Water Policy 22 (2020) 622–640

Application of the watershed sustainability index in the Piranhas-Açu watershed

D. D. Costa e Silva[a], H. M. L. Chaves[b], W. F. Curi[c], J. G. V. Baracuhy[c] and T. P. S. Cunha[d]

[a]Escola de Engenharia Civil e Ambiental, EECA – Universidade Federal de Goiás, Avenida Universitária, Quadra 86, Lote Área 1488, Setor Leste Universitário, Goiânia, GO, Brazil, CEP 74605-220

[b]Faculdade de Tecnologia – Secretaria de Pós-Graduação em Ciências Florestais, Universidade de Brasília, Campus Universitário Darcy Ribeiro, Brasília, DF, Brazil, CEP 70910-900

[c]Centro de Tecnologia e Recursos Naturais – CTRN, Universidade Federal de Campina Grande – Campus Universitário, Campina Grande, PB, Brazil, CEP 58429-140

[d]Corresponding author. Laboratório de Recursos Hídricos e Saneamento Ambiental – LARHISA, Universidade Federal do Rio Grande do Norte – Campus Universitário, Natal, RN, Brazil, CEP 59077-080. E-mail: tiagop.engenharia@gmail.com

Abstract

The current worldwide water resources issue is one of the crucial matters to overcome obstacles to sustainable development. This problem, formerly tackled in a sectored manner, is now pointing towards an analysis directed to treating the watershed as a management unit, with regards to all dimensions of knowledge and, especially, to the public participation in the decision-making processes. As an alternative to measure its performance, it has been sought out to develop indexes aimed to measure its sustainability, but there is still a lack of the use of composed efficient methodologies that also enable public participation in decision-making. This research presents a methodology comprising 15 indexes for the calculation of the Watershed Sustainability Index (WSI), followed by the application of the PROMETHEE multi-criteria analysis method and the COPELAND multi-decision-maker method. The methodology was applied to evaluate the performance of subwatersheds of the Piranhas-Açu watershed, located in the Brazilian northeast semi-arid region. The performance ordering, obtained through the application of the methods, emphasizes that subwatersheds' performances are uneven. It can be noticed that the subwatersheds' performances are still far from ideal in relation to water resources management, even in the ones that displayed satisfactory index levels.

Keywords: Multi-criteria; Multi-decision-maker methods; Sustainability indexes; Water resources

doi: 10.2166/wp.2020.011

Introduction

Nowadays, the issue of sustainability has expanded in discussions around the world and when it comes to the area of water resources this discussion is growing towards finding its best use performance through various analyses (Gleick, 1998; Loucks, 2000; Postel, 2000; Tundisi, 2003; Vieira, 2003; Mays, 2007). According to Gleick (1998), water is not only essential to sustain life, but it also plays a fundamental role in the support of ecosystems, in economic development, in community well-being and in cultural values. A starting point to seek an understanding of this relationship is upon the 'own' definition of water sustainability, and, in this sense, some authors have developed definitions that contemplate this connection (Gleick *et al.*, 1995; Loucks, 2000; Mays, 2007). To Mays (2007), water sustainability is the 'ability to provide and manage water in terms of quantity and quality in order to meet current human and environmental needs, while not impeding the next generations to do the same'. Gleick *et al.* (1995) conceptualize it as 'the use of water for support and the ability of the human society to strengthen and flourish for an indefinite future without harming the integrity of the water cycle or of the ecologic system that depends on it'. In turn, Veira (2003) defines water sustainability as 'the continuous and consistent fulfilment of society's demands through a guaranteed water supply, in quantity and quality'. Loucks (2000) defines water sustainability as 'the designation and planning of water resources to fully contribute to society's goals now and in the future while maintaining their ecological, environmental and hydrological integrity'. It seems that Loucks' definition is the more adequate when thinking in terms of indexes since it contemplates the necessity of planning and management based on the 'goals' of today's society as well as aiming towards its future. His definition approximates current methodologies that focus on measuring sustainability from a perspective that contemplates the participation of society in planning. This brings the idea of the identification of a set of indexes to perform the required analysis of water resources sustainability and, in this sense, it is a more adequate definition than those who wish to focus on water resources management (Chaves & Alipaz, 2007).

In terms of planning, in recent times there has been progress in the development of indexes that specifically cover water resources related performance analysis (Brown & Matlock, 2011), including the Basic Human Needs Index, the Imported Water and Cereal Availability Index, Indexes of Local Relative Use and Reuse of Water, the Watershed Sustainability Index (WSI), the Water Stress Supply Index and the Physical and Economic Water Shortage Index. Such indexes seek to perform water resources analysis in order to contribute to watershed planning. Amid such indexes, the WSI has the advantage of encompassing water resources sustainability (Loucks, 2000). The application of the WSI, however, has had some limitations when it comes to public participation (Juwana *et al.*, 2012) and, therefore, it lacks methodologies that complement it.

To compare water resources performance analysis, Carvalho & Curi (2013) opted for using the PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluation) method, since it has presented advantages over other methodologies (Brans *et al.*, 1986; Pomerol & Barba-Romero, 2012; Velasquez & Hester, 2013). The PROMETHEE II method can be applied to incorporate preferences of different decision-makers, especially in scenarios where there are several decision-makers, such as the Brazilian case of Watershed Committees. A method aimed at aggregating the ranking selections of decision-makers is the Copeland method, which has shown unique advantages over the Edge and Condorcet methods (Pomerol & Barba-Romero, 2012).

The aim of the present study is to propose the application of the WSI (Chaves & Alipaz, 2007) in the Piranhas-Açu watershed, located in the Brazilian semi-arid region. The indexes of the WSI are used in a multicriteria analysis using the PROMETHEE methodology, applied together with the multi-decision-maker ranking aggregation methodology (COPELAND), with a view to contemplating public participation in water resources analysis process, leading the WSI to a breakthrough in methodological terms. This sub-basin, as presented by Amorim *et al.* (2016), is among the most problematic in the Brazilian semi-arid region, considered by some to be one among the most problematic in the world (Cirilo, 2008), and, therefore, is an opportune scenario for the analysis intended here.

Literature review

Indexes aimed at water resources

Brown & Matlock (2011) stated that over the last few years there has been advancement in the elaboration of indexes aimed at measuring aspects related to water resources performance analysis and, in a recent review, presented some of the most internationally well-known indexes related to water[1]. In order to do so, researchers elaborated characterization of the various indexes highlighting categories in which such indexes are classified. A first category of indexes is aimed at basic human needs. In this category the authors have placed the Falkenmark Index, the Basic Human Needs Index, and Water Resources Availability and Cereal Import Index. In the second category are the indexes aimed at vulnerability of water resources where the Index of Local Relative Water Use and Reuse, the Watershed Sustainability Index (WSI), the Water Supply Stress Index and the Physical and Economical Water Scarcity Index were placed. A third category, in turn, consists of indexes aimed at incorporating environmental water requirements. In this category we highlight the Population Growth Impacts Water Resource Availability Index and the Index of Assessing Water Resource Supplies Using the Water Stress Index. Finally, the authors establish their own Water Footprinting category, highlighting the various aspects that are part of the index, including the analysis of social and environmental impacts.

