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Multi-criteria and Participatory Approach to Socio-Economic, Environmental and Institutional Indicators for Sustainable Water Use and Management at River Basin Level

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To my fammily, with all my love.

ABSTRACT

Water is a limited resource that is essential for life. Human activities have been exercising considerable pressures on this resource. The unsustainable use of water and the need to improve its management are among the largest global concerns of our time. Indicators are fundamental to monitoring progress towards, and trends in, water sustainability.

Despite the widespread recognition of the relevance of indicators to water sustainability worldwide, significant challenges remain. Improved knowledge, applied research and innovation around this subject are necessary to promote the transition towards sustainable water use and management. This demands also points to the need to develop indicators in a participatory way, with the active engagement of both scientists and stakeholders. Furthermore, these indicators should be suitable for the scale where the governance of water take place: the river basin scale.

The main objective of this research is to identify and validate, in a participatory way, a set of indicators that would allow decision makers to measure the sustainability of water use and management at river basin level.

This research combined relevant concepts in a holistic methodology that is scientifically robust and easy to understand. This study presents a detailed description of how to apply multi-criteria and participatory approaches to identify, select and validate indicators for sustainable water use and management at river basin level, considering their socio-economic, environmental and institutional aspects.

In the initial stage of this study, 60 criteria for the evaluation of indicators and 170 indicators linked to water resources were identified through extensive literature reviews. Subsequently, an international panel of experts selected from this set of indicators the 24 which best fulfilled the criteria of social, economic, environmental and institutional sustainability (Chapter 3).

It was then determined that 11 of the 24 indicators have the appropriate characteristics to assess water use and management in an actual watershed, fulfilling the criteria of: scientific foundation, individuality, geographic scale of application and specificity (Chapter 4).

In the next step, the Salitre River Basin (in the semiarid region of Bahia-Brazil) was selected for pilot implementation of this project. At that point, the major stakeholders were identified and involved in the development of the research. The indicators were then assessed based on the innovative eDPSIR methodology, in which the interconnectedness of the indicators becomes a key part of the selection process. The application of this method showed that 8 of the 11 indicators are of great relevance to address the complex issue of sustainable use and management of water in the pilot river basin (Chapter 5).

Finally, this set of eight indicators was validated against scientific and end-use criteria in a multistage and multistakeholder participatory approach (chapter 6). More than 100 international experts and local stakeholders participated in the development of this research. This study resulted in the selection and validation of a comprehensive set of eight key indicators to measure the social, economic, environmental and institutional sustainability of water use and management at the Salitre River Basin.

This research also provides a transparent, robust and reproducible set of methods that could be applied to identify, select and assess indicators at other river basins of interest. This knowledge could be used by the scientific community, international organizations, water resources managers, policy and decision makers, practitioners, as well as other stakeholders interested in the matter, to promote changes towards sustainable use and management of water. These changes can contribute to the harmonization of human and ecosystem needs at the present, and they are essential to "*building the future we want for all*".

RESUMEN

El agua es un recurso limitado esencial para la vida y las actividades humana han estado ejerciendo presiones considerables sobre el mismo. El uso insostenible del agua y la necesidad de mejorar su gestión están entre las principales preocupaciones actualmente. Los indicadores son fundamentales para monitorear el progreso hacia la sostenibilidad del agua.

A pesar del amplio reconocimiento global de la relevancia de los indicadores para la sostenibilidad, sigue habiendo retos importantes. Ampliar el conocimiento, la investigación y la innovación en torno a este tema es necesario para promover la transición hacia el uso y la gestión sostenible del agua. Esta demanda también apunta a la necesidad de desarrollar indicadores de manera participativa, con la colaboración activa de científicos y de las partes interesadas. Por otra parte, estos indicadores deben ser adecuados para la escala donde la gobernabilidad del agua tiene lugar: la escala de cuenca hidrográfica.

El objetivo principal de esta investigación ha sido la identificación y validación, de forma participativa, de un conjunto de indicadores que permitan a los tomadores de decisiones medir la sostenibilidad del uso y gestión del agua a nivel de cuencas.

Esta investigación ha combinado conceptos relevantes en una metodología holística científicamente sólida y fácil de entender. El estudio presenta una descripción detallada de cómo aplicar una aproximación multicriteria y un enfoque participativo para identificar, seleccionar y validar los indicadores de uso y gestión sostenible del agua a nivel de cuenca hidrográfica, considerando sus aspectos socio-económicos, ambientales e institucionales.

En la etapa inicial de este estudio se identificaron 60 criterios para la evaluación de los indicadores y 170 indicadores relacionados con los recursos hídricos a través de extensas revisiones de la literatura. Posteriormente, un panel internacional de expertos han seleccionado de este conjunto los 24 indicadores que mejor cumplen los criterios de sostenibilidad social, económica, ambiental e institucional (Capítulo 3).

Entonces se identificó que 11 de los 24 indicadores tienen las características apropiadas para evaluar el uso y gestión del agua en una cuenca real, cumpliendo los criterios de: fundamentación científica, individualidad, escala geográfica de aplicación y especificidad (Capítulo 4).

En el siguiente paso, la cuenca del río Salitre (en la región semiárida de Bahia-Brasil) fue seleccionado para la implementación piloto de esta investigación. En ese momento, fueron identificados e involucrados los principales actores locales relacionados con el desarrollo del proyecto. Los indicadores fueron evaluados en base a la innovadora metodología eDPSIR, donde la interconexión de los indicadores se convierte en una parte clave del proceso de selección. La aplicación de este método mostró que ocho de los 11 indicadores son de gran relevancia para abordar el complejo tema del uso sostenible y la gestión del agua a nivel de la cuenca piloto (Capítulo 5).

Por último, este conjunto de ocho indicadores se validó en base a criterios científicos y de uso final de forma participativa utilizando un proceso multi-etapas y multiactor (Capítulo 6). En total, más de 100 expertos internacionales y actores locales participaron en el desarrollo de este estudio. Esta investigación dio lugar a la selección y validación de un conjunto completo de ocho indicadores clave para medir la sostenibilidad social, económica, ambiental e institucional de uso y gestión del agua en la cuenca del río Salitre.

Esta investigación también proporciona un conjunto relevante de métodos transparentes, sólidos y reproducibles para ser aplicados en la identificación, selección y evalución de indicadores en otras cuencas hidrográficas.

Este conocimiento podría ser utilizado por la comunidad científica, las organizaciones internacionales, los gestores de recursos hídricos, los tomadores de decisiones, los formuladores de políticas, así como otras partes interesadas en la materia, para promover cambios hacia el uso sostenible y la gestión del agua. Estos cambios pueden contribuir a armonizar tanto las necesidades humanas como las de los ecosistemas en la actualidad, además de ser esenciales para "*construir el futuro que queremos para todos*".

RESUM

L'aigua és un recurs limitat essencial per a la vida i les activitats humana han estat exercint pressions considerables sobre el mateix. L'ús insostenible de l'aigua i la necessitat de millorar la seva gestió estan entre les principals preocupacions actuals. Els indicadors són fonamentals per monitoritzar el progrés cap a la sostenibilitat de l'aigua.

Malgrat l'ampli reconeixement global de la rellevància dels indicadors per a la sostenibilitat, continua havent-hi reptes importants. Ampliar el coneixement, la recerca i la innovació al voltant d'aquest tema és necessari per promoure la transició cap a l'ús i la gestió sostenible de l'aigua. Aquesta demanda també apunta a la necessitat de desenvolupar indicadors de manera participativa, amb la col·laboració activa de científics i de les parts interessades. D'altra banda, aquests indicadors han de ser adequats per a l'escala on la governabilitat de l'aigua té lloc: l'escala de conca hidrogràfica.

L'objectiu principal d'aquesta investigació ha estat la identificació i validació, de forma participativa, d'un conjunt d'indicadors que permetin als prenedors de decisions mesurar la sostenibilitat de l'ús i gestió de l'aigua a nivell de conques.

Aquesta recerca ha combinat conceptes rellevants en una metodologia holística científicament sòlida i fàcil d'entendre. L'estudi presenta una descripció detallada de com aplicar una aproximació multicriteria i un enfoc participatiu per identificar, seleccionar i validar els indicadors d'ús i gestió sostenible de l'aigua a nivell de conca hidrogràfica, considerant els seus aspectes socioeconòmics, ambientals i institucionals.

En l'etapa inicial d'aquest estudi es van identificar 60 criteris per a l'avaluació dels indicadors i 170 indicadors relacionats amb els recursos hídrics a través d'extenses revisions de la literatura. Posteriorment, un panell internacional d'experts han seleccionat d'aquest conjunt els 24 indicadors que millor compleixen els criteris de sostenibilitat social, econòmica, ambiental i institucional (capítol 3).

Llavors es va identificar que 11 dels 24 indicadors tenen les característiques apropiades per avaluar l'ús i gestió de l'aigua en una conca real, complint els criteris de: fonamentació científica, individualitat, escala geogràfica d'aplicació i especificitat (Capítol 4).

En el següent pas, la conca del riu Salitre (a la regió semiàrida de Bahia-Brasil) va ser seleccionat per a la implementació pilot d'aquesta investigació. En aquest moment, van ser identificats i involucrats els principals actors locals relacionats amb el desenvolupament del projecte. Els indicadors van ser avaluats sobre la base de la innovadora metodologia eDPSIR, on la interconnexió dels indicadors es converteix en una part clau del procés de selecció. L'aplicació d'aquest mètode va mostrar que vuit dels 11 indicadors són de gran rellevància per abordar el complex tema de l'ús sostenible i la gestió de l'aigua a nivell de la conca pilot (Capítol 5).

Finalment, aquest conjunt de vuit indicadors es va validar en base a criteris científics i d'ús final de manera participativa utilitzant un procés multi-etapes i multiactor (Capítol 6). En total, més de 100 experts internacionals i actors locals van participar en el desenvolupament d'aquest estudi.

Aquesta investigació va donar lloc a la selecció i validació d'un conjunt complet de vuit indicadors clau per mesurar la sostenibilitat social, econòmica, ambiental i institucional d'ús i gestió de l'aigua a la conca del riu Salitre. Aquest treball també proporciona un conjunt rellevant de mètodes transparents, sòlids i reproduïbles per ser aplicats per acadèmics, desenvolupadors / usuaris d'indicadors i / o prenedors de decisions en la identificació, selecció i avaluació d'indicadors en altres conques hidrogràfiques.

Aquest coneixement podria ser utilitzat per la comunitat científica, les organitzacions internacionals, els gestors de recursos hídrics, els prenedors de decisions, els formuladors de polítiques, així com altres parts interessades en la matèria, per promoure canvis cap a l'ús sostenible i la gestió de l’aigua. Aquests canvis poden contribuir a harmonitzar tant les necessitats humanes com les dels ecosistemes en l'actualitat, a més de ser essencials per a "construir el futur que volem per a tots".

Resumo

A água é um recurso limitado e essencial para a vida, mas as atividades humanas vêm exercendo pressões consideráveis sobre este precioso bem. O uso insustentável da água e a necessidade de melhorar a sua gestão estão entre as principais preocupações do nosso tempo. Diante disto, os indicadores se destacam como ferramentas importantes para monitorar o progresso em direção à sustentabilidade da água.

Apesar do amplo reconhecimento global da relevância dos indicadores para a sustentabilidade, continuam existindo desafios significativos a serem superados. Ampliar o conhecimento, desenvolver pesquisas aplicadas e promover a inovação em torno deste tema são medidas necessárias para promover a transição para um modelo de uso e gestão sustentável da água. Tais desafios também apontam para a necessidade de desenvolver indicadores de forma participativa, com a colaboração ativa de cientistas e demais partes interessadas (especialistas, gestores, usuários, poder público, sociedade civil, etc.). Além disso, esses indicadores devem ser adequados à escala em que se dá a governança dos recursos hídricos: a bacia hidrográfica.

O principal objetivo desta tese foi a identificação e validação, de forma participativa, de um conjunto de indicadores que permita aos tomadores de decisões medir o uso e gestão sustentável de água a nível das bacias hidrográficas.

Esta tese combinou conceitos relevantes em uma abordagem cientificamente sólida e holística de fácil compreensão. O estudo apresenta uma descrição detalhada de como aplicar uma abordagem multicritério e participativa para identificar, selecionar e validar os indicadores de uso e gestão sustentável da água a nível da bacia hidrográfica, considerando os aspectos sócio-econômicos, ambientais e institucionais.

Na fase inicial do estudo, 60 critérios de avaliação dos indicadores e 170 indicadores relacionados aos recursos hídricos foram identificados através de extensas revisões da literatura. Posteriormente, um painel internacional de expertos selecionou, a partir deste conjunto, 24 indicadores que melhor atenderam aos critérios de sustentabilidade social, econômica, ambiental e institucional (Capítulo 3).

Em seguida, este estudo identificou que 11 dos 24 indicadores são apropriados para avaliar o uso e gestão da água em uma bacia hidrográfica real, pois cumprem os critérios de: fundamentação científica, individualidade, escala geográfica de aplicação e especificidade (Capítulo 4).

Na próxima etapa, a Bacia do Rio Salitre (no semi-árido da Bahia-Brasil) foi selecionada para a implementação piloto do presente trabalho. Neste momento, os principais atores locais foram identificados e envolvidos no desenvolvimento participativo da pesquisa. Os indicadores foram avaliados com base na inovadora metodologia eDPSIR, onde a interrelação dos indicadores se torna uma parte fundamental do processo de seleção. A aplicação do método eDPSIR mostrou que oito dos 11 indicadores são de grande importância para abordar a complexa questão do uso e gestão sustentável de água ao nível da bacia hidrográfica piloto (Capítulo 5).

Finalmente, este conjunto de oito indicadores foi validado com base em dois tipos de critérios: científicos e de usuário final. Para isso foi adotada uma abordagem participativa usando um processo multiestágios e multi-atores (Capítulo 6). No total, mais de 100 especialistas internacionais e atores locais participaram do desenvolvimento da pesquisa, que resultou na seleção e validação de um conjunto compacto composto por oito indicadores fundamentais para medir a sustentabilidade social, econômica, ambiental e institucional de uso e gestão da água na Bacia do Rio Salitre.

A presente tese de doutorado também proporciona aos interessados no tema um importante acervo de métodos cientificamente sólidos, transparentes, confiáveis e reprodutíveis que podem ser aplicados para identificar, selecionar e avaliar indicadores em outras bacias hidrográficas. Esse conhecimento poderá ser utilizado pela comunidade científica, organizações internacionais, gestores de recursos hídricos, tomadores de decisões, formuladores de políticas, e outras partes interessadas no assunto, para promover mudanças em relação ao uso e à gestão sustentável da água. Essas mudanças podem ajudar a harmonizar as necessidades dos seres humanos e dos ecossistemas no presente, além de serem fundamentais para "*construir o futuro que queremos para todos*".

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Acronyms

AIS	Access to Improved Sanitation
ANA	National Agency of Water (Brazil)
BNIA	Baltimore Neighbourhood Indicators Alliance
BRIICS	Brazil, China, India, Indonesia, Russia and South Africa
Cap-Net	Capacity Development in Sustainable Water Management Network
CBD	Convention on Biological and Diversity
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVI	Climate Vulnerability Index
CYTED	Ibero-American Programme for Science, Technology and Development
DPSIR	Driving Forces ,Pressures, States, Impacts and Responses
EC	European Commission
EF	Ecological Footprint
EEA	European Environmental Agency
EG-IMD	Expert Group on Indicators, Monitoring, and Data Bases of UN
EuroStat	European Statistics
FAO	Food and Agriculture Organization of United Nations
GEF	Global Environment Facility
GRI	Global Reporting Initiative
GWP	Global Water Partnership
IC	Incidence of Cholera
ICOLD	The International Commission on Large Dams
IISD	International Institute for Sustainable Developed
INBO	International Network of Basin Organizations
INSWU	Index of Non-Sustainable Water Use
IPSs	Indicator Profile Sheets

IQR	Interquartile Range
ITFM	Intergovernmental Task Force on Monitoring Water Quality
IUCN	International Union for Conservation of Nature
IWA	International Water Association
IWRM	Integrated Water Resources Management
MDEC	Major Drought Events and their Consequences
MCA	Multiple Criteria Analysis
MCDA	Multi Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
MDG	Millennium Developed Goals
MFE	Ministry for the Environment
NRC	National Research Council
OAS	Organization of American States
OECD	Organization for Economic Cooperation and Development
OSE	Observatory of Sustainability in Spain
PUPLS	Proportion of Urban Population Living in Slums
RECNET	Recycling the City Network
RWSI	Relative Water Stress Index
MDG	Sustainable Developed Goals
SEID	Social and Economic Impacts from Drought
SNZ	Statistics New Zealand

UNDSD	United Nations Division for Sustainable Development
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UNESCOSOST	UNESCO Chair on Sustainability of UPC
UNICEF	United Nations International Children's Emergency Fund
UNU	United Nations University
US EPA	United States Environmental Protection Agency
UPC	Universitat Politècnica de Catalunya – Barcelona Tech
US GAO	United States Government Accountability Office
WF	Water Footprint
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WPI	Water Poverty Index
WRI	World Resource Institute
WRI	Water Reuse Index
WS	Water Shortages
WTSC	Water Topics in School Curriculum
WWAP	United Nations World Water Assessment Programme
WWC	World Water Council
WWF	World Wide Fund for Nature

CHAPTER 1 – INTRODUCTION

1.1 PROBLEM STATEMENT

Water is undoubtedly one of the most important natural resources as it is "*essential for life on this planet and it is the source and foundation of all living things*" (UN Water, 2015). Besides being responsible for the regulation of metabolic activities of all living beings, water also is crucial for the cycling of natural ecosystems and for climate regulation. Water has many uses that are fundamental for human development. According to WWAP (2015) "*Water is an essential resource in the production of most types of goods and services including food, energy and manufacturing*". As mentioned by Irina Bokova, Director-General of UNESCO, "*water is inextricably linked to the development of all societies and cultures*" (WWAP, 2015).

Furthermore, the escalating consumption and production of modern society is highly correlated with increasing water use (Karthe, Chalov & Borchardt, 2014). This generates significant pressures and impacts on water resources (Pahl-Wostl, 2007). This situation is also affected by the uncertainties generated from the current climate change and recent multiple global crises: economic crises, energy crises, security crises, biodiversity crises (UNEP, 2009). According to WWAP (2012), "u*ncertainty about future pressures on the resource affects water management, but uncertain water availability may itself pose a risk to economic activity*".

The agricultural sector presents a clear example of these risks. By 2050 the global demand for food will increase by 60% (Alexandratos & Bruinsma, 2012) and the developing countries demand will increase 100% (WWAP, 2015). Agricultural production is the main use of water resources at global level and the principal cause of the over-exploitation of several aquifers (Ladouche, 2015). Currently, approximately 20% of the world's aquifers are already over-exploited (WWAP, 2015). The balance between the demand for water resources and sustainable development needs to be established in order to mitigate the severe water deficit already being faced by several regions of the world and to prevent a major global crisis in the future.

As mentioned by UN Water (2013) "*cooperation is essential to strike a balance between the different needs and priorities and share this precious resource equitably*". According to the groundbreaking study on the Economics of Ecosystems and Biodiversity (TEEB, 2010), the health, livelihoods, economics and the performance of society in most sectors (industry, agriculture, transport, services, etc.) can be significantly affected by scarcity of water. Its availability in qualitative and quantitative terms is considered one of the largest global concerns of our time (TEEB, 2013). Luckmann, Grethe, MacDonald, Orlov & Sidding, (2014) further explain this issue, mentioning that "*water scarcity is an increasing problem in many parts of the world and the management of water has become an important issue on the political economy agenda in many countries*".

Ban Ki-moon, Secretary-General of the United Nations, stated in the preface of the recently launched UN World Water Development Report *"Water resources, and the essential services they provide, are among the keys to achieving poverty reduction, inclusive growth, public health, food security, lives of dignity for all and long-lasting harmony with Earth's essential ecosystems'* (WWAP, 2015).

1.1.1 Status of water resources in the world

The water is present in all forms of life on the planet: 71% of the earth's surface is made up of water and 66% of the human body is made of water (EPA US, 2004). This may give the impression that water is an abundant resource, but in reality, the water available for human use is limited. Approximately 110,000 km^3 of water per year falls in the form of rainfall on earth and nearly two-thirds of that amount evaporates from the soil or transpires through vegetation. Only 40,000 km^3 per year is converted into surface runoff and groundwater (FAO, 2013), which is the amount of renewable freshwater resources available for humans and ecosystems.

It must be also taken into account that the natural distribution of water around the planet is different in each region. According WBCSD (2006), 60% of the available stored fresh water flows through less than 10 countries (Brazil, Canada, China, Colombia, Democratic Republic of Congo, India, Indonesia, Russia, U.S.). Furthermore, human activities exercise considerable pressures on the availability of water resources. These pressures influence the balance of the natural cycles affecting directly the geographic distribution of water, which in turn can significantly affect the availability of freshwater.

It is essential to take into consideration that the availability of water does not ensure its utility for human society or nature. It is necessary to safeguard the quality, access, and long-term availability of water resources through sustainable management that takes into account environmental, economic, social and institutional issues. Currently the world population is more then 7 billion people and growing by about 80 million people per year (USCB, 2012). The challenges imposed by the increasing population mean that it is vital to reduce human pressures on natural resources in order to ensure the sustainable development of society.

"*Managing water sustainably to meet today's needs and future demands is ever more urgent*" (UN Water, 2015).

The relationship between demands and availability of water is another important aspect when aiming for sustainable water use. This relationship influences directly the well-being of present and future generations on earth. According to WWAP (2015), global water demand is projected to increase 55% by 2050 (Figure 1.1). This increase is especially relevant for the BRIICS (Brazil, China, India, Indonesia, Russia, South Africa). "W*hile global water resources may be finite, the same cannot be said of water demand… this means that water resource availability, or lack of it, is linked to economic and social progress, suggesting that development is likely to be influenced by how water resources are managed*" (Sullivan, 2002).

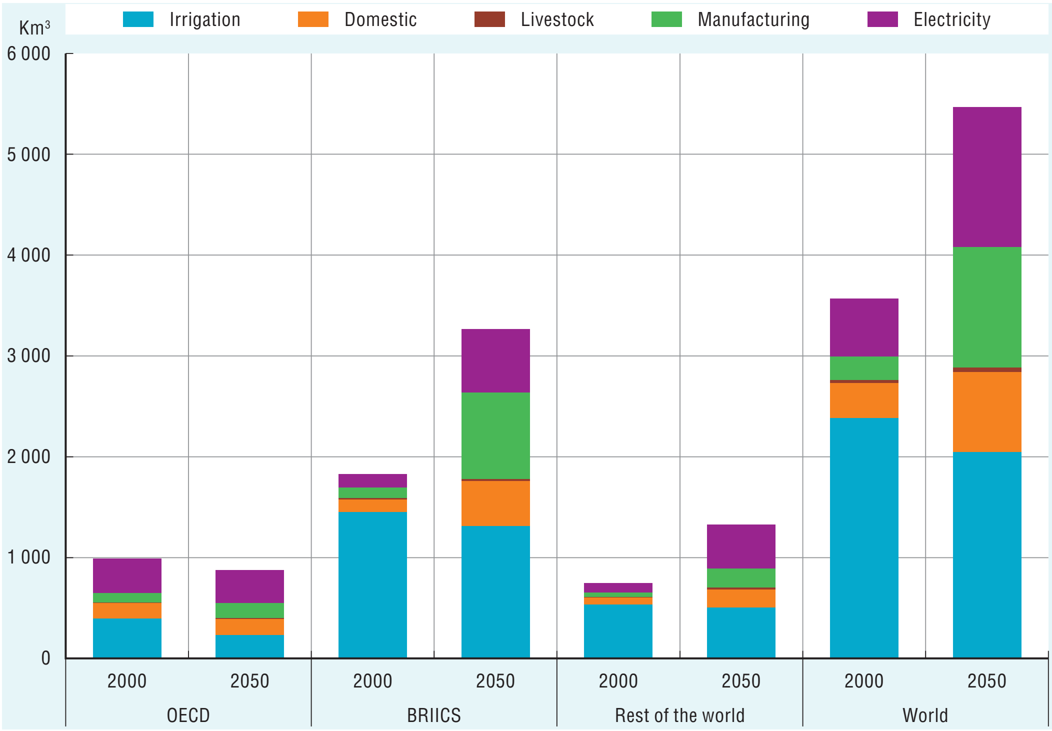

Figure 1.1 - Global water demand in 2000 and 2050, for the OECD countries, BRIICS and ROW (Rest of World). Source: OECD,2012

UNEP (2012) considers Latin America and the Caribbean (LAC) to be a region rich in water resources, mainly because it receives approximately 31 per cent of the world's freshwater resources annually. However, the sustainability of water should not be measured only by the amount of precipitation in a given area. It is a much complex issue and should be approached from multiple perspectives.

WWAP (2015) points out that the major priority for LAC countries is to *"improve and consolidate water governance, with a paradigm shift to the sustainable integration of water resources management and use into socio-economic development and poverty reduction"*. The relevance of water governance and sustainability can been seen in the current situation of water resources in the region of São Paulo, the most populous and economically developed state of Brazil. Despite its humid subtropical climate, São Paulo is currently facing the most severe drought in its history. Escobar (2015) notes, in *Science*, that *"the Cantareira system, which provides water for 8.8 million people, is so depleted that authorities are tapping the last 8%"*.

According to the UN (2000) the development of water management strategies at regional, national and local levels are indispensable to stop the unsustainable exploitation of water resources. Therefore, regional and locally adapted water management strategies are crucial to underpin the transition towards the green economy in the water sector (UNW-DPC, 2012). Proposed by UNEP (2011), the concept of the green economy can be understand as a way to achieve sustainable development resulting in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. In the view of a circular economy (Ellen MacArthur Foundation, 2014), these improvements should be reached by a renewed social and economic dynamic. This concept provides a platform for re-thinking the transition to a restorative and circular model of development.

These challenges require the adoption of an interdisciplinary approach that integrates ethical, cultural, educational and scientific perspectives and covers gender, social, legal, political, institutional and economic dimensions (UN Water, 2015). The integrated management of water resources can be considered a powerful strategy in this context as it adds information about the holistic interrelationships among these dimensions pertaining to water management. Furthermore, according to UN (1992) "*the widespread scarcity, gradual destruction and aggravated pollution of water resources many regions of the world, along with the progressive introduction of incompatible activities, demand water resources planning and integrated management*".

1.1.2 International concern for water sustainability

The concern of the international community regarding the need for a more comprehensive approach for water policy began to appear in 1972 at the UN Stockholm Conference (UN, 1972). It was further developed at the UN Conference on Water at Mar del Plata in 1977, which put water firmly on to the international agenda (UN, 1977). The 'Dublin Principles', agreed upon at the International Conference on Water and Environment in 1992, was another milestone, bringing more attention to the need for a participatory approach (ICWE, 1992). The publication of Agenda 21 agreed in the UN Conference on Environment and Development at Rio de Janeiro in 1992 was a major achievement of international community (UN, 1992). Agenda 21's Chapter 18 calls for *"application of integrated approaches to the development, management and use of water resources"*.

At the turn of the century, the Millennium Development Goals, a set of international development goals established following the Millennium Declaration (UNGA, 2001), considered *"developing water management strategies"* as one of its targets. The Millennium Ecosystem Assessment (MEA, 2005) brought to decision makers at a global level the state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide, highlighting the relevance of water. At that moment, it became clear that the need for indicators to monitor progress at regional, national and local levels are crucial to promote the sustainable use of water.

The "Water for Life Decade 2005-2015" was another international initiative to promote efforts to fulfil international commitments made on water (UNGA, 2003). During this period, several international agreements, such as the Aichi Targets (CBD, 2010) and global meetings such as the World Water Forums took place raising the relevance of water sustainability and the use of indicators.

In 2012, the UN Conference on Sustainable Development (Rio+20) - The Future We Want - recognized that 'water is at the core of sustainable development' (UNCSD, 2012). According to Irina Bokova, Director-General of UNESCO, "*The sustainable use and management of water is vital for welfare of all humanity today, and it is essential for building the future we want for all*" (WWAP, 2015).

Currently, the international community is building the Sustainable Development Goals (SDGs), the post-2015 development agenda for the world (UN, 2014). In relation to natural resource management, the SDGs focus on greater attention to the need for integrated ecosystem-based management of water resources to achieve sustainable development. Due to the importance, as mentioned, of conservation and strategic management of water resources, one of the proposed goals is "*Ensure availability and sustainable management of water and sanitation for all*" and one of the targets of this goal is to "*implement integrated water resources management at all levels, including through transboundary cooperation as appropriate*". Indicators are therefore a keystone in the monitoring framework for SDGs.

The UN World Water Assessment Programme has demonstrated in its series of reports (2003, 2006, 2009, 2012, 2014 and 2015) that the quality and availability of water resources has been affected by failures of governance and unsustainable decisions. These failures undermine the ability of water to generate social and economic benefits.

This UN-wide program has been extensively promoting the use of indicators to help society to monitor progress and trends on the path to water sustainability (WWAP, 2003). Indicators are widely recommended to evaluate the improvements towards sustainable development (Moldan et al., 2012; UNDESA, 2007; WWF, 2010), and provide decision-makers with information to guide the governance of water resources and to promote its sustainable use and management (WWAP, 2006).

1.2 NEED FOR RESEARCH

The development of applied research on strategies, methodologies and new alternatives related to the management and conservation of water resources has become increasingly important. The scientific community (Bolcárová & Kološta, 2015; Cornescu & Adam, 2014) strongly recommend the adoption of indicators for evaluation and monitoring of progress towards sustainable development. International organizations such as the OECD (2004) and WWAP (2003) consider indicators to be powerful decision-making tools. It has been clearly demonstrated that the application of indicators on water use and management can contribute to better allocation of this limited resource (Kang & Lee, 2011).

However, it is important to note that sustainable water management is not solely a technological issue. Therefore, indicator design should also reflect the environmental, social, institutional and economic aspects of sustainability (Spangenberg, 2004). Furthermore, 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 proposes, as one of its first steps, to identify and describe the indicators related to the water use and management presented by international institutions and scientific community. It was also noticed that studies are needed to further investigate if the current indicators of water resources fulfil the main components of sustainability, namely social, economic, environmental, and institutional criteria.

The quality and reliability of an indicator depends on the application of appropriate assessment criteria throughout its development, from design to validation (Niemeijer & de Groot, 2008). The identification and selection of criteria to evaluate indicators is not a trivial task and should be done in a transparent, replicable and scientifically valid way (Gudmundsson, 2010). Furthermore, indicators should be assessed against the criteria that are relevant for the problem in hand. A significant number of works and studies have been published about this topic. The total number of existing criteria appears to be in the order of hundreds. Nevertheless, there is no scientific consensus regarding which are the most relevant criteria, and in which cases to use one over another. It was noted that a comprehensive assessment of the most relevant criteria for evaluation of indicators was needed and that this would also be a relevant contribution of this study to the science of Criteria & Indicators.

In order to be of practical use to the target audience (e.g. decision makers in river basin organizations) the indicators should meet specific criteria that go beyond the sustainability criteria (IISD, 2008). Indicators should be consolidated by current scientific standards and principles (Aveline et al, 2009), should not duplicate each other (Kurka & Blackwood, 2013), should be appropriate for the geographic scale of interest and should be clearly and unambiguously defined (UNEP, 2006).

These criteria are considered to be of highest importance, mainly because they address strategic aspects and key attributes of the indicators related to consolidation, application and distinctiveness. These criteria are especially relevant for indicators that aim to be used by decision makers to measure the sustainability of water use and management at river basin level. Our research identifies the need to further study whether the indicators that measure the sustainability of water use and management fulfil these criteria.

Indicators are often interrelated and, consequently, it is conceivable that although assessing indicators individually appears to be enough, sustainability may require evaluating cross-indicator interactions (Mendoza & Prabhu, 2003). Currently, indicators are rarely selected based on how they jointly respond to environmental questions in an integrated manner, instead, they are mainly chosen based on the grade in which they independently fulfil individual criteria (Hak, Kovanda & Weinzettel, 2012).

Niemeijer and Groot (2008) propose a concept, called the enhanced DPSIR (eDPSIR), where the interconnectedness of the indicators becomes a key part of the selection process. Wolfslehner & Vacik (2011), among other authors, have demonstrated that this framework helps identify the most relevant indicators in terms of a specific field, problem and location, resulting in a set of indicators that allows the assessment of the environmental conditions in a clear, well-organized and effective manner.

Scientific and/or operational approaches that use network frameworks for the selection of indicators are still rare in the field of natural resource management, in general, and in the field of water resources management, in particular. This approach has been used in fields such as forest management, ecological systems assessment, environmental aspects of pork production, water shortage mitigation, wetland management, among others. Nevertheless, no previous work addressing the use of causal networks for the selection of indicators of water use and management could be found, pointing to the relevance, originality and opportunity of applying this method in the current research.

An indicator can be a “pragmatic tool” for measuring and describing complex issues (Allard & Pellerin, Bélanger, Parent, Vanasse, 2012). However, in order to rely on the guidance provided by these tools, critical review and validation of indicators is necessary to ensure their relevance and credibility (Meul, Nevens & Reheul, 2009). Validation of indicators is an essential step in the identification of an accurate and credible indicator set. Validation is also considered crucial to the scientific process and to the creation of an indicator that is “useful and used by the end users” (Bockstaller & Girardin, 2003). Therefore, any study related to the development and selection of indicators should assess the scientific and end-use validation of these indicators in a transparent and replicable way.

Development and validation of indicators is not solely the insular work of scientists and experts. Today there is greater recognition of the participation of end-users *"as being complementary to traditional scientific knowledge"* (Bélanger et al., 2012). Water management in a river basin is a complex issue, involving many stakeholders and competing uses of water. Stakeholders are usually the persons who, despite not being considered as academic experts, possess basic knowledge of the intrinsic interconnections between the environmental, social, cultural and economic processes that influence water use at the local level (Yavuz & Baycan, 2015). Our research adopted a participatory approach, with the active involvement of diverse stakeholders (Fitzpatrick & Sejer, Frauenberger, Good, 2015). This research therefore contributes to the current rise in the use of participatory methods in research (Voinov & Bousquet, 2010) by using clear and efficient tools to engage the stakeholders in the study.

