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Sustainability Assessment of indicators for integrated water resources management

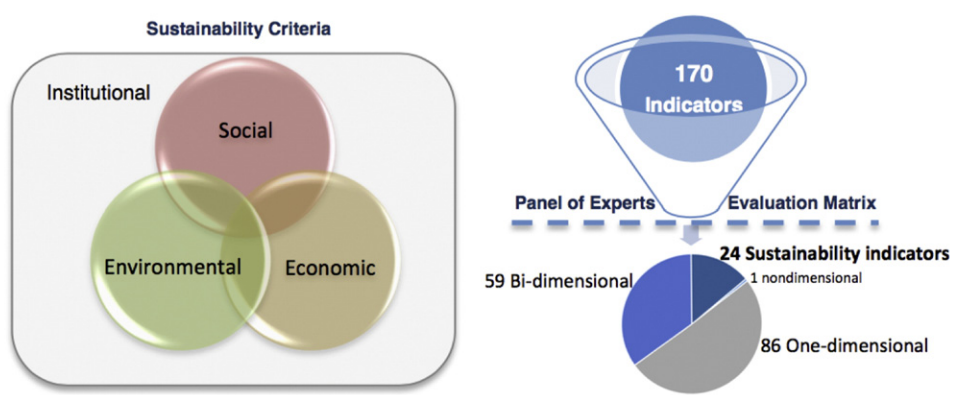
A. Pires [a,*], J. Morato [a], H. Peixoto [b], V. Botero [c], L. Zuluaga [c], A. Figueroa [d]

[a] *UNESCO Chair on Sustainability, Polytechnic University of Catalonia, Barcelona, Spain*
[b] *Earth Science Institute, Federal University of Bahia, Salvador, Brazil*
[c] *Environmental and Earth Science Institute, National University of Colombia, Medellin, Colombia*
[d] *Environmental Studies Group, Cauca University, Popayan, Colombia*

HIGHLIGHTS

- Indicators often fall short to include the main dimensions of sustainability.
- 170 indicators of water use and management were identified, described and evaluate.
- Evaluation matrix, panel of experts, pilot study and DPSIR framework were used.
- 24 indicators fulfil the majority of the sustainability criteria
- These indicators provide core information for integrated water management.

GRAPHICAL ABSTRACT



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ABSTRACT

The scientific community strongly recommends the adoption of indicators for the evaluation and monitoring of progress towards sustainable development. Furthermore, international organizations consider that indicators are powerful decision-making tools. Nevertheless, the quality and reliability of the indicators depends on the application of adequate and appropriate criteria to assess them. The general objective of this study was to evaluate how indicators related to water use and management perform against a set of sustainability criteria. Our research identified 170 indicators related to water use and management. These indicators were assessed by an international panel of experts that evaluated whether they fulfil the four sustainability criteria: social, economic, environmental, and institutional. We employed an evaluation matrix that classified all indicators according to the DPSIR (Driving Forces, Pressures, States, Impacts and Responses) framework. A pilot study served to test and approve the research methodology before carrying out the full implementation. The findings of the study show that 24 indicators comply with the majority of the sustainability criteria; 59 indicators are bi-dimensional (meaning that they comply with two sustainability criteria); 86 are one-dimensional indicators (fulfilling just one of the four sustainability criteria) and one indicator do not fulfil any of the sustainability criteria.

1. Introduction

Indicators are powerful decision making tools and the adoption of indicators to evaluate and monitor the progress towards sustainable

* Corresponding author at: Av. Luis Viana Filho, 6775, Jorge Amado University Center, Salvador 41745-130, Brazil.
E-mail addresses: alex.pires@catunesco.edu.br, alexpires.br@gmail.com (A. Pires).

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development is strongly recommended by scientists (Bolcárová and Kološta, 2015; Cornescu and Adam, 2014; Moldan et al., 2012), policy developers (UNDESA, 2007), international institutions (OECD, 2014; WWAP, 2003), governments (OSE, 2008), the business sector (WBCSD, 2000) and non-governmental organizations (WWF, 2010).

The application of indicators of water use and management can undoubtedly contribute to a better allocation of this limited resource (Kang and Lee, 2011). Nevertheless, for their formulation, it should not only be considered as a technological issue but also should include the environmental, social, institutional, and economic aspects related to sustainability (Spangenberg, 2004).