In this sense, in recent times, the United Nations[2] (UN) has promoted the creation of an index focused on the sustainability analysis of water resources from the watershed, known as the Watershed Sustainability Index (WSI), which has covered a wide field of application and from that, international boundaries have been embraced so that the application of the index has contributed to broader analyses around the world. In terms of Brazil, the WSI has recently been applied in the southeast and midwest regions, however, the major problems related to water resources are situated in the northeast, where the world's most problematic semi-arid region (Cirilo, 2008) is located, and where there still has been no progress in its application. Despite the many advantages of the WSI[3], Juwana *et al.* (2012) in a recent study comparing the most well-known water sustainability indexes in the world, highlighted some limitations of the WSI regarding public participation, especially in the composition of weights.

Thinking about public participation has been the hallmark of current water resource management systems, marked by management models that aim to contemplate the complexity through a participative process in construction. According to Cirilo (2008), Brazil, following the worldwide adopted logic,

---

[1] Here the authors have selected several water-related indexes and not necessarily indexes focused on sustainability in water resources.

[2] International Hydrological Programme of UNESCO (The United Nations Educational, Scientific and Cultural Organization).

[3] Among which is the fact of its originality in clearly having the watershed as the basis for its application.

currently has a decentralized management system in which public participation, exerted through the Watershed Committee, has a singular participation in the efficacy of the process.

Multi-criteria PROMETHEE methodology of support to decision-making

Seeking an effective decision-making process in watershed management, several methods have pointed to the use of multi-criteria decision support analysis and in the environmental area the methods of the PROMETHEE family (preference ranking organization method for enrichment evaluation) have stood out (Brans *et al.*, 1986; Pomerol & Barba-Romero, 2012; Velasquez & Hester, 2013).

In a comparative study with many current methods, Balali *et al.* (2014) concluded that PROMETHEE II is the favourite method aimed at decision-making support due to: (a) the method is consistent and easy to understand; (b) it does not require too much interaction with the decision-makers; (c) the linearity and the additive hypotheses for the preference function are acceptable for the decision-makers. To the authors, there are unique characteristics of PROMETHEE that are not available on AHP or on other famous multi-criteria decision-making support methods such as ELECTRE and TOPSIS (Balali *et al.*, 2014).

Velasquez & Hester (2013) presented a comprehensive analysis of various methodologies aimed at the decision-making, highlighting that, among the many methods, when it comes to applications that involve the environment, PROMETHEE has been the most chosen method and therefore the best suited for the application. Carvalho & Curi (2013) agreed with this point of view, stating that PROMETHEE is the most adequate method for studies aimed at water resources, arguing that: (a) it is a non-compensatory method; (b) it is a method that favours well-balanced alternatives, that is, seeks to establish a complete pre-order; (c) allows the use of various preference functions, best suited to questions that are objective and subjective. It is interesting to note here that this flexibility is mainly about the decision-maker's ability to establish preference functions. Considering possible application sites such as developing countries, the ease of use may be a defining factor to the use or not of a given method. Table 1 presents a comparison between various multi-criteria methods developed by Velasquez & Hester (2013).

A final factor to justify the use of PROMETHEE is that it can be complemented by other methodologies, especially those of rank aggregation of multi-participant decision-makers (Carvalho & Curi, 2013; De Araújo, 2016; Sugiartawan & Hartati, 2018) allowing for the attainment of a highly relevant final rank. In this sense, Carvalho & Curi (2013) presented a manner of using PROMETHEE jointly with the rank aggregation method of COPELAND, due to its good properties and generating good results. The decision-maker's participation takes place with the weighting of the multi-criteria that are considered in the analysis of the watershed performance.

Rank aggregation methods

The so-called rank aggregation methods are considered very intuitive and little demanding, both in terms of computational effort and in relation to the required information to be provided by the decision-maker. There are two forms of rank aggregation method: a priori aggregation method, which, in general, uses the average values of the criteria weights, and a posteriori aggregation methods, which combines the ranks attained for each of the decision-maker's weighting choices. The disadvantage of the a priori aggregation method is that the average of criteria weights may not represent any

Table 1. Analysis of methods aimed at decision-making support (adapted from Velasquez & Hester, 2013).

Method	Benefits	Application areas
Multi-attribute utility theory (MAUT)	Takes into account uncertainty; can incorporate preferences	Economy, finance, actuarial, water, management, energy management, agriculture
Analytic hierarchy process (AHP)	Easy to use; scalable; the hierarchical structure can easily be adjusted to fit many size issues; non-data intensive	Performance type issues, resource management, corporate and strategic policy, public policy, political strategy, planning
Case-based reasoning	Non-data intensive; requires little maintenance; may improve over time; can adapt to changes in the environment	Business, vehicle insurance, medicine and engineering design
Data envelopment analysis (DEA)	Able to handle multiple inputs and outputs; efficiency can be analyzed and quantified	Economics, medicine, utilities, road safety, agriculture, retail and business issues
Diffuse set theory	Allows inaccurate input; takes into account insufficient training	Engineering, economics, management, environment, sociology and medicine
Simple multi-attribute rating technique (SMART)	Simple; allows any type of weighting technique; less effort by decision-makers	Environment, construction, transportation and logistics, military, manufacturing and assembly issues
Goal programming (GP)	Able to deal with large-scale problems; can produce endless alternatives	Production planning, scheduling, health care, portfolio selection, distribution systems, energy planning, water reservoir management, wildlife management
ELECTRE	It takes into account uncertainty and inaccuracy	Energy, economy, environment, water management and transportation issues
PROMETHEE	**Easy to use; requires no assumption that the criteria are proportionate**	**Environment, hydrology, water management, business and finance, chemistry, logistics and transportation, manufacturing and assembly, energy, agriculture**
Simple additive weighting (SAW)	Ability to offset criteria; intuitive for manufacturers' decision; the calculation is simple, does not require complex computer programs	Water resources management, business and financial management
Technique for order preference by similarity to ideal solution	It has a simple process; easy to use and program; the number of steps remains the same regardless of the number of attributes	Supply chain and logistics management, engineering, manufacturing systems, business and marketing, environment, human resources and water resources management

decision-makers' preferences. In the published literature, the three most referenced a posteriori rank aggregation methods are Borda, Condorcet and Copeland (Pomerol & Barba-Romero, 2012), and other versions based on them. The main advantages of ease-of-use and comprehension of these methods in environmental studies is reported by Laukkanen *et al.* (2004) and Kangas *et al.* (2006), and more recently by Nascimento (2016), Carvalho & Curi (2013) and De Araújo (2016).

Borda method. The Borda method, proposed by Jean Charles de Borda (1733–1799), uses an ordinal scale, offered to the decision-maker and the options are awarded a rank through a score. Then, it consists of attributing one point to the 'most preferred' option, two points to the 'second preference' and so on until the last option (candidate or competitor). In the end, these points are summed and the option with the lowest score is selected. This method, which in its essence is a sum of points as described, has the main advantage of simplicity. However, despite its simplicity and the broad applications of its variants, the Borda method does not respect one of the most important Arrow's axioms, that of the independence of irrelevant alternatives. Such facts can generate distortions, especially the extreme dependence of the results in reference to the chosen evaluation set, and the possibility of dishonest manipulations.