Furthermore, Multiple Criteria Analysis (MCA), a framework for evaluating decision alternatives against multiple criteria, is deemed an effective approach for supporting multi-stakeholder, multi-criteria decisions (Hajkowicz, 2008), such as the ones faced by water resources managers at river basin level. The majority of environmental decisions are guided by many criteria and therefore MCA tools are required to properly guide the decision process (Derak & Cortina, 2014). In the last decades, researcher, decision-makers and planners outside the scientific community have been showing increasing interests in MCA. Our research incorporates Multi Criteria Analysis as a tool to assess the indicators in several stages of the study. By doing so, this study further contributes to the existing knowledge in this field of science and broadens our understanding of how to apply these tools to the sustainable use and management of water.

The selection of the optimal spatial scale is an important aspect in indicator development and use (WWAP, 2006). There seems to be no disagreement between scientists and end-users that the river basin is the most efficient, logical and dominant geographic scale for the integrated management of water resources (Dombrowsky & Horlemann, Houdret, 2014). Nevertheless, river basin boundaries rarely meet up with political jurisdictions (municipalities, states, countries, etc). Socio-economic statistics, which are crucial for indicators of sustainability, tend to be collected for administrative regions but not for river basin scale. These incongruities are considered one of the challenges faced by developers and users of water resources indicators. Discrepancies between natural (river basin) and administrative (municipalities, countries, etc) boundaries also affect the way decision makers manage and use indicators. Studies of water resources that use river basins as the geographic boundary contribute to advancing scientific knowledge at the most useful scale according to the needs of decision makers and the general society. Our research adopts the river basin as the geographical scale of interest for the study.

1.3 Objectives and Overview of the Dissertation

The main objective of this research is to identify and validate, in a participatory way, a set of indicators that would allow decision makers to measure the sustainability of water use and management at river basin level.

The specific objectives are:

a. to carry out a comprehensive assessment of the most relevant criteria for evaluation of indicators;
b. to identify the indicators related to the water use and management presented by international institutions and the scientific community;
c. to evaluate the sustainability criteria of indicators related to water use and management;
d. to select from among the indicators of sustainable water use and management the ones that are scientifically valid and suitable for application at river basin scale;
e. to visualise and explain to final users the interconnections of each indicator in the causal network
f. to select, based on the cause-effect relations of the indicators (eDPSIR), the most comprehensive set of indicators for the specific domain, question and location of the research;
g. to assess the scientific and end-use validation of the indicators using a transparent and replicable multistakeholder process.

These objectives were achieved through a sequential process of evaluation, where the result of one stage of the research was used as input for the next stage (see description of the chapters below). In order to reach these goals a participatory approach was applied, with the active involvement of a diverse set of stakeholders and the establishment of international panels of experts.

Pilot studies were employed to test and approve the research methodology and data analysis before carrying out the full implementation. Multi-criteria decision analyses were adopted in different stages of the study to point to possible solutions guided by multiple stakeholder interests and several criteria. With the aim of producing applied knowledge and transferring it immediately to end users, this research was developed using a pilot case application at the Salitre River Basin in Brazil. The methods and techniques adopted are transparent, scientifically robust and easy to be understood and employed by both scientists and end-users.

Chapter two presents the background knowledge about the central topics of the research: indicators of sustainable water use and management; development of indicators, multi-criteria analysis and participatory approach. In this chapter relevant definitions as well as the main points of view about the topics are introduced and discussed. Related studies that led up to the current research are cited in this chapter. Prior facts and ideas of great importance for the research are presented such as the relevance of river basin scale, the need for indicators for IWRM, uses of indicators, frameworks and validation of indicators, and participatory methods for sustainable water management among other topics.

The evaluation of criteria and indicators of sustainable water use and management is presented at **chapter three**. It begins with a comprehensive bibliographical research to identify criteria and indicators related to the water use and management presented by international institutions and national governments, as well as the ones addressed by the scientific community in peer reviewed international journals. Sixty criteria for the assessment of indicators and 170 indicators related to water use and management are listed, described and evaluated. This chapter also describes the transparent process adopted to assess the 170 indicators based on four sustainability criteria (social, economic, environmental, and institutional). The reader can find here the assessment matrix and the description of the pilot study and the international panel of experts used to perform this assessment. This chapter ends by displaying the 24 indicators of sustainable water use and management, as well the 59 bi-dimensional indicators and 86 one-dimensional indicators.

The next chapter (**chapter four**) presents the multi-criteria and multi-level sequential process used to select the indicators that are scientifically valid and suitable for application at river basin level. This chapter also identify the indicators that are not duplicated and clearly and unambiguously defined. Here, the readers are also introduced to the Indicator Profile Sheets (IPS), an important tool to organize and easily access the most relevant information about each indicator. It describes the 11 indicators that fulfil the selection criteria and discusses their main features. This chapter also addresses the reasons why the other 13 indicators did not comply with the criteria and proposes further studies on the subject.

Chapter five presents the eDPSIR framework and the multi-stakeholder participatory process adopted to select the most appropriate set of indicators to measure the sustainability of water use and management at the pilot river basin. This chapter begins with the selection of the pilot river basin that will be used to test the application of this method (the Salitre River Basin). In addition, the criteria used to identify and define the pilot river basin as well as the methods used to identify and engage the major stakeholders in the study are presented here. The methodology adopted is then described in greater detail, including the eight-step approach of the eDPSIR framework that resulted in a careful cause-effect analysis of indicators. Through this chapter the reader will notice that all 11 indicators selected in the previous stages of the research are interconnected in an intricate network of interrelations.

This chapter ends presenting the comprehensive set of eight key-indicators to measure the social, economic, environmental and institutional sustainability of water use and management at the Salitre River Basin: those suitable for the specific domain, question and location of the research.

Chapter six outlines the multistage and multistakeholder validation process of the eight key-indicators. These indicators were evaluated against a set of scientific and end-use criteria in a participatory process, involving the major stakeholders related to the subject. This chapter presents how the scientific panel composed of experts from the Ibero-american scientific community assessed the validation of the indicators using an evaluation matrix. It also describes how the end-use panel composed of stakeholders from the Salitre river basin examined the indicator set using the end-use criteria through a structured survey. The consolidated versions of the IPS of these eight indicators are also presented here. This chapter demonstrates that the eight indicators selected by this research are valid from both scientific and end-use perspectives.

The final discussion and conclusions related to this research, as well as the recommendations for further studies are summarized and presented in **chapter seven**.

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CHAPTER 2 – BACKGROUND

2.1 INDICATORS OF WATER USE AND MANAGEMENT

Indicators are key tools that help the society to monitor progress and trends on the path towards the sustainable use and management of natural resources (WWAP, 2003). The adoption of indicators to evaluate and monitor the progress towards sustainable development is strongly recommended by scientists (Moldan et al., 2012), policy developers (UNDESA, 2007), international institutions (OECD, 2014), governments (OSE, 2008), the business sector (WBCSD, 2000) and non-governmental organizations (WWF, 2010).

Indicators can be applied to natural elements, such as the environment (Zhang, 2015), ecosystems (Fu et al., 2015), forest management (Gossner el al., 2014), water (Lobato et al., 2015; Perez et al. 2015) and land (Zhao et al., 2015), as well as to socio-economic-institutional issues related to water resources, i.e. water economic value (Hellegers et al., 2010), governance (Norman et al, 2013; Pires & Fidélis, 2015), political framework (Blanchet & Girois, 2012) and management (Taugourdeau et al., 2014). Several authors (Juwana, et al. 2012; Spangenberg, 2008; McCool & 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). 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."* Hak et al. (2012) mention that this expansion in the use of indicators *"does not necessarily follow that they are scientifically sound and/or used appropriately"*.

Indicators do not have a uniform concept; authors use different and sometimes conflicting definitions. Juwana, et al (2012) defines an indicator as *"a measure, either qualitative or quantitative, of facts or conditions of particular issue(s)"*. Heink & Kowarick (2010) define an indicator as a measure or a component that can interpret the phenomenon of interest. Chevalier et al (1992) define an indicator as a hypothetical variable of a subject studied, that cannot be directly observed. According to Gallopin (2006), these ambiguities are not limited to the subject of environmental indicators or water resources indicators, and even can be applied to indicators in general.

According to the United Nations World Water Assessment Programme (WWAP, 2006) an indicator is a parameter or calculated variable based on the knowledge of a conceptual model of the dynamics and functions of a natural phenomenon. Based on this definition, an indicator describes the state of the phenomenon and its trends, considering the actions that regulate the dynamics and affect the studied phenomenon. This definition presented by the WWAP is also adopted in our research, mainly because it was tailored to integrate the concepts of sustainable development and water resources management.

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 & 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).

2.1.1 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. The concept of sustainable development came to evidence through the report of the Brundtland Commission, formally known as the World Commission on Environment and Development (WCED, 1987). It was stated as a development *"that meets the needs of the present without compromising the ability of future generations to meet their own needs"*.

IWRM also 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, Gain & Rouillard, 2015).

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, Slobbe & Cofino, 2013).

The New Water Culture (NWC) also shares these principles. The NWC is a scientific and social movement initiated in Spain in the late 1990's. It promotes an interdisciplinary approach to water management. Beyond assuring a socially equitable and efficient use of water, the NWC aims to guarantee sustainable management of the rivers and aquatic ecosystems (Arrojo and Martinez, 1999).

One of the key issues of IWRM and the New Water Culture 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).

Indicators have a relevant role in the promotion of sustainable development in general, and the water sector is no exception. Hence, as mentioned by Juwana (2012) and others (WWAP, 2003; Spangenberg, 2008), indicators should include the main dimensions of sustainability: social, economic, environmental, and institutional. The sustainable use of water resources involves the promotion of local sustainable development (Carneiro et al, 2006). One of the most important aspects is the integral view that the interest and trade-offs among persons (as individuals), society (as the collective), economy/development, and the natural environment must be considered as a combined/interlinked whole (Klostermann and Cramer, 2006).

Dahl et al. (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 which, according to Mays (2006), is the ability to provide and manage water so as to meet the present needs of humans and environmental ecosystems, while not impairing the needs of future generations.

2.1.2 Uses of Indicators

Indicators can be used in several ways. The WWAP (2003) mentions that the most common use of indicators is to describe the state of a phenomenon. Already since the 1960's there has been an interest in developing a meaningful set of water resource indicators. Several authors (Spreng & Wils, 2000; WWAP, 2003) point out that the work on developing indicators has improved significantly since the 1980s, when sustainable development became an increasingly global matter of concern and the need for combining variables for producing a more comprehensive value became evident. Therefore, concepts and frameworks needed to be developed in order to allocate these indicators into comprehensive frameworks and thus integrating the multiple dimensions of sustainable development (i.e. environmental, economic, social and institutional).

Indicators are often employed to measure, communicate and organize the information within complex data (Heink & Kowarik, 2010). Indicators are needed to describe baseline and current conditions (e.g., the amount or magnitude of something) and performance of a system (McCool & Stankey, 2004). Through the knowledge provided by indicators the public as well as policy makers will be better able to understand the phenomenon measured. In addition, indicators can support the monitoring of water use and management (Lorenz et al, 2001).

Indicators also make it easier to compare different results in different areas as well as to monitor the changes that take place over time. The often-complex tasks of monitoring and evaluating are usually done with the use of indicators, as is the examination of possible links between changing conditions, human behaviour and policy choices. Well-developed indicators are easy to understand and thus they are useful tools for raising awareness about water related issues for any society (WWAP, 2003). Early alert systems and predictive models are also based on a set of indicators (Naumann et al., 2014). Indicators are fundamental when establishing goals and objectives, i.e. the goals of water quality or ecosystem conditions, MDGs (Sengupta, Mukherjee & Sikdar, 2015).

2.1.3 Indicators for River Basin Scale

The selection of the optimal spatial scale is an important aspect in indicator development and use (WWAP, 2006). Depending on the scale, indicators may signify different things to decision makers. For example, an indicator defined for one certain scale may not make sense on another superior or inferior scale (Norman et al, 2013). Combining indicators from different levels does not always make sense (van der Zaag and Gupta, 2008). Furthermore, indicators developed for a certain scale may not be useful in other scales, as needs for information differ according to each level (local, regional, global).

As mentioned by Houdret, Dombrowsky & Horlemann (2014), the river basin approach to sustainable water use *"has become the dominant model of water governance"*. Furthermore, several authors consider that the river basin is the logical unit for addressing water related issues (WWAP, 2012; Jaspers, 2002; Gaiser et al, 2008). Jasper (2002) considers that the *"integrated river basin management can be understood as the management of all surface and subsurface water resources of the river basin in its entirety with due attention to water quality, water quantity and environmental integrity"*. The European Water Framework Directive also uses river basins as the basic unit for actions in the context of water resources management (Gaiser, 2008). The UN Conference on Environment and Development (UN, 1992) established in its Agenda 21 (Chapter 18) that *"Integrated water resources management should be carried out at the level of the catchment basin or sub-basin"*.

The river basin is also considered as the water management unit by the Brazilian National Water Management Law (Lei Federal 9433, 1997), by the World Water Assessment Program (WWAP, 2009) and by other relevant international organizations (Mukhtarov & Gerlak, 2013), such as INBO - International Network of Basin Organizations, the World Water Council (WWC), the International Water Resources Association (IWA), and Global Water Partnership (GWP). The river basin was defined as the geographical scale of interest for the current study.

For an integrated use of sustainability indicators, all data (social, economic, environmental and institutional) has to be changed to the suitable spatial level (Fraser et al., 2006). Socio-economic data tends to be collected for administrative regions and combined with larger spatial levels (e.g. country level), whereas environmental data are gathered at the local level (e.g. water body). Furthermore, river basin boundaries rarely correspond with political jurisdictions. These differences in scale are considered as one of the challenges faced by developers and users of water resources indicators (Ward & Kaczan, 2014). Inconsistencies between natural (river basin) and administrative (municipalities, countries, etc) boundaries also affect data collecting and aggregation.

2.1.4 Data for indicators

Indicators are made of data. Data can be defined *"as measures of values adopted by a variable in different times, different places, different populations or combinations of the three categories"* (WWAP, 2003). Data and indicators are formed by qualitative variables (nominal), rank variables (ordinal) or quantitative variables (cardinal). Indicators can be presented as individual variables or a function of variables, which can be classified as an index: a singular variable that is a simple function of two or more variables (Sullivan, Meigh & Fediw, 2002). In this study, the names "indicator" and "index" are used with the same meaning, nevertheless the authors recognize their differences.

The accurate calculation of indicators requires the availability of reliable data sources. Investment in data collection should be in balance with the information gained by the indicator (WWAP, 2006). Data collection matters because it determines whether the indicators provide correct information or not. Bad data processing may provide wrong information.

Information about the quality of data is important for proper assessment (Kurka and Blackwood, 2013). However, this is not the case with most indicator reports, which do not give out detailed information about data quality. With data gathered according to commonly agreed and standardized rules, it could be possible to derive lessons that are relevant across many locations. Data gathered over time can expose certain trends in development, while river basin specific data collected in a standard format makes inter-area comparison possible.

Even where data is available, that information may be either unreliable or out of date (UN, 2009). These problems relate to data quality. According to several authors (Cloquell-Ballester et al., 2006; FAO, 1999; OECD, 2003; Segnestam, 2002; World Bank, 2000;), "data quality" is another important criterion with which indicators should comply.

WWAP (2009) demonstrated that data often is not available for analysing and reporting on issues considered important for the water sector. The report of the UN World Water Assessment Programme (2009) states that water observation networks are in decline at global level. This decline generates significant threats for managing water resources and predicting future needs, due to incomplete and incompatible data on water quantity and quality.

Furthermore, the WWAP (2012) points out another concern regarding data for water resources indicators: climate change has resulted in the acknowledgment that 'stationary hydrology' assumption can no longer be accepted as the basis for high-level reviews of water availability. Even though data on precipitation is greatly available, changes in runoff to rivers or recharge of groundwater are more challenging to measure (WWAP, 2012). In fact, data on groundwater and water quality is scarce and rarely available. WWAP (2009) calls for "*investments in monitoring and more efficient use of existing data, including traditional ground-based observations and newer satellite-based data products*"

The UN (2009) considers that the primary challenge facing water management is "…*the systematic generation of a set of core data items that will allow a wide range of such indicators to be calculated to meet the many different needs of the potential audiences.*" Where actual data is lacking, indirect measures and imputation from available data are sometimes used to fill in the gaps. On one hand, Sullivan et al. (2003), Aveline et al. (2009) and Pandey & Jha (2012) consider that estimates or proxy data can be used where data is limited or lacking.

On the other hand, while practically useful, these approaches can be unsatisfactory because of the inherent assumptions made about the data, which may be unjustified at times (Niemeijer & Groot, 2008). Therefore the availability and reliability of data is a very important aspect to be considered by indicator developers and users. This issue will be addressed throughout this research, and it is one of the validation criteria assessed here.

2.2 DEVELOPMENT OF INDICATORS

The development of indicators usually is an intricate task that concerns the compilation, analysis and structuring of relevant data and information. Indicators recurrently summarize significant amounts of data and simplify the complexity of a single phenomenon or a group of phenomena into elementary and clear statements. In addition, however, indicators should have scientific robustness and encompass in their formulation the relevant interconnections and linkages that regulate the phenomenon (Kang et al., 2010).

Therefore, the development of indicators consists of a constant exercise of optimization and balance of often-diverging objectives and priorities that is limited by resource availability (i.e. data, time, economic resources, technical resources, and human resources). Optimization exercises of this nature may include *"many personal and negotiated decisions, explicit and implicit assumptions, normative and subjective judgment, disciplinary and method-specific rules"* (WWDR, 2003).

The literature shows many methods for the development of indicators (Bockstaller et al, 2008; Niemeijer and Groot, 2008; WWAP, 2003). Several authors point out to the relevance of adopting a clear and solid process to develop indicators based on:

- A transparent selection process (Niemeijer and Groot, 2008; Bockstaller and Girardin, 2003);
- A conceptual framework for the organization of indicators (WWAP, 2003; Wolfslehner & Vacik, 2011);
- Validation procedures to check the quality of indicators (Hak et al., 2012; Cloquell-Ballester et al, 2006)

2.2.1 Selection of Indicators

The selection process is a relevant stage in the development of indicators. Some authors (Dale and Beyeler, 2001; Niemeijer and Groot, 2008) comment that the reliability of indicators is sometimes questioned because of weak or unclear selection procedures.

Consequently, a robust and transparent selection process adds value and confidence to indicators so that they can be widely used and their meaning can be more easily understood. A carefully constructed selection process also allows a more suitable conceptual validation of indicators (Bockstaller and Girardin, 2003) and contributes to the identification of indicators that can promote synergies between environmental aspects and institutional, social, and economic aspects (Niemi and McDonald, 2004).

Indicators should obey a precise pre-defined criterion and must be selected by an adequate methodology. Indicator developers should aim to create a balance between the model indicator, well suited to theoretical definitions, and the practical one, based on feasibly measurable variables that provide acceptable approximations to the model (Kang et al., 2010). An adequate balance allows the collection of cost-efficient and cost-effective data (WWAP, 2006). Therefore, formulating and developing easy-to-use, easy-to-understand, and yet robust and reliable indicators is important.

Gudmundsson (2010), among other authors (Niemeijer & De Groot, 2008), considers that in general the selection of indicators can be theory-driven, policy-driven or data-driven. A theory-driven approach is defined as one that focuses on selecting the best possible indicators from a theoretical or scientific point of view (Niemeijer 2002). In policy-driven approaches indicators are selected based on issues that are currently on the socio-political agenda in a given society (Gudmundsson, 2010). Data-driven approaches select indicators on the basis of the availability of data. Our research adopts the combination of all these three approaches aiming at selecting an appropriate set of indicators that would be both scientific solid, useful and measurable.

2.2.2 Indicators Frameworks

Indicators can be more useful if they are organized into a coherent frame instead of being selected individually as a simple collection of elements (Mendoza and Prabhu, 2003; Wolfslehner and Vacik, 2011). The adoption of a framework is especially important in the case of indicators related to sustainable development issues, encompassing multiple dimensions. As a matter of fact, the IISD (2008) and WWAP (2006), relevant international institutions that have been developing extensive work on indicators of sustainability, also recommend that an indicator should be developed within an agreed-upon conceptual and operational framework.

The adoption of an adequate framework is helpful for organizing indicators into a consistent form and making them compatible with their application. The organizational structure also helps to guide the data harvesting and to identify missing information. Moreover, the use of a powerful framework suggests logical ways to integrate related information, facilitate communication with the decision-makers, and understand the generated information (Gallopin, 2006).

Indicator developers from the sustainability and environmental fields have applied a variety of framework models to structure indicators. Some of the most common approaches include: the **compartment approach** – classifying indicators according to their environmental compartment (i.e. water, air, earth, and biota) or sector (i.e. agriculture, industry, transport, etc.); the **bottom-up approach**, moving from aggregating available primary data into consolidation of indicators (Teitelbaum, 2014; Fraser et al., 2006); the **top-down approach**, also known as the logical framework, based on a predefined hierarchy in which indicators are usually structured from goal to activity i.e. indicators applied to the Millennium Development Goals (UN, 2007). Out of these framework models, special attention has been dedicated to the *Systems approach* and the *cause-effect approach (DPSIR)* by the WWAP (2003).

The **systems approach** is based on a comprehensive analysis of system inflows, stocks, and outputs, according to the concept of system dynamics (WWAP, 2003). The systems framework considers the concept of system thinking applied to the development of an indicator (Sanò and Medina, 2012). Systems Thinking helps to think holistically about problems focusing on the components and relations of complex systems (Sterman, 2000). The systems approach has been applied to the development of sustainability indicators not only by academics (Gallopin, 2006) but also by international institutions. For example, the UN Commission on Sustainable Development (2001) adopted a four-dimensional framework (social, environmental, economic, and institutional), which shows the potential to provide a holistic vision of sustainability. These four dimensions of sustainability were also adopted here using a systemic approach (see next chapter).

The cause–effect approach, also known as the **DPSIR model** (Driving Force – Pressure – State – Impact - Response), is based on the intrinsic cause–effect relations between the indictors. DPSIR was based on the pressure-state-response (PSR) conceptual framework firstly introduced by OECD (1994), and then amply adopted by the European Environmental Agency (EEA, 1999) and the UN system (WWAP, 2012). The cause–effect approach is largely used in the development of indicators (Spangenberg, et al., 2015; WWAP, 2003).

The DPSIR framework organizes the indicators under the cause–effect schema in the following categories: Drive Forces, Pressure, State, Impact, and Response. The DPSIR model adopts a causal chain: Driving Forces in the socio-economic system generate Pressures on the environment, which modify its State and cause Impacts on society and economy, provoking Responses of the society (Smeets and Weterings, 1999). These responses could aim to modify the driving forces, to reduce the pressure, to restore the environmental state and/or to mitigate the impacts. The application of this framework to water resources was presented by WWAP (2006), adapted from Costantino et al. (2004) – see Figure 2.1 below.

The DPSIR framework model contributes to the selection of indicators in coherent sets (Niemeijer and Groot, 2008). Well-developed indicators should not only describe the state of the phenomenon but also analyse the related driving forces and effects. Indicators should help users make decisions based on tendencies and cause–effect situations.

On one hand, as mentioned above, the IWRM is built upon a systems approach, asserting that the society, economy, environmental and institutional components should be balanced adequately (Spangenberg, 2008; Juwana, 2012). On the other hand, the model framework for indicator development is also relevant when there is a need for components related to driving forces, pressures, state, impact and responses of an environmental phenomenon (Niemeijer and Groot, 2008). Nevertheless, the careful development of indicators is a laborious process that includes the identification and understanding of causal relations of a given phenomenon in complex and dynamic systems. Thus, there is a clear need to adopt models that consider both the cause–effect relationships and the socio-economic-environmental-institutional aspects of the sustainability (Niemeijer & Groot, 2008). Considering the nature of the study (indicators related to the sustainable use and management of water), the systems approach and the cause–effect approach were the frameworks adopted here.

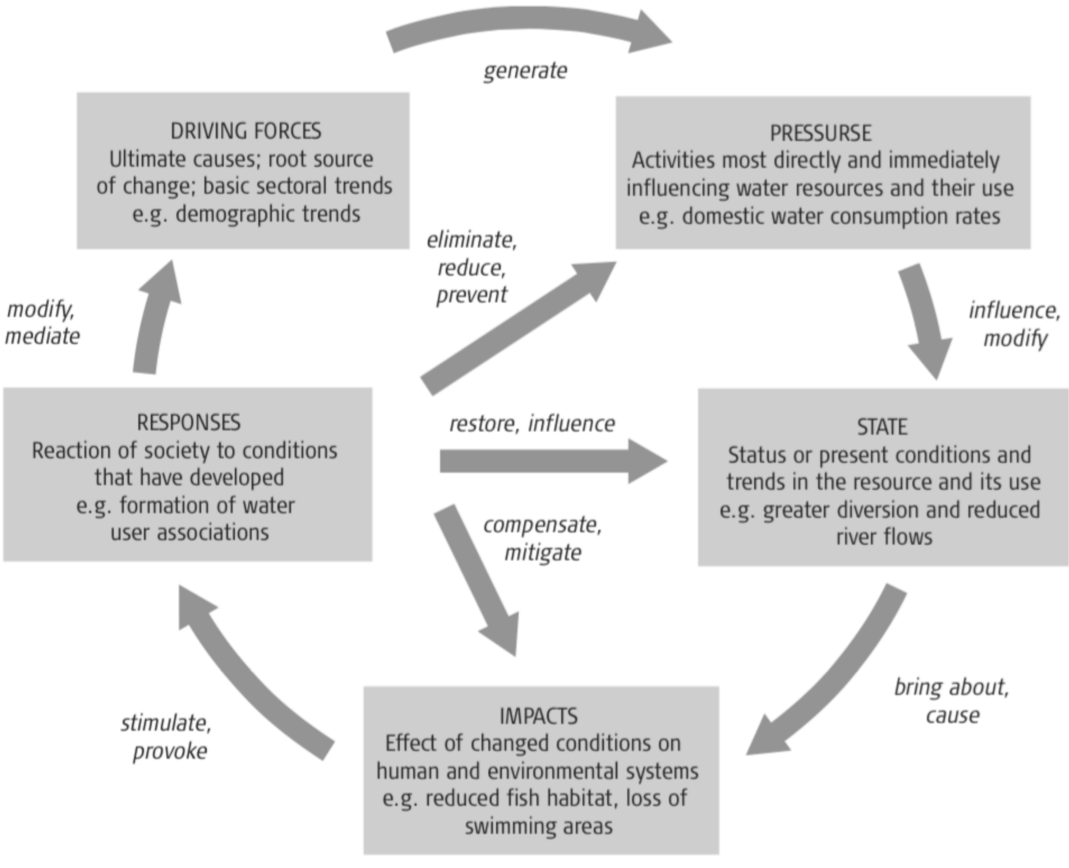

Figure 2.1 - DPSIR framework applied to water resources. Source: WWAP (2006) adapted from Costantino et al. (2004)

Although each approach presents its strengths and weaknesses, indicator development should involve the consideration of a meticulous perception of the process analysed based on a robust conceptual model (WWAP, 2003). Further, any development of indicators as a tool for decision-makers should start from the premise that the main focus is the structuring of a model to promote sustainable actions, in the ecological, social–cultural, economic, and political/institutional dimensions. These premises guide the work presented here.

2.2.3 Validation of Indicators

The rise of the sustainable development concept and of environmental concerns has led to an environmental indicator "explosion" (Hak et al., 2012). However, "*…while sustainability indicators are used ever more extensively and intensively by a wide range of users and in many different contexts, it does not necessarily follow that they are scientifically sound and/or used appropriately*" (Hak et al., 2012). Therefore the use of an appropriate set of indicators for a particular issue relies on a solid validation process. This validation process should assess the most relevant features of indicators.

Indicator validation has, in the past, been overlooked, perhaps partly because "*…validation is not an absolute objective procedure*" (Bockstaller & Girardin, 2003). Sometimes expert judgement must be substituted for more quantitative measurement comparison, and the inclusion of end-user perspectives in the process can further improve the procedure. Procedures or guidelines for the validation process are still rare, though criteria for validation procedures are increasingly outlined (Hak et al., 2012).

According to Bockstaller and Girardin (2003) "*…an indicator will be validated if it is scientifically designed, if the information it supplies is relevant, if it is useful and used by the end users.*" For indicator validation, experts may play a large role in assessing the output validity of an indicator because comparison of model output with measured data is not always an option. "*Such an approach should be considered as a minimum requirement for indicator validation*" (Bockstaller & Girardin, 2003). Cloquell-Ballester et al. (2006) built upon this methodology by emphasizing the role of stakeholders in the end-use validation, rather than using only specialists to judge the application of the indicators. Meul et al. (2009) built upon these ideas in validating an agricultural indicator, where the validation was divided into expert and stakeholder groups to discuss the application of the indicator.

There are several methods that could be used to check the quality of an indicator or a set of indicators: i.e. output validated by real data comparison to indicator (Aveline et. al, 2009); 3S method - self, scientific, social (Bockstaller & Girardin, 2003); assessed indicator against evaluation criterion (James et al., 2012; Cloquell-Ballester et al., 2006). Each method has its strengths and weaknesses. Despite these efforts, little consensus exists surrounding the methodology or criteria used for validating indicators.

As mentioned by Hak et al. (2012) "*to date, there are not many (if any?) indicators and/or indicator sets that are universally accepted, backed by compelling theory, rigorous data collection and analysis, and influential in policy*." Significant room exists for the future development of transparent, replicable methods of validation, which is of crucial importance to the success of indicators in influencing sustainability issues.

Validation requires criteria to measure the quality of the indicators. In the indicator literature a number of more or less elaborate methodologies for validating indicators using criteria in various ways can be found. The review of criteria based methods done by Gudmundsson (2010) demonstrated that "*a rich palette of criteria – more or less well-defined - is available to pick from the literature, but a universal list of criteria for assessing indicators does not exist*". The process of selecting and validating indicators, like the ones done in our research, should adopt appropriated tools for evaluating alternatives against multiple criteria.

2.3 MULTI-CRITERIA ANALYSIS

Multiple stakeholder interests guide the majority of environmental decisions and many criteria and indicators are used to point out possible solutions (Derak & Cortina, 2014). Multiple Criteria Analysis (MCA), a framework for evaluating decision alternatives against multiple criteria, is an effective approach for supporting multi-stakeholder multi-criteria decisions (Hajkowicz, 2008), such as the ones faced by this research. Hajkowicz (2008) considers that applying MCA in multi-stakeholder multi-criteria decisions "*provide a transparent, structured, rigorous and objective evaluation of options. Typically, MCA helps not only by providing 'the answer' but also by providing a process*".

Multi Criteria Decision Analysis (MCDA) is a form of MCA that supports decision-making processes by analysing and comparing different alternatives with multiple criteria (Manzardo et al., 2014). MCDA is also known as MCDM (Multi-Criteria Decision Making). As mentioned by Huang et al. (2011), MCDA "*provides a systematic methodology to combine scientific information and stakeholder views*" to compare alternatives (indicators, in the case of this study).

Huang et al. (2011) demonstrate that there was "*a significant growth in environmental applications of MCDA over the last decade across all environmental application areas*". Ananda & Herath, 2009 found that not only the researcher but also decision-makers and planners outside the scientific community have increasing interest in MCDA.

Regarding the use of MCA/MCDA in topics related to water resources, Hajkowicz & Higgins (2008) state that the "*characteristics of water planning decisions make multiple criteria* *analysis (MCA) an attractive approach".* Several authors also consider MCA/MCDA as an effective technique bringing organization, accountability, transparency and thoroughness to water management and the decision making process (Joubert et al., 2003; Flug et al., 2000; Hajkowicz & Higgins, 2008; Manzardo et al., 2014).

There are hundreds of methods of MCA and the diversity of techniques has grown in recent decades (Hajkowicz & Higgins, 2008; Wolfslehner & Vacik, 2011). MCA can be defined as a group of *"techniques for evaluating decision options against multiple criteria"* (Hajkowicz & Higgins, 2008). Mendoza & Prabhu (2005) describe MCA as "*a general approach that can be used to analyze complex problems involving multiple criteria".* Belton & Stewart (2002) define MCDA as *''an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter''*.

MCDA methods can be classified under two groups: continuous and discrete methods, depending on the alternatives to be evaluated (Hajkowicz & Young, 2000). The latter have a finite number of alternatives (this is also the casein our study), and the former has *"theoretically an infinite number of continuous alternatives defined by a set of constraints on a vector of decision variables"* (Mendoza & Martins, 2006). Ananda & Herath (2009) explain that discrete methods can be divided into the following: qualitative (using ordinal performance measures), quantitative (all data expressed in cardinal or ratio measurements), and mixed methods (applying different decision rules depending on data). This research adopted methods classified as MCDA discrete quantitative techniques to evaluate water resource indicators against multi criteria (i.e. sustainability, scientific foundation, etc) using a participatory approach.

Some features of MCDA are of great importance to a participatory study using criteria to assess indicators: (a) evaluation is usually transparent (Mendoza & Prabhu, 2005); (b) *"it is capable of accommodating multiple criteria in the participative analysis"* (Huang et al., 2011); (c) it can combine both qualitative and quantitative data, including expert and stakeholders judgements (Mendoza & Martins, 2006); (d) it allows the effective participation of multiple interest groups (Hajkowicz, 2008); and (e) it is a process that leads to rational, justifiable, and explainable decisions (Belton and Stewart, 2002). Focus groups, surveys and other techniques can be utilised by MCDA to look for local opinions of stakeholders and communities. These should then be integrated into the decision making process. Furthermore, Huang, et al. (2011) argues that the application of MCDA methods in a participatory way provides a significant improvement in the public acceptance of decision-making.

2.4 Participatory and Multistakeholder approach

Over the past few decades the use of participatory methods in research has increased significantly. These methods are most visible in ecology and natural resource management (Voinov & Bousquet, 2010). Where once experts dominated research and decision-making in environmental research, stakeholder involvement has now become "*de rigeur*" (Benson et al., 2014).

