Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Sustainability Assessment of indicators for integrated water resources management

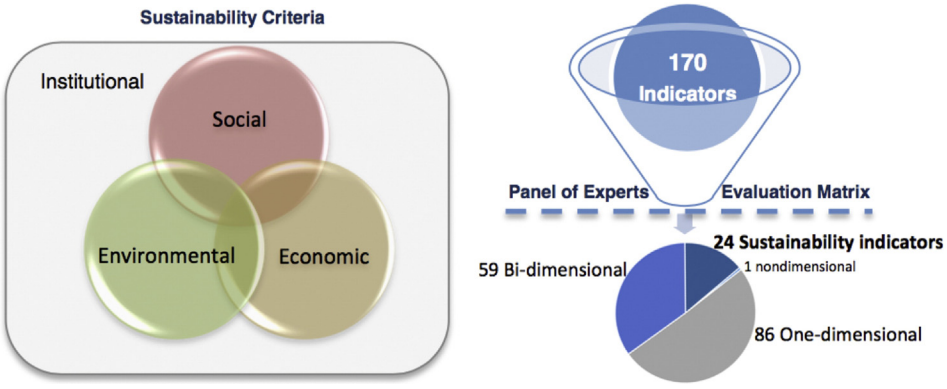
A. Pires [a,*], J. Morato [a], H. Peixoto [b], V. Botero [c], L. Zuluaga [c], A. Figueroa [d]

[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



ARTICLE INFO

Article history:
Received 6 September 2016
Received in revised form 28 October 2016
Accepted 28 October 2016
Available online xxxx

Keywords:
Criteria
Water use
Socio-economic
Decision-making
IWRM
DPSIR

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).

http://dx.doi.org/10.1016/j.scitotenv.2016.10.217
0048-9697/

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),

Please cite this article as: Pires, A., et al., Sustainability Assessment of indicators for integrated water resources management, Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.10.217