Condorcet method. According to Pomerol & Barba-Romero (2012), the Condorcet method, devised by Jean-Marie Antoine Nicolas de Caritat, Marquis of Condorcet (1743–1794), is considered a precursor of the current multi-criteria French school and works with relationships of surpassing. The alternatives are always compared two by two and a graph is constructed (Boaventura Neto, 2003) to express the relationship between them. This less simple method has the advantage of preventing distortion by making the relative position of two options independent of their relative positions to any other. However, it may lead to the so-called 'Condorcet paradox' or intransitivity situation. This happens when alternative A surpasses alternative B, which surpasses C, which in turn, surpasses alternative A. This situation can be exploited in certain problems when the goal is to group options. However, when it occurs, it makes it impossible to generate a ranking of the options. When intransitivity cycles do not appear, and a full pre-order is desired, the Condorcet method should be preferred over the Borda method. If the goal is to make a choice, even with intransitivities, the Condorcet method has one advantage: it requires interactive interventions with the decision-maker, avoiding the optimal paradigm. This paradigm is criticized by Clímaco (2003).

Copeland method. As presented by Pomerol & Barba-Romero (2012), the Copeland method is considered an improvement of the Condorcet method and uses the same adjacency matrix that represents the graph of the Condorcet method. From this matrix, the sum of wins minus the losses is calculated, in a voting by simple majority. The options are then ranked by the result of this sum. The Copeland method allies the advantage of always providing a full ranking (differently from Condorcet) with the fact of yield the same results as the Condorcet, when the latter does not display any intransitivity cycle. When these cycles are present, the Copeland method makes it possible to rank and keep the ranking of the options that do not belong to an intransitivity cycle. In spite of being more computationally demanding than Borda, when there is need to establish a pre-order, or *sensu lato* order, this method always yields an answer (in contrast to Condorcet method) and, although it does not eliminate, it greatly reduces the influence of irrelevant alternatives. Copeland's method can be considered an improvement between the opposite philosophies of Borda and Condorcet, bringing together, as much as possible, the advantages of both and, thus, is a more appropriate approach to the development of research, being already validated in studies in the Brazilian semi-arid (Carvalho & Curi, 2013; De Araújo, 2016; Nascimento, 2016), which is considered by some to be the most problematic semi-arid region in the world (Cirilo, 2008).

Issues in the Brazilian semi-arid and the Piranhas-Açu watershed

In an analysis aimed towards public policies, Cirilo (2008) affirms that the Brazilian semi-arid is considered one of the most problematic in the whole world, since this region displays issues that are more difficult to overcome than those of other semi-arid regions throughout the world. Among those issues, is the fact that the Brazilian semi-arid region has soils that, for the most part, are very shallow with almost outcropping rocks, which compromises the existence of aquifers, their recharge and water quality. It also presents high temperatures which lead to high evaporation rates. The presence of few perennial rivers and one of the highest population concentrations among world semi-arid regions exert unique and excessive pressures on the water resources. To Cirilo (2008), the Brazilian semi-arid region presented, until the 1990s, a history of bad public policies, or even non-existent, especially on the establishment of small reservoirs highly vulnerable to drought and well drilling in crystalline soils. Allied to these mistakes, the lack of water management was the key factor to maintaining the critical regional framework drought after drought. As a way of alleviating the suffering of underserved populations, the usual solutions are the use of water tankers, work fronts to provide them with some income or other purely palliative measures.

Broadening the discussion on water resources and political aspects, Amorim *et al.* (2016) points to a specific region within the Brazilian semi-arid that, in addition to the aforementioned issues presented by Cirilo (2008), has stood out as one of the most problematic, due to the conflict for the use of water resources as it comprises a subwatershed that includes part of two of the poorest Brazilian states. The Piranhas-Açu subwatershed, situated in an area where there is widespread dispute about the use of water, has generated concerning prognostics. According to Amorim *et al.* (2016), in this subwatershed the intensive use of water from the Curema-Açu system is causing conflicts between users, mainly for irrigation and shrimp culture purposes (in the stretch downstream to the Armando Ribeiro Gonçavels dam, located in the state of Rio Grande do Norte), and also between the governments of Paraíba and Rio Grande do Norte states. The intensity of this usage was reflected in the increase of water grant requests that exceeded the capacity of regularization of the water systems of the basin. This scenario has generated several impasses and studies have been made to understand how to better decide this issue. Analysing the basin, Amorim *et al.* (2016) highlights the following need:

> *'It is concluded that there is a need to create participatory environments within the Committee. Among these should be the management committees in each reservoir of the watershed. It is also important to create a Technical Chamber for Conflict Resolution […] Considering the point of view of the managing body (the National Water Agency), with the water scarcity in the Watershed increasing since 2012, institutional measures began to be conducted by the Agency, such as the reactivation of the Operational Technical Group (mid-2013) and the issuance of resolutions in 2014 and 2015 to discipline water use in the Watershed.'*

Indexes, sustainability and policy

Amidst problematic scenarios such as those of the Brazilian semi-arid region, sustainability analysis could provide subsidies for better development of political actions becoming an important alternative to contribute to this process. According to Hák *et al.* (2016), there is a necessity to formulate sustainable development indexes that encompass the political process, as the ultimate target of a sustainability index is many times linked to a political process issue. To Hák *et al.* (2016), in favour of an efficient operationalization process, as well as the success of the entire agenda of sustainable development objectives, the political process must consider scientific knowledge and evidence already in the early stages of the political cycle. Underdevelopment or underestimation of an index characteristic could lead to false assessments of the degree of achievement of targets and thereby erode the credibility of sustainable development objectives. Hence, the index structure for sustainable development objectives needs more conceptual and methodological work than merely the production of new social, economic and environmental statistics. In a similar manner, Caldas *et al.* (2018), in a study based on the Portuguese municipalities, analysed the relationship between sustainability and the European Union's investment programme. Such studies contributed to a broad economic analysis through applied models (Caldas *et al.*, 2019a, 2019b). Carvalho & Curi (2013), in a different analysis, presented broad research involving various aspects related to water resources and from this developed a sustainability index aimed to better understand this problem. MacGillivray (2017) highlights the Index of Sustainable Economic Welfare (ISEW) compiled by various US and European research organizations, strongly resonating with growing concerns about the gap between economic prosperity and the 'quality of life' experienced by the citizens of the richest nations on earth. According to Lowe *et al.* (2015), indexes are being used at the national, state and local levels to compare the liveability of cities and regions. However, there are challenges in adopting such indexes. Planning researchers find it a challenge to create indexes that measure something that is publicly evaluated, while other researchers are concerned with the scarce systemic research on the relationships between policies, the built environment and well-being. Thus, the elaboration of a coherent index can become an important step to a sustainable future that is to come.

Materials and methods

Piranhas-Açu watershed

The Piranhas-Açu river watershed (Figure 1) encompasses a 42,900 km^2 territory, distributed between the states of Paraíba and Rio Grande do Norte. Approximately 1,552,000 people inhabit the region of the watershed. Farming is the main economic activity of the area, where the small subsistence agriculture of beans, intercropped corn and extensive livestock can be highlighted. The watershed is fully located in semi-arid territory, with average rainfall ranging from 400 to 800 mm yearly, and mainly concentrated between February and May (ANA, 2016). The Piranhas-Açu river watershed, located in the north-eastern semi-arid, is formed by one Federal Government-managed river and several tributary rivers from the states of Paraíba and Rio Grande do Norte.