This increase is a result of both researcher recognition of the right of stakeholders to participate in those decisions that affect them, and also an increasing interest on the part of stakeholders in contributing to the decision-making process. *"As such, integration the heterogeneous and uncertain information demands a systematic and understandable framework to organize the technical information and requires expert judgment."* (Huang et al., 2011)

The traditional top-down structure has been deemed ineffective in tackling the complex hurdles to sustainable resource management (Mendoza & Prabhu, 2006). Participatory design of research implies that some control over the outcomes of a project or policy is transferred to stakeholders (Frauenberger et al., 2015). The inclusion of stakeholder perspectives in fields historically dominated by experts and policymakers has been a positive, and just, development. Engagement of the diverse perspectives held by stakeholders is key. Multistakeholder approaches have therefore been used widely for environmental management (Ravier et al., 2015). Mendoza & Prahbu (2005) argue a few different advantages to stakeholder involvement in modeling and research:

- Local knowledge of the pressures, history, and development of water resource and local conditions may complement outside and expert information held by outside individuals.
- Active engagement of stakeholders may increase their perceived ownership of a project thereby enhancing the likelihood of adoption
- Input and participation may increase local perception of project credibility.

2.4.1 Typologies of Participatory Methods

Participation is defined here as "*a process where individuals, group and organisations choose ot take an active role in making decisions that affect them*" (Rowe & Frewer, 2010). This definition focuses on the stakeholders associated with a region or project, rather than the idea of engaging the public as a whole. However, the definition of participation as well as the nature of participatory methods has varied extensively in the literature. Participatory typologies are used to explain both the level of stakeholder involvement, as well as the nature of their engagement.

One useful typology applied to understand the nature of participatory methods describes the process as either normative, or pragmatic. Normative participation implies the right of stakeholders to participation in decision-making that affects them. A pragmatic participatory approach, on the other hand, engages stakeholders for their ability to positively influence the outcomes of the study or project (Reed 2008; Reed et al., 2009). Some claims of **normative participation** include: reduced marginalization of periphery people, increase in public trust through perceptions of transparency and fairness, empowerment of stakeholders through knowledge cogeneration, and social learning. Claims of **pragmatic participation** reference potential improvements to decision-making as a result of stakeholder engagement. These include: adaptation of solutions to local socio-cultural and environmental conditions thereby improving adoption rate and credibility of solutions, a fuller a fuller picture of the local situation which can help anticipate and prevent issues, and establishment of common ground leading to a sense of ownership by stakeholders contributing to long term support (Reed, 2008).

The type of participatory method used can significantly impact quality of decision-making, project outcomes and perceptions of those outcomes. However, the type of engagement that is appropriate will depend on the project and the local context, and should be carefully considered prior to commencement. Any stakeholder involvement should, however, involve the principles of trust, respect and reciprocity (Reed, 2009; Benson et al., 2014).

2.4.2 Participatory Approach for Sustainable Water Management

Though stakeholder involvement has been woven into many different areas of environmental research, "*participation is most highly visible in water governance*" partly due to the influence of the IWRM concept worldwide (UN, 1992) and, most recently, of the Water Framework Directive in the EU (Benson et al., 2014). The directive encourages increased stakeholder involvement in the management of river basins in Europe and helped to further spread the concept of the IWMR, and highlights the need for greater participation of stakeholders in driving the sustainable use and management of water resources (WWAP, 2003). Juwana et al., (2012) argue that stakeholder participation is integral to water resources management, and all relevant stakeholders should participate in the development and management of water resource initiatives.

Issues of water quality and quantity often go far beyond the physical limitations of resources, or 'supply and demand' (Gain & Giupponi, 2015). Social and economic factors inherent in the use and management of water resources invariably affect a large and diverse group of stakeholders with conflicting interests. "…*Flawed water planning and management approaches, institutional incapability to provide water services, unsustainable economic policies, unequal power relationships, inequality and poverty that exacerbate scarcity*" all contribute to these conflicts

(Gain & Giupponi, 2015). Technical, reductionary solutions that ignore the complexity of water issues and the role of stakeholders are inadequate to provide lasting solutions (Juwana et al., 2012), especially in the context of climate change and increasing local vulnerability. Stakeholders can aid in the identification of problems, the source of issues, and in finding adaptive solutions for those issues (Dungumaro & Madulu, 2003).

According to Kemper (2010) participatory decision-making plays a key role in the implementation of river basin management because this approach is believed to improve adaptation to local conditions, enhance the use of local knowledge and institutions, and ensure greater involvement of stakeholders. Komakech & Zaag (2015) showed in their studies that a lot of information could be collected through the interaction with the river basin committees, especially information concerning the management of water resources. Dungumaro and Madulu (2003) conclude in their research that the stakeholders' involvement is crucial for a successful and sustainable water resource management.

As mentioned above, participatory approaches to the management of water resources are useful for a number of reasons. Similarly to Gain & Giupponi (2015), our research also adopted a participatory approach *"as a fundamental means for the involvement of stakeholder in the process of integrated water resources management"*.

2.4.3 Criticisms and Best Practices

Participatory approaches have enjoyed significant support and popularity. However, some claims of benefits resulting from these methods have also been critiqued in recent years. The sometimes blanket use of stakeholder engagement that assumes the *de facto* utility of this method can lead to disillusionment by some over its benefits (Voinov & Bousquet, 2010). "…*While many of the existing participatory methodologies are strong in terms of inviting participation, they are still lacking in terms of providing a structured framework by which debate about management alternatives and strategies can be sufficiently analyzed and evaluated*." (Mendoza & Prabhu, 2006)

Participatory methods are often highly qualitative making it difficult to quantify the benefits of stakeholder input. Other criticisms cite a lack of rigor and systematic procedure for analyzing how stakeholders contribute to the process (Mendoza & Prabhu, 2005). More quantitative approaches may allow for greater faith in the robustness of methods and greater reproducibility of procedures, but may also restrict flexibility of the process. The participation of multiple stakeholders in decision-making also increases the complexity of the research as it aggregates different point of view on the same subject (Mendoza & Martins, 2006) *"the individuals, along with other members of the community, usually have different expectations and possibly conflicting goals, which certainly increase the complexity of decision-making in natural resources management"*.

The fact of stakeholder involvement is important in and of itself, but participatory methods do not necessarily ensure greater success of objectives. Benefits of the participatory approach depend on the quality of the process rather than on the sole fact of stakeholder involvement.

The methodology is a very important factor determining the extent to which stakeholders are involved, and the quality of that involvement. Therefore, researchers have looked to outline best practice in participatory approaches to better understand where this method contributes to the desired outcome. Reed (2008) outlines a series of best practice methods from a review of participatory methods in environmental research, which advise that:

- *"Participation should be based upon the fundamentals of empowerment, equity, trust and learning*
- *Participation should be considered early and throughout the research*
- *Clear objectives are best*
- *Highly skilled facilitation should be used where necessary*
- *The combination of local and scientific knowledges can provide a more holistic understanding of the complex systems at play than either group by itself*
- *Institutionalize participation of stakeholders*
- *Participatory methods can be risky, but it is a risk worth taking."*

Good environmental management support is based in transparency, representative participants, constructive participation of stakeholders, strong guidance by a facilitator, and uses solid, replicable methodology (Reichert et al., 2015). Transparency and participation *throughout* the process can increase the credibility of an initiative. If participants understand the tools developed through research, they will have more ownership over the tools, higher confidence in the results therefore will be more likely to accept policy and decisions that arise as a result of that tool (Mendoza & Prabhu, 2006). Despite the difficulty in quantitatively assessing the contribution of stakeholder participation to a process, "…*it is generally agreed that better decisions are implemented with less conflict and more success when they are driven by stakeholders, that is by those who will be bearing their consequences"* (Voinov & Bousquet, 2010). Our research was built upon these lessons learnt, best practices and recommendations and they were adopted through out the study.

2.5 Reference

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Chapter 3 – Evaluation of Criteria and Indicators of Sustainable Water Use and Management

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 identification and selection of criteria to evaluate indicators is not a trivial task. Our research a) performed a comprehensive assessment of the most relevant criteria for evaluation of indicators; and b) identified the indicators related to water use and management. Sixty assessment criteria and 170 indicators are listed and described. These 170 indicators were assessed by an international panel of experts that evaluated whether they fulfil the four sustainability criteria: social, economic, environmental, and institutional. Our research employed an evaluation matrix that classified all indicators according to the DPSIR 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) and 86 are one-dimensional indicators (fulfilling just one of the four sustainability criteria).

3.1 Introduction

Indicators are powerful decision making tools and international organizations (OECD, 2004; WWAP, 2003) as well as the scientific community (Bolcárová & Kološta, 2015; Cornescu & Adam, 2014;) strongly recommend the adoption of indicators for evaluation and monitoring of progress towards sustainable development. The application of indicators of water use and management can undoubtedly contribute to a better allocation of this limited resource (Kang & 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).

The quality and reliability of the indicators depends on the application of adequate and appropriate criteria to assess them (Niemeijer & de Groot, 2008). The identification and selection of criteria to evaluate indicators is not a trivial task and should be done in a transparent, replicable and scientifically valid way (Gudmundsson, 2010). Furthermore, indicators should be assessed against the criteria that are relevant for the problem in hand.

The general objectives of this stage of the research are: a) to carry out a comprehensive assessment of the most relevant criteria for evaluation of indicators and; b) to evaluate the sustainability criteria of indicators related to water use and management. This evaluation includes the assessment of the social, institutional, economic, and environmental components of the indicators. The initial step of the study was a comprehensive bibliographical search to identify criteria and indicators related to the water use and management presented by international institutions and national governments, as well as the ones addressed by the scientific community in peer reviewed international journals. The methodology to evaluate the indicators according to sustainability criteria (social, economic, environmental, and institutional) is described below, followed by the presentation of the results and discussions. This research identified 60 assessment criteria, 170 indicators related to water use and management and, among them, selected a set of 24 indicators that adequately consider sustainability criteria.

3.2 METHODOLOGY

The study first identified the most relevant criteria for evaluation of indicators and then identified the indicators related to water use and management. In order to do this, an extensive revision of the specialized literature screening the criteria and 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 components of sustainability were selected as indicators of interest for the research.

3.2.1 Identification of the Assessment Criteria

The identification of the assessment criteria was the first step of this research and, as mentioned by several authors (Gudmundsson, 2010; Niemeijer & de Groot, 2008; among others), it is not considered a trivial task. The quality and reliability of the selection process depends on the application of adequate and appropriate criteria to assess the indicators. The majority of the publications analysed by this research provided insufficient detail about the criteria selection process, reducing the possibility of scientific replication (Aveline et al., 2009). Therefore, this research performed an extensive revision of criteria for evaluating indicators, focusing on the domains of sustainability and environment, aiming to identify in a transparent and reproducible way, the criteria to be adopted in this study.

It is worth mentioning here that some authors refer to Criteria and Indicators, usually called C&I, using a different definition of criteria. According to this definition, mainly used in the forest sector (Brand, 1997), criteria constitute a set of key elements that define the scope of the indicators. Indicators are then associated to the criteria to provide measurable features. According to this view, criteria and indicators are represented in a hierarchical structure and criteria cannot be used as a standard by which the indicators are judged, but as a way to organize the indicators. Our study adopts a broader perspective and considers that criteria are standards used to evaluate the quality of an indicator or a set of indicators.

In total, 74 sources were examined containing a total of 346 mentions of criteria used for the indicator assessment. These sources include publications from internationally recognized institutions that are renowned for their reliable work with indicators, such as the CBD (1999), EEA (2005), FAO (1999), GRI (2002), IISD (2008), OECD (2003), UN (2007), UNEP (2006), US EPA (2000), US GAO (2004), World Bank (2000), WHO (2002) and WWAP (2006). This study also examined a significant number of recent/relevant peer reviewed scientific papers (Aveline et al. 2009; Bélanger, Vanasse, Parent, Allard & Pellerin, 2012; Bringhenti et al. 2011; Cloquell-Ballester, Monterde-Díaz, Santamarina-Siurana, 2006; Gudmundsson 2010; Kurka & Blackwood, 2013; Meul et al. 2009, Niemeijer & de Groot 2008;). The work has included several electronic searches using databases and academic search engines (including Web of Science, SCOPUS, ScienceDirect, Google Scholar and others), complemented by relevant grey literature (mainly international institutions). The majority of the sources contain a list of criteria for the evaluation of indicators related to several fields such as water resources, fishery, agriculture, transportation, forestry, health, energy, biodiversity and planning – on multiple levels: local/national/international.

Five meta-reviews of the criteria were used to select indicators, namely: WWAP (2006)[1], UNEP (2006)[2], Niemeijer & Groot (2008)[3] and Kurka and Blackwood (2013).

An in-depth review of the 74 sources performed by our research revealed that:

- Different authors adopt different criteria to evaluate the quality of an indicator;
- What this research calls "criteria" is sometimes defined by other publications as "guidelines", "requirements", "indicator quality", "desirable properties" among other terminologies referring to elements that should be considered for the evaluation of the quality of an indicator or a set of indicators;
- A detailed analysis of each criterion makes clear that no standard definition exists. The same criterion may be called by different names, and similarly named criteria may have different definitions (meaning, that they are different criteria).

Based on these findings, a matrix of the 346 criteria identified by the sources was built to perform an in-depth review. This matrix aimed to identify the most relevant criteria to assess the quality of indicators. The name and definition of the criteria were transferred from the original sources to the matrix and each criterion was examined comprehensively in order to avoid overlapping, redundancy and ambiguity. This comprehensive examination revealed that the 346 criteria were in fact 60 different criteria (some had the same name but different definitions; some had different names but their definitions indicated that they were, in fact, the same criterion). The next step was to count the number of sources that consider each criterion in question as relevant. This matrix gives a clear view of the relevance of each criterion, based on the number of sources that mention each criterion – citation counts (Lutz & Hans-Dieter, 2008; Radicchi & Castellano, 2012).

Similarly to WWAP (2006), our research organized the criteria into two major groups: scientific criteria and end-use criteria (Annex 3.1). The scientific criteria (25 in total) are related to the foundation and theoretical aspects of the indicator that are useful for indicator developers and the academy. The end-use criteria (35 in total) are the practical ones related to the use and application of the indicator by primary and end-uses. The classification under scientific and end-use criteria are sometimes ambiguous and certainly not a definitive classification, but rather a way to organize the criteria that suits the needs of the current research. This study also proposes a standard name and a description for each criterion, based on the ones presented by the sources analyzed and the intrinsic aspects of each criterion (Annex 3.1). This contribution aims to provide more clarity and reduce ambiguity in the development and application of indicators and criteria. Figure 3.1 below presents the most relevant criteria identified by this study.

[1] Sources analysed by WWAP (2006): De Zwart (1995), Hendriks (1995), Hoon et al. (1997), Kuik & Verbruggen (1991), Liverman et al. (1988), OECD (1994), Swart & Bakkes (1995), Van Harten et al. (1995).

[2] Sources analysed by UNEP (2006): Bossel (1999), NRC (2000), CSIRO (1999), Dale & Beyeler (2001), EC (2003), EEA (2003), Gallopín (1997), GRI (2002), Hardi & Terrence (1997), MFE (1996), MFE (2000), Mortensen (1997), OECD (2003), Pastille Consortium (2002), Rump (1996), Singh et al. (2002), US GAO (2004)

[3] Sources analysed by Niemeijer & Groot (2008): CBD (1999), Dale & Beyeler (2001), EEA (2005), Kurtz et al. (2001), NRC (2000), OECD (2001), Pannell & Glenn (2000), Riley (2000), Schomaker (1997).

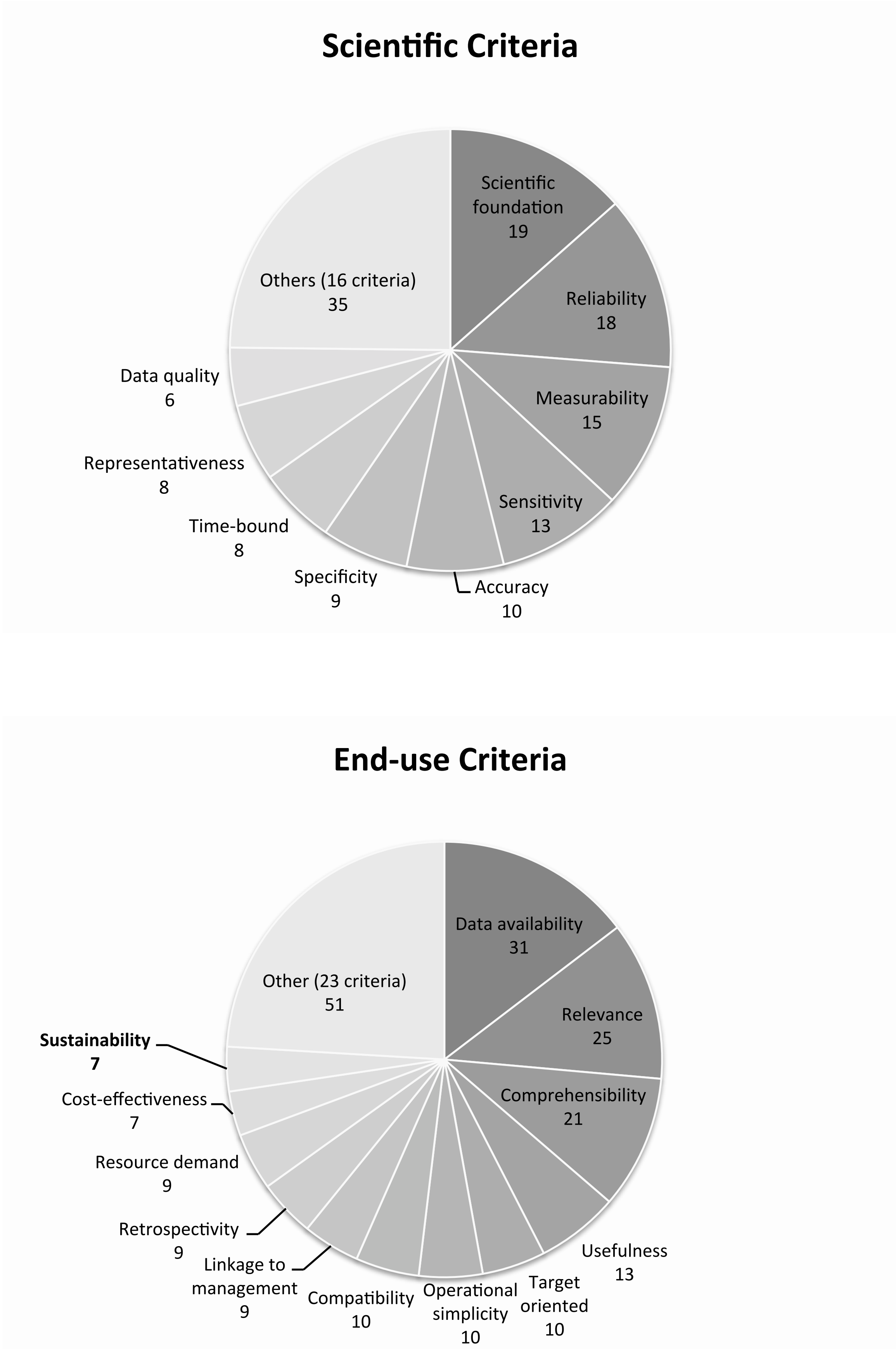

Figure 3.1 – Pie chart of the most relevant scientific and end-use criteria, indicating the number of mentions.

3.2.2 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. Similarly to the previous stage, 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 (including Web of Science, SCOPUS, ScienceDirect, Google Scholar and others). 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 & UNICEF (2010), World Bank (2007), WRI (1998) and WWAP (2009). This study also examined a significant number of relevant peer reviewed scientific papers related to the subject, including Aldaya & Llamas (2008), Bradfor (2008), Ding, Widhalm & Hayes (2010), Hoekstra (2010), Lawrence et al (2002), Maneta et al (2009), Milman & Short (2008), Scudder (2005), Sullivan & Huntingford (2009), Vörösmarty et al (2005a), Wilhite el 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 surface water, groundwater, rainwater and reclaimed water. 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 practises 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.

The literature review also found indicators that were not directly related to water use and management. These indicators were not considered of interest to this study. These indicators, despite having been mentioned in specialized publications about water, in fact, only have a thin connection with water resources. On the one hand, their main focus is on other resources (i.e. "carbon intensity of electricity production", "number of endemic bird areas"). On the other hand, they have a general scope that is implicitly related to water but not directly to its use and management (i.e. "average food price", "number of megacities around the world"). They might be relevant for other applications but do not contribute to the main objective of this research. Therefore, they were not assessed in this study.

3.2.3 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 & Meitner, 2005). They have been regularly adopted in several fields including sustainability (Graymore, Sipe, & Rickson, 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, this research has 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.

3.2.4 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 & Prabhu, 2003; Niemeijer & Groot, 2008; Niemi & McDonald, 2004; Wolfslehner & 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 research team 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 Costantino et al. (2004) – as described in the Table 3.1 below.

Table 3.1 – 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; Costantino et al., 2004

3.2.5 Sustainability Criteria

At this stage of the research, the indicators related to water use and management were evaluated according to the sustainability criteria. Indicators are key tools that help the society to monitor progress and trends on the path towards sustainable water use and management (WWAP, 2003). Hence, as mentioned by Niemeijer & Groot (2008) and others (BNIA, 2006; SNZ, 2002; WHO, 2002), indicators should include the sustainability criteria. The revision of criteria for evaluating indicators (see previous section) identified that sustainability is one of the most relevant criteria for evaluating indicators (Bélanger et al, 2012; IISD, 2008; UN, 2007;).

One of the most well-known sustainability principles is the "triple bottom-line approach", also called the "three pillars of sustainability", which includes the environmental, economic and social dimensions of sustainability (Elkington, 1997; Juwana, Muttil & Perera, 2012). However, in 1995 the UN Division for Sustainable Development (UNDPCSD, 1995) formally introduced the institutional dimension as the fourth dimension of sustainable development. According to the International Institute for Sustainable Development (IISD, 2008), the sustainability criterion "*considers the underlying social, economic and environmental system as a whole, including issues related to governance*". Governance can be understood as the main element of the institutional dimension of sustainability. It should be mentioned that there are also other possible dimensions of sustainability such as the cultural dimension (Hawkes, 2001).

Our research 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.

3.2.6 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 (see previous section).

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 other researchers to provide independent, expert judgement to the assessment of indicators (Singh, Murty, Gupta, & Dikshit, 2009). Fourteen experts from the Ibero-american 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. 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.

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 3.2).

Table 3.2 - Classification levels 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.

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 & Dominick, 2010).

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).

$$Si_{(c)} \equiv \frac{\sum_{1}^{n} Si_{(c)}}{n}$$

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 (expert panel) were also used to graphically represent the results. The frequency histograms show in what ranges most of the data is or around what value the results tend to concentrate. It indicates the dispersion of the data obtained from the results of the study.

Selection of the indicators

This study aimed at selecting indicators 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.

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 & Medina, 2012; WWAP, 2003). This research adopted a four-components system framework (social, environmental, economic, and institutional), based on the sustainability criteria presented above.

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 the Table below. The classification into these categories is based on the number of criteria fulfilled by the indicator. The indicators of interest for our research are the ones that fulfil the majority of the sustainability criteria (3 or more criteria).

Table 3.3 – 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	-

3.2.7 Pilot Study

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 & 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.

3.3 RESULTS

This study identified 170 indicators related to water use and management in the literature. In total, the 14 members of the panel provided 9,520 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 3.3, 3.4 and 3.5.

From this initial list of 170 indicators of water use and management, 24 indicators (14%) comply with the majority of the sustainability criteria (Annex 3.3). They are the indicators of interest for this research. Fifty-nine are bi-dimensional indicators, meaning that they comply with two sustainability criteria (Annex 3.4) and 86 indicators are one-dimensional indicators, fulfilling one sustainability criterion (Annex 3.5). This last annex also presents the only one indicator that did not fulfil any of the 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 3.2 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.

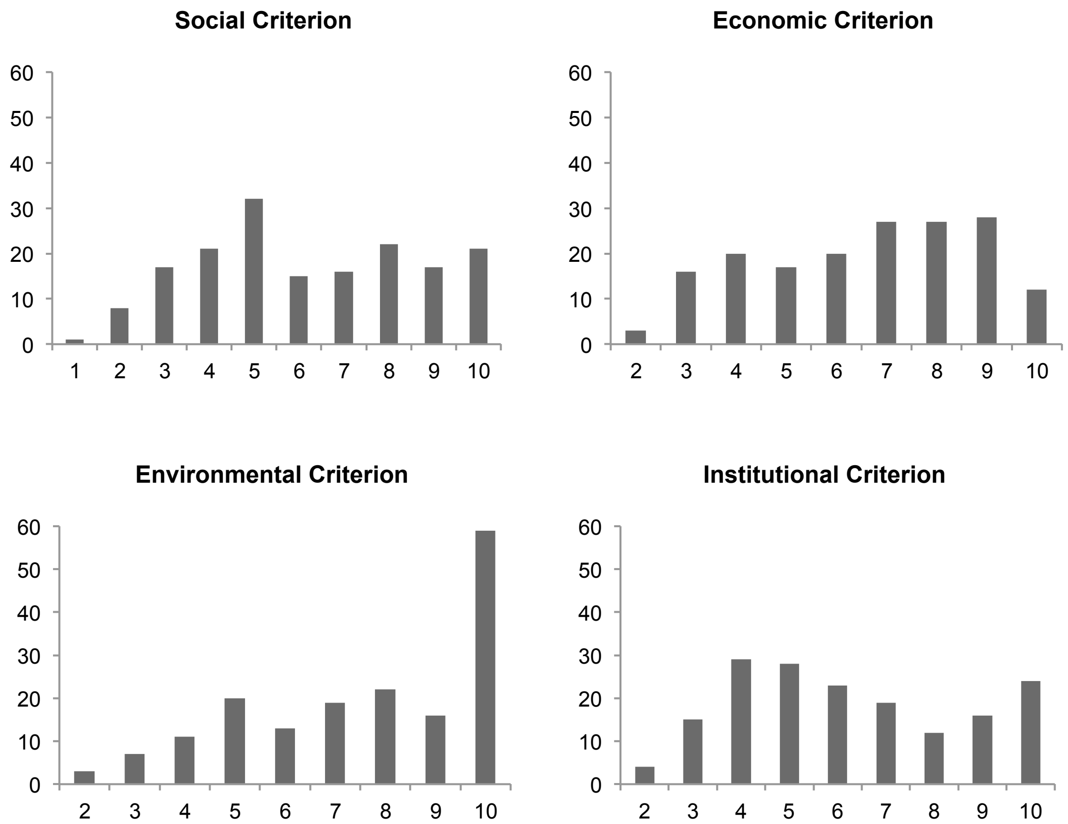

Figure 3.2 - Frequency histograms for the average scores of the 170 indicators related to water use and management by each of the four sustainability criteria (vertical axis represents the frequency of the answers, and the horizontal represents the scores).

Table 3.4 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 3.5 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.

Table 3.4 – 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 3.5 – 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%

3.4 DISCUSSION

3.4.1 Criteria Assessment

The assessment of the 74 publications reviewed by this research indicated that the end-use criteria were considered more relevant and broader in scope in comparison with the scientific criteria. The publications analysed by this study listed a total of 205 mentions of the end-use criteria and 141 mentions of the scientific criteria (Annexes 3.1 and 3.2). There are 35 different end-use criteria identified by this research and only 25 scientific criteria, showing a greater variety of the former. This points to a broader scope of end-use criteria in the assessment of indicators. Thus, it is crucial that indicator developers not only consider the scientific aspects of the indicators but also assess the most relevant end-use criteria for their application. Several authors also notice the importance of the end-use criteria, including (Bockstaller and Girardin, 2003; Cloquell-Ballester et al., 2006; Meul et al., 2009).

It is worth mentioning that several criteria were assessed by the following stages of the research:

- Chapter 4 addresses the assessments of the indicators based on three criteria: “scientific foundation”, “individuality”, “spatial scale” and “specificity”;
- Chapter 5 evaluates the criterion “causal links” using eDPSIR as the framework to identify the cause-effect chain of the selected indicators.
- Chapter 6 presents the validation process of the selected indicators based on the most relevant scientific and end-use criteria, namely “reliability”, “measurability”, “sensitivity”, “ data availability”, “relevance” and “comprehensibility”

The study used 12 criteria in total to assess the indicators. Six of them are scientific criteria: scientific foundation, specificity, spatial scale, reliability, measurability and sensitivity. Six are end-use criteria: sustainability, individuality, causal links, data availability, relevance and comprehensibility. They represent only 12 of the long list of criteria (60 in total), but they are very relevant covering 51% of all mentions found in the bibliography (178 out of 346 mentions).

When selecting criteria to assess indicator performance it is important to consider that certain criteria are divergent (i.e. “applicable to many areas, situations and scales” and “specific for a certain stress or effect”). Therefore no one should expect that an indicator fulfills all the criteria listed by this research. Nevertheless, the indicator should be assessed against the criteria that are relevant for the problem at hand. The number of criteria used to assess indicators is important both from a scientific standpoint, and from an appraiser standpoint (Cloquell-Ballester et al., 2006).

Using a greater number of criteria can increase the quality of the assessment by assessing validity from a greater number of angles (Niemeijer & de Groot, 2008). However, the quality of the selection process also depends on the engagement and interest of participants. Too many criteria would take a longer time and would require more concentration, and therefore increases the chance of respondent fatigue, as well as deteriorates the attention and motivation of respondents (Ben-Nun, 2008).

The names and the definitions of the criteria presented in this study also resulted in bringing some clarity in a field that lacks standardization (Niemeijer & de Groot, 2008; Gudmundsson, 2010). Nevertheless, they are not exempt from certain levels of overlapping, redundancy or ambiguity and thus, could be further improved in future studies. Furthermore, the assessment of the criteria is a crucial element on the process of evaluating indicators, by allowing appraisers to performance quality check and validation procedures.

The criteria assessment presented by this study could be considered a relevant contribution for the research on indicators, since no previous work was found that has conducted such a broad and up-to-date review. Furthermore, the tables of criteria, ordered according to their relevance (Annexes 3.1 and 3.2), could be used by future studies to identify and select the criteria that fits their interests. This assessment of criteria was built in a transparent and replicable way, so that it can be further developed with the incorporation of new sources, of new criteria and/or regular updates.

3.4.2 Indicators of Sustainable Water Use and Management

The ultimate purpose of this stage of the research was to identify the indicators of water use and management that fulfil the sustainability criteria. In order to reach this objective, the study analysed specialized literature, constructed an assessment matrix, convened an international panel of experts and run a pilot study prior to full implementation. Findings of the current study support that 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.

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 3.3) 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. Chapter 4 addresses in greater detail these 24 indicators.

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.

It should be mentioned, that this research 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 living planet index", tracks changes in freshwater species found in freshwater ecosystems, since the baseline year of 1970, including data on 2,750 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).

It is also worth mentioning that the assessment of the 170 indicators related to water use and management can be considered as a useful contribution to water resources and sustainability science. Our study briefly described and organized these indicators in comprehensive lists. Their classifications under two relevant frameworks (DPSIR and system approach) were presented. Furthermore, they were categorized according to their sustainability criteria by an international panel of experts. So far, no other scientific publication that has done a similar assessment has been found. Furthermore, several authors (Dahl, 2012; WWAP, 2003; among others) point out that indicator development is a continuous process and therefore this list is not encircled in itself and other indicators may be included by future studies.

3.4.3 Further Discussions

Niemeijer & Groot (2008), Wolfslehner & Vacik (2011), WWAP (2003), among other authors consider that the adoption of an adequate framework, such as the ones adopted in this study (DPSIR and system approaches), is helpful for organizing indicators into a coherent form and making them compatible with their application. The organizational structure also helps to guide the data harvesting and to identify missing information. Moreover, the use of a powerful framework suggests logical ways to integrate related information, facilitate communication with the decision-makers and understand the generated information (Gallopin, 2006).

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 then 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".

Vacik, Wolfslehner, Seidl & Lexer (2006) highlight that *"in practice, it is not an easy task to assign an indicator to one of the DPSIR clusters because 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.

Another issue that should be considered when applying the DPSIR approach to indicators of water use and management is that some of these indicators 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), it is expected that an index to measure sustainability would be 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 & Huntingford, 2009).

The utilization of a pilot study was a relevant stage of research prior to engaging in full scale. As mentioned by Van Teijlingen & Hundley (2001) some methodological issues may only become clear when put into practice. The pilot study provided an invaluable opportunity to assess the methodology and to identify and make necessary changes prior to complete implementation. The methodology and data analysis were largely approved through this exercise. Participants provided feedback on the evaluation matrix and methodology, leading to improvements in the design of the study. This research recommends the use of pilot tests in similar studies.

Last but not least, 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 research.

3.5 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. In addition, the application of proper criteria to assess indicators is crucial to guarantee the quality and reliability of the indicator set. Nevertheless, the identification and selection of criteria and indicators is usually not done in a transparent, replicable and scientifically valid way.

Our study aimed to fill these gaps by presenting solid and reliable knowledge on criteria and indicators of sustainable water use and management. In order to do this, the research carried out a comprehensive assessment of the criteria for the evaluation of indicators; identified the indicators related to water use and management, and evaluated by an international panel of experts to assess whether these indicators fulfil the sustainability criteria.

Sixty criteria for the assessment of indicators were identified, properly named and described. They were organized into two groups (scientific and end-use criteria) and ranked according to their relevance. This assessment is one of the broader and most up-to-date reviews on this subject. It gave solid ground for the next steps of our research and provided transparency and proper fundaments for the selection of criteria, that surely will benefit further research on this topic.

A significant number of indicators related to water use and management were also identified: 170 indicators in total. 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 146 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,.

Finally, this section of the research reached its objective and 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.

Although the identification of sustainability indicators is essential, the research project has a broader objective that goes beyond. The main objective is to identify and validate a set of indicators that would allow decision makers to evaluate the sustainability of water use and management at river basin level. In other to address the key concerns of water managers, the indicators should meet other criteria such as validity for the proper geographic scale and whether it is based on currently sound and internationally accepted scientific standards. These issues are addressed in the next chapter, where a multi-criteria and sequential process is used to select out of the 24 indicators, those that fulfil four key criteria: scientific foundation, individuality, river basin scale and specificity.