Indicators can be applied to natural elements, such as the environment (Zhang, 2015), ecosystems (Fu et al., 2015), forest management (Gossner et al., 2014), water (Lobato et al., 2015; Perez et al., 2014) and land (Zhao et al., 2013; Rosén et al., 2015), as well as to socio-economic-institutional issues related to water resources, i.e. water economic value (Hellegers et al., 2010), urban water systems (Spiller, 2016), governance (Norman et al., 2013; Pires and Fidélis, 2015), political framework (Blanchet and Girois, 2012) and management (Taugourdeau et al., 2014). Several authors (Juwana et al., 2012; Spangenberg, 2008; McCool and Stankey, 2004) mention that the rise of sustainable development concepts and environmental concerns have led to an extensive and intense application of indicators by a wide range of users in different contexts. In response to the growing search for indicators based on ad hoc approaches, the Bellagio Principles (Hardi and Zdan, 1997) were established to guide the use of indicators to measure progress towards sustainability.

So far, no comprehensive analysis about the precise number of indicators related to sustainable development, environment or water resources has been found, however, authors point to thousands of such metrics (Hak et al., 2012). The United Nations World Water Assessment Programme (WWAP, 2012) remarks that *"a staggeringly extensive array of indicators have been developed, or are proposed, to monitor the state, use and management of water resources, for a wide range of purposes."*

The relevance of indicators for the decision-making process is one of the most important features of the indicators in relation to other forms of information. Indicators can be powerful policy decision tools (Nicholson et al., 2012). Therefore, indicators should present attributes that are considered relevant by the decision makers and not necessarily by a specialized audience (Klug and Kmoch, 2014). Well-developed indicators should condense and unscramble relevant data by measuring, quantifying/qualifying, and transmitting information in a way that is easy to understand (Kurka and Blackwood, 2013).

1.1. IWRM, sustainable development and indicators

Indicators that are selected to address the key concerns of water managers provide critical data for water governance. Water governance is the set of political, social, economic, and administrative systems that make the Integrated Water Resources Management possible (Hooper, 2006). Integrated Water Resources Management (IWRM) takes the view of sustainable development and applies it to the water sector. IWRM became apparent in the late 1980′s and is in fact an *"umbrella concept encompassing multiple principles"*, which aims at a more coordinated management of water resources (Benson et al., 2014).

IWRM adopts a holistic approach: as mentioned by WWAP (2003) the purpose of IWRM *"is maximizing the economic benefits and social welfare of the use of water without jeopardizing the sustainability of the ecosystem"*. Hooper (2006) further explains, *"IWRM involves cross-sectoral collaboration and adaptive management rather than single sector, 'line' management and planning of land and water resources"*. One of the principles of IWRM is the integration of interconnection between several aspects: e.g. up-stream and down-stream; quality and quantity of water resources; economic and environmental needs; technical and political decisions, etc. (Ludwig et al., 2013).

One of the key issues of IWRM is the need for greater participation from different groups of stakeholders, e.g. policy and decision makers, planners, managers, scientists, and the general public (UN, 1992). To promote adequate participation in the IWRM from such diverse groups, there must be tools for effective communication among them. Indicators can help simplify information on IWRM and establish effective communication among the various groups in the water resources field (WWAP, 2003).

Dahl (2012) urged the scientific community to find better indicators of progress towards sustainability. They demonstrated in their paper *Achievements and gaps in indicators for sustainability* that *"the available indicators mostly succeed at measuring unsustainable trends that can be targeted by management action, but fall short of defining or ensuring sustainability"*. This limitation also applies to water resources sustainability (Mays, 2006). Despite several publications and work on this matter, no comprehensive list of the available indicators to assess the sustainable use and management of water can be found. Our research therefore identifies and describes a set of 170 indicators related to the water use and management presented by international institutions and scientific community. So far, no other scientific publication has been found that has compiled and described such an extensive list of water indicators.

It was also noticed that there was no previous study that further investigate if these indicators of water resources fulfil the main components of sustainability. On one hand, some studies have faced similar questions (Juwana et al., 2012; Kang and Lee, 2011; Perez et al., 2014; Spiller, 2016), on the other hand they analysed a limited set of indicators. This paper aims to contribute to fulfil this gap. The general objective of this study was to evaluate how the 170 indicators related to water use and management identified by with study perform against a set of sustainability criteria.

2. Methodology

The study identified the indicators related to water use and management. In order to do this, an extensive revision of the specialized literature screening the indicators related to water use and management was performed. An assessment matrix with the identification and description of the indicators was constructed classifying them according to the DPSIR framework.

A pilot study served to test and approve the research methodology and data analysis before carrying out the full implementation. This was followed by an international panel of experts, assessing the indicators based on the sustainability criteria. The assessment followed by the classification of the indicators according to the system approach (social, economic, environmental, and institutional components) and the organization of the indicators into four categories: indicators of sustainability, bi-dimensional indicators, one-dimensional indicators and indicators with no relation with sustainability criteria.

The ones that adequately cover the majority of the social, economic, environmental, and institutional criteria were selected as indicators suitable to measure the sustainability of water use and management.