Methodological procedures

The applied methodology, in accordance with Figure 2, can be divided into four steps, with the first relating to the calculation of indicators of the watershed sustainability index and the other three related to the application of the multi-criteria and multi-decision-maker analyses.

The following is a breakdown of each step of the proposed methodology sequence.

Watershed sustainability index. Aiming to provide the Hydrological Programme of UNESCO with an index that includes the analysis of water resources (at the watershed level), Chaves & Alipaz (2007) elaborated an index from a set of four different indicators: hydrology, environment, life and policy,

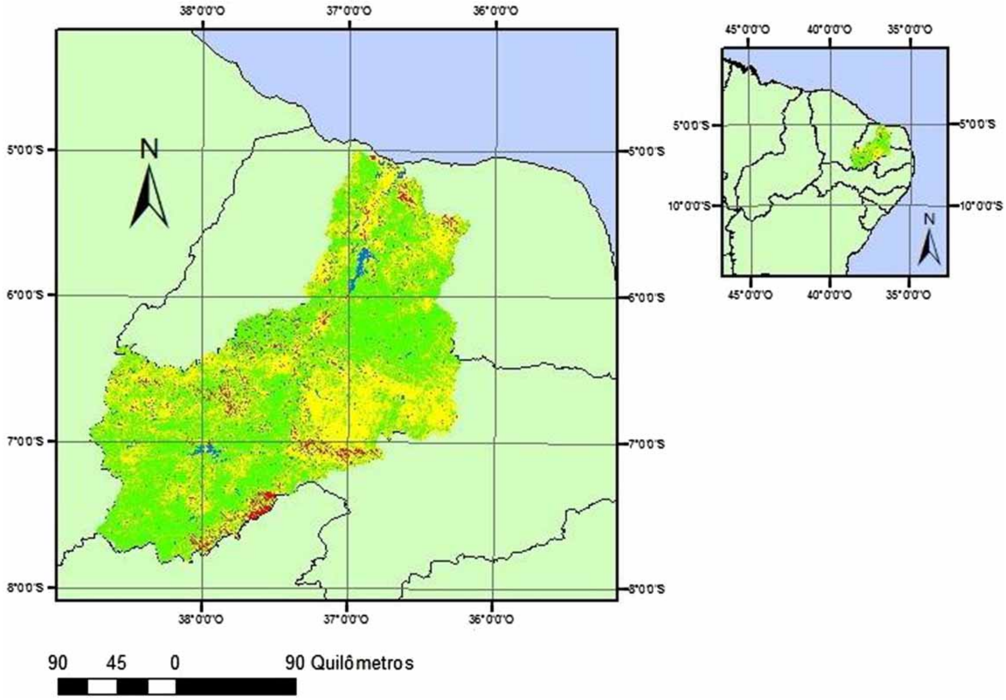
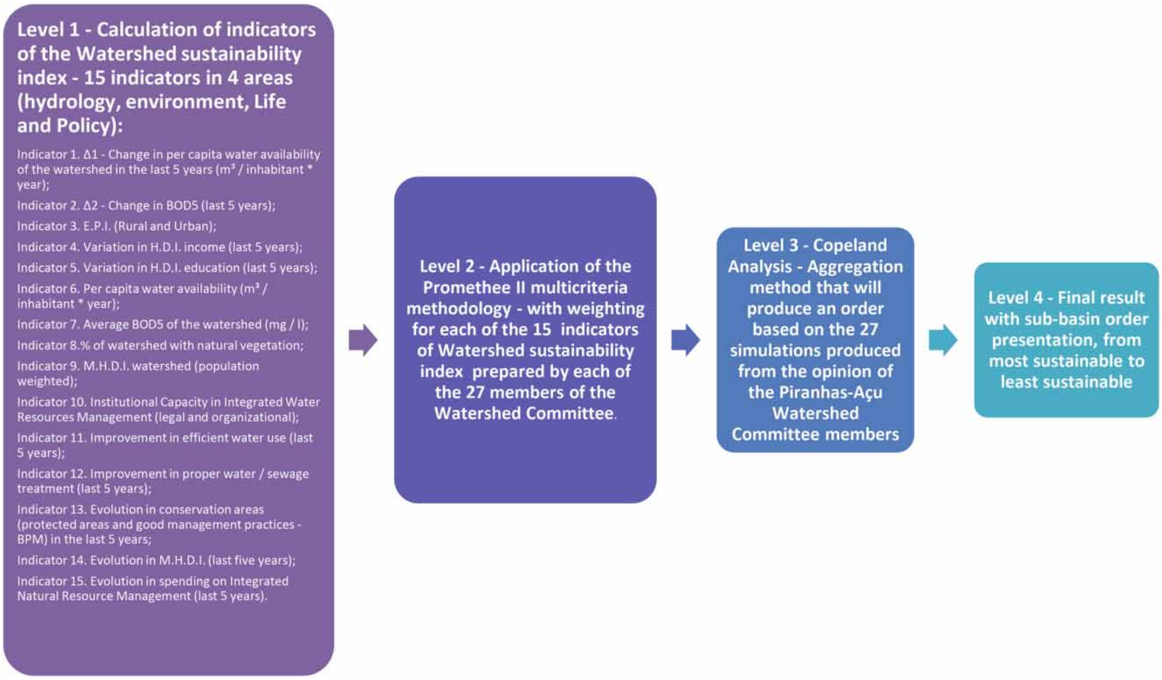


Fig. 1. Location of the Piranhas-Açu watershed (*Source*: author).



Level 1 - Calculation of indicators of the Watershed sustainability index - 15 indicators in 4 areas (hydrology, environment, Life and Policy):

Indicator 1. Δ1 - Change in per capita water availability of the watershed in the last 5 years (m³ / inhabitant * year);

Indicator 2. Δ2 - Change in BOD5 (last 5 years);

Indicator 3. E.P.I. (Rural and Urban);

Indicator 4. Variation in H.D.I. income (last 5 years);

Indicator 5. Variation in H.D.I. education (last 5 years);

Indicator 6. Per capita water availability (m³ / inhabitant * year);

Indicator 7. Average BOD5 of the watershed (mg / l);

Indicator 8.% of watershed with natural vegetation;

Indicator 9. M.H.D.I. watershed (population weighted);

Indicator 10. Institutional Capacity in Integrated Water Resources Management (legal and organizational);

Indicator 11. Improvement in efficient water use (last 5 years);

Indicator 12. Improvement in proper water / sewage treatment (last 5 years);

Indicator 13. Evolution in conservation areas (protected areas and good management practices - BPM) in the last 5 years;

Indicator 14. Evolution in M.H.D.I. (last five years);

Indicator 15. Evolution in spending on Integrated Natural Resource Management (last 5 years).

Level 2 - Application of the Promethee II multicriteria methodology - with weighting for each of the 15 indicators of Watershed sustainability index prepared by each of the 27 members of the Watershed Committee.