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3.7 ANNEXES

Annex 3.1 – Scientific criteria to assess indicators.

Citations*	Name and Definition of the Criteria	Sources
19	**Scientific foundation** "The extent to which an indicator is based on currently sound and internationally accepted theoretical, conceptual, technical, and scientific standards and principles. (adapted from UNEP, 2006)	Niemeijer & Groot, 2008 (4x)**; WWAP, 2006; Bockstaller and Girardin, 2003; Bockstaller et al 2008; Aveline et al, 2009; Cloquell-Ballester et al., 2006; Parris and Kates, 2003; Clark & Dickson, 1999; UNEP, 2006; SNZ, 2002; UN, 2007; BNIA, 2006; WHO, 2002; OECD, 2003; FAO, 1999, World Bank, 2000
18	**Reliability** "The extent to which an experiment, test, or measuring procedure yields the same results on repeated trials" (Websters Dictionay)	Niemeijer & Groot, 2008 (2x)**; Bringhenti et al, 2011; Cloquell-Ballester et al., 2006; UNEP, 2006; SNZ, 2002; ITFM, 1995; BNIA, 2006; Kurka and Blackwood, 2013; Rovere et al, 2010; Graymore et al, 2009; Buchholz et al, 2009; Singh et al, 2009; Wang et al, 2009; Bélanger et al, 2012; Segnestam, 2002; OECD, 2003; World Bank, 2000; Gudmundsson, 2010
15	**Measurability** "The extent to which the proposed measurement procedures to obtain the indicator adopts standardized methods" (adapted from Cloquell-Ballester et al., 2006)	Niemeijer & Groot, 2008 (4x)**; WWAP, 2006; IISD, 2008; Cloquell-Ballester et al., 2006; Prescott-Allen, 2001; US EPA, 2000; UNEP, 2006; SNZ, 2002; ITFM, 1995; BNIA, 2006; WHO, 2002; World Bank, 2000
13	**Sensitivity** "The extent to which a small change in the factor measured should result in a measurable change in the indicator" (adapted from WWAP, 2006)	Niemeijer & Groot, 2008; WWAP, 2006; Aveline et al, 2009; Bockstaller et al 2008; IISD, 2008; Cloquell-Ballester et al., 2006; SNZ, 2002; ITFM, 1995; Bélanger et al, 2012; WHO, 2002; OECD, 2003; World Bank, 2000; Gudmundsson, 2010
10	**Accuracy** - "The extend to which the result of a measurement, or of an indicator conforms to the correct value" (adapted Oxford Dictionary of English, 2014)	Bockstaller and Girardin, 2003; Bockstaller et al 2008; Aveline et al, 2009; ITFM, 1995; Bringhenti et al, 2011; Cloquell-Ballester et al., 2006; Meul et al, 2009; OECD; 2003; FAO, 1999; Gudmundsson, 2010
9	**Specificity** - "Clearly and unambiguously defined" (Niemeijer & Groot, 2008)	Niemeijer & Groot, 2008 (4x)**; WWAP, 2006; UNEP, 2006; SNZ, 2002; Segnestam, 2002; World Bank, 2000
8	**Time-bound -** "Measure changes on an appropriate temporal scale" (SNZ, 2002)	Niemeijer & Groot, 2008 (4x)**; IISD, 2008; US EPA, 2000; SNZ, 2002; ITFM, 1995
8	**Representativeness -** "Related to a specific question or issue of concern and representative of the conditions in question" (WHO, 2002)	Niemeijer & Groot, 2008; WWAP, 2006; Bringhenti et al, 2011; ITFM, 1995; WHO, 2002; Prescott-Allen, 2001; SNZ, 2002; World Bank, 2000
6	**Data quality -** "The data used to establish the indicator are adequately documented and of known quality" (adapted from OECD, 2003)	US EPA, 2000; Segnestam, 2002; OECD, 2003; FAO, 1999; World Bank, 2000; Cloquell-Ballester et al., 2006
5	**Space-bound -** "Adopt an appropriate geographical scope" (IISD, 2008)	Niemeijer & Groot, 2008; IISD, 2008; US EPA, 2000; SNZ, 2002; ITFM, 1995
5	**Anticipatory** - "Provides an early warning of changes" (ITFM, 1995)	Niemeijer & Groot, 2008; WWAP, 2006; ITFM, 1995; WHO, 2002; World Bank, 2000
5	**Spatial and temporal scales of applicability** "Provide information at the appropriate spatial and temporal scales" (Niemeijer & Groot, 2008)	Niemeijer & Groot, 2008 (2x)**; Segnestam, 2002; ITFM, 1995; World Bank, 2000
4	**Robustness -** "Be relatively insensitive to expected sources of interference" (Niemeijer & Groot, 2008)	Niemeijer & Groot, 2008; WWAP, 2006; WHO, 2002; FAO, 1999
2	**Predictability** - "Respond in a predictable manner to changes and stresses" (Niemeijer & Groot, 2008)	Niemeijer & Groot, 2008; SNZ, 2002
2	**Universality** - "Applicable to many areas, situations and scales" (Niemeijer & Groot, 2008)	Niemeijer & Groot, 2008; WWAP, 2006
2	**Discriminatory - "**Ability to discriminate differences separating extraneous variability" (US EPA, 2000)	US EPA, 2000; ITFM, 1995
2	**Uncertainty -** "Detailed with regards to uncertainties and limitations" (WWAP, 2006)	Niemeijer & Groot, 2008; WWAP, 2006

Annex 3.1 – Scientific criteria to assess indicators (cont.).

Citations*	Name and Definition of the Criteria	Sources
1	**"Portability** – Be repeatable and reproducible in different contexts"	Niemeijer & Groot, 2008
1	**"Specific** for a certain stress or effect"	WWAP, 2006
1	**"General importance** – Bear on a fundamental process or widespread change"	Niemeijer & Groot, 2008
1	**"Formulation** - The mathematical formulation of the indicator is suitable with regard to the concept which is to be quantified"	Cloquell-Ballester et al., 2006
1	**"Transformable** – intelligent"	WWAP, 2006
1	**"Estimation of measurement error** - must be estimated and reported"	US EPA, 2000
1	**"Integrates effects/exposure** - Integrates effects or exposure over time and space"	ITFM, 1995
1	**"Focus on causes**, not symptoms"	BNIA, 2006

Total: 141 mentions of 24 scientific criteria
*Number of sources that mentions the criterion under analyses
** Number of the sources that mentioned the criteria on the meta-review done by Niemeijer & Groot (2008)

Annex 3.2 – End-use criteria to assess indicators.

Citations*	Name and Definition of the Criteria	Sources
31	**Data availability** "The extent which the data required for the indicator is easy or possible to get at a reasonable cost" (adapted from Merriam-Webster Dictionary of English, 2014 and OECD, 2013)	Niemeijer & Groot, 2008 (3x)**; WWAP, 2006; Bringhenti, et al 2011; BNIA, 2006; Cloquell-Ballester et al., 2006; Prescott-Allen, 2001; UNEP, 2006; SNZ, 2002; Segnestam, 2002; ITFM, 1995; UN, 2007; Kurka and Blackwood, 2013; Lattimore et al, 2009; Vera & Langlois, 2007; Fraser et al, 2006; Olsthoorn et al, 2001; Rovere et al, 2010; Shmelev & Rodríguez-Labajos, 2009; Graymore et al, 2009; Buchholz et al, 2009; Singh et al, 2009; Wang et al, 2009; Butler et al, 2003; Bélanger et al, 2012; WHO, 2002; OECD, 2003; FAO, 1999; World Bank, 2000; Gudmundsson, 2010
25	**Relevance** "The extent which an indicator is related or connected to the matter in hand" (adapted from Merriam-Webster Dictionary of English, 2014)	Niemeijer & Groot, 2008 (4x)**; Cloquell-Ballester et al., 2006; Parris and Kates, 2003; Clark and Dickson, 1999; US EPA, 2000; UNEP, 2006; SNZ, 2002; ITFM, 1995; UN, 2007; BNIA, 2006; Kurka and Blackwood, 2013; Lattimore et al, 2009; Rovere et al, 2010: Graymore et al, 2009; Gilmour et al, 2007; Buchholz et al, 2009; Wang et al, 2009; Doukas et al, 2007; Baker et al, 2002; Butler et al, 2003; WHO, 2002; World Bank, 2000
21	**Comprehensibility** "The extent which the indicator is able to be understood by the target audience" (adapted from Oxford Dictionary of English, 2014)	Niemeijer & Groot, 2008 (2x)**; WWAP, 2006; Aveline et al, 2009; Bockstaller et al 2008; IISD, 2008; Cloquell-Ballester et al., 2006; UNEP, 2006; SNZ, 2002; ITFM, 1995; UN, 2007; BNIA, 2006; Kurka and Blackwood, 2013; Fraser et al, 2006; Singh et al, 2009; Butler et al, 2003; Bélanger et al, 2012; WHO, 2002; OECD, 2003; FAO, 1999; Gudmundsson, 2010
13	**Usefulness -** "User-driven to be relevant to target-audience" (Niemeijer & Groot, 2008)	Niemeijer & Groot, 2008; WWAP, 2006; Bockstaller and Girardin, 2003; Bockstaller et al, 2008; Aveline et al, 2009; IISD, 2008; Meul et al, 2009; Segnestam, 2002; BNIA, 2006; Bélanger et al, 2012; WHO, 2002; FAO, 1999; World Bank, 2000
10	**Target oriented -** "Have a threshold and/or target against which to compare the indicator" (adapted from OECD, 2003)	Niemeijer & Groot, 2008; WWAP, 2006; IISD, 2008; US EPA, 2000; UNEP, 2006; SNZ, 2002; ITFM, 1995; BNIA, 2006; OECD, 2003; Gudmundsson, 2010
10	**Operational simplicity** "Simple to measure, manage and analyse" (Niemeijer & Groot, 2008)	Niemeijer & Groot, 2008 (2x)**; Aveline et al, 2009; Bockstaller et al 2008; SNZ, 2002; ITFM, 1995; UN, 2007; FAO, 1999; World Bank, 2000; Gudmundsson, 2010
10	**Compatibility – "**Be compatible with indicators developed and used in other regions" (Niemeijer & Groot, 2008)	Niemeijer & Groot, 2008 (2x)**; WWAP, 2006; UNEP, 2006; UN, 2007; Kurka and Blackwood, 2013; Rovere et al, 2010; Wang et al, 2009; Doukas et al, 2007; OECD, 2003
9	**Linkage to management action** – "Provide information to support a management decision or to quantify the success of past decisions" (US EPA, 2000)	Niemeijer & Groot, 2008 (3x)**; WWAP, 2006; US EPA, 2000; UNEP, 2006; SNZ, 2002; FAO, 1999; Gudmundsson, 2010
9	**Retrospectivity** – "Able to show trends over time" (OECD, 2003)	Niemeijer & Groot, 2008 (2x)**; WWAP, 2006; SNZ, 2002; IISD, 2008; ITFM, 1995; OECD, 2003; FAO, 1999; FAO, 2000
9	**Resource demand –** "Logistical requirements (personnel, equipment, training) are reasonable" (US EPA, 2000)	Niemeijer & Groot, 2008 (5x)**; IISD, 2008; US EPA, 2000; UNEP; 2006; UN, 2007
7	**Sustainability** – "Consider the underlying social, economic and environmental system as a whole, including issues related to governance and the interactions among its components" (IISD, 2008)	Niemeijer & Groot, 2008; IISD, 2008; SNZ, 2002; UN, 2007; BNIA, 2006; Bélanger et al, 2012; WHO, 2002
7	**Cost-Effectiveness** – "Benefits of the information provided by the indicators should outweigh the cost of usage" (Niemeijer & Groot, 2008)	Niemeijer & Groot, 2008; Cloquell-Ballester et al., 2006; US EPA, 2000; Segnestam, 2002; ITFM, 1995; FAO, 1999; World Bank, 2000
5	**Participatory –** "Developed with the participation of a broad range of stakeholders to ensure the indicators: encompass community visions and values; and promote ownership" (UNEP, 2006)	IISD, 2008; Parris and Kates, 2003; Clark and Dickson, 1999; WWAP, 2006; UNEP, 2006

Annex 3.2 – End-use criteria to assess indicators (cont.).

Citations*	Name and Definition of the Criteria	Sources
5	**Causal links –** "Cause-effect chain has to be known to enable tackling of the problem" (WWAP, 2006)	WWAP, 2006; IISD, 2008; SNZ, 2002; OECD, 2003; World Bank, 2000
5	**Individuality** – "Are the indicators independent enough or do they duplicate other C&I?" (Kurka and Blackwood, 2013)	Kurka & Blackwood, 2013; Rovere et al, 2010; Graymore et al, 2009; Wang et al, 2009; Doukas et al, 2007
3	**Transparency** – "ensure it is accessible to the public; explain the underlined choices, assumptions and uncertainties; disclose data sources and methods; and disclose all sources of funding and potential conflicts of interest." (IISD, 2008)	IISD, 2008; Gudmundsson, 2010; UNEP, 2006
3	**Flexibility – "**Are flexible, so new information can lead to adjustments in the indicator" (UNEP, 2006)	Aveline et al, 2009; Bockstaller et al 2008; UNEP, 2006
2	**Linked to models, forecasting and information systems**	WWAP, 2006; OECD, 2003
2	**Conceptual framework –** "Be developed within an agreed-upon conceptual and operational framework" (WWAP, 2006)	IISD, 2008; WWAP, 2006
2	**National in scope** – "Be either national in scope or applicable to regional environmental issues of national significance" (OECD, 2003)	UN, 2007; OECD, 2003
2	**Ecological function** – "Conceptually linked to ecological function of concern" (US EPA, 2000)	US EPA, 2000; Segnestam, 2002
2	**Pedagogy:** Educational aim "helps to make the factors understandable to the public" (Aveline et al, 2009)	Aveline et al, 2009; Bockstaller et al 2008
1	**Quantified** – "Information should be quantified in such a way that it is significant apparent"	Niemeijer & Groot, 2008)
1	**Policy Changes - "**Recording either changes in the means recommended by policy or changes in the development impact attributable to policy "	WWAP, 2006
1	**Guiding vision** - be guided by the goal of delivering well being within the capacity of the biosphere to sustain it for future generations	IISD, 2008
1	**Boundaries** - Takes into consideration risks, uncertainties, and activities that can have an impact across boundaries	IISD, 2008
1	**Continuous learning and improvement**	IISD, 2008
1	**Ethical concerns -** An indicator must comply with fundamental human rights and must require only data that are consistent with morals, beliefs or values of the population	Gudmundsson, 2010
1	**Information management** - requirements for data analysis, storage, processing, documentation and retrieval are feasible	US EPA, 2000
1	**Quality assurance** - degree of validity of the steps in collation and computation of data aiming to assure the quality of the indicator	US EPA, 2000
1	**Program coverage -** Program uses suite of indicators that encompass major components of the ecosystem over the range of environmental conditions that can be expected	ITFM, 1995
1	**Relate to the whole community**	BNIA, 2006
1	**Focus on resources and assets** (framed in a positive way / focus on problems or assets)	BNIA, 2006
1	**Adapted to the objectives** - Does the indicator meet the objectives?	Bélanger et al, 2012
1	**Formal (legal) foundation**	FAO, 1999

Total: 205 mentions of 25 end-use criteria

*Number of sources that mentions the criteria

** Number of the sources that mentioned the criteria on the meta-review done by Niemeijer & Groot (2008)

Annex 3.3 – The 24 indicators that fulfil the majority of the sustainability criteria - selected indicators for our research.

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Water Poverty Index	Provides a better understanding of the relationship among the physical extent of water availability, its ease of abstraction and the level of community welfare. Evaluates 5 strategic elements: resource, access, management capacity, uses, and environment.	P, S, I, R	**9.8**	**8.9**	**9.3**	**8.8**	9.2
Climate Vulnerability Index	Links water resources with human vulnerability assessments, considering the following aspects: geographical vulnerability of the location, water resources available, access to water, how effectively water is used, capacity to manage water, and environmental impacts.	P, S, I, R	**9.4**	**7.6**	**9.8**	**7.9**	8.7
Water shortages	Represents the number of people and countries affected by water shortages, the number of countries unable to supply minimum drinking water.	I	**9.5**	**8.9**	**7.6**	**7.5**	8.4
Fraction of the burden of ill-health from nutritional deficiencies	Accounts for the percentage of the burden of ill-health resulting from nutritional deficiencies, attributable to water scarcity effects on food supply.	I	**8.9**	**8.2**	**7.1**	**7.4**	7.9
Water Reuse Index	Considers consecutive water withdrawals for domestic, industrial, and agricultural water use along a river network relative to available water supplies. A measure of upstream competition and potential ecosystem and human health impacts.	P, S	**9.6**	**8.1**	**9.6**	6.9	8.5
Water Footprint	The sum of water directly used and virtual water. Represents the amount of water required to produce the resources needed by one person, based on lifestyle and consumption.	P	**9.1**	**8.6**	**9.5**	5.7	8.2
Incidence of worms, scabies, trachoma, diarrhea	Represents the number of countries that have presented incidence of worms, scabies, trachoma, and diarrhea above predefined limits. Considers health problems in urban populations linked to contaminated water, lack of water supply, and sanitation.	I	**9.4**	6.8	**8.5**	**8.2**	8.2
Performance Index of Water Utilities	Accounts for the performance of water service providers in urban areas assessed in terms of affordability, quality of water supplied, accessibility to service, quantity of water supplied, and reliability. The level of performance of these utilities dictates how well the cities are being served.	S	**9.3**	**7.9**	6.3	**9.3**	8.2
Access to Improved Sanitation	Represents the proportion of the population (total, urban, and rural) with access to an improved sanitation facility (for defecating).	I	**9.5**	6.9	**8.2**	**7.6**	8.0
Proportion of Urban Population Living in Slums	Provides a measure for identifying the percentage of the urban population living in slums based on an assessment of the following several conditions: access to safe water, access to sanitation, secure tenure, durability of housing, and sufficient living area.	P, S	**9.3**	**8.6**	6.6	**7.5**	8.0
Social and Economic Impacts from Drought	Considers water-related disasters: number of drought and the socioeconomic losses associated with them (deaths, people affected, and property damage).	I	**7.7**	**8.4**	**9.4**	**5.9**	7.8
Incidence of cholera	Represents the number of cholera cases per region. The disease is linked to contaminated water and food and occurs more frequently where access to safe drinking water and basic sanitation cannot be ensured.	I	**9.6**	**6.6**	**8.0**	**7.1**	7.8

Annex 3.3 – The 24 indicators that fulfil the majority of the sustainability criteria - selected indicators for our research (cont.).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Causes of food emergencies	Considers the causes of food emergencies: comparison between number of countries affected vs. human-induced disasters and number of countries affected vs. natural disasters.	I	**8.1**	**7.6**	**8.9**	6.6	7.8
Ecological footprint	The amount of land required to produce the resources needed by one person, based on land type (arable, pasture, forest, fossil energy land, built-up area, and water area) and consumption (food, housing, transportation, goods, services. and waste).	P	**9.1**	**7.3**	**9.5**	5.2	7.8
Progress towards achieving IWRM target	Categorizes countries into three groups based on ten specific criteria of Integrated Water Resources Management: 1) good progress and being on the road towards meeting the target; 2) only some progress; 3) hardly any progress made.	R	**7.3**	**7.1**	6.6	**10.0**	7.7
Water Provision Resilience	Provides a means of approximating the ability of a city or water provider to maintain or increase the portion of the population with access to safe water. Assesses six aspects: supply, finances, infrastructure, service provision, water quality, and governance.	S, R	**8.0**	**7.6**	5.6	**9.1**	7.6
Major drought events and their consequences	List of major drought events and their associated loss of life and economic losses in the last 100 years.	I	**7.3**	**9.1**	**8.0**	4.9	7.3
Relative Water Stress Index	Domestic, Industrial, and Agricultural water demand per available water supply. This indicator is also known as Relative Water Demand (RWD). RWSI = DIA / Q	P, S	**8.5**	**8.7**	**7.0**	4.9	7.3
Index of Non-sustainable Water Use	It is the result of renewable available freshwater resources (Q) minus geospatially distributed human water demand for Domestic, Industrial, and Agricultural (DIA). INSWU = Q - DIA	P, S	**8.9**	**8.5**	**8.0**	3.2	7.2
Water sector share in total public spending	Represents the percentage of the national budget spent in the water sector for expanding access to water supplies and improving water resources management and governance.	R	**7.3**	**7.3**	4.7	**9.4**	7.2
Country's dependence ratio	The relation between the surface and ground water that inflows from neighboring countries (or other given geographic divisions) and the total amount of water available at annual bases.	P, S, I	**7.0**	**7.2**	6.8	**7.5**	7.1
Pro-poor and pro-efficiency water fees	Assesses the application of economic and financial tools in water allocation (fees and charges) favoring the poor (pro-poor policy) and efficient water use.	S, I	**7.1**	**8.4**	4.0	**8.9**	7.1
Water topics in school curriculum	Represents the number of countries (or other geographic division) that have introduced water-related content into school curricula.	S	**8.9**	2.4	**7.1**	**8.3**	6.7
Total water storage capacity	The total water storage capacity in artificial storage structures above a minimum size (e.g. 5000 m^3)	P, S, R	4.5	**7.2**	**7.1**	**7.2**	6.5

*Criteria average score: Social, Economic, Environmental and Institutional.

Sources: see Annex 3.5

Annex 3.4 - Indicators that comply with two sustainability criteria (bi-dimensional).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Existence of legislation advocating Dublin principles for water (1992)	Existence of legislation in issues related to water sustainability and management, participatory approach, gender and economic value (is the base-line for IWRM)	R	6.8	6.8	**7.6**	**9.8**	7.8
Access to safe drinking water	The proportion of the population (total, urban and rural) with access to an improved drinking water source as their main source of drinking water.	I	**9.8**	**7.6**	6.4	6.6	7.6
Water use by sector	Water withdrawal by sector as a percentage of total water withdrawal	S	**8.5**	**8.5**	6.3	6.4	7.4
Burden of water-associated diseases (expressed in DALYs) with Comparative Risk Assessment	Total amount of DALYs related to water-associated diseases. In the poorest regions of the world, unsafe water, sanitation and hygiene are major contributors to loss of healthy life, expressed in DALYs (Disability Adjusted Life Years). The sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability.The Comparative Risk Assessment (CRA), aims to assess risk factors in an unified framework. It provides a vision of potential gains in population health by reducing exposure to a risk factor or a group of risk factors.	I	**9.3**	6.3	**7.3**	6.6	7.4
Risk reduction and preparedness action plans formulated	Existence of Risk Reduction Plans and preparedness actions implanted to face uncontroled water-related climatic events (drought, floods, etc.).	R	6.1	6.1	**7.4**	**9.8**	7.3
Basin Water Dependency	Relation between the number of people that depend exclusively on internal renewable water resources and the total number of habitants.	P, S, I	**9.4**	5.6	**8.2**	5.9	7.3
Disaster Risk Index	Compares the average population exposed to water-related hazards with average annual deaths caused by these hazards. Risk is model ledusing socio-economical parameters. Multiparameter equation.	S,I	**8.6**	**8.2**	6.6	5.0	7.1
Cooperation and conflict on Shared basins / aquifers	The number of events related to conflicts or cooperation in shared basins / aquifers. The WWDR, 2003 proposed to classify each event in a 15 levels scale that varies from the conflict side (formal war, extensive military acts, etc) to the cooperation side (water treaties, unification, etc)	R	**7.2**	6.4	6.1	**8.8**	7.1
Demand changes (sectoral) and distribution	Changes over time in the demand of water by sector (industrial, agricultural and domestic), expressed in annual growing.	P	**8.7**	**8.3**	5.8	5.6	7.1
Human Poverty Index: 5 indicators	HDI consists of three main components; longevity, knowledge and standard of living, and assesses these components as development.	S	**9.1**	**7.8**	4.2	6.8	7.0

Annex 3.4 - Indicators that comply with two sustainability criteria (bi-dimensional) (cont. 2/6).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Number of surface and groundwater users licensed according to the regulations	Number of licenses issued. May be further divided by total number of user.	R	**7.4**	6.4	5.8	**8.4**	7.0
Industrial use of water per capita	Annual amount of water used by the industrial sector divided by the number of inhabitants at a given region	P	**7.6**	**8.7**	5.9	5.4	6.9
Child mortality rates: deaths per 1,000 live births	Number of children (presented in relation to 1,000 live births) that died due to causes related to water provision, sanitation, drainage, waste removal and healthcare system (i.e. diarrhoea diseases, etc.).	S,I	**9.6**	5.4	5.6	**7.0**	6.9
Land cover profile	Distribution of the land cover in a given region according to categories such as: forest, cropland (irrigated and no-irrigated), grassland, wetland, urban area, etc.	S	**7.2**	5.6	**9.3**	5.3	6.8
Investment in debugging (cleaning up)	Annual budget for water quality programs, including proceedings in treatment and management of public water.	R	4.1	**7.8**	6.1	9.1	6.8
Groundwater development indicator	Indicates the groundwater abstraction as a percent of the groundwater recharge component (GAR)of the Total Actual Renewable Water Resources(TARWR). The quantity of groundwater resource susedby major sectors(municipal, agricultural, industrial) depends on the groundwater recharge component(GAR) of TARWR.	S	6.1	**7.7**	**8.6**	4.8	6.8
Overharvesting – fisheries catch	Overharvesting and exploitation of depletes living resources in relation to the natural restore rate of the fish specie: impacts on biodiversity loss and ecosystem functions. Collapse of fisheries or dramatic decline	P,I	3.9	**8.5**	**9.8**	4.8	6.8
Budget allocation for water risk mitigation	Total amount of money allocated by public (and private sector, in some cases) each year to deal with water risk mitigation – compared to the total budget of the institutions.	P, I	4.2	**7.6**	5.6	**9.5**	6.8
Land converted to agriculture	Total forest are a per year converted to agricultural use. As forest land is changed to agriculture use, the products and services provided by that ecosystem (such as timber, water, wildlife, carbon storage, aesthetic beauty, etc.) are reduced/lost.	D, P, S, I	3.9	**8.6**	**9.5**	4.8	6.7
Knowledge Index (KI)	Average of the rankings of the performance of a country or region in three areas: education, innovation, and information and communications technology.	S	**8.0**	6.1	3.7	**8.9**	6.7
Metals in groundwater	Indicates the presence of hazardous substances in groundwater. Includes metals and metalloids: Arsenic, Cadmium, Lead and Mercury, naturally occurring and / or as result of human activities. It is an indicator of water quality for human consumption.	I	**7.2**	5.3	**10.0**	4.2	6.7
Population density	Number of people living per square 41ilometre of the basin.	P	**8.2**	6.1	**7.6**	4.7	6.7

Annex 3.4 - Indicators that comply with two sustainability criteria (bi-dimensional) (cont. 3/6).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Water source distance from demand centre: > 8 km	Percent of the total population of a given area that its water supply comes from a source over 8 km far from the demand centre.	P,S,I	**9.6**	**7.1**	4.1	5.8	6.6
Water supply cost related to users I income	Annual cost of water supply paid by user divided by the total annual income of the user (applied to urban, industrial and agriculture uses).	R	**8.4**	**9.8**	2.0	6.1	6.6
Great natural catastrophes	List of major natural catastrophes: number of occurrences of floods, windstorms, earthquakes and volcanic 42ruption. Ns, that lead to considerable human deaths and significant economic losses.	I	6.9	**7.8**	**8.0**	3.6	6.6
Water Policy accounts and statements	Existence of water policies-setting goals for water use, protection and conservation.	R	4.7	3.5	**8.5**	**9.5**	6.6
Pesticides in groundwater	Pesticide active substances, including metabolites and degradation and reaction products that are relevant. Indicator of pollution by agricultural activities	I	4.8	**7.7**	**10.0**	3.8	6.6
Average per capita food consumption	Per capita food consumption at global and developing country levels, and other specific regions. The indicator shows a global food security situation, and is used as the indicator of food intake.	S,R	**8.3**	**8.4**	4.9	4.6	6.5
Dependence of agricultural population on water	The Proportion of total population of a region using water irrigation technics (both traditional and modern) to enhance the productivity of agriculture or livestock enterprise.	D	**7.6**	**8.8**	6.0	3.7	6.5
Status of surface water bodies (in risk)	The indicator measures the risk level of not achieving the environmental objectives proposed by the institutions responsible for the manegment surface water bodies The indicator is calculated as the ratio of number of surface water bodies located in each of the four risk levels considered and the total number of surface water bodies in each river basin district or the national average.	S	4.3	4.9	**9.5**	**7.3**	6.5
Population exposed polluted water	Percentage of population exposed to several kind of pollutants (coliforms, industrial substances, acid, heavy metals, ammonia, nitrates, pesticides, sediments, salinization). Poor water quality affects both human health and ecosystem health.	S, I	**9.4**	3.9	**9.1**	3.6	6.5
Emissions of water pollutants by sector	Indicates the Biological Oxygen Demand (BOD) loads to waterways by sector (agriculture, house, hold, and, industry) as well as the nitrogen loads to waterways due to agriculture.	S, I	5.0	**7.2**	**9.3**	4.5	6.5

Annex 3.4 - Indicators that comply with two sustainability criteria (bi-dimensional) (cont. 4/6).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Groundwater as a percentage of total use of drinking water	The indicator expresses the present state and trends of surface water and groundwater use for drinking purposes.	S	**7.5**	5.6	**8.4**	4.5	6.5
Food production trends	Trends in food production: increase in annual production. It is relevant to remember that the amount of water involved in food production is significant.	D, P	6.4	**9.5**	**7.2**	2.6	6.4
Investment in water management	Annual budget for management actions and water infrastructure.	R	3.9	**8.9**	4.2	**8.4**	6.4
Ratio of actual to desired level of public investment in water supply	Ratio of actual to desired level of public investment in water supply.	R	5.4	**8.8**	2.3	**8.9**	6.4
Access to electricity rural and urban coverage for the whole world	Rural and urban households with access to electricity for each country. Access to electricity is a prerequisite for economic and social development and in some case to access water (pumps, etc).	R	**7.6**	**7.6**	4.0	6.2	6.3
Percentage of Health Impact Assessments (HIA) of water resources development and compliance with HIA recommendations	Definition – HIA is a combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population	R	**8.6**	3.2	4.0	**9.5**	6.3
Productivity in terms of jobs per m3	Number of jobs generated in irrigated agriculture and industry by each m3 of water abstraction.	S	**8.0**	**9.6**	1.2	6.2	6.3
Ammonium in groundwater	Indicates the amounts of ammonium ions present as a result of human activities. It is an indicator of water quality for human consumption.	I	**7.3**	4.8	**9.5**	3.2	6.2
Existence of participatory framework and operational guidelines	Existence of participatory framework for the management of water including operational guidelines to its implementation and follow-up.	R	**8.3**	2.6	4.3	**9.8**	6.2
Amount of underwater or wetland area placed into protected management, including the establishment of no fishing zones	Amount of underwater or wetland area placed into protected management, including the establishment of no fishing zones.	I, R	2.4	5.1	**9.1**	**8.2**	6.2

Annex 3.4 - Indicators that comply with two sustainability criteria (bi-dimensional) (cont. 5/6).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Existence of water quality standards, for effluent discharges, minimum river water quality targets	Indicates the existence of water quantity and quality standards.	S, I	4.9	3.2	**9.3**	**7.0**	6.1
Mining waste pools	This indicator estimates the influence of mining waste pools that contamine water depending on the productive sector (PS), potential storage (PS), permeability (P) and water table depth (WTD). The pressure is significant if the indicator presents values greater than 5.	P	3.2	**7.9**	**9.3**	3.8	6.0
Percentage of compliance of the wastewater treatment plant with current regulations	The indicator is calculated by the ratio of the number of wastewater treatment plants that meet compliance criteria established by the legislation (pollution load expressed in population equivalents) and the total number of wastewater treatment plants existing.	S	4.2	4.2	**7.1**	**8.7**	6.0
Naturally occurring inorganic contaminants fluor and arsenic	Percentage or contaminated water sources and number or people exposed through drinking water supply by naturally occurring inorganic pollutants (Fluor and arsenic) as a critical determinant of chemical contamination of drinking water.	S, I	**7.8**	3.2	**9.5**	3.4	6.0
Intensive crop area	Total agricultural area for the production of crops considered intensive due to their higher water needs. Cropping intensity is estimated as total crop area divided by total cultivated area.	D	3.2	**9.3**	**8.3**	3.2	6.0
Restoration schemes	Existence of restoration schemes/projects focused on freshwater and coastal ecosystems degradation issues.	R	3.2	2.9	**8.8**	**8.8**	5.9
Nutrition productivity	Total generation of food products generated by agriculture (calculated in calories or other nutritional indicator) divided by the total abstraction of water for irrigation.	D	**7.6**	**7.8**	4.5	3.7	5.9
Total investment (private, state, development agencies) in irrigation and drainage	Total investment (private, state, development agencies) in irrigation and drainage, expressed in millions dollars.	S,R	2.9	**9.5**	3.7	**7.5**	5.9
Water availability per capita	Percentage of the world's water resources that a region has divided by the world's population (in %) living in that region.	P,S	**8.5**	3.7	**7.4**	3.2	5.7

Annex 3.4 - Indicators that comply with two sustainability criteria (bi-dimensional) (cont. 6/6).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Uptake of strategies/legislation for environmental protection	Use of adequete strategies/legislation for environmental protection.	R	2.9	2.9	**7.4**	**9.6**	5.7
Crop Area	Agricultural area used for crop production or pasture.	D	3.5	**9.2**	**7.2**	2.8	5.7
Proportion of water pollution permit holders complying with permit conditions.	Number of monitoring visits with water quality samples not complying with estabilished conditions divided by the total number of visits.	P, S, I, R	4.2	3.0	**7.3**	**8.0**	5.6
Crop-Water Productive Index	Amount of water required per unit of yield. It is a vital parameter to assess the performance of irrigated and rainfed agriculture. Crop water productivity will vary greatly according to the specific conditions under which the crop is grown.	D,P,S,I	2.6	**8.4**	**7.7**	3.4	5.5
Fish consumption (marine, inland and aquaculture)	Average consumption of fish from diferent sources (marine, inland and aquaculture).	P, S, I	**7.1**	**7.9**	5.5	1.4	5.5
Water used for irrigation	Annual amount of water used in irrigation systems. It can bee classified by source (groundwater and surface), by system type (surface irrigation, spate irrigation, sprinkler irrigation, drip irrigation, local water harvesting, etc), among others classifications.	P, S, I	2.9	**7.6**	**7.5**	3.8	5.5
Consumption of livestock food products	Consumption of food from livestock including meat (beef, pork, poultry), vegetables, crops, dairy products, eggs, milk, etc.	D, P, S, I	**7.4**	**7.5**	4.7	2.2	5.4
Density hydrological monitoring stations	Number of hydrological observing/monitoring stations in a given region / country.	S, R	2.1	2.6	**7.1**	**8.2**	5.0

*Criteria average score: Social, Economic, Environmental and Institutional.