2.1. Identification of the indicators

This research performed an extensive revision of the specialized literature, aiming at identifying the initial set of indicators to take part in this study. This research carried out several electronic searches accessing a number of journal and institutional websites (including relevant grey literature), as well as databases and academic search engines. In total, 54 sources were examined in detail. Among them were publications from internationally institutions renowned for their reliable work on indicators, water resources and/or sustainability, such as FAO (2003), GWP (2006), IISD (1999), OECD (2004), UN (2009), WHO and UNICEF (2010), World Bank (2007), WRI (1998) and WWAP (2009). This study also examined relevant peer reviewed scientific papers related to the subject, including Aldaya and Llamas (2008), Bradfor (2008), Ding et al. (2010), Hoekstra (2010), Lawrence et al. (2002), Maneta et al. (2009), Milman and Short (2008), Scudder (2005), Sullivan and Huntingford (2009), Vörösmarty et al. (2005a), Wilhite et al. (2007). Official publications from key governments were also examined including Brazil (MMA, 2006), Spain (OSE, 2008), Catalonia (De Felipe et al., 2008), European Union (Eurostat, 2009), among others.

The indicators of interest to this study are the ones related to water use and management from the perspective of the integrate water cycle including, but not limited to, surface water, groundwater, rainwater and reclaimed water. The river basin is the geographical scale of interest for this study, nevertheless the indicators identified here are not limited to this scope. The indicators identified by this study address one or more of the following aspects:

- Indicators that measure consumptive use of water: indicators associated with extractive uses that alter the amount of water and are mainly linked with three sectors: agriculture, industrial, and domestic uses.
- Indicators of non-consumptive use of water: indicators related to non-extractive practices such as recreation, transportation, power generation, acceptance of waste (pollution), and religious and cultural uses.
- Indicators related to the environmental role of water resources (e.g. conservation of aquatic life, biodiversity, and the preservation of wetlands), water quality, and conservation of natural resources.
- Indicators related to water governance (e.g. legislation, institutional capacity building, user participation, environmental education, knowledge production and management, water economics, water culture, etc.).
- Hydrological indicators (e.g. precipitation, evapotranspiration, stream flow, soil moisture, hydrological status, etc.) that are considered essential to planning, operation and efficiency of water use.

2.2. Construction of the assessment matrix

This study created an assessment matrix aiming to organize the information of the indicators identified and to be used as an evaluation tool to assess their sustainability criteria. Assessment matrixes are useful tools to systematize complex information under evaluation (Sheppard and Meitner, 2005). They have been regularly adopted in several fields including sustainability (Graymore et al., 2008), environment (Canter, 1999), among others.

This matrix presented the basic information about each indicator, including name, brief description, position under DPSIR framework (see next section), among others. It is worth mentioning that some original sources analysed presented the indicator's name, but did not provide a definition for it. This was the case with several indicators proposed by the UN World Water Assessment Programme (WWAP, 2003). When needed, we have proposed a summarized description of these indicators based on the consultation of additional sources. This effort aimed to bring enough elements to the members of the panel of experts in order to allow them to assess the indicators based on an actual description in order to reduce ambiguity and misinterpretation.

2.3. Classification under the DPSIR framework

The next step was to classify the indicators under the DPSIR framework. Several authors argue (Constantino et al., 2004; Mendoza and Prabhu, 2003; Niemeijer and de Groot, 2008; Niemi and McDonald, 2004; Wolfslehner and Vacik, 2011) that indicators can be more useful if they are organized in a coherent framework instead of individually as a simple collection of elements. The adoption of a framework is especially important in the case of indicators related to sustainable development, which encompass many subjects and dimensions (IISD, 2008; WWAP, 2006).

The DPSIR approach is the most widely used framework applied for environmental indicators (Spangenberg et al., 2015; WWAP, 2003). DPSIR is based on the pressure-state-response (PSR) conceptual framework firstly introduced by the OECD (1994), and then amply adopted by the EEA (1999) and UN system (WWAP, 2012).

The DPSIR framework organizes the indicators according to the cause–effect schema under the following categories: Drive Forces, Pressure, State, Impact and Response. An indicator, depending on its nature and attributes can be classified under one or more of these components.

The classification of the indicators under this framework was based primarily on the definition by the original source presenting the indicator. When this information was not available, the authors analysed the indicator and proposed a classification. The classification of each indicator under the DPSIR framework was done according to the definitions presented by the EEA (1999) and their adaptation to the water resources sector done by WWAP (2006) based on Constantino et al. (2004) – as described in the Table 1 below.

Table 1
Definitions of the DSPIR categories to classify indicators.