Level 3 - Copeland Analysis - Aggregation method that will produce an order based on the 27 simulations produced from the opinion of the Piranhas-Açu Watershed Committee members

Level 4 - Final result with sub-basin order presentation, from most sustainable to least sustainable

Fig. 2. Methodological sequence.

forming the acronym HELP, and seeking to promote an adequate methodology for the application in various contexts around the world. Such index has been currently classified as one of the most well regarded globally (Juwana *et al.*, 2012). Table 2 presents the indicators of the WSI, split into three categories: pressure, state and response. The advantage of using this model (PRESSURE–STATE–RESPONSE) is that it incorporates the cause and effect process, aiding society stakeholders and the decision-making politicians in visualizing the interconnections between parameters. The WSI is applied to the watershed by selecting a period of five (or four) years, enabling the follow-up of its development.

In its classic form of application the WSI index is calculated from a simple average of the values referring to the set of indicators, through the following formula:

$$\mathrm{WSI} = \mathrm{H} * \mathrm{E} * \mathrm{L} * \mathrm{P}/4 \tag{1}$$

where:

H = hydrology indicators (6 indicators)
E = environment indicators (3 indicators)
L = life indicators (3 indicators)
P = policy indicators (3 indicators)

As presented by Juwana *et al.* (2012), this index is calculated in a manner in which there is no consultation with the representatives of the watershed, and this generates uncertainty as to the participation of decision-makers. With a view to filling this void in the current research, public participation was introduced in the weighting (importance) evaluation of each of the 15 indicators. The decision-makers were members of the Watershed Committee. To proceed with this analysis, the PROMETHEE

Table 2. Indicators and parameters of the Watershed Sustainability Index (Chaves & Alipaz, 2007).

Indicators	Pressure parameters	State	Response
Hydrology	Variation in per capita water availability in the last 5 years	Per capita water availability	Improvements in water use efficiency over the period
	BOD5 over the past 5 years	Average BOD5 (long term)	Improvements in sewage treatment over the period
Environment	EPI of the watershed	Percentage of the watershed with natural vegetation	Evolution in terms of watershed conservation (reserves, good management practices)
Life	Variation of the HDI of the watershed region over the past five years	HDI weighted by municipal area	Evolution in the HDI of the watershed region in the period
Policy	Variation in HDI in education (HDI-education)	Legal and institutional capacity in terms of integrated watershed management	Evolution of IWRM spending in the period

EPI, Environmental pressure indicator; WSI, Watershed Sustainability Index; DBO5, Biochemical oxygen demand variation; HDI, Human Development Index; IWRM, integrated water resources management.

method was applied to establish a calculation simulation with the weights of the decision-makers (a total of 27, since there were 27 members of the committee). Finally, with the possession of these 27 calculated results, the Copeland aggregation method was applied with the goal of establishing a final score and presenting a result.

PROMETHEE multi-criteria method. The PROMETHEE II method has the advantage of requiring very clear additional information, which can be easily obtained and managed either by the decision-maker or by the analyst, highlighting its characteristics related to objectivity and flexibility, and therefore being adequate in a relevant way to the WSI, marked by the necessity of an easy application. In terms of the method, for the purpose of the present application, two steps are necessary for each indicator (criterion): (a) definition of the preference function; (b) definition of indicator weights.

Definition of the preference function: Among the PROMETHEE II method preference functions, the following ones were selected: function type I (U-usual), type II (U-Shape), type III (V-Shape) and type V (Linear). The computational support was accomplished through the *Visual* PROMETHEE® 1.4 software. The definition of parameters was carried out through the application of descriptive statistics in accordance with Carvalho & Curi (2013).

Definition of indicator weights: For each of the 27 decision-makers that answered the questionnaire regarding the evaluation of their preferences (weights), a simulation was generated. The weights, following Carvalho & Curi (2013), were assigned according to the following sequence (Table 3).

After the results obtained from PROMETHEE II, 27 matrices were elaborated, obtained from pairwise comparisons with each of the subwatersheds in order to find the following step (multi-decision-maker ranking).

Copeland's multi-decision-maker method. After simulating and obtaining the respective subwatersheds' performance according to each expert opinion, the next step was to determine the final ranking of the subwatersheds using the COPELAND method, considering the comparisons that were drawn after the application of PROMETHEE II. At this stage, pairwise comparison matrices were built between the watersheds and later the final matrix that presents the final ranking of the watershed. Finally, the last step consisted of the analysis of the results and final consideration of the study.

Methodological classification of the research

The adapted WSI is fed from two sources: secondary and primary data (through interviews) (Table 4). Regarding the primary data, they were collected following the same criteria adopted by Carvalho & Curi (2013) in their sampling that aimed to compose an index focused on the sustainability of water

Table 3. Definition of indicator weights.

Answer to the questionnaire	Value
Very important	1
Important	0.75
Medium	0.5
Low	0.25
None	0

Table 4. Data sources for the composition of the WSI index.

Indicator	Source
Hydrology quantity	Brazilian National Water Agency – ANA[a]/Geological Survey of Brazil – CPRM
Hydrology quality	Brazilian National Water Agency – ANA[b]
Environment	U.S. Department of the Interior U.S. Geological Survey USGS[c]
Life	Brazilian Institute of Geography and Statistics – IBGE[d]
Policy	Brazilian Institute of Geography and Statistics – IBGE[e]

[a] ANA (2012) Brazilian National Water Agency [WWW Document]. Hidroweb. URL http://hidroweb.ana.gov.br.
[b] Same as above.
[c] Satellite images Landsat 5 collected from the U.S. Department of the Interior U.S. Geological Survey, URL: http://earthexplorer.usgs.gov
[d] Brazilian Institute of Geography and Statistics – IBGE (2015) [WWW Document] URL http://www.cidades.ibge.gov.br/xtras/home.php.
[e] Same as above.

resources. The interviews took place with members of the Piancó-Piranhas-Açu Watershed Committee, through participation in their meetings. Regarding the secondary data (aimed at feeding the WSI model), a database (from water resources agencies) search was carried out to compose the hydrological indicator (hydrological series and water quality monitoring). In turn, the environmental indicator was determined from satellite image analysis (applying supervised classification on the ArcGis 10.5 software for land-use map composition) provided by the United States Geological Survey database (in the 'earthexplorer' section). Furthermore, the 'life' indicator was fed by information from the Human Development Index (HDI). Regarding the policy aspects, the composition of the adapted indicator used information collected from the application of questionnaires (primary data, as already mentioned).

Results

Indicator weights from the evaluation of members of the watershed committee

Once the indicator values were presented and the questionnaire[4] was highlighted at the 14th Meeting of the Watershed Committee, it is necessary to present the value of the indicator weights based on the perception of the committee members (Table 5).

PROMETHEE evaluation matrix

As mentioned above, for the PROMETHEE method, an evaluation matrix was built where the columns represent the criteria (C1, C2, etc.), and the lines represent the options (A1, A2, A3, etc.). For the purposes of application in the present case, the criteria are the indicators of the Watershed Sustainability Index [$C1 = \Delta 1$ – Variation in per capita water availability of the watershed in the last 5 years (m^3/inhabitant * year); $C2 = \Delta 2$ – Variation in BOD5 (last 5 years), and so on] and the options are

---

[4] Questionnaire available in Appendix II.