Sources: see Annex 3.5

Annex 3.5 - Indicators that comply with one sustainability criterion (one-dimensional).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Index of groundwater explotation	Percentage of extracted groundwater per year in relation to the total volume of the aquifer.Pressure is considered significant when the total groundwater extraction exceeds 20% of resources allocated.	P	6.1	6.6	**9.5**	5.8	7.0
Urban Water and Sanitation Governance Index	It is a combination of the fowling 4 indicators. Percentage of departments establishing programme monitoring water and sanitation coverage. Percentage of councils that provide for external audit of the departments. Percentage of departments meeting water quality standards.Percentage of departments with improved public quality control of the service provided.	S	6.3	5.6	6.1	**10.0**	7.0
Groundwater depletion	Is calculated as the total area with groundwater depletion problem (means the area in which regional level decline is observed resulting from excessive exploitation of groundwater) divided per the total area of studied aquifer.	S, I	6.1	6.4	**9.3**	5.8	6.9
Groundwater usability with respect to treatment requirements	Usability of abstracted groundwater that is publicly distributed with respect to treatment requirements.	S,R	5.5	6.8	**8.5**	6.1	6.8
Wetlands: % threatened	Percent of threatened wetlands due to presuares from agriculture, settlements, urbanization and other land uses.	S,I	6.1	6.7	**9.5**	4.8	6.8
Reduced releases of pollution to groundwater recharge zones	Reduction of the amount of pollutants discharged to groundwater recharge zones.	S, I, R	4.8	6.4	**9.8**	6.0	6.7
Index of groundwater abstraction	Evaluates the recharge-discharge aquifer balance and therefore the sustainability of exploitation. The threshold considered is Ind abs > 40%.	P	5.6	5.8	**9.5**	4.8	6.4
Nitrate in aquifers	The indicator measures the concentration of nitrate in groundwater in mg/l. It is an indicator related to the pressure from farming activities and the chemical status of groundwater. High concentrations of nitrates in surface water and groundwater may affect its fitness for potable uses.	S,I	4.8	6.9	**10.0**	4.0	6.4
Renewable groundwater resources per capita	Total amount of groundwater resources (m3 per year) per capita at a national, regional or natural (aquifer, basin) level that comes from a renewable source.	D, S	6.0	6.8	**8.8**	3.9	6.4
Groundwater vulnerability	The concept of groundwater vulnerability is based on the assumption that the physical environment (the soil properties, lithology and thicknesss of the unsaturated zone and groundwater level) provides some degree of protection to groundwater against natural influences and human impacts.	P,S	5.5	4.8	**9.8**	6.0	6.4

Annex 3.5 – Indicators that comply with one sustainability criterion (one-dimensional) (cont. 2/8).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Percentage of undernourished people	Percentage of people not having access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.	S	**9.5**	6.5	2.9	6.5	6.4
Disability-Adjusted-Life Year (DALY)	Is a summary measure of population health, integrating mortality with morbidity and disability information in a single unit. Is an indicator of the time lived with a disability and the time lost due to premature mortality.	I	**9.0**	6.9	4.3	5.2	6.4
Area of wetland drained	Transformations of wetlands due to human uses: area of wetland drained	S,I	6.8	4.8	**9.5**	4.2	6.3
Trends in freshwater habitat protection	The percentage of area of different types of freshwater habitat set aside for protection.	S, R	4.5	4.0	**10.0**	6.8	6.3
Food imports/exports between regions	Amount of food imports/exports for individual countries and between regions The indicator shows the difference between production and consumption and also the virtual water flow between regions.	S	6.6	**9.1**	3.9	5.4	6.3
Groundwater quality	This indicator can be applied to both natural and anthropogenic contamination, as presented below:A) For natural quality contamination: Relation between the total area of aquifefers with groundwater natural-quality problema divided by the total area of studied aquifers; B) for anthropogenic contamination: Relation between the total area with increment of concentration for specific parameter divided by the total area of studied aquifers.	S,I	6.6	4.6	**9.3**	4.6	6.3
Non-point source pollution programs implemented (area treated with best management practices; kg reduced)	Area treated with best management practices as a result of implemented nonpoint source pollution programs The goal of these programs is to minimize nonpoint source pollution from new land use activities and to reduce pollution from existing activities.	R	4.5	4.5	**9.1**	6.8	6.2
Number of dams in basin and in main stem of river	Number of large and major dams in each basin.	D,R	3.8	6.3	**8.5**	6.3	6.2
Discharges to groundwater	Includes waste water and cooling water discharge in aquifers. Moreover, landfill underground pollution: storage of CO2 and brine. Direct discharges are a important source of point pollution of groundwater.	P	4.5	5.8	**10.0**	4.2	6.1
Water table	The steady decline of water table (in free water aquifers) or the level of groundwater in confined aquifers, are the main impact indicator of excessive water extraction.	I	5.0	6.1	**9.8**	3.7	6.1

Annex 3.5 – Indicators that comply with one sustainability criterion (one-dimensional) (cont. 3/8).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Runoff: % used by humans	Relation between the total annual abstraction of water and the total annual runoff at a given basin.	S, I	6.0	6.1	**9.5**	2.9	6.1
State Hydrological index	This indicator provides information on hydrological drought resulting from the rainfall eficits. The hydrological drought may lead to periods of scarcity.	S	5.4	5.2	**9.5**	4.3	6.1
Mentions of water in international agenda,CC, WB, GEF, WSSD	Number of times that water issues appears in the main international agenda – i.e. Climate Change negociation, UN initiatives, GEF projects, World Bank activities, World Summit on Sustainable Development, etc.	R	3.7	4.5	6.3	**9.5**	6.0
Loss of original forest	Indicates the difference between the original forest extent and the current forest extent.	S	4.3	5.8	**9.3**	4.5	6.0
Total Actual Renewable Water Resources (TARWR)	TARWR = (External inflows + Surface water runoff + Groundwater Recharge) – (Overlap +Treaty obligations).	S	4.2	5.6	**9.3**	4.8	6.0
Increased stakeholder awareness and documented stakeholder involvement in water use decisions	Evaluates how is the stakeholders awareness and documented involvement in water uses decisions.	R	5.8	4.5	4.5	**9.1**	6.0
Agricultural water use (by country)	Annual amount of water (including irrigation and green water – rainfall, snowfall, etc) used by the agricultural sector. It is usually compared to industrial and domestic use (expressed in %).	P,S,I	5.2	**8.8**	6.3	3.5	6.0
Water lending for irrigation and drainage	Annual amount of water lending for irrigation and drainage and costs associated.	P,S,I	2.9	**8.8**	6.6	5.3	5.9
Formation and empowerment of regulatory or other institutions	Formation/creation and empowerment of regulatory institutions to control / monitor the use of water resources and the protection of the ecosystems.	R	3.4	3.4	6.8	**10.0**	5.9
Existence of institutions responsible for water management, that are independent of sectorial water users.	Existence of institutions (water resources authorities) responsible for water management (including issuing abstraction and discharge licenses), that are independent of sectorial water users (irrigators associations, etc).	R	5.5	3.5	5.0	**9.5**	5.9
Private sector involvement and stakeholders responsibility established and implemented	Existence of legal framework and local capacity to promote / regulate the involvement of private sector and stakeholders responsabilit in the management of water resources.	R	4.5	5.3	4.0	**9.8**	5.9
Asset ownership properly defined	Existence of legal framework to asset ownership in order to have water rights properly defined.	R	5.4	4.2	4.2	**9.6**	5.8

Annex 3.5 – Indicators that comply with one sustainability criterion (one-dimensional) (cont. 4/8).

Indicator	**Description**	**DPSIR Frame-work**	**Criteria average score***				**Overall average**
			Soc.	**Econ.**	**Env.**	**Inst.**	
Unaccounted for Water (Water Losses)	Unaccounted-for-Water (UfW) is the difference between the water delivered to the distribution system and the water sold. It has two basic components: physical losses, such as water lost from pipes and overflows from tanks, and commercial losses, which include water used but not paid for.	P	4.2	**9.1**	3.9	6.1	5.8
Water Productivity	Economic value generated per cubic metre of water withdrawn by sector / user	P	4.4	**9.6**	4.1	5.1	5.8
Existence of law for judicious distribution of water	Existence of laws for determining equitable allocation of water – defining the rules needed to achieve policies and goals.	R	6.5	5.0	1.8	**9.8**	5.8
Water Availability index (WAI)	This index is used to forecast water availability in the short term (i.e., days). It combines water quantity and quality data, evapotransporation, soil moisture, and surface water and ground water flux information into nonparameterized variables in mathematical formulations. Water quality is based on the calculation of another index called Potential Use Index, which enables one to classify the water in terms of its measured quality and to determine its suitability for a defined use.	S	4,7	4,2	**9,3**	5,0	5,8
Price of water charged to farmers for irrigation	Cost of using irrigation water to farmers compared with their incomes.	S, R	4.5	**9.3**	4.5	4.7	5.8
Sources of Contemporary Nitrogen Loading	Total and inorganic nitrogen loads as deposition, fixation, fertilizer, livestock loads, human loads and total distributed nitrogen to the land and aquatic system.	S, P	5.6	4.2	**9.5**	3.5	5.7
Salinization in groundwater	The conductivity is used as a parameter indicative of saline and is an indicator of total dissolved ions. The increase in salinity often indicates the presence of discharges, over-exploitation of the aquifer or seawater intrusion or inland saline aquifers, due to changes in flow by exploitation.	I	4.2	5.6	**10.0**	2.9	5.7
Percentage of poor people living in rural areas	Number of poor people living in rural areas (RPP) / Total population (TP).	S	**8.6**	5.6	2.7	5.7	5.7
Prevalence of underweight children under five years of age	Percentage of children under five years old whose weight-for-age is below minus two standard deviations from the median of the NCHS/WHO reference population.	I	**9.5**	5.2	2.4	5.5	5.7
Withdrawals: % of total annual renewable freshwater	Relation of the total annual abstraction of water and the total annual renewable freshwater (both superficial and groundwater).	S	4.7	4.5	**9.8**	3.7	5.7

Annex 3.5 – Indicators that comply with one sustainability criterion (one-dimensional) (cont. 5/8).

Indicator	Description	DPSIR Framework	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Area of arable land (whole world)	Amount (expressed in million hectares) of arable land in the world in relation to population (arable land per person or hectares per 100 inhabitants).	P, S, I	5.8	**7.4**	6.8	2.6	5.6
Rate of recovery	Measures water fees actually collected as percent of the total collectable charges billed by the water utility.	D, R	5.5	**8.3**	2.9	5.8	5.6
No. of water resource scientists	Number of scientists that develop research on water related themes.	R	3.5	4.0	6.8	**8.3**	5.6
Biological water quality (based on community response)	Biological water quality indicators provide a complementary measure to chemical water quality and are useful in assessing intermittent pollution or impacts of unknown contaminants.	S,I	4.5	2.9	**10.0**	5.0	5.6
Prevalence of stunting among children under five years of age	Percentage of children under five years old whose height-for-age is below minus two standard deviations from the median of the NCHS/WHO reference population.	I	**9.5**	5.1	2.3	5.3	5.6
Artificial induced recharge	Volume of resources available artificially introduced into aquifers by irrigation returns or by reversing the flow (of the river to the aquifer) due to intensive exploitation of groundwater.	P	3.2	6.3	**8.5**	4.2	5.6
Capability for hydropower generation	Gross theoretical capability of hydropower generation, technically exploitable capability and economically exploitable capability.	S	3.2	**8.9**	5.1	4.9	5.6
Mortality rate of children under-five years of age	Probability of dying between birth and exactly five years of age expressed per 1000 live births.	I	**8.4**	4.6	3.1	5.9	5.5
Volume of desalinated water produced	Volume of desalinated water produced per year.	R	4.2	**7.1**	6.8	4.0	5.5
Mechanisms for sharing within country (allocations/priorities) both routinely and at times of resource shortage	Existence of legal / institutional mechanisms for sharing water within country (allocations / priorities) both routinely and at times of resource shortage.	R	4.1	3.7	4.2	**9.8**	5.5
Extent of land salinized by irrigation	Area of soil salinized by irrigation as a percentage of total irrigated land.	S	2.9	6.3	**8.5**	4.0	5.4
Compliance with water quality standards for key pollutants	Number of rivers / aquifers that meet water quality standards for key pollutants.	I, R	3.9	2.7	**9.3**	5.8	5.4
Drinking Water Quality	Share of samples failing drinking water quality standards in the total number of drinking water samples.	S,I	5.5	3.2	**8.1**	5.0	5.4

Annex 3.5 – Indicators that comply with one sustainability criterion (one-dimensional) (cont. 6/8).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Fragmentation and flow regulation of rivers	A complex calculation of the negative impact on ecosystems of altering waterways by dams, water transfers and canals.	S, I	2.6	4.2	**10.0**	4.8	5.4
Ecological Flow	Percent of actual flow of a river in relation to the estimated ecological flow.	S	3.5	3.5	**9.8**	4.8	5.4
Biological assessment (perturbation from reference condition)	In biological assessment, reference conditions are established by identifying least impaired reference sites, characterizing the biological condition of the reference sites, and setting thres holds forscoring the measurements. The basic procedural steps for biological assessment are as follows: 1. Sample the biological groups (assemblages) selected by the program; 2. Calculate chosen metrics using relative abundance and other measurements; 3. Compare each to its expected value under reference conditions and assign a numeric score; 4. Sum the scores of all metrics of an assemblage to derive a total score for the assemblage; 5. Compare the total score to the biological criterion based in part on the expected total score under reference conditions.	S,I	4.0	3.2	**10.0**	4.3	5.4
Compliance with environmental objectives. Status of groundwater bodies	According to the pressure and impact analysis, this indicator evaluates the risk of ground water bodies failing to achieve the environmental objectives in a specified period.	P, S, I	2.4	3.2	**10.0**	5.8	5.3
Institutional strengthening and reform (post-1992)	Existence of institutional strengthenig and reform of national / regional water management model for the implemetation of IWRM and Dublin principles.	R	3.7	2.9	4.7	**10.0**	5.3
Percent of protected area	Percentage of protected area divided by the total of a given area.	S	1.8	2.9	**9.8**	6.5	5.3
Per capita food consumption (and its broken down into cereals, oil crops, livestock and fish)	Avarege per capita food consuption per year (and its breakdown into categories: cereals, oil crops, livestock, fish, etc.).	P,S,I	**7.8**	6.9	5.9	2.4	5.2
Defined roles of government (central and local)	Existence of legal framework that defines with clarity the roles of central and local governments to manage water resources.	R	3.7	2.9	4.2	**10.0**	5.2
Irrigated land as percentage of cultivated land	Area under irrigation as a proportion of total cultivated land.	S,P	2.9	**8.6**	5.8	3.5	5.2
Relative importance of agriculture in the economy	The share of the country's GDP derived from agriculture.	S	2.9	**9.5**	4.5	3.9	5.2
Trends in ISO 14001 certification	Number of companies receiving ISO 14001 certification per the total number of companies	R	2.0	5.2	5.6	**8.0**	5.2

Annex 3.5 – Indicators that comply with one sustainability criterion (one-dimensional) (cont. 7/8).

Indicator	Description	DPSIR Frame-work	Criteria average score*				Overall average
			Soc.	Econ.	Env.	Inst.	
Access to information, participation and justice	Proportion of countries with strong, intermediate or weak access to information, participation and justice. (to water related themes).	R	6.9	2.5	2.5	**8.9**	5.2
Organic pollutants load	Concentrations of the follow organic pollutants: COD: chemical oxygen demand; NH4-N: ammonium; PAH: polycyclic aromatic hydrocarbons; DEHP: diethylhexylphthalate; EE2: ethinylestradiol; E2: estradiol; EDTA: ethy-lenediamine tetraacetic acid.	S, I	4.9	3.2	**9.4**	3.2	5.2
Climate Moisture Index (coefficient of variation)	CMI is a statistical measure of variability in the ratio of plant water demand to precipitation. It is useful for identifying regions with highly variable climates as potentially vulnerable to periodic water stress and/or scarcity.	S	3.5	4.5	**9.1**	3.5	5.1
Importance of groundwater for irrigation	Percentage of land under irrigation relying on groundwater	S, P	3.2	6.5	**7.1**	3.8	5.1
Seawater intrusion in groundwater	The indicator measures the concentration of chloride in mg / l in groundwater. It is a status indicator that measures the degree of salinization of coastal groundwater bodies due to seawater intrusion and its suitability for different uses such as drinking or irrigation water.	P, S	4.2	4.0	**9.5**	2.7	5.1
Area equipped for irrigation vs. total arable land	Percent of the arable land that is equipped for irrigation (by country or geographical division).	P, S	2.4	**8.1**	5.8	4.0	5.1
Biological contaminants (E. coli/thermotolerant coliform)	Presence of biological contaminants in water (E. coli/thermotolerant coliform) Escherichia coli and thermotolerant coliforms are of major importance as indicators of fecal contamination of water.	S, I	6.4	1.7	**9.1**	2.7	5.0
Proportion of water allocation permit holders complying with permit conditions	Number of monitoring visits not complying with conditions divided by the total number of visits.	P, S, R	4.2	3.0	3.7	**8.2**	4.8
Organic pollution emissions (BOD) by the industrial sector	Proportion of organic water pollution (calculated in BOD), generated by industrial sector.	I	3.4	5.4	**9.1**	1.2	4.8
Numbers or presence/absence of non-native (alien) species	Is an indicator that evaluates the ecosystem condition by measuring the number of introduced species, focusing on aquatic species (e.g. fish, molluscs, benthic organisms, plants).	S, I	2.2	3.5	**9.8**	2.7	4.5

Annex 3.5 – Indicators that comply with one sustainability criterion (one-dimensional) (cont. 8/8).

Indicator	**Description**	**DPSIR Frame-work**	**Criteria average score***				**Overall average**
			Soc.	**Econ.**	**Env.**	**Inst.**	
Number of endemic fish	Total number of fish endemic species in a river basin. This indicator should be taken as general indicator of fish diversity.	S	1.1	5.3	**9.3**	2.2	4.5
Areas covered or half covered in water	Percentage groundwater mass: area covered by humid, swampy, or intertidal zones, lakes, lagoons, reservoirs, coastal lagoons, estuaries, seas and oceans.	P	2.3	2.9	**9.8**	2.6	4.4
Impact of Sediment Trapping by Large Dams and Reservoirs	This indicator evaluates the residence time of water held in large reservoirs, sediment trapping efficiency of large reservoirs and determinates how many years takes to full-fill a reservoir with water transported sediment.	P	1.8	3.2	**9.1**	3.5	4.4
Freshwater species population trends index	A measure of change and trends in the populations of freshwater species.	S	1.6	3.7	**9.3**	2.7	4.3
Head of cattle	Number of head of cattle (cattle, sheep, swine and goats).	D	2.6	**7.9**	4.9	1.4	4.2
Use of water in thermal towers and competition with other uses	Total annual amount of water used in thermal towers. It is usually compared with others industrial uses (presented in percent).	P	0.5	**8.7**	4.4	3.2	4.2
Number of Amphibian Species	Number of Amphibian Species in each basin. Amphibians are a sensitive biological indicator of environmental quality.	S	1.6	2.4	**9.8**	2.2	4.0
Ministerial statements mentioning water	Number of ministerial statements that mention water.	R	1.7	1.2	3.4	**9.5**	3.9
Nivale reserve	Volume of water stored as snow.	S	1.3	2.4	**8.8**	2.1	3.7
Biological oxygen demand (BOD)	Is the quantity of oxygen necessary for biological and chemical oxidation of water-borne substances.	S	2.4	1.2	**9.1**	1.7	3.6
Water impounding reservoirs (dams): supply volume m3 per year	Annual amount of water impounded in dams and others reservoirs.	S	4.2	6.5	6.8	6.1	5.9

*Criteria average score: Social, Economic, Environmental and Institutional.

Source: Aldaya & Llamas (2008), Bradfor (2008), Cap-Net UNDP (2008), Carneiro et al. (2006), Ding et al. (2010), Eurostat (2009), Falkenmark & Lindh (1974), FAO (2003), GWP (2004a), GWP (2004b), GWP (2006), Grey & Sadoff (2006), Hoekstra (2009), Hoekstra (2010), IISD (1999), Lawrence et al (2002), Maneta et al (2009), Milman & Short (2008), MMA (2006), OECD (2004), OSE (2008), Scudder(2005), Sullivan (2001), Sullivan and Meight (2005), Sullivan and Huntingford (2009), Sullivan et al (2002), Sullivan et al (2006), UN Water (2008), UN Water (2010), UN-Habitat (2003), UN-Habitat (2008), UN-Habitat (2009), UN (2007a), UN (2007b), UN (2009), UN (2010), UNECE (2003), UNECE (2007), Vörösmarty et al (2000), Vörösmarty et al (2005a), Vörösmarty et al (2005b), WBCSD & IUCN (2010), WHO (2006), WHO/UNICEF (2008), WHO/UNICEF (2010), Wilhite (2005), Wilhite et al. (2007), World Bank (2007), WWAP (2003), WWAP (2006), WWAP (2009), WWAP (2012), WRI (1998).

CHAPTER 4 – SELECTION OF INDICATORS FOR SUSTAINABLE WATER USE AND MANAGEMENT AT RIVER BASIN SCALE

ABSTRACT

In order to be of practical use to the target audience the indicators should meet specific criteria. This chapter presents the multi-criteria and multi-level sequential processes applied to select the indicators (out of the 24 indicators short-listed in the previous chapter) that fulfil the following four criteria: scientific foundation, individuality, river basin scale and specificity. The findings show that 11 indicators fulfil the selection criteria, they are discussed in details and their main features are presented. This chapter also addresses the reasons for why the other 13 indicators did not comply with the criteria and proposes further studies on the subject. The Indicator Profile Sheets (IPS), an important tool to organize and easily access the most relevant information about each indicator, is also presented at this chapter.

4.1 INTRODUCTION

Indicators that consider sustainability criteria are key in evaluating the multiple perspectives of water resources, namely: social, economic, environmental and institutional aspects (Juwana, 2012; WWAP, 2003). At the previous phase (see chapter 3), 170 indicators related to water use and management were identified through a comprehensive bibliographic review. By applying a multi-criteria analysis, 24 indicators of the 170 were identified as indicators that fulfil the majority of the sustainability criteria (table 4.1). In order to conduct this analysis, an international panel of experts was convened, a rating scale of quali-quantitative attributes was adopted and the definition of each indicator was presented, as well as their DPSIR classification.

The identification of these 24 indicators can be considered to be a relevant contribution to sustainability research and practice for the water resources sector. Although this contribution matters, the current research has a broader objective that goes beyond the identification of sustainability indicators. The main objective of this research is to identify and validate a set of indicators that would allow decision makers to evaluate the sustainability of water use and management at river basin level (for details see chapter 1).

Table 4.1 – The 24 indicators that fulfil the sustainability criteria (previous chapter).

Water Poverty Index	Causes of food emergencies
Climate Vulnerability Index	Ecological Footprint
Water Reuse Index	Progress towards achieving IWRM target
Water shortages	Water Provision Resilience
Water Footprint	Major drought events and their consequences
Incidence of worms, scabies, trachoma, diarrhea	Relative Water Stress Index
Performance Index of Water Utilities	Index of Non-sustainable Water Use
Access to Improved Sanitation	Water sector share in total public spending
Proportion of Urban Population Living in Slums	Country's Dependence Ratio
Fraction of the burden of ill-health from nutritional deficit	Pro-poor and pro-efficiency water fees
Social and Economic Impacts from Drought	Water topics in school curriculum
Incidence of Cholera	Total Water Storage Capacity

In order to be of practical use to the target audience (e.g. decision makers in river basin organizations) the indicators should meet other specific criteria that go beyond the sustainability criteria (Niemeijer & Groot, 2008; IISD, 2008; BNIA, 2006; Bélanger et al, 2012; WHO, 2002). Indicators should be consolidated by current scientific standards and principles (Aveline et al, 2009; Bockstaller et al, 2008; OECD, 2003; Parris & Kates, 2003; UN, 2007), should not duplicate each other (Doukas et al, 2007; Graymore et al, 2009; Kurka & Blackwood, 2013; Rovere et al, 2010; Wang et al, 2009), should be appropriate for the geographic scale of interest (IISD, 2008; ITFM, 1995; SNZ, 2002; US EPA, 2000) and should be clearly and unambiguosly defined (Niemeijer & Groot, 2008; WWAP, 2006; UNEP, 2006; Segnestam, 2002; World Bank, 2000).

The main objective of this chapter was to select out of the 24 indicators short-listed in the previous chapter, those that fulfil these four criteria: scientific foundation, individuality, scale of application and specificity. These criteria were considered to be of highest importance, mainly because they address strategic aspects and key attributes of the indicators related to consolidation, application and distinctiveness closely linked to the research object (indicators that could be used by decision makers to measure the sustainability of water use and management at river basin level).

This chapter begins with the creation of the "Indicator Profile Sheets", an important tool to organize and easily access the most relevant information about each indicator. Then, the 24 indicators selected are assessed using a multi-criteria and multi-level sequential approach. The 11 indicators that fulfil the four criteria are described, including comments about their main features. This chapter also addresses the reasons for why the other indicators were considered not to be of interest, and proposes further studies on the subject.

4.2 METHODOLOGY

This study adopted a multi-criteria and multi-level sequential approach to select the indicators of interest for this research. The indicators of interest are those that are scientifically valid, not duplicated, suitable for the scale of application (river basin) and clearly and unambiguosly defined. In order to perform this assessment, 24 "Indicator Profile Sheets" (IPS) were created, one for each indicator that aim at systematizing and organizing their main information.

4.2.1 Indicator Profile Sheet

The "Indicator Profile Sheet" (IPS) is an effective tool to organize and display relevant information about the indicators in an easy format. The IPSs were proposed by WWAP (2006) aiming *"to provide guidance and insight into the rationale of the selection and development of indicators"*. WWAP (2006) further points that the clear and concise information available at the IPSs make for more effective communication, even with no specialized audiences, and contribute to the application of the indicators by end-users.

For each of the 24 indicators that fulfil the sustainability criteria accessed in chapter 3 (see list in table 4.1), an "Indicator Profile Sheet" (IPS) was created. The IPSs of these 24 indicators can be found in Annex 4.1. Each IPS presents basic information about the indicator in an "easy to understand" format, including:

- a brief description of the indicator, its classification on the DPSIR approach (Drive Force, Pressure, State, Impact, Response);
- its classification on the system approach based on sustainability criteria (Social, Economic, Environmental, Institutional) and
- sources for further information (major references about the indicator).

In the IPSs of the indicators of interest, one can find two additional and relevant fields: the "underlining definitions and concepts" of the indicator and at least one example (table, graphic, map, etc) of an actual application of the indicator. All information presented in the IPSs was referenced by recent sources.

4.2.2 Selection of the Indicators of Interest

Four criteria were applied to assess the suitability of the indicators of interest to this research. Indicators were assessed based on current and sound scientific standards (scientific foundation), on whether they were unduplicated (individuality), on their validity for river basin scale and whether they were clearly and unambiguously defined (specificity). These criteria were considered to be extremely important for the research, mainly because they address strategic aspects related to key attributes of the indicators: consolidation, application and distinctiveness.

The assessment of these criteria was developed as a detailed analysis of the characteristics and properties from each indicator. This analysis was done based on a comprehensive literature review, including the verification of diverse sources discussing the indicators (see IPSs for further information). This study, according to the current practice of academic research (Gudmundsson, 2010), involved several electronic searches using a number of journal and institutional websites (including relevant grey literature), as well as databases and academic search engines (including Web of Science, SCOPUS, ScienceDirect, Google Scholar and others). These searches aimed to identify peer reviewed papers and/or other relevant publications that further developed, validated or tested the indicators, regarding their scientific foundation, individuality, scale of application and specificity.

The 24 indicators selected in chapter three were assessed in a multi-criteria and multi-level sequential method. A multi-criteria evaluation involves a set of criteria with the aim of supporting decision-making (Linkov & Moberg, 2011), which in the case of this research helps to select indicators. As mentioned by Rosel et al (2015), among other authors, multi-criteria methods provide *"a comprehensive and transparent basis for performing sustainability assessments"*. The multi-level evaluation can be used as a way of organizing the multi-criteria selection. Levels are set in sequence to guide the implementation of pre-established criteria logically. These ensure that the selected indicators will fulfil all the criteria, in a process of gradual refinement (Berre et al., 2009).

Four criteria (scientific foundation, individuality, river basin scale and specificity) and four levels of assessment were adopted in this study. Three levels were sequential: the first level corresponds to the assessment of the scientific foundation criterion, the second to the individuality criterion and the 3rd to River Basin Scale. The specificity criterion was assessed in a crosscutting level. This multilevel structure of assessment adopted by this study is presented in the flow chart below (Figure 2.1). The indicators that fulfil these four criteria were the ones selected for the research. The ones that do not comply with at least one of the criteria were considered not of interest to the research.

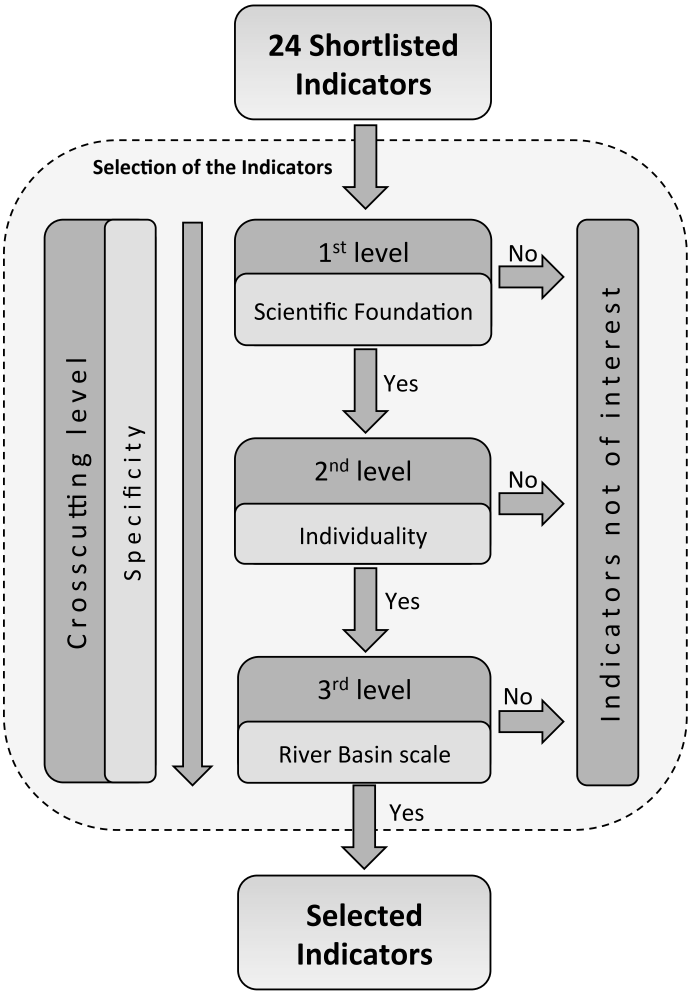

Figure 4.1 –Flow chart of the process used to select the indicators of interest for the current research, based on four criteria (scientific foundation, individuality, river basin scale and specificity).

Scientific Foundation (1st Level Assessment)

The scientific foundation was the first criterion assessed. The definition of this criterion could vary depending on the source (Bockstaller et al 2008; Aveline et al, 2009; OECD, 2003). The concept of "scientific foundation" adopted by this study was based on the definition by UNEP (2006): *"the extent to which an indicator is based on currently sound and internationally accepted theoretical, conceptual, technical, and scientific standards and principles*". This criterion was considered by the assessment performed in chapter three as the most relevant scientific criterion to evaluate indicators. It has been mentioned as an important criterion by 19 different sources, including BNIA (2006), Bockstaller & Girardin (2003), Clark & Dickson (1999), Cloquell-Ballester et al. (2006), FAO (1999), Niemeijer & Groot (2008), SNZ (2002), UNEP (2006), WHO (2002), World Bank (2000), WWAP (2006). Scientific foundation aims to ensure a solid and concrete scientific relevance to the selection of indicators. According to Niemeijer & Groot (2008) an indicator should bear a strong scientific basis and have a proven track record.

This research assessed whether the indicator was consolidated by current science, whether it was a proposal for an indicator, or whether it was a concept yet to be developed and tested. Indicators approved under this criterion were the ones that have a clear standard and principals, and have been tested and validated by the international scientific community.

On the other hand, indicators not approved by this criterion were the ones that are still at a conceptual stage with no clear detailed information about their theoretical, conceptual and operational principles. No publication confirming whether they have been tested or validated by current scientific standards was found. Indicators that are so far only a general proposition or an idea to be further developed, were also considered as not fulfilling this criterion. The indicators approved by this criterion were assessed and evaluated by the second criterion - Individuality.