	Original definition by EEA (1999)	Adaptation of WWAP (2006) to water resources sector
Indicators for driving forces	Describe the social, demographic and economic developments in societies and the corresponding changes in life styles, overall levels of consumption and production patterns. These driving forces exert pressure on the environment.	The basic sectorial trends, the underlying factors and the root causes affecting the development of society, the economy and environmental conditions.
Pressure indicators	Describe developments in release of substances (emissions), physical and biological agents, the use of resources and the use of land. The pressures exerted by society are transported and transformed in a variety of natural processes to manifest themselves in changes in environmental conditions.	Human activities directly influencing water resources supply, quantity or quality, or water use; the immediate stress agents or proximate causes.
State indicators	Give a description of the quantity and quality of physical phenomena (such as temperature), biological phenomena (such as fish stocks) and chemical phenomena (such as atmospheric CO^2 concentrations) in a certain area.	Current conditions and trends; situation or status of the resource or the sector vis-à-vis water at the present time.
Impact indicators	Describe the impacts on the social and economic functions on the environment, such as the provision of adequate conditions for health, resources availability and biodiversity. These impacts are caused by changes on state of the environment.	The effects of changed water-related conditions on human and natural systems; physical and economic losses due to deteriorating water conditions; the effective consequence of the altered state of the resource or its use.
Response indicators	Refer to responses by groups (and individuals) in society, as well as government attempts to prevent, compensate, ameliorate or adapt to the impact of the changes in the state of the environment. Some societal responses may be regarded to reduce or eliminate negative driving forces, other responses may aim at raising the efficiency of products and processes.	The reaction, or efforts of society — at all levels — to change undesirable conditions, to solve the problems that have developed or to counter the stress and impacts imposed on human systems; coping mechanisms as reflected in changes in policies and institutions, production practices or human behaviour.

Sources: EEA, 1999; WWAP, 2006; Constantino et al., 2004.

Our study adopted the institutional dimension as the fourth pillar of sustainability as presented by Juwana et al. (2012), IISD (2008), UNDPCSD (1995), Spangenberg (2008), WWAP (2003), among others. These four dimensions were then translated to the perspectives of water use and management:

- **Social Sustainability**: to ensure access to water of a quality and amount necessary for human needs;
- **Economic Sustainability**: to ensure the handling and efficient use of water promoting urban and rural development;
- **Environmental Sustainability**: to ensure the appropriate protection of natural resources: soil, biota, and water;
- **Institutional Sustainability**: to ensure an adequate institutional framework to promote the principles of IWRM.

2.4. Evaluation of the indicators

The indicators were evaluated by an international panel of experts using the assessment matrix and grading each indicator according to their significance in relation to each one of the four sustainability criteria.

2.4.1. Panel of experts

A panel of experts was assembled to assess whether the indicators fulfil the sustainability criteria. Panels of experts have been used by researchers to provide independent, expert judgement to the assessment of indicators (Singh et al., 2009). Fourteen experts from the scientific community were selected to form the evaluation panel. In order to select them, the following principles, also adopted by Cloquell-Ballester et al. (2006), were considered: a) level of knowledge on the subject; b) expected ability to perform the task; c) interest in participating in the process.

These individuals have proven professional experience related to water resources and were selected from international networks related to the topic of the research, mainly the CYTED (Ibero-American Programme for Science, Technology and Development) and the UNESCOSOST Network (UNESCO Chair of Sustainability at UPC - Barcelona). The members of the panel, seven females and seven males, are high-level experts. All of them possesses or pursue a PhD. They are from diverse age ranges with different backgrounds from several Ibero-american countries.

Using the assessment matrix, these experts expressed, based on the evaluation scale (see next section), how they consider each indicator fulfilling each sustainability criterion. They were also invited to provide their comments or observations on the indicators. The experts performed independent evaluations, both remotely and in person. In order to support the work of the panel as well as possible, all materials provided to them (assessment matrix, instructions, e-mails, etc.) were designed to be user friendly.

A **pilot study** was carried out in order to test the methodology and statistical techniques employed in this research prior to full-scale implementation. It was performed in order to check if the research design and settings would work as expected. Pilot studies, like the one done here, are of crucial importance in qualitative research due to their ability to reveal any methodological limitations and flaws, and to point for design improvements (Van Teijlingen and Hundley, 2001). Pilot studies give researchers the opportunity to make any necessary revisions prior to full implementation, in order to increase the likelihood of success (Turner, 2010).

This pilot study simulated the application of the assessment matrix using the evaluation scale and settings, as presented above, to a group of eight experts from the network of the UNESCO Chair on Sustainability. The test participants were limited in number but diverse in their representation, including professors and PhD/Master students, males and females from diverse age ranges with different backgrounds, from several Ibero-american countries. A sample of 10 indicators related to water use and management was randomly chosen for this pilot study. The results were statistically treated in the same way as the final results would be.