Table 5. Weights of indicators[a] of the WSI according to the perception of members of the Piranhas-Açu Watershed Committee.

	Indicator 1		Indicator 2		Indicator 3		Indicator 4	
	F	%	*F*	%	*F*	%	*F*	%
Very high	13	48.1	13	48.1	11	40.7	7	25.9
High	9	33.3	5	18.5	7	25.9	9	33.3
Medium	2	7.4	4	14.8	5	18.5	7	25.9
Low	2	7.4	1	3.7	0	0	2	7.4
None	1	3.7	0	0	2	7.4	0	0
No opinion	0	0	4	14.8	2	7.4	2	7.4
Total of decision-makers	27	100	27	100	27	100	27	100
	Indicator 5		Indicator 6		Indicator 7		Indicator 8	
	F	%	*F*	%	*F*	%	*F*	%
Very high	10	37	15	55.6	12	44.4	16	59.3
High	8	29.6	7	25.9	7	25.9	5	18.5
Medium	6	22.2	2	7.4	3	11.1	3	11.1
Low	1	3.7	1	3.7	2	7.4	1	3.7
None	0	0	0	0	0	0	0	0
No opinion	0	0	2	7.4	3	11.1	2	7.4
Total of decision-makers	27	100	27	100	27	100	27	100
	Indicator 9		Indicator 10		Indicator 11		Indicator 12	
	F	%	*F*	%	*F*	%	*F*	%
Very high	7	25.9	17	63	16	59.3	18	66.7
High	11	40.7	6	22.2	6	22.2	6	22.2
Medium	6	22.2	2	7.4	3	11.1	0	0
Low	1	3.7	0	0	0	0	1	3.7
None	0	0	0	0	1	3.7	0	0
No opinion	2	7.4	2	7.4	1	3.7	2	7.4
Total of decision-makers	27	100	27	100	27	100	27	100
	Indicator 13		Indicator 14		Indicator 15			
	F	%	*F*	%	*F*	%		
Very high	11	40.7	10	37	15	55.6		
High	12	44.4	11	40.7	8	29.6		
Medium	2	7.4	3	11.1	3	11.1		
Low	1	3.7	1	3.7	0	0		
None	0	0	0	0	0	0		
No opinion	1	3.7	2	7.4	1	3.7		
Total of decision-makers	27	100	27	100	27	100		

[a] Indicator 1. Δ1, Change in per capita water availability of the watershed in the last 5 years (m^3/inhabitant * year); Indicator 2. Δ2, Change in BOD5 (last 5 years); Indicator 3. E.P.I. (Rural and Urban); Indicator 4. Variation in H.D.I. income (last 5 years); Indicator 5. Variation in H.D.I. education (last 5 years); Indicator 6. Per capita water availability (m^3/inhabitant * year); Indicator 7. Average BOD5 of the watershed (mg/l); Indicator 8.% of watershed with natural vegetation; Indicator 9. M.H.D.I. watershed (population weighted); Indicator 10. Institutional Capacity in Integrated Water Resources Management (legal and organizational); Indicator 11. Improvement in efficient water use (last 5 years); Indicator 12. Improvement in proper water/sewage treatment (last 5 years); Indicator 13. Evolution in conservation areas (protected areas and good management practices, BPM) in the last 5 years; Indicator 14. Evolution in M.H.D.I. (last five years); Indicator 15. Evolution in spending on Integrated Natural Resource Management (last 5 years).

the Piranhas-Açu watershed subwatersheds (A1 = Seridó, A2 = Piancó, and so on). The evaluation matrix for the analysis of the watershed sustainability index indicators is presented next (Table 6).

The criteria weights for the above evaluation were the ones attained for each participant of the Piranhas-Açu River Basin Committee.

Results of the application of Copeland's multi decision-maker method

With the application of the PROMETHEE II method, it was possible to rank the options under the individual preferences of each member who answered the questionnaire (a total of 27 responses) of a group of decision-makers. Thus, it was sought to aggregate this information in a single rank, which represents the group's preference. Table 7 presents a matrix elaborated from the results of the PROMETHEE II application that served as the base for an analysis, aiming at the final aggregation of the options' rankings, in order to take into consideration all the different opinions regarding the weights of the criteria. For this analysis, the COPELAND ranking aggregation method was adopted. In terms of score, the Piancó subwatershed obtained the highest score (264 wins and 6 losses), hence being in a better situation than any other subwatershed of the Piranhas-Açu watershed. On the other hand, Pataxó got the lowest score (1 win and 269 losses) and therefore has the worst performance among all of Piranhas-Açu subwatersheds. Table 7 presents the relationship between wins and losses as a matrix.

Finalizing the calculations (applying the COPELAND method to the numbers of wins minus the number of losses), the watershed that obtained the best result and thus is the one in the best condition in terms of sustainability is the Piancó watershed (net result of 258), followed by Média Piranhas Potiguar (net result of 190). The worst and therefore least sustainable result (and with priority in actions in terms of management) was displayed by the Pataxó watershed (with a net result of −268).

Conclusions

Results observed in terms of watershed sustainability

In terms of results observed (Table 8), the Pataxó subwatershed demonstrated having the greatest need for intervention, hence being the least sustainable according to its lowest final score (−268), followed by Difusas Baixo Piranhas (−192) and Seridó (−150). Deepening the analysis of the least sustainable subwatershed (Pataxó), it can be noticed that in this watershed the hydrology indicator in terms of state (1,434.4 m^3/hab*year) and of life (M.H.D.I = 0.58) can be highlighted, generating the necessity of future measures in terms of increasing the water availability as well as measures directed to improving the quality of life.

PROMETHEE multi-criteria method

The application of the multi-criteria method PROMETHEE II has proven to be very effective in helping decision-making in watershed management, when well used and when the decision-maker is certain in relation to his objectives and preferences. The presented case study aimed to insert a more participatory approach to evaluate watershed performance through the use of indicators of the watershed

Table 6. Evaluation matrix.