Individuality (2nd Level Assessment)

Individuality, the second criterion assessed, shows whether the indicators are independent enough or if they duplicate other indicators (Kurka and Blackwood, 2013). Individuality was considered by several authors to be a relevant criterion for the evaluation of indicators (including, Doukas et al., 2007; Graymore et al, 2009; Rovere et al., 2010). The assessment of this criterion aimed to avoid duplication of the indicators of interest. It is not unusual to see indicators that have different names yet measure similar or even the same attribute. In fact, several authors have also noted this issue (Doukas et al, 2007; Graymore et al, 2009; Kurka and Blackwood, 2013; Rovere et al, 2010; Wang et al., 2009). These authors point out that an indicator should not be duplicated in order to make the set of indicators concise and more efficient. Two or more indicators that measure the same attribute usually do not offer complementary information and might cause overrepresentation of a specific issue under a set of indicators.

In order to access this criterion, each indicator that fulfilled the previous criterion (scientific foundations) was analysed in detail aiming at verifying whether it measures a similar attribute of any other indicator shortlisted by the research. The assessment of this criterion was made in two stages: first, the duplication of indicators was assessed. A pairwise comparison based on the definition of each indicator was performed in order to confirm whether it was a case of duplication. Secondly, if indicators were duplicated, an in-depth analysis was done in order to select the indicator of interest. This analysis considered elements such as its acceptance by the scientific community and its suitability for the research. The indicators approved by this criterion were moved to the next level of the assessment and were then evaluated by the criterion called Scale of Application.

Scale of Application - River Basin (3rd Level Assessment)

This criterion addresses the geographic scale of the application of the indicator (river basin scale). The current research focuses on indicators that could be applied to the management of water resources at river basin level (see chapter 1). Furthermore, Lorenz et al. (2001) mentioned that the use of indicators *"at a river basin scale provides integrated information on the use and supply of goods and services, underlying cause–effect relationships and possible trade-offs and their spatial distribution*".

Therefore, it was imperative that the selected indicators were suitable for measuring water use at the scale of watershed. According to several authors (ITFM, 1995; IISD, 2008; Niemeijer & Groot, 2008; SNZ, 2002; US EPA, 2000), the adoption of an appropriated geographical scope is one of the most relevant criteria that an indicator should fulfil.

Each indicator that satisfied both previous criteria (scientific foundations and individuality) was analysed to confirm whether the river basin is an acceptable scale of application. Comprehensive bibliographical reviews of the scale of application of each indicator were completed. A detailed analysis of their characteristics was also done to check if the indicator was valid for application at river basin scale. Whenever possible, previous publications that confirm the use of the indicator at river basin scale were referenced and listed in the field "Source for Further Information" of the IPS of the indicator.

Specificity (Crosscutting Assessment)

The criterion called Specificity is also highly referenced by many authors as an important attribute to evaluate the quality of indicators (Segnestam, 2002; SNZ, 2002; UNEP, 2006; WWAP, 2006; World Bank, 2000). Specificity assesses whether the definition of the indicator is clear and unambiguous. Segnestam (2002) considers that indicators should be "*defined clearly in order to avoid confusion in their development or interpretation".* Furthermore, WWAP (2006) considers this as a relevant criterion in order to avoid indicators "*to be unambiguous or lend themselves to various interpretations, or to give inconsistent results in different situations".*

This criterion was addressed in a crosscutting way by this evaluation. The analysis of the indicators and whether they fulfil this criterion or not, was conducted simultaneously with the assessment of the previous three levels of this research (scientific foundations, individuality and scale of application). The purpose of the analysis was not to select nor to eliminate indicators based on this criterion, but to see if the definition of the indicator was clear and unambiguous. When needed, the definition of the indicator was further developed, in order to guarantee that all indicators of interest fulfil this criterion as well as the previous three criteria.

4.3 Results

Eleven indicators, out of the initial 24, fulfilled the four criteria (scientific foundation, individuality, river basin scale and specificity). Therefore, they were classified as indicators of interest to the research (see Figure 2.2). Nevertheless, thirteen indicators were classified as not being of interest, due to not complying with at least one of the criteria assessed, as presented below:

- nine do not comply with the "scientific foundation" criterion;
- three do not comply with "individuality" and
- one is not valid for the "river basin scale".

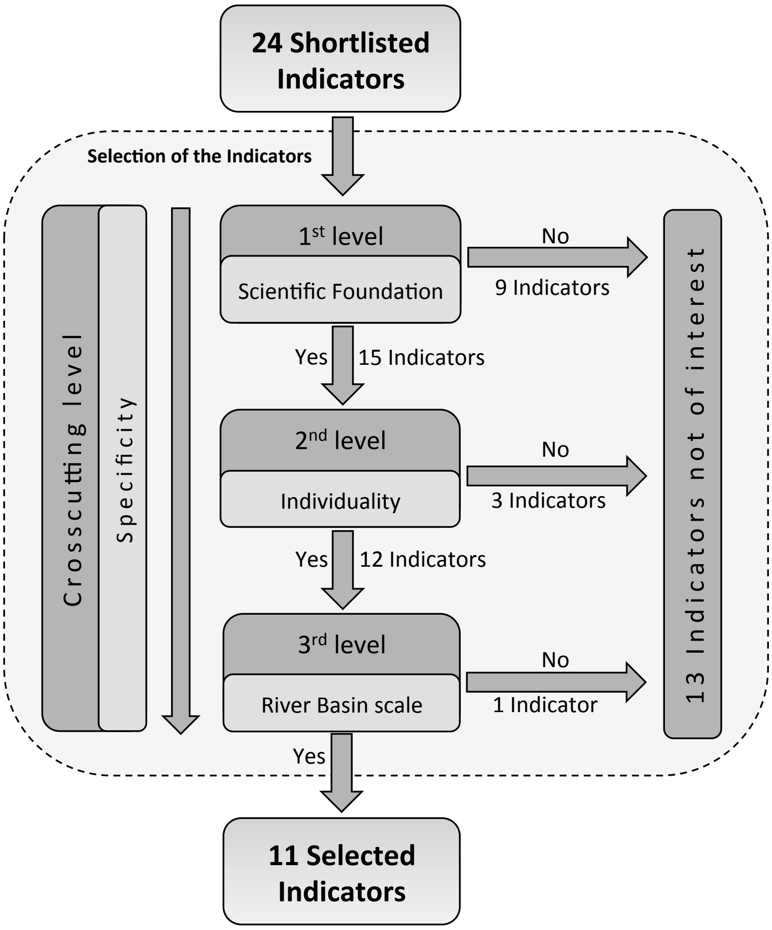

Figure 4.2 –Selection of the indicators of interest for the current research, based on scientific foundation, individuality, river basin scale and specificity.

The definitions of the majority of the indicators were adjusted to comply with the specificity criterion. These adjustments did not change their descriptions significantly, but brought additional clarity to the definition of the indicators and contributed to avoiding ambiguity. The list of indicators assessed at this stage, pointing out the ones of interest to this research and the criteria they fulfil is presented in the Table 4.2.

Table 4.2 - Indicators assessed at this stage of the study, pointing out the ones of interest to this research and the criteria they fulfil.

		CRITERIA ASSESSED			
	Indicator's Name	**Scientific Foundation**	**Individuality**	**River Basin Scale**	**Specificity**
Indicators of Interest	Water Poverty Index	✓	✓	✓	✓
	Climate Vulnerability Index	✓	✓	✓	✓
	Water Reuse Index	✓	✓	✓	✓
	Access to Improved Sanitation	✓	✓	✓	✓
	Proportion of Urban Population Living in Slums	✓	✓	✓	✓
	Incidence of Cholera	✓	✓	✓	✓
	Index of Non-sust. Water Use	✓	✓	✓	✓
	Total Water Storage Capacity	✓	✓	✓	✓
	Relative Water Stress Index	✓	✓	✓	✓
	Water Footprint	✓	✓	✓	✓
	Social and Economic Impacts from Drought	✓	✓	✓	✓
Indicators Not of Interest	Country's dependence ratio	✓	✓	**No**	-
	Water shortage	✓	**No**	-	-
	Ecological footprint	✓	**No**	-	-
	Major drought events and their consequences	✓	**No**	-	-
	Incidence of worms, scabies, trachoma and diarrhoea	**No**	-	-	-
	Water topics in school curriculum	**No**	-	-	-
	Fraction of the burden of ill-health resulting from nutritional deficiencies	**No**	-	-	-
	Causes of food emergencies	**No**	-	-	-
	Performance index of water utilities	**No**	-	-	-
	Water sector share in total public spending	**No**	-	-	-
	Water provision resilience	**No**	-	-	-
	Pro-poor and pro-efficiency water fees	**No**	-	-	-
	Progress towards achieving IWRM target	**No**	-	-	-

Subtitles: ✓ Comply with the criterion / No: Do not comply with the criterion / - not applicable

4.4 DISCUSSION

This study achieved its ultimate goal: to identify out of the indicators short-listed in the previous chapter, the ones that fulfil the four selection criteria: scientific foundation, individuality, scale of application and specificity. The 11 indicators that fulfil these criteria are described below, including comments about their main features and limitations. To conclude, the reasons for why the other indicators were considered not of interest to this research are presented, and further studies about the subject are proposed.

4.4.1 Indicators of Interest

Water Poverty Index (WPI) and the **Climate Vulnerability Index (CVI)** are two of the eleven indicators of interest. Both indicators were devised in the last decade by Dr Sullivan, of the Centre for Ecology and Hydrology - UK (Sullivan, 2001; Sullivan and Meigh, 2005) and have been received well by decision makers at the international level: they have been applied to over 140 countries (WWAP, 2012; Sullivan et al 2002).

WPI and CVI are indexes that draw together data from the bio-physical, economic and social sciences. They combine them in order to make holistic assessments linking water and poverty issues, in the case of WPI (Sullivan et al, 2002), and water and vulnerability, in the case of CVI (Sullivan & Huntingford, 2009). They provide a means for understanding the complexities of water issues by providing a systematic, open, flexible and transparent approach applying different combined components to create a composite index (Sullivan & Lawrence, 2006).

The main difference between WPI and CVI is component G, geospatial variability, used in the computation of the CVI, but not considered by the WPI. The G component addresses the geographical vulnerability of the location under analysis (Sullivan and Meigh, 2005). The other 5 components considered by both indicators are: resource quantification, accessibility and property rights, utilisation and economic efficiency, capacity of people and institutions, and ecological integrity maintenance (Sullivan, 2001; Sullivan and Meigh, 2005). Each of these components is constructed by a selection of sub-components, which can be identified on the basis of available data. When a component cannot be measured, proxy elements are used in its place. In order to aggregate the components in an index, they are weighted according to their estimated importance representing the degree of their relevance for the location in question (WWAP, 2012).

The **Water Footprint (WF)**, introduced by Hoekstra and Hung (2002), is also a multi-component indicator identified as of interest for this study. The WF consists of three components: green, blue and grey water. As mentioned by Hoekstra et al (2011), 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. The WF is an indicator of water use, showing different sorts of water consumption and pollution as a spatial and temporal localisation as well as flows of water (UNEP, 2011). This indicator follows the same concept as the Ecological Footprint, but applying it to water related issues (detailed information about the relation between Ecological Footprint and Water Footprint can be found in the next section).

As mentioned by Hoekstra et al (2011), the process of calculating this indicator within a geographically delineated area could require detailed (and often complex) analyses of "process water footprints" of all processes taking place in the area. The water footprint of one single "process step" is the basic building block of all water footprint accounts. Some authors (Vanham & Bidoglio, 2013) consider that "*completing a WF assessment in practice can be difficult due to data availability and reliability, as well as inconsistencies in the underlying databases".* Zeng et al (2012) and UNEP (2011) agree that the lack of statistical data at the river basin level is a major limiting factor for further development of WF assessment at the river basin level.

Nevertheless, WF has been adopted at river basin level (Aldaya & Llamas, 2008; Zeng et al., 2012) and has been considered to be an important indicator for the actual consumptive water use (Steen-Olsen et al., 2012). As mentioned by UNEP (2011) it goes beyond the traditional indicators of 'water withdrawal', which does not consider that part of the withdrawal goes back to catchment (water course or groundwater), and overlooks green and grey water. Furthermore, according to Galli et al. (2012) the Water Footprint is a powerful communication tool, illustrating the hidden links between human consumption-production and water use as well as between trade and water resources management.

Among the eleven selected indicators, there is a set of three indicators devised by the Water Systems Analysis Group of the University of New Hampshire-USA, led by C. Vörösmarty, namely: **Water Reuse Index (WRI)**, **Relative Water Stress Index (RWSI)** and **Index of Non-sustainable Water Use (INSWU)**. They address the sustainability of water use considering the available supplies. All three indicators use the same row data, but are computed in singular ways resulting in distinctive indicators. They express different ways of measuring the water stress in a given region. Table 4.3 presents the main similarities and differences in the computation, units of expression and thresholds of these indicators.

Table 4.3 – Differences and similarities in the computation, unit of expression and thresholds of the indicators WRI, RWSI and INSWU.

Indicator	**Water Reuse Index**	**Relative Water Stress Index**	**Index of Non-sustainable Water Use**
Computation	$WRI = \frac{\sum D + \sum I + \sum A}{Q}$	$RWSI = \frac{D + I + A}{Q}$	$INSWU = Q - (D+I+A)$
Variables	ΣD = upstream domestic water demand (km3/yr); ΣI = upstream industrial water demand (km3/yr); ΣA = upstream agricultural water demand (km3/yr); Q = water supply (km3/yr)	D = domestic water demand (km3/yr); I = industrial water demand (km3/yr); A = agricultural water demand (km3/yr); Q = water supply (km3/yr)	
Unit of Expression	WRI and RWSI are non-dimensional. They can be expressed as a percentage (0-100) or as an absolute value (0 - ∞). Usually RWSI is presented to the general public and decision makers as the number of people exposed to water stress (based on the threshold).		The unit of expression of INSWU is volume per time (i.e., cubic kilo-metres per year).
Thresholds and Reference Values	Water Reuse Index exceeding 1 means that the water use in that section of the catchment is in excess of natural river flow.	Areas experiencing water stress and water scarcity can be identified by RWSI ratios exceeding 0.2 and 0.4, respectively.	Non-sustainable use is tabulated when INSWU < 0, and classified as low (0 to -.1), moderate (-.1 to -1) and high (INSWU< -1)

Sources: Adapted from Vörösmarty et al. 2000; WWAP, 2006, WWAP, 2012

The water reuse index measures how many times water is used sequentially during its path towards the river mouth. It reflects the aggregation of the competition for water throughout the river basin (WWAP, 2012). When a river system serves water to large populations, industrial development and irrigated fields, the society could be using its water resources in excess of natural river flow (i.e. WRI>1). According to WWAP (2006) *"with high values for this Index, we can expect increasing competition for water between users, both nature and society, as well as pollution and potential public health problems"*. As Vörösmarty et al (2005a) pointed out *"It typically increases in a downstream direction, indicating reuse and recycling of river corridor water. This index can, however, decrease when mainstream flow is diluted by more pristine (less recycled) tributary waters"*. The Water Reuse Index can present significant variation in reaction to changes in climate and precipitation, especially seasonally.

The Relative Water Stress Index, also known as Relative Water Demand, offers a measure of the pressures generated by the water demands from the domestic, industrial and agricultural sectors relative to the local water supplies (Vörösmarty et al. 2000). One relevant element to consider regarding this indicator is the geographic scale of application.

Vörösmarty et al. (2000) highlights that *"when relative water demand is tabulated at the country scale for global level, fewer than 0.5 billion people live under conditions of severe scarcity, whereas the use of 30 degrees resolution (latitude × longitude) grids yields well over 1.5 billion people".* Applying gridded population data also allows to identify water stress "hot spots": areas where a great number of people might be affected by the effects of water stress or scarcity (RWSI > 0.2 and > 0.4, respectively) and its consequent impacts on the economy, environment, health and general well-being (WWAP, 2006).

The Index of Non-sustainable Water Use compares water demand to renewable water supply, showing where non-sustainable uses may be occurring (WWAP, 2012). As the WRI and RWSI this indicator also provides a measure for human demand for water in excess of natural water supply (local runoff plus river flow). Decrease in this index indicates an increase in accumulated water demand, a decrease in discharge, or both. It points out to areas where non-sustainable practices may be occurring (INSWU<0). Vörösmarty et al. (2005b) considers that *"for most parts of the planet, this will refer to mining non-renewable ground-water, especially in arid and semiarid areas, where recharge rates to the underground aquifer are limited. It could also embody the interbasin transport of fresh water from water rich to water poor areas".* These practices might be non-sustainable over the long-term.

These indicators, WRI, RWSI and INSWU, were chosen by the United Nations World Water Assessment Program (WWAP) as "key indicators" for monitoring the level of stress on water resources in its tri-annual "World Water Development Report". WWAP (2012) considers that these three indicators are: "*well defined and validated indicators, that have global coverage and are linked directly to policy goals"*.

The **Total Water Storage Capacity (TWSC)** is another indicator selected and that has received international support from UN institutions, as described below:

- it was included by Cap-Net UNDP (the International Network for Capacity Building in IWRM – Integrated Water Resources Management - hosted by the United Nations Development Programme) as one of the *"Minimum Indicator Set for Water Resources Management Function"* that should be considered by decision makers for monitoring functions (Cap-Net UNDP, 2008);
- it was selected, out of a set of 15 indicators by the Expert Group on Indicators, Monitoring, and Data Bases (EG-IMD, hosted by UN-WWAP) as a key global indicator for the state of water resources to meet the needs of policy and decision makers at all levels (UN, 2009);
- and last but not least, it was considered by the UN-Water Task Force on Indicators, Monitoring and Reporting (TF-IMR, coordinated by UN-Water) as one of the indicators that compose a core set of indicators to monitor and communicate the status of water resources and progress in the water sector (UN, 2010).

Nevertheless, these three UN initiatives adopt slightly distinct nomenclature and definitions of the indicator. The EG-IMD (UN, 2009) names it as *"Resource Storage in the System"* and highlights that it should be considered as *"ideally both surface reservoirs and groundwater and data that could indicate depletion on an annual and long term basis"*. The TF-IMR (UN, 2010) adopts the *"Storage Capacity per Person"*, defined as *"total cumulative storage capacity of all large surface reservoirs and groundwater per person"*. The name proposed by Cap-Net UNDP (2008) was the one adopted for this research "Total Water Storage Capacity". The definition for the concept adopted here took into consideration relevant issues addressed by all three initiatives (Cap-Net UNDP, 2008; UN, 2009; UN, 2010) - see IPS in the annex for detailed information.

TWSC indicates the country's ability to face the variability and unpredictability of precipitations, which could be deteriorated due to climate change (UN, 2010). It considers the cumulative water storage capacity of all large reservoirs. Data on large storage is usually available[1], but less often one could find gathered information on small and middle storages (UN, 2010). Yet, storage capacity is only one connection between available water resources and its accessibility to human use. UNEP (2008) highlights that "*most of the storage capacity is geared towards power generation and large scale irrigation, with a very limited infrastructure for agricultural smallholders. There is also a flip side to large-scale water infrastructure, highlighted in the ongoing debate about the appropriate scale of interventions"*.

The total water storage capacity, if compared with volume of water storage available at a given time, could signal problems with water scarcity and drought. This comparison indicates the level of water storage reservoirs (usually represented as percentage) and has been proved to be appealing to decision makers and the general public as well as easily communicated information. The media often uses this indicator to inform the population about situations of drought or water scarcity, usually showing images of the low level of water in the surface reservoirs – lakes, dams, etc (Bernstein & Maler, 2014).

Social and Economic Impacts from Drought (SEID) is an indicator also used by the media to inform the general public about the effects of drought (Cerrillo & Ricou, 2012). This indicator addresses the socioeconomic losses associated with drought in a given location and at a given period of time (Jenkins, 2011). Using a valid methodology, these losses are converted into socio-economic variables, such as deaths (human/stocks), people affected, economic losses and property damage.

Drought is a weather-related phenomenon possibly affecting any region, regardless of its precipitation or climate regimes, although it occurs more often in arid and semi-arid climates (Wilhite, 2005). One of the particularities of using SEID is that, there is no single

[1] The International Commission on Large Dams (ICOLD) gather data on large surface reservoirs at global level and data on large groundwater reservoirs can be found at International Groundwater Resources Assessment Centre (IGRAC).

universal definition of drought. Its definition can differ based on the subjective views, the particularity of the region, impacts and sectors being considered (Wilhite, 2005). Droughts are often considered the most complex of all natural hazards to understand and analyse (Wilhite et al., 2007). They are unlike other weather-related hazards such as floods and hurricanes. These other weather-related events, distinctive from droughts, happen over finite periods and short of time, occur in a limited spatial coverage and leave damages that are visually obvious. Drought develops slowly and quietly, has an unclear onset or ending, spreads in a large spatial coverage (usually not so easy to define clearly its limits), and can affect regions for weeks, months or years (Ding et al., 2010). All these aspects make drought impact assessment a challenging task, especially when it lacks highly visible and structural impacts (Jenkins, 2011).

The impacts of drought can be divided into two main categories: direct and indirect impacts. The direct impacts usually are on the reduction of food (i.e. destroying crops) and water supply (scarcity and quality problems). These direct impacts can indirectly affect quality of life, malnutrition, starvation, disease, migration, economic stagnation-crises, and risk of conflict, all triggering financial, humanitarian and development concerns (Jenkins, 2011). Wilhite et al. (2007) argues that these indirect effects can spread rapidly through the economic system (both upstream and downstream) and the society in general affecting regions far from the origin and persist even after the drought has ended. Identifying adequately the direct and indirect impacts is both a challenging and important task. It is challenging due to the unambiguous classification of these effects. It is important because the limits established by such classification guide the range of impacts that may or may not be considered in the computation of the indicator (Ding et al., 2010).

For a long time drought impacts have usually been grouped together into three principal areas: social, economic and environmental (Wilhite & Easterling, 1987). While environmental and social impacts of drought could be substantial, computations of ecosystem losses are rarely incorporated into drought impact assessment (Jenkins, 2011). Furthermore, Low (2013) points out that even the estimates of direct economic impact vary widely and are very inaccurate. Low (2013) and Ding et al. (2010) argue that possible reasons that impede the estimation of socio-environmental impacts as well as the accuracy of the economic ones are: that they are difficult, expensive and time-consuming studies; the lack of reliable biophysical measurements of the extent and rate of drought; the use of different estimation methods; the need to have specialized expertise in data collection and modelling; and some impacts might be incommensurable or intangible. Thus, several authors (Wilhite, 2005; Low, 2013; Jenkins, 2011) consider that very few studies have strived to identify the complexity of drought impacts.

Yet considering these difficulties to achieve accuracy, measuring the socio-economic impacts of drought can lead to relevant information for decision makers, in order to reduce vulnerability and take action to mitigate its impact. By identifying and quantifying these impacts the society can build strategies to increase local adaptive capacity and resilience (Sena, et al., 2014). Information of this kind is key to efficiently address the challenges of drought, especially the set policy alternatives for managing drought risks to protect livelihoods (Shiferan, et al., 2014).

The indicator "**Access to Improved Sanitation**" has a worldwide coverage, mainly because it is one of the official indicators used by the UN to measure progress in the Millennium Development Goals. It addresses Target 7.C *"to halve, by 2015, the proportion of the population without sustainable access to safe drinking-water and basic sanitation*" (UN-Water, 2010). The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JPM), the official United Nations mechanism tasked with monitoring progress towards this MDG target, hosts a global database that draws upon more than 1700 datasets, mainly composed of nationally representative household surveys and censuses (WHO/UNICEF, 2013).

The WHO/UNICEF JMP (2008) defines the types of excreta disposal classified as "improved sanitation" considering that by nature of their design they should ensure a hygienic and healthy environment (separating human excreta from human contact). However, this indicator does not address where wastewater ends up and whether it is being treated (WWAP, 2006). If negative health consequences of poor sanitation are to be avoided, adequate excreta disposal alternatives should be accessible to all. The UN-WWAP (2006) reveals that *"indiscriminate defecation and improper excreta disposal are principal determinants for both morbidity and mortality in the world"*. Therefore, this indicator offers an important measure of the action needed to improve domestic sanitation and, at the same time, it assesses the risk of exposure of the population to health problems caused by poor sanitation.

The indicator "**Proportion of Urban Population Living in Slums" (PUPLS)** also takes into account the access to improved sanitation, considering it as one of the five parameters used for its calculation. The other four are: access to safe drinking water, secure tenure, durability of housing and sufficient living area (UN-HABITAT, 2008). PULPS represents the proportion of urban population lacking at least one of these five housing conditions. Therefore, it is clear that this indicator goes beyond the water resource issues and addresses poverty in an urban context.

Four of the five parameters (namely: water, sanitation, durability and living area) have well developed definitions and data can be obtained from household surveys and national censuses of population and housing (UN-HABITAT, 2008). But data from secure tenure is not uniformly available through mainstream systems of data collection and lacks a clear operational definition (WWAP, 2006).

UN-HABITAT is the UN agency that proposed this indicator. It is directly related to MDG 7D: *"by 2020, to have achieved a significant improvement in the lives of at least 100 million slum* *dwellers*". PUPLS has been used by the WWAP (2012) as a key indicator for the World Water Assessment Reports, considering it as a *"well defined and validated indicator that has global coverage and is linked directly to policy goals"*. This indicator addresses the human need for shelter, a human right. WWAP (2006) recalls *"the unstructured growth of slums is also a major cause of pollution leading to environmental degradation of urban water courses"*.

Similarly to the last two indicators commented above, the "**Incidence of Cholera**" (IC) also addresses human health. Cholera is an acute enteric infection produced by the intake of bacterium *Vibrio cholerae* found in water or food contaminated with faeces (Ashbolt, 2004). Cholera is one of the diseases demanding report to WHO (World Health Organization) under the International Health Regulations. WHO (2006) points out that the actual number of cases could be considered to be much higher than the ones reported mainly because of poor surveillance systems and under-reporting, in some cases, motivated by fear of trade sanctions and lost tourism.

This indicator gives account of one of the impacts on the populations suffering from the lack of adequate sanitation and drinkable water supply, indicating problems related to the quality of water and hygiene (Chaignat & Monti, 2007). WHO (2006) points out that IC is one of the key indicators of social development and that Cholera remains a global threat. The "Incidence of Cholera" can be a key tool to help decision makers to reduce the proportion of vulnerable populations who live in unsanitary conditions, and to avoid the re-emerging of this disease (Tirado, Clarke, Jaykus, McQuatters-Gollop & Frank, 2010).

4.4.2 Indicators that need further improvements on the scientific foundations

The findings of this study showed that nine indicators assessed by this research did not fulfil the scientific foundation criterion. For these nine indicators no known peer reviewed paper and/or other relevant publication further developing, validating or testing the indicators current scientific standards were found. They are in fact indicators still on a formative stage and therefore they require further improvement of their theoretical, conceptual, technical, and scientific standards in order to be applicable as indicators for sustainable water use and management.

Four of the indicators assessed here are concepts proposed by the UN World Water Assessment Program (WWAP) at its first World Water Development Report (2003), namely: "**Incidence of worms, scabies, trachoma and diarrhea**", "**Water topics in school curriculum**", "**Fraction of the burden of ill-health resulting from nutritional deficiencies**" and "**Causes of food emergencies**". No further reference to this indicator was made by WWAP in the next versions of the report, published in 2006, 2009 and 2012. WWAP recognized in its second report (WWAP, 2006) *"that these indicators require testing with regard to the relevance and practicality."*

It is also worth noting that the indicators "Water topics in school curriculum" and "Fraction of the burden of ill-health resulting from nutritional deficiencies" were proposed by WWAP in 2003 as possible *"future indicator"*, confirming that they are in fact proposals to be further developed.

Another indicator also addressed by the WWAP that is at a conceptual stage is the "**Performance index of water utilities**". It was proposed by UN-HABITAT (WWAP, 2006), aiming at combining a group of indicators (affordability, quality of water supplied, accessibility to service, quantity of water supplied and reliability) linking the operation of water utility to adequate services for urban residents. Nevertheless, it was classified as "under development" by the second World Water Development Report (WWAP, 2006).

No further reference to this indicator was made in the next versions of the reports (WWAP, 2009; WWAP, 2012 and WWAP, 2015). WRI (2005) considers that *"this indicator would be very valuable in assessing the performance of water utilities to meet people's needs"*, however "*there is no specific on the methodology that would be applied in order to create this index"*. These potentials and limitations point towards the need of further studies, aiming at improving its scientific foundation and applicability.

The WWAP in its previous reports (WWAP, 2006; WWAP, 2012) presented an interesting proposal for indicator, called "**Water sector share in total public spending**". However, this does not yet have adequate scientific foundations. WWAP (2012) mentions that it is *"in a formative stage and may evolve into key indicator following refinement of methodological issues or data development and testing"*. According to this source, this indicator measures the *"national budget spent in water sector for expanding, rehabilitating and maintaining water related infrastructures and improving water resources management and governance"*. Several authors, including the World Bank (2012) consider that deciding what share of the public budget is allocated to the water sector is important for the management of water resources, mainly because it shows tangibly the political commitment as well as the consistency with policy objectives and priorities of the government in terms of meeting sector targets. Nevertheless, WWAP (2006) highlights that, since the indicator is "*expressed in terms of a public expenditure, it might not adequately capture the investments made by the private sector or civil society or local communities in the sector"*.

The relevance of measuring investment in the water sector and the limitations presented above should be taken into consideration by further studies aiming at advancing the scientific foundations of this indicator.

"**Pro-poor and pro-efficiency water fees**", also called "Charges and fees for water allocation favouring the poor and efficient water use", is an indicator at a conceptual stage, proposed by Cap-Net UNDP (2008). It was proposed in order to *"examine the application of economic and financial tools in water allocation aiming at efficient water use and pro-poor policy"*.

Cap-Net UNDP (2008) presented this proposal among other indicators as *"a minimum set of indicators for assisting the River Basin Organizations to assess progress towards sustainable management of water resources"*. However, there is no clear methodology for its use and calculation, just a brief description of its definition. Nonetheless, no comment was made about field tests and validation of the indicator. Similarly to the other indicators addressed in this section of the document, no relevant paper and/or publication that validated the indicator by current scientific standards was found.

Milman & Short (2008) proposed the indicator "**Water Provision Resilience**". Their goal in developing this indicator was *"to provide a starting point for re-thinking the metrics used to measure progress and sustainability"*. They have proposed this indicator as to serve *"as an example of how resilience can be incorporated into indicators of sustainability"*. Furthermore, they state *"Our intention in creating the Water Provision Resilience indicator is to provide a starting point for re-conceptualizing static indicators of sustainability so that they reflect resilience"*. Milman and Short (2008) also affirm that *"The indicator presented here is an early attempt for this effort and there are many improvements that could be made*." These comments signal that so far it is only a proposal or as they said, an indicator that is at its *"starting point"*. It can be considered as a concept for an indicator aimed at reflecting resilience in the measuring of sustainability, but that needs further studies and applications in order to demonstrate its scientific foundation.

"**Progress towards achieving IWRM target**" is an indicator, proposed by the Global Water Partnership (GWP, 2004) in a global study conducted in an *ad hoc* way based on an informal stakeholder survey. GWP (2004) highlights that "*... the survey remains a qualitative exercise. The assessments made reflect the best judgments of senior professionals drawing primarily on the accumulated information available within the GWP networks at regional and country levels."* GWP (2006) and UN Water (2008) proposed further improvements of this concept, nevertheless the indicator can still be considered as a kind of assessment done through an opinion survey at national level using questionnaires. These authors (UN Water, 2008; GWP, 2006 and GWP, 2004) imply that this indicator is still at a conceptual stage with no clear detailed information on how to apply, replicate and/or calculate it. WRI (2005) confirms this by saying that this indicator "*...is a more subjective and qualitative exercise than a scientific one."* Furthermore, UN Water (2008) states, *"There is a recognized need to develop a set of indicators which would characterize the status of implementation of the IWRM approach within countries."*

Despite these facts, UN-WWAP (2012) considers that it is a key indicator and several authors (UN Water, 2008; WRI, 2005) confirm the importance of having an indicator to measure progress towards setting in place the IWRM. Therefore this research recommends further improvement of its theoretical, conceptual, technical, and scientific standards.

4.4.3 Indicators that are duplicated

This study identified three pairs of indicators that were duplicated under the indicator set; showing that despite having different names they in fact measure a similar or even the same attribute.

The indicators "**Water shortages**" and "Relative Water Stress Index" measure the same attribute: the scarcity of water at a given geographic location. On one hand, the indicator "Water shortages", as presented by WWAP (2003), only indicates the number of people and countries affected by water shortages. The definition proposed by WWAP for this indicator is vague and could lead to misunderstandings regarding its calculation and use. On the other hand, the indicator "Relative Water Stress Index" has a robust and clear methodology for its calculation and analysis. Furthermore, "Relative Water Stress Index", also known as "Relative water demand" or "Environmental water stress indicator", has been well accepted and used by the water resources community, including academia (Vörösmarty et al, 2005), the business sector (WBCSD & IUCN, 2010) and international organizations (WWAP, 2012). Therefore, the indicator "Relative Water Stress Index" was selected as the indicator of interest for this research.

"**Major drought events and their consequences**" and "Social and Economic Impacts from Drought" are indicators that measure a similar attribute: the identification of the major drought events in a given location and the estimation of the associated loss of life and economic losses (WWAP, 2003; Jenkins, 2011). However, the latter goes beyond the scope of the former, mainly because it uses valid methodologies to also consider social aspects such as number/characteristics of people affected and even the relevant indirect socioeconomic impacts from drought (Low, 2013). Furthermore, "Social and Economic Impacts from Drought", has been well accepted and used by the water resources community (Jenkins, 2011; Ding et al, 2010; Wilhite et al, 2007; Low, 2013) and even by the general public (Cerrillo & Ricou, 2012). Therefore, the indicator "Social and Economic Impacts from Drought" was selected as the indicator of interest.

The indicators "**Ecological Footprint**" and "Water Footprint" use the same approach (Galli et al, 2012), similar methodologies (Hoekstra, 2009), and, in a certain way, it also measures a similar attribute: the human appropriation of natural resources for the production and consumption of goods and services (Steen-Olsen et al., 2012).