The participants of the pilot study welcomed the design and the material produced. Nevertheless, they provided relevant feedback and suggestions to further improve them, such as, the inclusion of information about the units of measurement for each indicator in the assessment matrix and adjusting the sequence of the indicator in the matrix in order to group indicators according to the topic addressed. The methodology was validated through the pilot study, and the main recommendations from the pilot study were incorporated into the research design.

Table 2
Three-level qualitative scale for the classification of sustainability criteria.

Social Sustainability	Economic Sustainability	Environmental Sustainability	Institutional Sustainability
Not Significant			
No significant social component included	No significant economic component included	No significant environmental component included	No significant Institutional component included
Significant			
Includes social components that contribute to improving access to quality water and the amount needed for human needs	Includes economic components that contribute to the efficient use of water by promoting urban and rural development	It includes components of the environment that contribute to the protection of natural resources-soil, biota and water	Includes institutional components that contribute to promoting the principles of IWRM
Highly significant			
Aims to ensure access to quality water and the amount needed for human needs.	Aims to ensure the efficiency of the management and use of water, promoting urban and rural development.	Aims to ensure adequate protection of natural resources-soil, biota and water (especially the springs and groundwater).	Aims to ensure the appropriate institutional framework to promote the principles of IWRM.

2.4.2. Evaluation scale

The evaluation process involved a three-level qualitative scale in which the members of the panel classified each indicator as: not significant, significant, or highly significant, based on its level of compliance with the social, economic, environmental and institutional criteria (Table 2).

These results were scaled numerically as follows: not significant equal to zero; significant equal to seven; and highly significant equal to ten. This zero to ten scale was used because the experts could easily apply it; and because it is a general and largely used scale for rating (Wimmer and Dominick, 2010).

2.4.3. Analyses of the data

The data obtained from the panel of experts was categorized, processed and analysed applying the fundamentals of descriptive statistics. The summarization of the results was done based on the averages of the ratings assigned by each evaluator to a given criterion. The arithmetic mean was the average measure applied in order to represent the central value on the set of data. The following equation shows how the average scores were calculated for each indicator in relation to each criterion (social, economic, environmental, and institutional).

$$\mathrm{Si}_{(c)} \equiv \frac{\sum_{1}^{n} \mathrm{Si}_{(c)}}{n}$$

where Si(c) is the score for indicator i and criterion c (social, economic, environmental, and institutional), and n is the number of experts.

The frequency histograms of the data obtained with the evaluation were also used to graphically represent the results.

2.4.4. Selection of the indicators

This study aimed at selecting indicators of water use and management that presented adequate sustainability criteria. In order to select them, the average score of seven was considered as the threshold value to define whether an indicator fulfils the criterion or not. On the evaluation scale adopted by this study, this value corresponds to the classification of "significant". Thus, every indicator with an average score greater than or equal to seven for any sustainability criterion (social, economic, environmental, or institutional) met the sufficiency cut-off for each specific sustainability criterion.

2.4.5. System approach

The assessment of the four categories of the sustainability criteria provided the classification of the indicators under the system framework. The systems approach is based on the concept of system dynamics. It contributes to provide a holistic vision of sustainability and it has often been applied to indicators (Gallopin, 2006; Sterman, 2000; Sanò and Medina, 2012; WWAP, 2003). This research adopted a four-component system framework (social, environmental, economic, and institutional), based on the sustainability criteria presented above.

2.4.6. Categories of the Sustainability Assessment

The results were then classified into four categories (sustainability indicators, bi-dimensional indicators, one-dimensional indicators, and the ones with no relation with sustainability criteria) as described in Table 3 below. The classification into these categories is based on the number of criteria fulfilled by the indicator. The selected indicators are the ones that fulfil the majority of the sustainability criteria (3 or more criteria).

3. Results

This study identified 170 indicators related to water use and management in the literature. In total, the 14 members of the panel provided 9520 results; corresponding to the evaluation of the four sustainability criteria for each of the 170 indicators. The frequency distribution of the results was analysed and summarized in the tables and figures below. The evaluation process yielded from this initial list of 24 key indicators that fulfil the majority of the sustainability criteria. The main findings are presented below.

In the first stage, over 240 indicators related to water resources were found in the specialized literature. Out of those, 170 indicators were identified as addressing aspects related to water use and management. These indicators can be found in Annexes 1, 2 and 3.

From this initial list of 170 indicators of water use and management, 24 indicators (14%) comply with the majority of the sustainability criteria (Annex 1). Fifty-nine are bi-dimensional indicators, meaning that they comply with two sustainability criteria (Annex 2) and 86 indicators are one-dimensional indicators, fulfilling one sustainability criterion (Annex 3). This last annex also presents the only one indicator that did not fulfil any of the sustainability criteria.