Indicator of the Watershed Sustainability Index (WSI)		Δ1, Change in per capita water availability of the watershed in the last 5 years (m^3/inhabitant * year)	Δ2, Change in BOD5 (last 5 years)	E.P.I. (Rural and Urban)	Variation in H.D.I. income (last 5 years)	Variation in H.D.I. education (last 5 years)	Per capita water availability (m^3/inhabitant * year)	Average BOD5 of the watershed (mg/l)	% of watershed with natural vegetation	M.H.D.I. watershed (population weighted)	Institutional Capacity in Integrated Water Resources Management (legal and organizational)	Improvement in efficient water use (last 5 years)	Improvement in proper water/sewage treatment (last 5 years)	Evolution in conservation areas (protected areas and good management practices – BPM) in the last 5 years	Evolution in M.H.D.I. (last five years)	Evolution in spending on Integrated Natural Resource Management (last 5 years)
Criterion		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Preference function (type)		3	3	5	3	3	2	3	5	1	1	1	1	1	3	1
Weight		The weight of each criterion was defined by each Watershed Committee participant[a]														
Objective		Ma[b]	Mi[c]	Mi	Ma	Ma	Ma	Mi	Ma	Ma	Ma	Ma	Ma	Ma	Ma	Ma
Subwatershed	Serido (A1)	11.9	– 41.0	13.3	5.6	20.4	1,409	11.7	47.0	0.64	Mean[d]	Mean	bad[e]	– 20	9.7	– 20
	Pianco (A2)	3.5	– 64.7	– 6.3	8.6	31.8	4,569	1.9	68.4	0.57	Mean	Mean	bad	– 20	15.5	– 20
	Peixe (A3)	2.9	5.4	– 23.5	6.0	28.8	1,904	1.4	48.8	0.62	Mean	Mean	bad	– 20	13.6	– 20
	Pataxó (A4)	2.9	– 6.7	11.4	3.7	19.5	1,434	3.9	51.5	0.58	Mean	Mean	bad	– 20	– 10.8	– 20
	Paraú (A5)	– 2.1	– 4.0	– 17.7	5.3	25.3	7,330	6.23	43.9	0.59	Mean	Mean	bad	– 20	12.4	– 20
	Média Piranhas Po (A6)	1.6	– 100	– 49.2	5.6	26.5	4,983	2.2	66.4	0.59	Mean	Mean	bad	– 20	12.08	– 20
	Média Piranhas Pa. Po (A7)	8.9	2.5	– 25.8	4.1	24.5	3,369	1.5	67.7	0.6	Mean	Mean	bad	– 20	10.74	– 20
	Média Piranhas Pa (A8)	4.1	365.4	50.3	5.0	29.6	4,216	2.1	74.0	0.57	Mean	Mean	bad	– 20	13.42	– 20
	Espiranhas (A9)	– 0.2	– 16.5	34.4	6.0	32.1	1,547	1.9	47.6	0.58	Mean	Mean	bad	– 20	– 15.34	– 20
	Difusas Baixo P (A10)	2.7	0.1	18.8	3.8	18.3	1,832	3.0	42.0	0.62	Mean	Mean	bad	– 20	8.58	– 20
	Alto piranhas (A11)	3.7	6.8	23.4	7.1	32.6	6,713	1.6	58.9	0.55	Mean	Mean	bad	– 20	15.38	– 20

[a] The weights were established by interviewing the members of the Watershed Committee and in this sense each distinct weight forms a different scenario.

[b] Maximize.

[c] Minimize.

[d] Average.

[e] Bad.

Table 7. Final results of COPELAND analysis.

Subwatershed	Seridó	Piancó	Peixe	Pataxó	Paraú	Média Piranhas Potiguar	Médio P. Paraibano Potiguar	Médio Piranhas Paraibano	Espinharas	Difusas Baixo Piranhas	Alto Piranhas	Losses
Seridó	0	27	27	0	26	27	27	26	18	5	27	210
Piancó	0	0	1	0	0	4	1	0	0	0	0	6
Peixe	0	26	0	0	1	24	11	1	0	0	24	87
Pataxó	27	27	27	0	27	27	27	27	26	27	27	269
Paraú	1	27	26	0	0	26	23	11	2	1	27	144
Média Piranhas Potiguar	0	23	3	0	1	0	1	1	0	0	11	40
Médio P. Paraibano Potiguar	0	26	16	0	4	26	0	2	1	0	23	98
Médio Piranhas Paraibano	1	27	26	0	16	26	25	0	2	0	26	149
Espiranhass	9	27	27	1	25	27	26	25	0	6	27	200
Difusas Baixo Piranhas	22	27	27	0	26	27	27	27	21	0	27	231
Alto Piranhas	0	27	3	0	0	16	4	1	0	0	0	51
Wins	60	264	183	1	126	230	172	121	70	39	219	

Table 8. Final result.

Final ranking	Subwatershed	Net values (wins – losses)
1	Piancó	258
2	Média Piranhas Potiguar	190
3	Alto Piranhas	168
4	Peixe	96
5	Médio P. Paraibano Potiguar	74
6	Paraú	−18
7	Médio Piranhas Paraibano	−28
8	Espinharas	−130
9	Seridó	−150
10	Difusas Baixo Piranhas	−192
11	Pataxó	−268

sustainability index. It was observed that in the decision-making process one of the main aspects was the choice of weighting factors for each decision-maker.

In this sense, the search for the inclusion of society in this decision process was important, since it made it possible to know the priorities of the public by weighting the criteria in the evaluated scenarios. In the watershed committee meeting there was a significant response rate, with about 80% of participants answering the questionnaire, showing that in the presented case there is a willingness to contribute directly to the improvement of the planning unit.

The multi-criteria methodology presented advantages already observed in other studies. For example, an option may be very good from a hydrological point of view, but it may present a great risk to the environment. Therefore, the context itself directs the problem to an over-sorting approach, not admitting compensations between the criteria, thus alternatives are sought out to better balance the main factors involved with the decision-maker's preference structure.

Analysis of Copeland's multi-decision-maker method

By adopting this strategy (Copeland's method), in addition to the already mentioned advantages of the method (among which is being superior to Borda and Condorcet), results were sought considering individual decision-maker opinions and rankings in order to define the final ranking. It was possible to build flow matrices of gains and losses after multi-criteria analysis for each decision-maker subwatersheds' rankings and comparing one by one (pairwise) to achieve the final results.

The method proved to be effective as it represented the reality of opinions of the watershed committee members, which is marked by various different interests and, in this sense, the local sustainability analysis process through the watershed sustainability index better represents a broader participation of decision-makers.

Political outlines

Amidst the problems in the Brazilian Piranhas-Açu subwatershed, the application of the approach presented in this work has enabled a broad participation, as it has included the opinions of various different classes of members of the Brazilian Watershed Committee in the analysis of the indicators of the

Watershed Sustainability Index, thus establishing a decision simulation for each member (PROMETHEE method), then aggregating it to a final outcome (Copeland method).

With the understanding that the members of the Brazilian Watershed Committee come from various segments of the population, it is clear that the adapted application of the WSI, with the possibility of analysing what really matters or not from the committee member's standpoint before the application, had a relevant effect on reliability and future acceptance, as they participated in the process and thus allowed for some democracy in building the application process.

In terms of management, it is noteworthy that the Piancó subwatershed, located in the Brazilian state of Paraíba, presented greater sustainability in contrast with Pataxó subwatershed (located in the Rio Grande do Norte state), showing important indications for the Federal Government in terms of defining in which political region to intervene. A curious fact that the methodology pointed out is precisely the fact that the Pataxó watershed is relatively close to a large reservoir known as Armando Ribeiro Gonçalves. In turn, Piancó has a different reservoir known as Curemas Mãe D'agua. However, it seems that the indicators point to a scenario where the equity and distribution of this resource is wider and, therefore, has reflected in a scenario of better sustainability. Pataxó's low sustainability opposed to Piancó's high sustainability demonstrates that it is not enough to be near the water, but a subwatershed should enjoy the asset through sustainable management of water resources and perhaps this is a good starting point for future analyses.

References

Amorim, A. L. D., Ribeiro, M. M. R. & Braga, C. F. C. (2016). Water resources conflicts in shared water basins: the Piranhas-Açu Water Basin case study. *RBRH 21*(1), 36–45.