The concept of Ecological Footprint established in the 1990s was used as an analogy, for the creation of the Water Footprint in 2002, by the Water Footprint Network (Hoekstra, 2009). The author further states the main difference between them: *"whereas the ecological footprint denotes the bioproductive area (hectares) needed to sustain a population, the water footprint represents the freshwater volume (cubic metres per year) required".*

The indicator "Water Footprint" focuses exclusively on water resource issues (Hoekstra et al., 2011). This is not the case with the indicator "Ecological Footprint", that considers water only as one of several components used for its calculation (Fang et al., 2014). Since the use and management of water is the main subject of this study, "Water Footprint" was selected as the indicator of interest here, instead of "Ecological Footprint", mainly because the former is more suitable for the scope of this research than the latter.

4.4.4 Indicators not suitable for river basin scale

Only one indicator was considered as not valid to river basin scale, namely "**Country's dependence ratio**". This indicator, also known as "Dependence of country's water resources on inflow from neighbouring countries" or "Water Dependency Ratio" was devised by FAO (2003). In the way it was formulated, this indicator is suitable for country level but not river basin scale. Its definition, calculation and methods were tailored for a geographic scale of a specific country, and then, in some cases, aggregated to a larger spatial scale such as sub-continental and continental.

In fact, several authors mention the use of this indicator at the international level - always considering the country level scale (FAO, 2003; Hoekstra, 2010; Islam & Susskin, 2012; World Bank, 2007). This indicator measures the relation between the surface and groundwater that inflow from other countries and the total amount of water available in the country at annual basis (FAO, 2003).

The total amount of water available is the *"sum of total internal renewable water resources and the amount of water flowing in from neighbouring countries"* (World Bank, 2007). The Dependence Ratio points towards the part of the total renewable water resources of a country coming from outside is. These concepts addressed by the indicators are also relevant for water use and management at watershed level, therefore this research recommends further studies in order to convert and/or adjust them to an indicator suitable for river basin scale.

4.4.5 Further discussions

The 11 indicators, that fulfil the four criteria analysed in this chapter, can be considered as relevant tools to support decision makers to measure the sustainability in the water use and management at river basin level. The previous chapter demonstrated that even the 13 indicators that did not reach the four criteria assessed, are in fact very interesting indicators that fulfil the sustainability criteria. Therefore, this study recommends developing additional applied research about these indicators. These further studies could focus on improving the methodology for its use and calculation, and/or field-tests and practical validation.

Findings of the current study show that the majority of the indicators analysed fulfil the scientific foundation criterion. Nevertheless nine of them did not yet present solid scientific fundaments to be approved under this criterion. It is worth mentioning that these indicators are interesting proposals and concepts that, as demonstrated above, address in a holistic way the main elements of the sustainability of water use and management. Based on these findings, the current research recommends the development of further studies to improve their theoretical, conceptual, technical, and scientific standards.

The assessment of the four selection criteria (scientific foundation, individuality, river basin scale and specificity) was considered to be of highest importance for this research. They address strategic aspects and key attributes of the indicators related to: consolidation, application and distinctiveness. The findings of this research support what several authors have mentioned before (Niemeijer & Groot, 2008; Segnestam, 2002; UNEP, 2006; World Bank, 2000; WWAP, 2006; among others): that the verification of the scientific foundation, the individuality, specificity and the scale of application is a crucial part of the assessment of indicators. Furthermore, the selection of the indicators followed clearly outlined procedures that are replicable and scientifically robust. This study recommends the application of these criteria for the assessment of indicators related to sustainable water use and management.

4.5 Conclusions

Indicators have a key role in the promotion of sustainable development in general, and the water sector is no exception. The selection process is an important stage of the development of indicators and it should obey a precise pre-defined criterion. Our study selected out of the 24 indicators for sustainable water use and management (short-listed in the previous chapter), those that fulfil four key criteria. Indicators were assessed based on current and sound scientific standards (scientific foundation), on whether they were unduplicated (individuality), on their validity for river basin scale (geographic scale) and whether they were clearly and unambiguously defined (specificity).

The findings of the study show that 13 indicators did not comply with at least one of the criteria assessed. The majority of them (nine) did not present an adequate scientific foundation, a few (three) were duplicated and one was not suitable for river basin scale. These indicators were classified as not being of interest for this study. Nevertheless, we recommend further studies to improve these indicators because, once these limitations are solved, they could become very useful tools to measure sustainability of water resources, considering that all of them fulfil the majority of the sustainability criteria (see previous chapter).

This study showed that **11 indicators fulfilled the four criteria assessed and were classified as indicators of interest to the research**. These indicators address strategic aspects and key attributes of the indicators related to: consolidation, application and distinctiveness. Decision makers could use individually these indicators to measure the sustainability of water use and management at river basin level.

Nevertheless, several authors (Lin et al., 2009; Mendoza & Prabhu, 2003; Niemeijer & Groot, 2008; Niemi & McDonald 2004; Wolfslehner & Vacik, 2011) point out that the systematic usefulness of indicators should be examined within the entire set of the selected indicators. According to this concept, the selection of the indicator based on the degree to which they meet criteria individually should be complemented by analyzing the particular function that each indicator in the set has in addressing the problem under consideration. The next chapter presents how this research applied the eDPSIR approach addressing this issue and better visualizing the functions and interconnections of each indicator within the total collection of a selected set of indicator.

4.6 References

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4.7 ANNEXES - INDICATOR PROFILE SHEETS (IPSS) – 24 INDICATORS

Water Poverty Index

Climate Vulnerability Index

Water Reuse Index

Water shortages

Water Footprint

Incidence of worms, scabies, trachoma, diarrhea

Performance Index of Water Utilities

Access to Improved Sanitation

Proportion of Urban Population Living in Slums

Fraction of the burden of ill-health from nutritional deficit

Social and Economic Impacts from Drought

Incidence of Cholera

Causes of food emergencies

Ecological Footprint

Progress towards achieving IWRM target

Water Provision Resilience

Major drought events and their consequences

Relative Water Stress Index

Index of Non-sustainable Water Use

Water sector share in total public spending

Country's Dependence Ratio

Pro-poor and pro-efficiency water fees

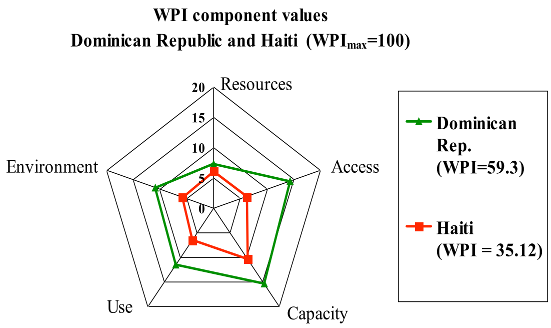
Water topics in school curriculum

Total Water Storage Capacity

Indicator Profile Sheet

Water Poverty Index (WPI)	
Definition	Integrates physical, social, economic and environmental factors, and links water and poverty issues. Evaluates 5 strategic components: water resources available, access to water, how effectively water is used, capacity to manage water and environmental impacts. Source: Sullivan et al, 2002.
Underlying definitions and concepts	Water poverty is not only measured by the availability of water in a given location. Other components should be taken in consideration to assess if an area is rich or poor in relation to its water resources (i.e access, use, capacity, environmental impacts). The WPI is mainly designed to help improve the situation for populations facing poor water endowments and poor adaptive capacity.
DPSIR classification	Pressure, State, Impact, Response
Sustainability criteria	Social, Economic, Environmental, Institutional
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	Jemmali, H., & Sullivan, C. a. (2012). Multidimensional Analysis of Water Poverty in MENA Region: An Empirical Comparison with Physical Indicators. *Social Indicators Research*. doi:10.1007/s11205-012-0218-2 Juwana, I., Muttil, N., & Perera, B. J. C. (2012). Indicator-based water sustainability assessment - a review. The Science of the total environment, 438, 357–71. doi:10.1016/j.scitotenv.2012.08.093 Sullivan CA (2001) The potential for calculating a meaningful Water Poverty Index.Water Int 26:471–480 Sullivan, C. (2002). Calculating a Water Poverty Index. World Development, 30(7), 1195–1210. doi:10.1016/S0305-750X(02)00035-9 Sullivan, C. (n.d.). Using the Water Poverty Index to monitor progress in the water sector. Wallingford: CEH Wallingford. Retrieved from http://www.managingforimpact.org/sites/default/files/resource/water_poverty_index.pdf Sullivan, C., Meigh, J. ., & Fediw, T. (2002). *Derivation and Testing of the Water Poverty Index Phase 1. Center for Ecology and Hydrology CEH. Natural …* (Vol. 1, p. 53). Wallingford. Retrieved from http://www.soas.ac.uk/water/publications/papers/file38386.pdf Sullivan, C., Meigh, J., Ecology, C., & Lawrence, P. (2006). Application of the Water Poverty Index at Different Scales: A Cautionary Tale, *31*(3), 412–426

Examples of indicator “Water Poverty Index” (WPI)



Source: Sullivan & Lawrence, 2006

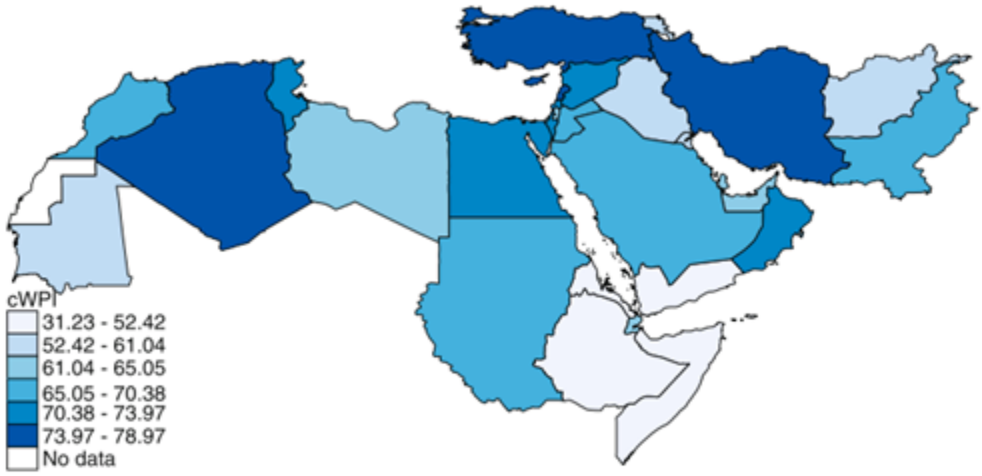


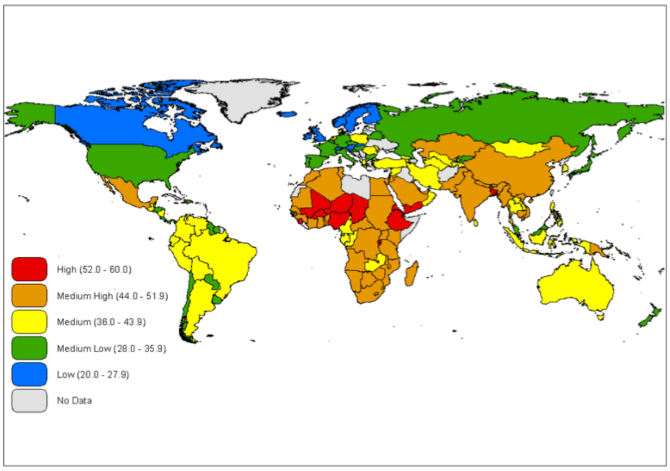
Fig. 7 Classical Water Poverty Index

Source: Jemmali & Sullivan, 2012

Indicator Profile Sheet

Climate Vulnerability Index (CVI)	
Definition	Draws together data from the bio-physical, economic and social sciences (similar to WPI), but, in this case, combines them in order to make a holistic assessment of human vulnerability in the context of climate and global threats to water resources. It considers 6 aspects: 5 are the same as WPI (resource, access, uses, capacity and environment) plus the geographical vulnerability of the location. Source: adapted from WWAP (2006), WWAP (2012) and Sullivan & Huntingford (2009).
Underlying definitions and concepts	The CVI does not consider all aspects of vulnerability, but it focuses on water, since water is a key component of all life and an essential element in all people's livelihoods (Sullivan & Huntingford, 2009). It is a multidimensional vulnerability assessment acting as a *"tool to identify which human communities are the most vulnerable to the combined impacts of climate and global change."* Source WWAP, 2012.
DPSIR classification	Pressure, State, Impact and Response
Sustainability criteria	Social, Economic, Environmental, Institutional
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	Sullivan, C., & Huntingford, C. (2009). Water resources, climate change and human vulnerability. *18th World IMACS/MODSIM Congress,* …, (July), 3984–3990. Retrieved from http://www.kmafrica.com/files/sullivan_ca.pdf Sullivan C.A. & Meigh, J.R. (2005) Targeting attention on local vulnerabilities using an integrated indicator approach: the example of the Climate Vulnerability Index. Water Science and Technology, Special Issue on Climate Change Vol 51 No 5 pp 69–78, 30, 1195-1210. WWAP (World Water Assessment Programme). 2006. The United Nations World Water Development Report 2: Water a shared responsibility. Paris, UNESCO WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

Example of Indicator "Climate Vulnerability index" CVI:

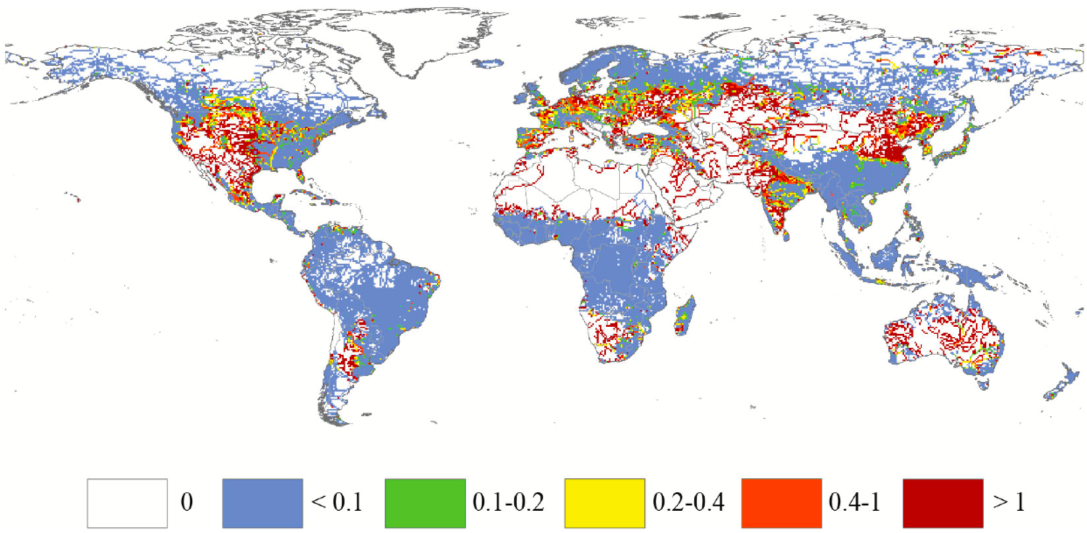


Source: WWAP, 2012

Indicator Profile Sheet

Water Reuse Index (WRI)	
Definition	Aggregate upstream water demand/use per available water supply along river network. It measures consecutive water withdrawals for domestic, industrial and agricultural water use along a river network relative to available water supplies. Source: WWAP, 2012
Underlying definitions and concepts	Represents the extent to which runoff is recycled or reused as it accumulates and flows toward the basin mouth (Vörösmarty et al 2005). It is a measure of upstream competition for water, its reuse and potential ecosystem and human health impacts (Vörösmarty et al, 2000).
DPSIR classification	Pressure, State
Sustainability criteria	Social, Economic, Environmental
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	Vörösmarty, C. J., Douglas, E. M., Green, P. A., & Revenga, C. (2005). Geospatial indicators of emerging water stress: an application to Africa. Ambio, 34(3), 230–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16042282 Vörösmarty, C. J., Green, P., Salibury, J., & Lammers, R. (2000). Global Water Resources: Vulnerability from Climate Change and Population Growth. Science, 289(5477), 284–288. doi:10.1126/science.289.5477.284 WWAP (World Water Assessment Programme). 2006. The United Nations World Water Development Report 2: Water a shared responsibility. Paris, UNESCO WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

Example of indicator “Water Reuse Index” (WRI)



Source: WWAP, 2012

Indicator Profile Sheet

Water shortages	
Definition	The number of people and countries affected by water shortages (unable to supply minimum drinking water). Source: WWAP, 2003
DPSIR classification	Impact
Sustainability criteria	Social, Economic, Environmental, Institutional
Criteria verified	Scientific Foundation
Sources of further information	WWAP (World Water Assessment Programme). 2003. The United Nations World Water Development Report: Water for People Water for Life. Paris, UNESCO

Indicator Profile Sheet

Water Footprint (WF)	
Definition	Expresses human appropriation of freshwater in volume terms. The water footprint within a geographically delineated area (for example, a municipality, province, state, nation, catchment or river basin) is equal to the sum of the process water footprints of all processes taking place in the area. Source: Hoekstra et al, 2011
Underlying definitions and concepts	The water footprint of one single 'process step' is the basic building block of all water footprint accounts. This indicator has the same concept of ecological footprint, but it takes in account water related issues. The water footprint of a river basin shows the water that is used to produce the goods and services within that geographically limited area. Source: Hoekstra et al, 2011
DPSIR classification	Pressure
Sustainability criteria	Social, Economic, Environmental
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	Aldaya, M. M., & Llamas, M. R. (2008). Water footprint analysis for the Guadiana river basin Value of Water Research Report Series No. 35. *Value of Water Research Report Series*. Delft, the Netherlands: UNESCO-IHE. Aldaya, M. M., & M. R. Llamas. (2008). *Water footprint analysis for the Guadiana river basin*. (Fundación Marcelino Botín, Ed.) (p. 112). Madrid, Spain. Ercin, A. E., & Hoekstra, A. Y. (2012). Carbon and Water Footprints: Concepts, Methodologies and Policy Responses. Fang, K., Heijungs, R., & de Snoo, G. R. (2014). Theoretical exploration for the combination of the ecological, energy, carbon, and water footprints: Overview of a footprint family. *Ecological Indicators*, *36*(0), 508–518. doi:http://dx.doi.org/10.1016/j.ecolind.2013.08.017 Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., & Giljum, S. (2012). Integrating Ecological, Carbon and Water footprint into a "Footprint Family" of indicators: Definition and role in tracking human pressure on the planet. *Ecological Indicators*, *16*, 100–112. doi:10.1016/j.ecolind.2011.06.017 Hoekstra, A. Y. (2009). Human appropriation of natural capital: A comparison of ecological footprint and water footprint analysis. *Ecological Economics*, *68*(7), 1963–1974. doi:10.1016/j.ecolecon.2008.06.021 Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, M. M. (2011). *The Water Footprint Assessment Manual: Setting the Global Standard*. *Social and Environmental Accountability Journal* (p. 228). London • Washington, DC: Earthscan. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/0969160X.2011.593864 Hoekstra, A., & Mekonnen, M. (2011). Global water scarcity: the monthly blue water footprint compared to blue water availability for the world's major river basins. *Value of Water Research Report Series*. Delft, the Netherlands: UNESCO-IHE. Retrieved from http://doc.utwente.nl/80237/ Steen-Olsen, K., Weinzettel, J., Cranston, G., Ercin, a E., & Hertwich, E. G. (2012). Carbon, land, and water footprint accounts for the European Union: consumption, production, and displacements through international trade. *Environmental science & technology*, *46*(20), 10883–91. doi:10.1021/es301949t UNEP. (2011). *Water Footprint and Corporate Water Accounting for Resource Efficiency*. Vanham, D., & Bidoglio, G. (2013). A review on the indicator water footprint for the EU28. *Ecological Indicators*, *26*, 61–75. doi:10.1016/j.ecolind.2012.10.021 Water Footprint Network Website: www.waterfootprint.org (accessed May 2013) Zeng, Z., Liu, J., Koeneman, P. H., Zarate, E., & Hoekstra, a. Y. (2012). Assessing water footprint at river basin level: a case study for the Heihe River Basin in northwest China. *Hydrology and Earth System Sciences*, *16*(8), 2771–2781. doi:10.5194/hess-16-2771-2012

Example of indicator “Water Footprint” (WF)

Table 2. Virtual water content (VWC), water footprint (WF) and blue water proportion (BWP) of crop and livestock production within the HRB (2004–2006).

Crop Type	VWC	WF	BWP
	($m^3\,t^{-1}$)	(million $m^3\,yr^{-1}$)	
Wheat	826	266	64 %
Maize	763	182	62 %
Other cereals	1045	368	27 %
Soybean	2216	48	72 %
Starchy roots	110	10	45 %
Oil crops	466	22	0 %
Sugar crops	94	18	0 %
Cotton	3384	156	56 %
Apple	855	23	34 %
Other fruits	918	210	34 %
Vegetables	150	111	48 %
Other crops	614	225	45 %
Pork	3910	10.32	26 %
Beef	20360	7.62	3 %
Sheep/goat	14670	42.87	0.3 %
Poultry	4029	5.01	39 %

Source: Zeng et al 2012

Indicator Profile Sheet

Incidence of worms, scabies, trachoma and diarrhoea	
Definition	The number of cases of worms, scabies, trachoma and diarrhea in a defined population at a specified point in time Source: adapted from WWAP, 2003.
DPSIR classification	Impact
Sustainability criteria	Social, Environmental, Institutional
Sources of further information	WWAP (World Water Assessment Programme). 2003. The United Nations World Water Development Report: Water for People Water for Life. Paris, UNESCO

Indicator Profile Sheet

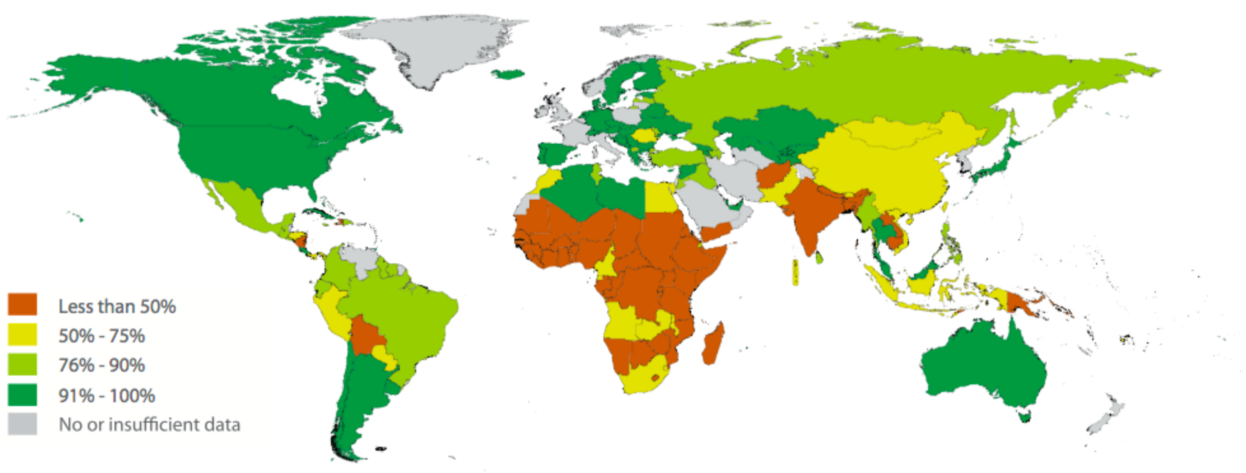
Performance Index of Water Utilities	
Definition	The performance of water service providers in urban areas assessed in terms of: affordability, quality of water supplied, accessibility to service, quantity of water supplied and reliability. Provision of water and sanitation in cities can be undertaken by public or private utilities. The level of performance of these utilities will dictate how well the cities are being served according to the aforementioned criteria. Source: WWAP, 2006
DPSIR classification	State
Sustainability criteria	Social, Economic, Institutional
Sources of further information	WWAP (World Water Assessment Programme). 2006. The United Nations World Water Development Report 2: Water a shared responsibility. Paris, UNESCO

Indicator Profile Sheet

Access to Improved Sanitation (AIS)	
Definition	The proportion of the population (total, urban and rural) with access to an improved sanitation facility (for defecating). Source: WWAP, 2012
Underlying definitions and concepts	An improved sanitation facility is defined as a facility used for excreta disposal whereby the human excreta are hygienically separated from human contact or their immediate environment, thus reducing the risk of faecal-oral transmission to its users. Such facilities include: • Toilet with sewer connection or septic tank • Pour flush toilet/pour flush latrine to sewer, septic tank or pit • Ventilated Improved Pit (VIP) latrine • Latrine with a slab • Ecological sanitation A shared or public facility is a facility regularly used by members of more than one household (extended families living on the same compound, plot or yard are generally considered one and the same household). Shared or public facilities are not considered improved for reasons of poor cleanliness and lack of privacy. Definitions used for urban and rural areas are those defined by individual countries. Source: WWAP, 2012
DPSIR classification	Impact
Sustainability criteria	Social, Environmental, Institutional
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	UN-Water. (2010). *UN-water global annual assessment of sanitation and drinking-water (GLAAS) 2010: targeting resources for better results* (p. 90). Retrieved from http://whqlibdoc.who.int/publications/2010/9789241599351_eng.pdf WHO/UNICEF. (2008). *Progress on Drinking Water and Sanitation: Special Focus on Sanitation*. (p. 58). New York / Geneva. Retrieved from http://www.who.int/water_sanitation_health/monitoring/jmp2008.pdf WHO/UNICEF. (2010). *Progress on Sanitation and Drinking-water: 2010 Update* (p. 60). New York 10017,. Retrieved from http://www.unicef.org/media/files/JMP-2010Final.pdf WWAP (World Water Assessment Programme). 2006. The United Nations World Water Development Report 2: Water a shared responsibility. Paris, UNESCO WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

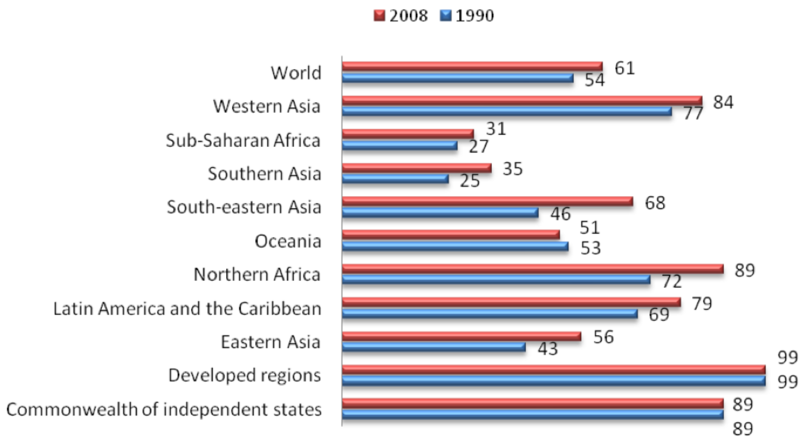
Examples of indicator “Access to Improved Sanitation” (AIS)

Improved sanitation coverage, 2006



Source: WHO/UNICEF, 2008

Use of improved sanitation facilities in total (% of population)



Source: WWAP, 2012

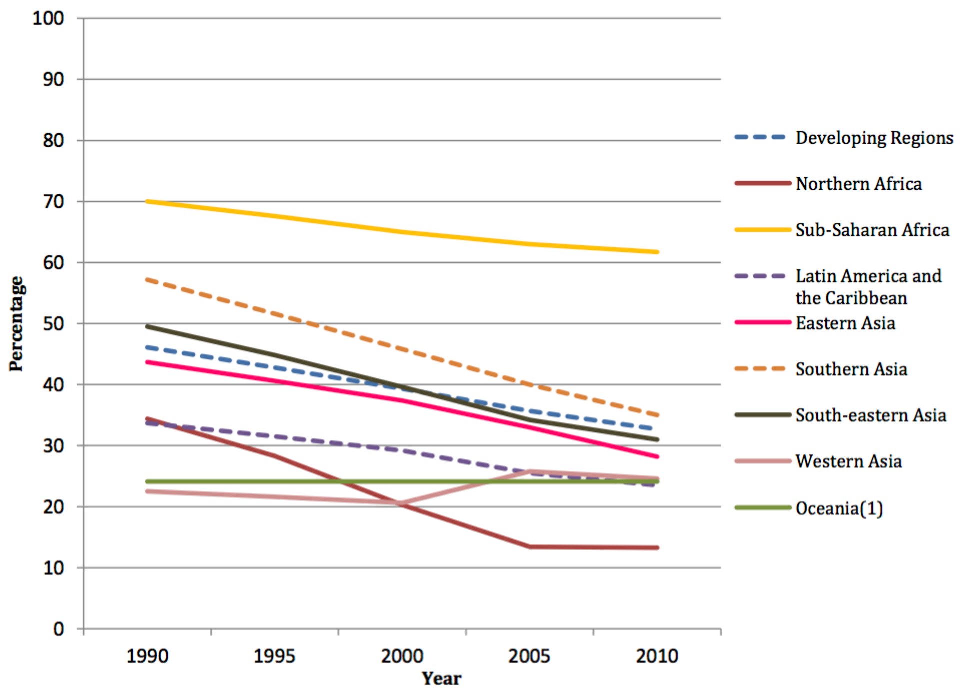
Indicator Profile Sheet

Proportion of Urban Population Living in Slums (PUPLS)	
Definition of indicator	The proportion of urban population lacking at least one of the following five housing conditions: Access to improved water; Access to improved sanitation facilities; Sufficient-living area, not overcrowded; Structural quality/durability of dwellings; Security of tenure. Source: WWAP, 2012
Underlying definitions and concepts	This indicator measures the proportion of urban dwellers living in deprived housing conditions. It is a key indicator measuring the adequacy of the basic human need for shelter. An increase of this indicator is sign for deteriorating living conditions in urban areas. Source: WWAP, 2012
DPSIR classification	Pressure, State
Sustainability criteria	Social, Economic, Institutional
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	UN-HABITAT. (2003). *Guide to Monitoring Target 11: Improving the lives of 100 million slum dwellers* (p. 15). NAIROBI. Retrieved from http://ww2.unhabitat.org/programmes/guo/documents/mdgtarget11.pdf UN-HABITAT. (2008). *State of the World´s Cities 2010/2011: Bridging the Urban Divide*. (Earthscan, Ed.) (p. 244). London: UN-HABITAT. UN-HABITAT. (2009). *Global Urban Indicators – Selected statistics: Monitoring the Habitat Agenda and the Millennium Development Goals* (p. 123). NAIROBI. Retrieved from http://www.unhabitat.org/downloads/docs/global_urban_indicators.pdf WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

Examples of indicator “Proportion of Urban Population Living in Slums” (PUPLS)

Proportion of urban population living in slum (%)					
Regions	1990	1995	2000	2005	2010
Developing Regions	46.1	42.8	39.3	35.7	32.7
Northern Africa	34.4	28.3	20.3	13.4	13.3
Sub-Saharan Africa	70.0	67.6	65.0	63.0	61.7
Latin America and the Caribbean	33.7	31.5	29.2	25.5	23.5
Eastern Asia	43.7	40.6	37.4	33.0	28.2
Southern Asia	57.2	51.6	45.8	40.0	35.0
South-eastern Asia	49.5	44.8	39.6	34.2	31.0
Western Asia	22.5	21.6	20.6	25.8	24.6
Oceania(1)	24.1	24.1	24.1	24.1	24.1

(1) Trends data are not available for Oceania. A constant figure does not mean there is no change



Source: UN-HABITAT, 2009

Indicator Profile Sheet

Social and Economic Impacts from Drought (SEID)	
Definition	The direct and indirect socio-economic impacts caused by drought, in a given area and given period of time, are converted, using a valid methodology, considering aspects such as deaths (human/livestock), people affected, economic losses, property damage, etc. Source: adapted from Jenkins, 2011
Underlying definitions and concepts	Drought events and their impacts generate considerable consequences for the society and individuals. Economic damages from drought can be severe and their social impacts can affect millions of people changing their life style definitively, generating mass migration, increasing poverty, and even causing significant loss of lives. Drought events can happen in practically any part of the world, regardless of its climate regime. Drought is a weather-related phenomenon influenced by anthropogenic aspects. Drought develops slowly and quietly, is spatially extensive and can affect regions for months or years. Furthermore, because of its slow and progressive development, the impacts of drought are not as visible as the ones from other weather-related events (i.e. floods, hurricanes, etc.). Therefore, it is crucial to measure the social-economic impacts of drought in order to take action to mitigate and prevent them, influencing policy decision and public response to the crises. Source: adapted from Jenkins, 2011; Ding et al., 2010; and Wilhite et al., 2007
DPSIR classification	Impact
Sustainability criteria	Social, Economic, Environmental
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	Jenkins, K. L. (2011). *Modelling the Economic and Social Consequences of Drought under Future Projections of Climate Change*. University of Cambridge. Retrieved from http://www.dspace.cam.ac.uk/bitstream/1810/242439/1/KJenkins_PhD_Thesis.pdf Low, P. S. (ed). (2013). *Economic and Social impacts of desertification, land degradation and drought*. (UNCCC, Ed.) (UNCCD 2nd., p. 79). Retrieved from http://2sc.unccd.int Ding, Y., Widhalm, M., & Hayes, M. J. (2010). Measuring Economic Impacts of Drought: A Review and Discussion. *Papers in Natural Resources. Paper 196.*, 26. Retrieved from http://digitalcommons.unl.edu/natrespapers/196 Wilhite, D. (2005). *Drought and Water Crises: Science, Technology, and Management Issues*. (T. & Francis, Ed.) (p. 406). London: CRC Press. Wilhite, D. a., Svoboda, M. D., & Hayes, M. J. (2007). Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness. *Water Resources Management*, *21*(5), 763–774. doi:10.1007/s11269-006-9076-5

Examples of indicator “Social and Economic Impacts of Drought” (SEID)

(a)

Country	Date	Damage (000 US$)
China P Rep	1994	13,755,200
Australia	1981	6,000,000
Spain	1990	4,500,000
Iran Islam Rep	1999	3,300,000
United States	2002	3,300,000
Spain	1999	3,200,000
Canada	1977	3,000,000
China P Rep	2006	2,910,000
Zimbabwe	1982	2,500,000
Brazil	1978	2,300,000

(b)

Country	Date	People Killed
China P Rep	1928	3,000,000
Bangladesh	1943	1,900,000
India	1942	1,500,000
India	1965	1,500,000
India	1900	1,250,000
Soviet Union	1921	1,200,000
China P Rep	1920	500,000
Ethiopia	1983	300,000
Sudan	1983	150,000
Ethiopia	1973	100,000