Table 3
Categories of the Sustainability Assessment.

Category	Meaning	Number of sustainability criteria complied
Sustainability indicators	Fulfil the majority of the sustainability criteria	3 or more criteria
Other multi-criteria indicator (or bi-dimensional)	Fulfil two sustainability criteria	2 criteria
Uno-criterion indicator (or one-dimensional)	Fulfil one sustainability criterion	1 criterion
No relation with sustainability criteria	Do not fulfil any sustainability criteria	–

The average result of the set of 170 indicators showed the highest score for the environmental criterion (7.1), followed by the economic (6.1), institutional (5.8), and social (5.7) criteria. Regarding the final list of 24 indicators of sustainability, their average scores range from 8.4 to 7.3. Moreover, in the latter case, the social criterion presents the highest score (8.4), followed by the economic and environmental (7.6 for each case), and institutional (7.3) criteria.

Figure 1 presents the **frequency histograms** for the 170 indicators of water use and management by each of the four sustainability criteria assessed by this research. The main findings are summarized below:

- Forty-five per cent of the scores for the **social** sustainability criterion were greater than or equal to seven. The lowest scores (between one and two) were very unlikely. The most frequent score was five.
- In terms of the **economic** criterion, the scores were between four and ten for 89% of the cases. Fifty-five per cent of the scores were between seven and ten.
- For the **environmental** sustainability criterion, 68% of the indicators had scores between seven and ten. The highest value of the scale (ten) was by far the most frequent grade under this criterion, with 35% of the results.
- The histogram for the **institutional** sustainability criterion showed that four and five were the most common scores, with 17% and 16.5% of the results, respectively. Forty-two per cent of the indicators had average scores greater than or equal to seven.

Table 4 presents the results of the system approach classification of the initial set of 170 indicators and the final set of 24 indicators. It corresponds to the percentage of the indicators that presents each component of the system framework (social, economic, environmental and institutional). Out of the initial set of 170 indicators, 58% (98 indicators) addressed the environmental component, being the highest result among the four components. Nevertheless, the social component was the most frequent one in the final set of 24 indicators: 96% of them (23 indicators).

Table 5 presents the results of the classification for the initial set of 170 indicators and the final set of 24 indicators for the DPSIR framework. On one hand, it is noticeable for both sets that a very limited number of indicators relate to the drive forces (7% of the initial set and none of the final). On the other hand, indicators that describe the state of the environment form the majority of the initial set (53%) and half of the final set of indicators.

4. Discussion

4.1. Indicators of sustainable water use and management

The ultimate purpose of this study was to identify the indicators of water use and management that fulfil the sustainability criteria. In order to reach this objective, we analysed specialized literature, constructed an assessment matrix and convened an international panel of experts. Findings of the current study support that 14% (24 indicators) of water use and management fulfil the sustainability criteria.

Eighty-six per cent of the indicators do not fulfil the majority of sustainability criteria, suggesting that most indicators of water use and management reflect the conventional limited view of not considering the multi-dimensionality of sustainability. According to WWAP (2009), the usage of indicators that integrate sustainability criteria is a powerful tool for identifying and monitoring water problems, defining solutions, and evaluating the achievements or failures of policies, plans and programs. However, for their determination, the multi-dimensional perspective of sustainability should be considered. This includes aspects related to the environmental effects (positive and/or negative), the social-economic issues, and the institutional aspects of the indicators.

