources available. Further, another important factor to be analyzed is its concentration within the system since it may intensify so much water use that it may endanger the water environment, especially related to sewage construction which will become more concentrated in the region. Both indicators will be human pressures on the use of water in the system.

According to SEPOF/PA (2007), between 1997 and 2007 the population of Rondon do Pará increased 26.89% (from 28,096 to 35,651 inhabitants). Since the territorial estate of the town remained stable (approximately 12 km^2) and demography density increased by 31.31%, the latter rose from 2,262.58 to 2,970.92 hab km^{-2}. However, the rather small population growth presents its first social problems: shanty districts are beginning to be seen everywhere and, consequently, health problems become more extensive due especially to lack of sufficient water supply and sewage. Results may be considered good since the public administration is dealing with the above issues, especially in the housing area, and the rate of population growth is not so big.

Percentage of treated sewage

Efficient sewage treatment is a highly important factor for the maintenance of the elements' quality in the entire system. It should be emphasized that an urban nucleus with an efficient sewage treatment, especially human wastes, has better chances in avoiding water-related diseases. Only human wastes are treated adequately in Rondon do Pará, and all other types of water pass through the urban drainage system and then to the receiving water bodies, or rather, to the river Ararandeua. Each premise has its own treatment unit (septic cesspit or more primitive cesspools) and its efficiency with sewage complementary treatment (anaerobic filter) amounts to a 90% removal of Oxygen Biochemical Demand (OBD). The efficiency of units without an anaerobic filter ranges between 30 and 61% of OBD removal.

It should be underscored that, in quantitative terms, total sewage treatment is represented by the treatment of domestic sewage since an in loco investigation identified a lack of industrial sewage treatment in the region. When the efficiency of the types of sewage treatment in the town is taken into account, the septic cesspit is the only satisfactory type within the local context under investigation. The indicator has only taken into account the population section that uses septic cesspits in sewage treatment. Since the factor amounts to only 5.4% (IBGE, 2000), the water use indicator in considered very bad within the system's context.

Policy against the waste of drinkable water

Water supply in Rondon do Pará comes from underground water retrieval systems for which consumers pay fixed monthly rates for tap water. Since the paying system does not include amount of water volume used, waste of drinkable water is a common liability. Policies against waste of tap water to lessen the negative impacts implied, albeit not extant in Rondon do Pará, are an important response indicator. As a rule, the index is very bad for the water resources issues.

Degradation of riparian vegetation

The removal of riparian vegetation in the rivers of Rondon do Pará is one of the main environmental issues that the municipal administration has to face. Silting of the rivers Ararandeua and Pebas is there for all to see and lies in the collective memory of the local population. Under such conditions, the pressure indicator reveals the natural degradation conditions of the water bodies. The river stretches that cross the town (Figure 1) show in loco the lack of riparian vegetation. However, results of the indicator are very good for the maintenance of the quality of local water resources.

Water use sustainability 'radar' in Rondon do Pará

A set of indicators was prepared as water use sustainability 'radar' to give a general view of the research results and to facilitate decision-taking for hydric resources. Evaluation consisted of pressures and responses identified in the water system of Rondon do Pará where indicators received the following scores on the system and its respective marks (Table 3).

Table 3. Evaluation of PSR for the hydric system.

Indicator	Evaluation	Score	Mean
Pressure			
Population growth	Good	2	
Demographic density	Very bad	5	
Percentage of population without proper sewage	Fair	3	3.20
Growth of agricultural and cattle-raising production	Bad	4	
Degradation of riparian vegetation	Good	2	
State			
Municipal Human Development Index – HDI-M	Fair	3	3.66
Water quality indicator	Fair	3	
Gross Internal Product per capita	Very good	5	
Response			
Policy against drinkable water waste	Bad	2	2.66
Percentage of treated sewage	Very bad	1	
Percentage of population with tap water	Very good	5	

Through a control of the calculated scores for each point of the PSR conceptual model, the relevance of each within the sustainability evaluation of water use is identified. Based on data on water quality and local social and economical conditions, the hydric system in Rondon do Pará is scored as fair. The pressures by water-demanding processes are higher than the responses to minimize the impacts in the area. In other words, the system is characteristically directed towards non-sustainability in water use, as Figure 6 shows.
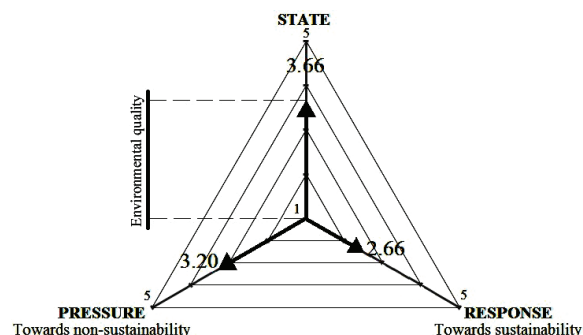

Figura 6. Sustainability in the use of water in Rondon do Pará.

When the worsening perspectives of the main factors that put pressure on the system are taken into account, a trend towards a weakened hydric system is characterized since the elements that foreground the use of hydric resources, the rivers Ararandeua and Pebas, already show bad results with regard to water quality in certain places. Social and economical indicators may be considered good, as a rule, within the context of sustainable development, In fact, income reflects a moderate improvement in Rondon do Pará within the schooling and health aspects, even though environmental indicators reveal the worst results.

It should be emphasized that the 'Water use sustainability radar' was a working graphic representation of results and thus made easy information for the town administration and for society in general.

Conclusion

In Rondon do Pará, since sanitary sewage is highly deficient in the treatment of liquid residues, it contributes towards the pollution of water of the Rivers Ararandeua and Pebas.

Since the region is comprised within the Amazon deforestation area, it has been highly degraded by the timber industry and impacts on the hydric resources increased through new economical, agricultural, cattle-raising and dairy activities. Although these activities push the local economy, they do not reflect social and environmental improvements for the town and the municipality.

Pressure on water use is greater than the response to mitigate impacts. The weakening of the system is a consequence.

Acknowledgements

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