ANA (2012). *Agência Nacional de Águas (Brazilian National Water Agency) Hidroweb*. Available from: http://hidroweb.ana.gov.br (accessed 15 March 2015).

ANA (2016). *Agência Nacional de Águas (Brazilian National Water Agency)*. Piranhas-Açu Watershed Resources Plan, Brasília.

Balali, V., Zahraie, B. & Roozbahani, A. (2014). A comparison of AHP and PROMETHEE family decision making methods for selection of building structural system. *American Journal of Civil Engineering and Architecture 2*(5), 149–159.

Boaventura Neto, P. O. (2003). *Grafos: teoria, modelos, algoritmos (Graphs: Theory, Models, Algorithms)*. Editora Edgard Blücher, São Paulo, Brazil, p. 328.

Brans, J. P., Vincke, P. & Mareschal, B. (1986). How to select and how to rank projects: the PROMETHEE method. *European Journal of Operational Research 24*, 228–238.

Brown, A. & Matlock, M. D. (2011). A Review of Water Scarcity Indices and Methodologies, University of Arkansas, The Sustainability Consortium, White Paper No. 106, Sustainability Consortium web [online]. Available from: http://www.sustainabilityconsortium.org/wpcontent/themes/sustainability/assets/pdf/whitepapers/2011_Brown_Matlock_Water-Availability-AssessmentIndices-and-Methodologies-Lit-Review.pdf (accessed 29 January 2015).

Caldas, P., Ferreira, D. C., Dollery, B. & Marques, R. C. (2018). Municipal sustainability influence by European Union investment programs on the Portuguese local government. *Sustainability 10*(4), 910. doi:10.3390/su10040910.

Caldas, P., Ferreira, D. C., Dollery, B. & Marques, R. C. (2019a). Economies of scope in Portuguese local government using an augmented Hicks–Moorsteen approach. *Regional Studies 53*(7), 963–976. doi:10.1080/00343404.2018.1508872.

Caldas, P., Ferreira, D., Dollery, B. & Marques, R. (2019b). Are there scale economies in urban waste and wastewater municipal services? a non-radial input-oriented model applied to the Portuguese local government. *Journal of Cleaner Production 219*, 531–539. doi: 10.1016/j.jclepro.2019.02.076.

Carvalho, J. R. M. D. & Curi, W. F. (2013). Construção de um índice de sustentabilidade hidro-ambiental através da análise multicritério: estudo em municípios paraibanos (Construction of a hydro-environmental sustainability index through multicriteria analysis: study in Paraíba municipalities). *Sociedade & Natureza 25*(1), 91–106.

Chaves, H. M. L. & Alipaz, S. (2007). An integrated indicator for basin hydrology, environment, life and policy: the watershed sustainability index. *Water Resources Management 21*, 883–895.

Cirilo, J. A. (2008). Políticas públicas de recursos hídricos para o semi-árido (Water resources public policies for the semi-arid). *Estudos Avançados 22*(63), 61–82. Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-40142008000200005&lng=en&tlng=pt. doi:10.1590/S0103-40142008000200005.

Clímaco, J. C. N. A. (2003). Critical reflection on optimal decision. *European Journal of Operational Research 153*, 506–516.

De Araújo, D. C. (2016). *Metodologia de análise de conflitos na gestão de águas pluviais urbanas com auxílio de métodos multicritérios e multidecisores (Methodology for Decision Support in Urban Rain Water Management Combining Multi-Criteria and Multi-Decision-Maker Methods). Doctoral dissertation*, Universidade Federal de Pernambuco, Recife. Available from: http://www.gota.eng.br/downloads/teses/tesedaniel.pdf.

Gleick, P. H. (1998). Water in crisis: paths to sustainable water use. *Ecological Applications 8*, 571–579. http://dx.doi.org/10.1890/10510761(1998)008[0571:wicpts]2.0.co;2.

Gleick, P. H., Loh, P., Gomez, S. & Morrison, J. (1995). *California Water 2020: A Sustainable Vision*. Pacific Institute for Studies in Development, Environment, and Security, Oakland, CA, USA.

Hák, T., Janoušková, S. & Moldan, B. (2016). Sustainable development goals: a need for relevant indicators. *Ecological Indicators 60*, 565–573.

IBGE (2015). *Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics)*. Available from: http://www.cidades.ibge.gov.br/xtras/home.php (accessed 18 March 2015).

Juwana, I., Muttil, N. & Perera, B. J. C. (2012). Indicator-based water sustainability assessment – a review. *Science of the Total Environment 438*, 357–371.

Kangas, A., Laukkanen, S. & Kangas, J. (2006). J. Social choice theory and its applications in sustainable forest management-a review. *Forest Policy and Economics 9*, 77–92.

Laukkanen, S., Palander, T. & Kangas, J. (2004). Applying voting theory in participatory decision support for sustainable timber harvesting. *Canadian Journal of Forest Research 34*, 1511–1524.

Loucks, D. P. (2000). Sustainable water resources management. *Water International 25*(1), 3–10.

Lowe, M., Whitzman, C., Badland, H., Davern, M., Aye, L., Hes, D., Butterworth, I. & Giles-Corti, B. (2015). Planning healthy, liveable and sustainable cities: how can indicators inform policy? *Urban Policy and Research 33*(2), 131–144.

MacGillivray, A. (2017). Accounting for change: indicators for sustainable development. In: *Tomorrow's History*. Zadek, S. (ed.). Routledge, Abingdon, UK, pp. 122–129.

Mays, L. W. (ed.) (2007). *Water Resources Sustainability*. McGraw-Hill, New York, USA.

Nascimento, R. S. (2016). *Modelo Conceitual para Gestão da Qualidade da água em Sistemas de Abastecimento de Médio Porte (Conceptual Model for Water Quality Management in Medium-Sized Supply Systems). Doctoral dissertation*, Universidade Federal de Campina Grande, Campina Grande. Available from: http://www.gota.eng.br/downloads/teses/teseruth.pdf.

Pomerol, J. -C. & Barba-Romero, S. (2012). *Multicriterion Decision in Management: Principles and Practice*. Springer Science & Business Media.

Postel, S. I. (2000). Entering an era of water scarcity: the challenges ahead. *Ecological Applications 10*, 941–948.

Sugiartawan, P. & Hartati, S. (2018). 2018 Third international conference on informatics and computing (ICIC). In: *Group Decision Support System to Selection Tourism Object in Bali Using Analytic Hierarchy Process (AHP) and Copeland Score Model*, Sumatra, Indonesia, pp. 1–6.

Tundisi, J. G. (2003). *Água no século xxi: enfrentando a escassez (Water in the XXI Century: Facing Scarcity)*. RiMa, São Carlos, Brazil.

Velasquez, M. & Hester, P. T. (2013). An analysis of multi-criteria decision making methods. *International Journal of Operations Research 10*(2), 56–66.

Vieira, Vicente p.p.b (2003). Desafios da gestão integrada de recursos hídricos no semiárido (Challenges of integrated water resources management in the semiarid region). *Revista Brasileira de Recursos Hídricos 8*(2), 7–17.

Received 16 January 2019; accepted in revised form 21 March 2020. Available online 25 June 2020