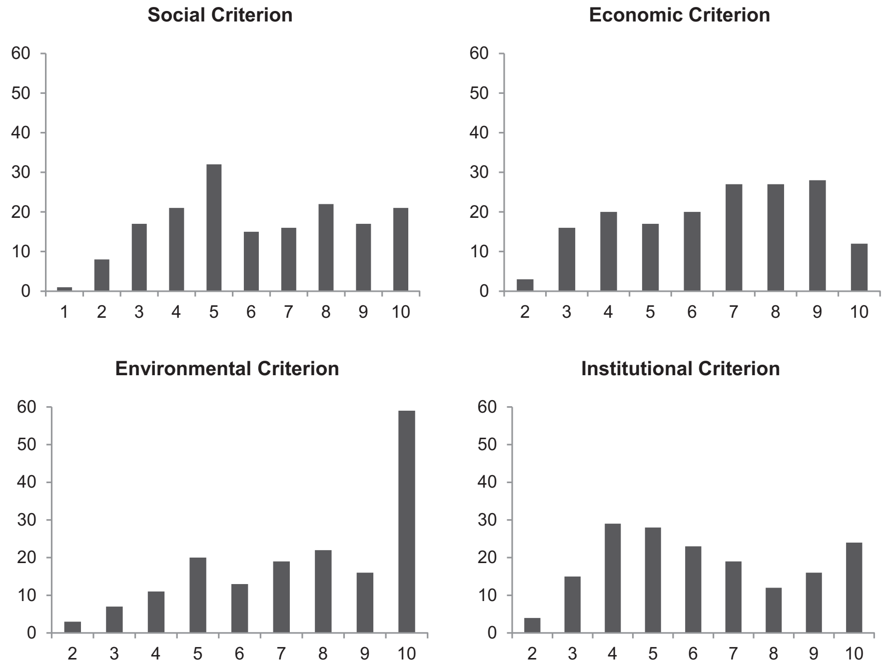

Fig. 1. Frequency histograms for the average scores of the 170 indicators related to water use and management by each of the four sustainability criteria (vertical axis represents the frequency of the answers, and the horizontal represents the scores).

As noted in the findings of this study, the environmental criterion of the 170 evaluated indicators exhibited a significant number of results between 9 and 10. It shows that generally, the experts coincided in their scores and these values are considered high (68% of the scores are greater than or equal to 7). This prevalence confirmed that, indicators related to water use and management have been usually built for environmental studies.

In general, the 24 indicators that fulfil the sustainability criteria (Annex 1) describe an extensive range of subjects related to water resources. These indicators address issues such as growth in consumption, populations without access to drinking water and/or sanitation, exposure to polluted water sources, and water-related diseases that are associated with imbalances in access to clean and safe water.

The indicator with the highest average score (9.2) is the “water poverty index”, which takes into account the relationships of five components, including the physical extent of water availability, its ease of abstraction, and the level of community welfare (Sullivan and Meigh, 2005). The “Water poverty index” together with the “climate vulnerability index”, “water shortages” and “fraction of the burden of ill-health from nutritional deficiencies” were the only indicators that comply with all four dimensions of sustainability: the average score for each of the four criteria of sustainability was above the threshold.

Among the 24 sustainable indicators, it is noticeable the “water footprint” (WF): a multi-component indicator introduced by Hoekstra and Hung (2002). The WF consists of three components: green, blue and grey water. As mentioned by Hoekstra (2009), blue water corresponds to fresh surface or ground water, green water is the precipitation stored in the soil as soil moisture, and grey water is related to water pollution. Pellicer-Martínez and Martínez-Paz (2016) points that water footprint is an indicator that allows a comprehensive view of the sustainability of water use and can be assessed within the framework of IWRM. We recommend further study on this indicator, specially aiming to overcome some limitations regarding the methods for its calculation, as mentioned by Lovarelli et al. (2016).

It should be mentioned, that this study also identified 59 indicators that fulfil two sustainability criteria. Among them are relevant indicators such as “access to safe drinking water”: one of the indicators adopted by the United Nations to monitor progress towards the Millennium Development Goals (UN, 2010). These 59 bi-dimensional indicators are distinctive in considering more than just one aspect of sustainability. Therefore, this research recommends the development of further studies about these indicators, especially the ones that presented outstanding grades, i.e. “existence of legislation advocating Dublin principles for water”. This indicator received one of the highest scores for the institutional criterion (9.8 as average). It measures the existence of legislation in issues related to water sustainability and management, participatory approach, gender and economic value (ICWE, 1992).

Eighty-six indicators that comply with one of the four sustainability criteria were also identified. They are one-dimensional indicators; which should not be seen as a limitation rather than as a characteristic. They address in an adequate way one of the four components of sustainability, meaning that they are interesting tools that allow seeing, from a specific angle, one of the multiple aspects of water use and management. An interesting example of the former is the “freshwater species population trends index”. This indicator, also known as the “freshwater

Table 4
Components of the systems approach of the initial set of 170 indicators and the final set of 24 indicators.

Component	Initial set of 170 indicators	Final set of 24 indicators
Social	36%	96%
Economic	39%	83%
Environmental	58%	71%
Institutional	32%	67%

Table 5
Components of the DPSIR framework of the initial set of 170 indicators and the final set of 24 indicators.

Component	Initial set of 170 indicators	Final set of 24 indicators
Drive forces	7%	–
Pressure	27%	42%
State	53%	50%
Impact	36%	50%
Response	29%	25%

living planet index", tracks changes in freshwater species found in freshwater ecosystems, since the baseline year of 1970, including data on 2750 populations of 714 species of fish, birds, reptiles, amphibians and mammals (WWF, 2010). It is a very relevant indicator related to the ecological conditions of the watercourses, in fact it received a very high score for the environmental criteria (9.3).

The assessment of the sustainability criteria presented here was the result of the work of an international panel of experts from Ibero-american countries. Therefore future studies could investigate how these indicators perform when assessed by a broader group, including experts from other parts of the world. These further studies could aim to compare results and even identify possible generalizations of the findings. Furthermore, this replication could perhaps point to differences and/or similarities among results and, by doing so, broaden the scope of this study.

4.2. DPSIR framework

The findings of this study showed a noticeable difference in the number of indicators that are classified under the "drive forces" and "state" categories. A much higher amount of indicators (half or more of them) addressed the component "state" and just a few (less than 7%) address the "drive forces". This imbalance emphasizes the need to further develop indicators to assess "drive forces" related to the challenge of sustainable water use and management. These types of indicators are important, as according to WWAP (2006), they assesses the *"underlying factors and the root causes affecting the development of society, the economy and environmental conditions"*. Therefore, this research recommends that indicator developers devote efforts to produce indicators of water use and management focusing on "drive forces".

The assignation of a DSPIR cluster to each of the 170 indicators done by this study was a complex task and confirms Vacik et al. (2006) *"it is always a matter of perspectives"*. The perspective adopted by this study focused on indicators that could measure the sustainable use and management of water. Therefore, other studies could find different framework classifications for these indicators: it is just a matter of perspective.

Several of the indicators assessed in this study are in fact indexes, made up of several sub-components. Considering the multi-dimensional nature of sustainability (social, economic, environmental and institutional issues are interlinked), these indexes were classified in more than one position of the DPSIR framework. For example, the Climate Vulnerability Index (CVI) is an index that considers 6 sub-components (resource, access, uses, capacity, environment and vulnerability). It is classified under four different DPSIR positions, namely Pressure, State, Impact and Response, mainly because its sub-components address very diverse issues, combining them in order to make a holistic assessment of human vulnerability in the context of threats to water resources (Sullivan and Huntingford, 2009).

4.3. Usefulness for researchers and policy makers

The list of 170 indicators of water use and management and the set of 24 indicators that fulfil the sustainability criteria are important contributions of our study. They present relevant information in a format that is easy to assess (Annexes 1, 2 and 3). End-users, such as water management institutions, river basin committees, policy and decision makers, can consult these lists in order to identify and select indicators according to their specific needs.

The set of 24 indicators, identified by this study, allows decision makers to measure the sustainability of water use and management. The use of these indicators could contribute to identify and monitor unsustainable water practices, define solutions, and evaluate the achievements or failures of policies, plans, and programs regarding the sustainability of water use and management. Water Management Authorities could use these indicators as relevant elements to set goals and monitor progress at Water Management Plans as well as at Water Management Information Systems. Other possibilities for applying these indicators include supporting the decision-making concerning the concessions of water permits for more sustainable water use.

This study also provides a transparent and reproducible methodological framework that could be applied by the scientific community and indicator developers to identify, select and assess indicators of sustainable water use and management.

5. Conclusions

Indicators are powerful decision making tools and key elements to monitor progress towards sustainable development in the water sector. They should encompass the four dimensions of sustainability: social, economic, environmental, and institutional. Our study aimed to fill these gaps by presenting solid and reliable knowledge on indicators of sustainable water use and management. In order to do this, the research identified the indicators related to IWRM, and evaluated by an international panel of experts to assess whether these indicators fulfil the sustainability criteria.

One hundred and seventy indicators related to water use and management were identified. They were organized in an assessment matrix, described and classified according to the DPSIR framework and the "system approach". The findings showed that 86% of them do not fulfil the majority of sustainability criteria, suggesting that they do not provide the holistic and multi-dimensional perspectives of sustainability. This should not be seen as a limitation rather than as a characteristic that should be taken into account by decision makers. It is worth mentioning, that 145 indicators addressed in an adequate way one or two of the four components of sustainability, meaning that they are interesting tools that allow us to see some of the multiple aspects of water use and management from specific angles.

This study found that 24 key indicators of water use and management fulfil the majority of the sustainability criteria. The identification of these indicators can be considered a relevant contribution to sustainability research and practice for the water resources sector. These indicators should also provide critical information for water governability.

So far, no other scientific publication that has done a similar assessment has been found. Furthermore, indicator development is a continuous process and therefore this list is not encircled in itself and other indicators may be included by future studies.

Although the identification of these indicators matters, in other to address the key concerns of water managers, the indicators should meet other criteria that go beyond the sustainability criteria. We recommend the development of further studies in order to evaluate the selected indicators based on additional criteria. These criteria should be relevant for the water management community and could include issues such as validity for the proper geographic scale and whether the indicator is based on currently sound and internationally accepted scientific standards.

Despite the widespread recognition of the relevance of indicators to water sustainability worldwide, significant challenges remain. Improved knowledge, research and innovation around this subject are necessary to promote the transition towards sustainable water use and management.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2016.10.217.

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