Table 1.1: Top ten drought disasters during 1900 to 2010 defined by (a) economic damage (000 US$ in year of event), and (b) number of people killed at a country level. Source: EM-DAT, 2010

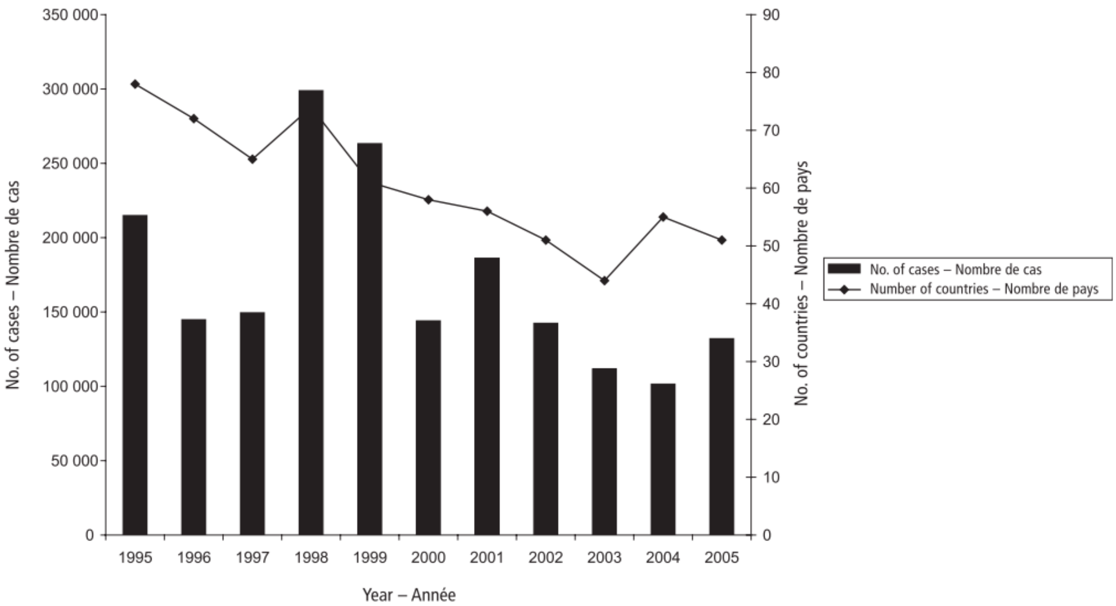
Source: Jenkins, 2011

Indicator Profile Sheet

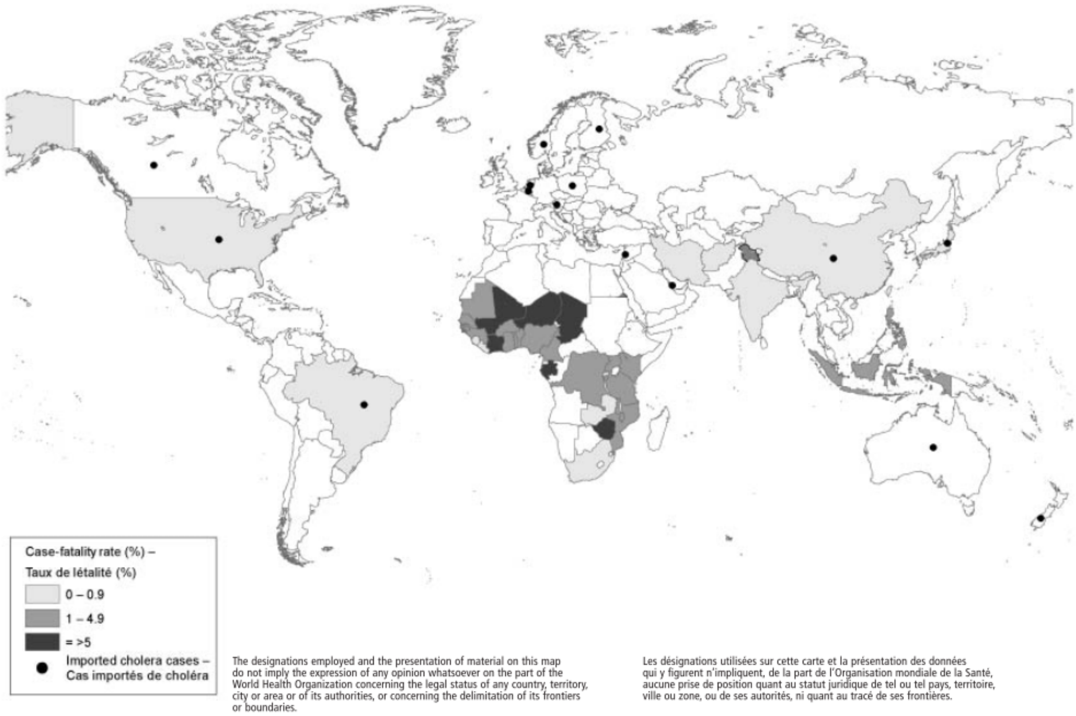
Incidence of Cholera (IC)	
Definition	Number of cholera cases per administrative division - country, sub-national, municipality (showed as percentage of global cholera cases). Source: adapted from WWAP, 2003
Underlying definitions and concepts	Cholera is an acute enteric infection caused by the ingestion of bacterium *vibrio cholerae* present in faecally contaminated water or food. Primarily linked to insufficient access to safe water and proper sanitation, its impact can be even more dramatic in areas where basic environmental infrastructures are disrupted or have been destroyed. Source: WHO website (accessed at May 2013)
DPSIR classification	Impact
Sustainability criteria	Social, Environmental, Institutional
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	WWAP (World Water Assessment Programme). 2003. The United Nations World Water Development Report: Water for People Water for Life. Paris, UNESCO World Health Organization (WHO): http://www.who.int/topics/cholera/en/ (accessed May 2013) WHO. (2006). Weekly epidemiological record. *Relevé épidémiologique hebdomadaire*, *81*(31), 297–308. Retrieved from http://www.who.int/wer/2006/wer8131.pdf

Examples of indicator "Incidence of Cholera" (IC)

Fig. 1 **Countries/areas reporting cholera and cases reported by year, 1995–2005**
Fig. 1 **Pays/territoires ayant déclarés des cas de cholera et nombre de cas déclarés par année, 1995-2005**



Map 1 **Countries/areas reporting cholera cases in 2005**
Carte 1 **Pays/territoires ayant déclarés des cas de choléra en 2005**



The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Les désignations utilisées sur cette carte et la présentation des données qui y figurent n'impliquent, de la part de l'Organisation mondiale de la Santé, aucune prise de position quant au statut juridique de tel ou tel pays, territoire, ville ou zone, ou de ses autorités, ni quant au tracé de ses frontières.

Source: WHO, 2006

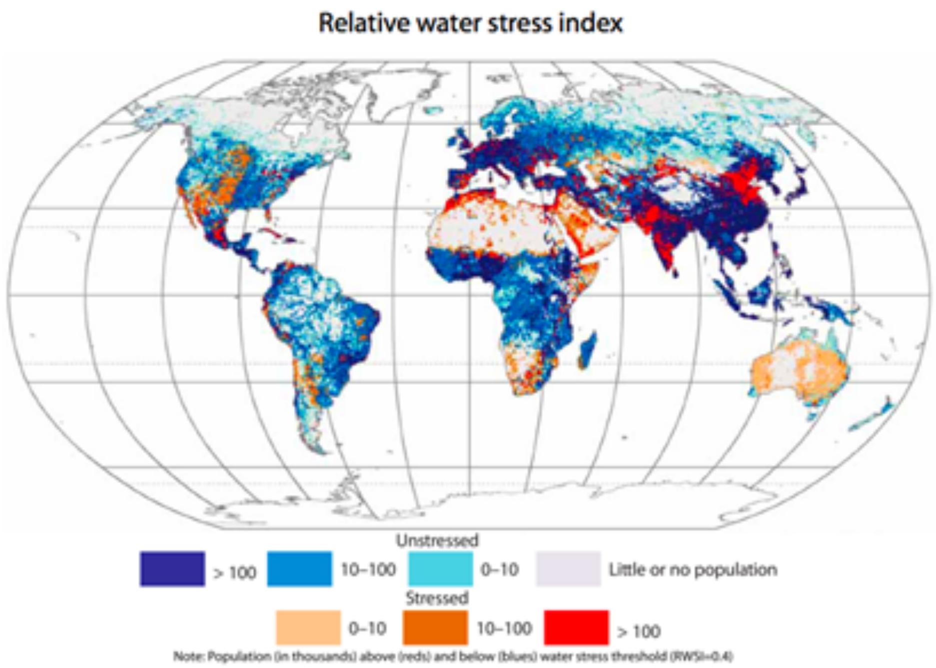
Indicator Profile Sheet

Water Provision Resilience	
Definition	Provides a means of approximating the ability of a city or water provider to maintain or increase the portion of the population with access to safe water. To do so, a qualitative questionnaire is used to assess six critical aspects of urban water supply systems: supply, finances, infrastructure, service provision, water quality, and governance Source: Milman and Short, 2008
DPSIR classification	State, Response
Sustainability criteria	Social, Economic, Institutional
Sources of further information	Milman, A., & Short, A. (2008). Incorporating resilience into sustainability indicators: An example for the urban water sector. *Global Environmental Change*, *18*(4), 758–767. doi:10.1016/j.gloenvcha.2008.08.002

Indicator Profile Sheet

Relative Water Stress Index (RWSI)	
Definition	Water demand pressures from the domestic, industrial and agricultural sectors relative to the local water supplies. The Domestic, Industrial and Agricultural water demand are compared with the available water supply in a given area/point. Sources: Vörösmarty et al. 2000 and WWAP, 2012
Underlying definitions and concepts	Also known as Relative Water Demand (RWD), it indicates water shortage or abundance in a given region in relation to the water demand (adapted from WWAP, 2012).
DPSIR classification	Pressure, State
Sustainability criteria	Social, Economic, Environmental
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	Vorosmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2000). Global Water Resources: Vulnerability from Climate Change and Population Growth. *Science*, *289*(5477), 284–288. doi:10.1126/science.289.5477.284 Vörösmarty, C. J., Douglas, E. M., Green, P. A., & Revenga, C. (2005). Geospatial indicators of emerging water stress: an application to Africa. *Ambio*, *34*(3), 230–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16042282 WBCSD & IUCN. (2010). *Water for Business: Initiatives guiding sustainable water management in the private sector* (Geneva and., p. 40). Retrieved from http://www.wbcsd.org/web/water4business.pdf WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

Example of indicator “Relative Water Stress Index” (RWSI)

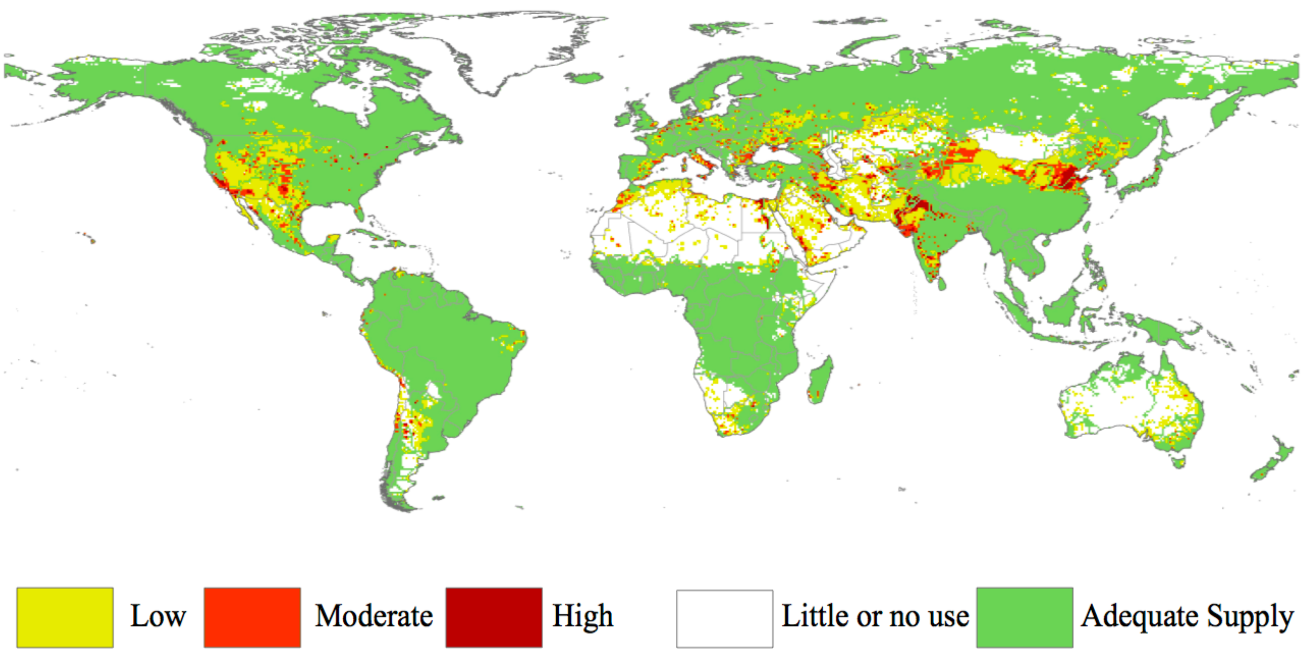


Source: WWAP, 2012

Indicator Profile Sheet

Index of Non-sustainable Water Use (INSWU)	
Definition	Renewable freshwater resources (streamflow) minus geospatially distributed human water demand. This indicator provides a measure of the human water demand in excess of natural water supply in a given area/point. Source: WWAP, 2012
Underlying definitions and concepts	Comparison of water demands to renewable water supply, indicating areas where non-sustainable practices may be occurring (WWAP, 2012).
DPSIR classification	Pressure, State
Sustainability criteria	Social, Economic, Environmental
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	Falkenmark, M. and Lindh, G. (1974). Impact of Water Resources on Population. *Submitted by the Swedish Delegation to the UN World Population Conference*, Bucharest Vörösmarty, C. J., Revenga, C., Le, C., Authors, L., Bos, R., Caudill, C., Chilton, J., et al. (2005). Fresh Water. *Millennium Ecosystem Assessment*. Island Press. WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

Example of indicator "Index of Non-sustainable Water Use" (INSWU)



Source: WWAP, 2012

Indicator Profile Sheet

Water sector share in total public spending	
Definition	Percentage of the national budget spent in water sector for expanding, rehabilitating and maintaining water related infrastructures and improving water resources management and governance vis-à-vis other economic sectors. Source: WWAP, 2012
DPSIR classification	Response
Sustainability criteria	Social, Economical, Institutional
Sources of further information	WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

Indicator Profile Sheet

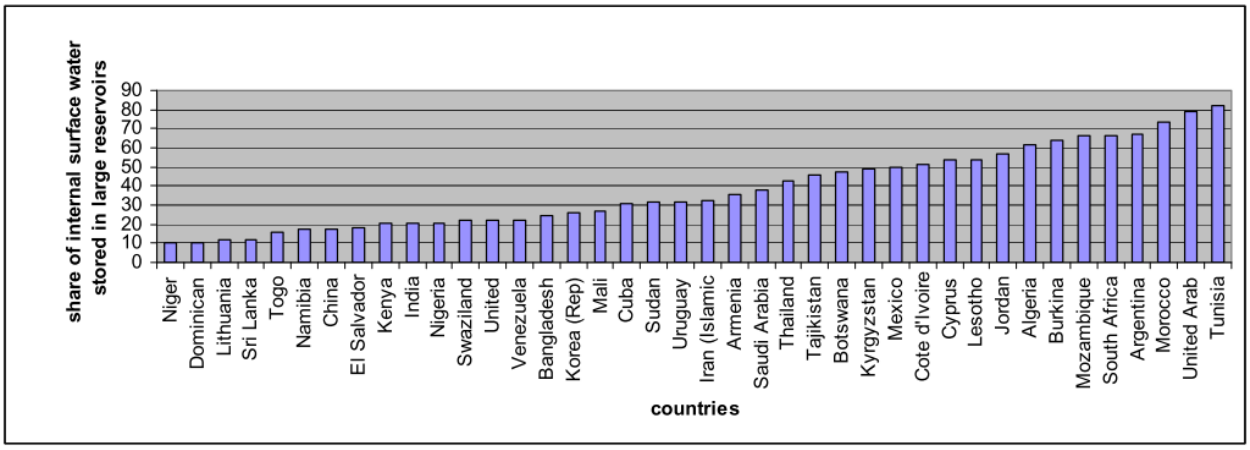
Pro-poor and pro-efficiency water fees	
Definition	Examines the application of economic and financial tools in water allocation aiming efficient water use and pro-poor policy. It is also called “Charges and fees for water allocation favoring the poor and efficient water use” Source: adapted from Cap-Net UNDP, 2008
DPSIR classification	State, Impact
Sustainability criteria	Social, Economic, Institutional
Sources of further information	Cap-Net UNDP. (2008). Integrated Water Resources Management for River Basin Organisations (Training Manual). Pretoria.

Indicator Profile Sheet

Total water storage capacity (TWSC)	
Definition	Total cumulative water storage capacity of all large surface reservoirs and groundwater, in a given area. Surface water storages include natural and man-made ponds, lakes, reservoirs, dams and lagoons. Source: adapted from Cap-Net UNDP, 2008 and United Nations, 2009
Underlying definitions and concepts	This indicator can point to the capacity to face a water shortage, by measuring the presence of adequate natural or built infrastructure to store water. It can also indicate the depletion of water reservoirs on an annual and long-term basis (when comparing water storage capacity with current water level of reservoirs).
DPSIR classification	Pressure, State, Response
Sustainability criteria	Economic, Environmental, Institutional
Criteria verified	Scientific Foundation, Individuality, River Basin Scale, Specificity
Sources of further information	Cap-Net UNDP. (2008). Integrated Water Resources Management for River Basin Organisations. Pretoria. Grey, D. And Sadoff, C. (2006) *Water for Growth and Development. Thematic Documents of the IV World Water Forum. Comision Nacional del Agua: Mexico City*. Scudder, Thayer (2005) *The Future of Large Dams: Dealing with Social, Environmental, Institutional and political costs. London.* United Nations. (2009). *Final Report of the Expert Group on Indicators, Monitoring, and Data Bases (EG-IMD)* (p. 26). Colombella. United Nations. (2010). *UN-Water Task Force on Indicators, Monitoring and Reporting - Final Report - Monitoring progress in the water sector: A selected set of indicators - Annexes: Indicators in use* (p. 47).

Example of indicator "Total Water Storage Capacity" (TWSC)

Figure 3. Countries with the largest storage capacity compared to their internal surface water ***(Aquastat)***



Source: UN, 2010

Indicator Profile Sheet

Water topics in school curriculum	
Definition	Number of countries (or other administrative division) that have introduced water-related contents in school curriculum. Source: adapted from WWAP, 2003
DPSIR classification	State
Sustainability criteria	Social, Environmental, Institutional
Sources of further information	WWAP (World Water Assessment Programme). 2003. The United Nations World Water Development Report: Water for People Water for Life. Paris, UNESCO

Indicator Profile Sheet

Fraction of Burden of ill-health resulting from nutritional deficiencies	
Definition	Fraction of the burden of ill-health resulting from nutritional deficiencies, attributable to water scarcity impacts on food supply. Source: WWAP, 2003
DPSIR classification	Impact
Sustainability criteria	Social, Economical, Environmental, Institutional
Sources of further information	WWAP (World Water Assessment Programme). 2003. The United Nations World Water Development Report: Water for People Water for Life. Paris, UNESCO

Indicator Profile Sheet

	Causes of food emergencies
Definition	It presents the comparison in the trends of the two major causes of food emergencies: human-induced disasters and natural disasters. This comparison is made accessing the number of countries affected by human-induced disasters and by natural disasters. Source: adapted from WWAP, 2003
DPSIR classification	Impact
Sustainability criteria	Social, Economic, Environmental
Sources of further information	WWAP (World Water Assessment Programme). 2003. The United Nations World Water Development Report: Water for People Water for Life. Paris, UNESCO

Indicator Profile Sheet

Ecological footprint	
Definition	Measures the area of biologically productive land and water required to produce all the resources consumed and to absorb the waste generated, considering prevailing technology and resource management practices. Source: Bastianoni et al. (2012)
DPSIR classification	Pressure
Sustainability criteria	Social, Economic, Environmental
Criteria verified	Scientific Foundation
Sources of further information	Bastianoni, S., Niccolucci, V., Pulselli, R. M., & Marchettini, N. (2012). Indicator and indicandum: "Sustainable way" vs "prevailing conditions" in the Ecological Footprint. *Ecological Indicators*, *16*, 47–50. doi:10.1016/j.ecolind.2011.10.001Čuček, L., Klemeš, J. J., & Kravanja, Z. (2012). A Review of Footprint analysis tools for monitoring impacts on sustainability. *Journal of Cleaner Production*, *34*, 9–20. doi:10.1016/j.jclepro.2012.02.036 Fang, K., Heijungs, R., & de Snoo, G. R. (2014). Theoretical exploration for the combination of the ecological, energy, carbon, and water footprints: Overview of a footprint family. *Ecological Indicators*, *36*(0), 508–518. doi:http://dx.doi.org/10.1016/j.ecolind.2013.08.017 Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., & Giljum, S. (2012). Integrating Ecological, Carbon and Water footprint into a "Footprint Family" of indicators: Definition and role in tracking human pressure on the planet. *Ecological Indicators*, *16*, 100–112. doi:10.1016/j.ecolind.2011.06.017 Hoekstra, A. Y. (2009). Human appropriation of natural capital: A comparison of ecological footprint and water footprint analysis. *Ecological Economics*, *68*(7), 1963–1974. doi:10.1016/j.ecolecon.2008.06.021

Indicator Profile Sheet

Progress towards achieving IWRM target	
Definition	Assessment of progress in implementation of national or federal integrated water resources management target. Source: WWAP, 2012
DPSIR classification	Response
Sustainability criteria	Social, Economic, Institutional
Sources of further information	Global Water Partnership - GWP. (2004). *Current Status of National Efforts to Move Towards Sustainable Water Management Using an IWRM Approach* (p. 29). Stockholm: GWP. Global Water Partnership – GWP. (2004). *2005 WSSD Target on National IWRM Planning: Informal Stakeholder Baseline Survey*. Global Water Partnership. (2006). *Setting the stage for change - Second informal survey by the GWP network giving the status of the 2005 WSSD target on national integrated water resources management and water efficiency plans* (p. 84). Retrieved from http://www.gwptoolbox.org/images/stories/Docs/gwp_setting the stage for change 2006.pdf UN Water. (2008). *Status Report on Integrated Water Resources Management and Water Efficiency Plans for CSD16* (p. 53). Retrieved from http://www.unwater.org/downloads/UNW_Status_Report_IWRM.pdf WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

Indicator Profile Sheet

Country's dependence ratio	
Definition	Measures the relation between the surface and groundwater that inflow from other countries and the total amount of water available in the country at annual bases. The total amount of water available is the sum of total internal renewable water resources and the amount of water flowing in from neighbouring countries. The Dependence Ratio points what is the part of the total renewable water resources of a country coming from outside. Sources: FAO, 2003 and World Bank, 2007
DPSIR classification	Pressure, State, Impact
Sustainability criteria	Social, Economic, Institutional
Criteria verified	Scientific Foundation, Individuality
Sources of further information	FAO. (2003). *Review of world water resources by country* (p. 127). Rome. Retrieved from http://www.fao.org/DOCREP/005/Y4473E/y4473e07.htm Hoekstra, A. Y. (2010). The Global Dimension of Water Governance: Why the River Basin Approach Is No Longer Sufficient and Why Cooperative Action at Global Level Is Needed. *Water*, 3, 21-46; doi:10.3390/w3010021 Islam, Shafiqul & Susskind, Lawrence (2012). *Water Diplomacy: A Negotiated Approach to Managing Complex Water Networks* (p. 352) Routledge, 2012 World Bank (2007). *Making the Most of Scarcity: Accountability for Better Water Management Results in the Middle East and North Africa* (p. 235) WWAP (World Water Assessment Programme). 2003. The United Nations World Water Development Report: Water for People Water for Life. Paris, UNESCO

Indicator Profile Sheet

Major drought events and their consequences	
Definition	List of major drought events and their associated loss of life and economic losses in the last 100 years Source: WWAP, 2003
DPSIR classification	Impact
Sustainability criteria	Social, Economic, Environmental
Criteria verified	Scientific Foundation
Sources of further information	WWAP (World Water Assessment Programme). 2003. The United Nations World Water Development Report: Water for People Water for Life. Paris, UNESCO

CHAPTER 5 – eDPSIR APPROACH FOR THE SELECTION OF THE SET OF INDICATORS FOR SUSTAINABLE WATER USE AND MANAGEMENT

ABSTRACT

Selecting indicators for sustainable water use and management requires an integrated conceptual framework. The enhanced DPSIR framework (eDPSIR) combines the systems approach, causal networks and the DPSIR framework making the interconnectedness of the indicators a key component of the selection process. This chapter presents the eDPSIR framework and the multi-stakeholder participatory process adopted to select the most appropriate set of indicators to measure the sustainability of water use and management at the pilot river basin. The Salitre River Basin was selected to pilot test the application of this method. An eight steps approach of the eDPSIR framework was adopted resulting in a careful cause-effect analysis of indicators as well as the identification of a set of eight indicators suitable for the specific domain, question and location of the research. Supporting this, the participatory process facilitated the engagement of the major stakeholders in the process. The eDPSIR approach helped to better understand the complexity of the interrelations of the set of indicators. The findings of this research showed that all indicators are interconnected in an intricate network of cause-effect relations.

5.1 INTRODUCTION

Indicators are often interrelated and, consequently, it is conceivable that although assessing indicators individually appears to be enough, sustainability may require evaluating cross-indicator interactions (Mendoza and Prabhu, 2003). Currently indicators are rarely selected based on how they jointly respond to environmental questions in an integrated manner, instead, they are mainly chosen based on the grade in which they independently fulfil individual criteria (Aveline et al., 2009; Bringhenti et al. 2011; Hak et al., 2012).

The use of a conceptual framework may provide an important approach when developing or selecting concise sets of indicators in an integrated way (Niemeijer and Groot, 2008a). It is considered by these authors that it is important to examine an *"indicator's analytical utility within the total constellation of a selected set of indicators"*.

Niemeijer and Groot (2008a) propose a conceptual framework for the assessment of environmental indicators in which the set of indicators is considered the principal element of the selection process. This framework is called the enhanced DPSIR (eDPSIR). It integrates the systems approach, causal networks and the DPSIR framework in such a way that the interconnectedness of the indicators becomes a key part of the selection process (Niemeijer and Groot, 2008a). Wolfslehner & Vacik (2011) and Mendoza and Prabhu (2003), among other authors, have demonstrated that causal networks may help identify the most relevant indicators in terms of a specific field, problem and location resulting in a set of indicators that help to assess the environmental conditions in a clear, well-organized and effective manner.

To effectively use this method, Niemeijer and Groot (2008a) recommend defining a specific location for its application, aiming to bring an objective view and more pragmatism to the process of selecting the indicators. As mentioned by Houdret (2014), river basin approach to sustainable water use *"has become the dominant model of water governance"*. Furthermore, several authors consider that river basin is the logical unit for addressing water related issues (WWAP, 2012; Jaspers, 2002; Gaiser, 2008). The **river basin was defined as the geographical scale of interest for the current study.**

The application of experimental methods, such as the eDPSIR, in a pilot scale before proposing their widespread use is also recommended (Innocenti, 2014). Pilot tests aim to check the performance of procedures prior to full-scale implementation. According to Jasper (2003) and Kemper (2010) a **key element of integrated river basin management is the participation of stakeholders in the process**. The participation of stakeholders in the selection of indicators at a river basin scale can add significant amount of information, increase its credibility and contribute to the acceptance of the indicators set. This research involved the major stakeholders in the pilot test application of the eDPSIR approach at river basin scale.

In the previous stages of this research 11 indicators were selected, from an initial list of 170, based on individual criteria that were of crucial relevance for this study. Initially, they were evaluated based on the criteria of social, economic, environmental and institutional sustainability (chapter 3). Subsequently they were assessed based on scientific foundation, individuality, geographic scale of interest and specificity (chapter 4).

The main objective of this phase of the research was to select, out of the 11 short-listed indicators (see previous chapters), the most relevant ones for the specific domain, question and location of the research. To do this, the **eDPSIR framework was applied in a participatory way aiming at a comprehensive visualisation of the interconnections of each indicator in the causal network**. This systematic function of the relations between the indicators was an essential part of the indicator selection process.

This chapter begins with the selection of the river basin that will be used to pilot test the application of this method (the Salitre River Basin). In addition, the criteria used to identify and define the pilot river basin are presented here. The methodology adopted here is then described in greater detail, including the multi-stakeholder participatory process and the eDPSIR framework. In the next section the results are presented followed by the discussions on the findings concerning the application of the eDPSIR approach in a participatory way, including considerations about the key-nodes and the cause-effect relations between the indicators. This chapter presents the most comprehensive set of eight key-indicators to measure the social, economic, environmental and institutional sustainability of water use and management at the Salitre River Basin.

5.2 Selection of the Pilot River Basin

This phase of the research started with the selection of the pilot river basin for the application of the participatory multi-stakeholder process for assessment of the indicator set. Before selecting the river basin it was established a set of criteria to guide this process.

5.2.1 Selection Criteria

The criteria for the selection of pilot river basin were established considering the specific needs, boundaries and objectives of the current study. It is worthy to say, that criteria for the selection of river basin for research projects usually relays on specifics characteristics of the project (Zhang, Xiao & Singh, 2015; Yoon & Shah, 2015), and often are not clearly stated (Sánchez, Carrasco & Andreo, 2009; Yoa et al., 2015). Similarly to Martínez y Reyes (2007), the criteria adopted by the research address a set of conditions related to the geographic characteristics of the site, as well as to some features of the stakeholders, and are clearly stated at Table 5.1.

The geographical scope of interest of the research is the Ibero-American region. Nevertheless, the goal was to identify a pilot river basin not far from the Brazilian Office of the UNESCO Chair on Sustainability from the UPC (located in Salvador-Bahia).

This decision was based on the following factors: 1) the need to travel regularly to the pilot river basin in order to host stakeholder meetings and field missions, to ensure a truly participative research; 2) the available resources (time, research grant and human resources).

Table 5.1 – Criteria to guide the selection of the pilot river basin of this research.

Criteria		Description
Geographic characteristics	Location	A river basin located in the Ibero-American countries, not too far from the headquarters of UNESCOSOST in Brazil.
	Water scarcity	Should present a situation of water scarcity and actual conflicts over water use.
	Size	Should not be too large nor too small.
Stakeholder's features	Interest	The stakeholders of the pilot river basin should have strong interest in the topic of the research.
	Organized and mobilized	They should already be mobilized around the topic and structured in an organizational framework similar to a river basin committee.
	Diversity	They should represent diverse sectors and regions of the pilot river basin.

Source: Adapted from Martínez & Reyes, 2007

Regions suffering from water stress, especially the ones with conflicts over water use, are more likely to benefit from, and be interested in the outcomes of this study. Therefore this research aimed at identifying a pilot river basin suffering from water scarcity and with recorded conflicts over water use.

The **maximum and minimum size of the river basin** of interest was determined by a number of factors. First, the travel distance limited the maximum size of the river basin. The travel distance corresponds with how long stakeholders from upper, medium and lower regions of the watershed would need to travel in order to participate in the meetings to be organized during the research process (see next section). It was expected that the majority of stakeholders would not need to travel for more than four hours. Second, this research required a pilot river basin that was large enough for having multiple water uses (preferably also conflicting ones), a diversity of stakeholders and relevant for regional development. Due to these requirements small watersheds were considered not to be of interest to the current study.

The interest of stakeholders in the research topic was also a key criterion in the selection of the pilot river basin. If stakeholders were not interested, it is likely that they would not contribute to the development of this research. In addition, stakeholders' involvement is essential for the participative nature of this study. Furthermore, the research aimed at finding a river basin where stakeholders were already mobilized around the topic and were able to carry out substantial discussions about issues related to water resources. The river basin committees provide an effective platform in undertaking the participative component of this research. The stakeholders should also represent a diversity of sectors (i.e. governmental institutions; different users including at least agriculture, urban supply and industry; universities; non-governmental organizations; among others) and regions of the pilot river basin (upper, medium and lower regions). This diversity is fundamental for reaching a variety of perspectives and interests needed for an effective multi-stakeholder assessment.

Based on these six criteria, a screening process was completed aiming at identifying the most suitable river basin. In order to support the identification of the most promising candidates, meetings and interviews were convened with senior staff of water management institutions and the Environmental Agency of the State of Bahia, experts, head of river basin committees, among other key actors.

5.2.2 The Pilot Basin – Salitre River

The Salitre River Basin, located in the Northeast region of Brazil, was selected as the pilot river basin. It fulfils all the criteria applied in the selection of the pilot river basin of this research (Table 5.1).

The Salitre River Basin, located in the State of Bahia, is a sub-basin of the São Francisco river (Figure 5.1). The basin lies between latitudes 9 ° 27 ' and 11 ° 30' south and between longitudes 40 ° 22 ' and 41 ° 30 ' west, in an area of 14,136 km^2 (Lopes et al, 2011). It is located 450 km from the headquarters of UNESCOSOST-Brazil at the UFBA, in the city of Salvador, the capital of the state of Bahia. The length of the Salitre River is approximately 333 km. It is comprised of nine different municipalities with over 430,000 inhabitants (Medeiros, 2003). The climate is classified as BSh (tropical semi-arid), according to the Köppen climate classification, and the average annual rainfall ranges from 400 to 800 mm (Brito et al, 2005). However, 32 % of the area corresponds to the arid climate, with annual rainfall of less than 500 mm (Lopes et al, 2011).

The distribution of rainfall in the basin is very irregular, and water deficit is intensified by high evaporation rates. Its main tributaries and rivers are intermittent, with sections that dry out completely during periods of low rainfall, especially in the months from August to October (De Oliveira et al., 2010).

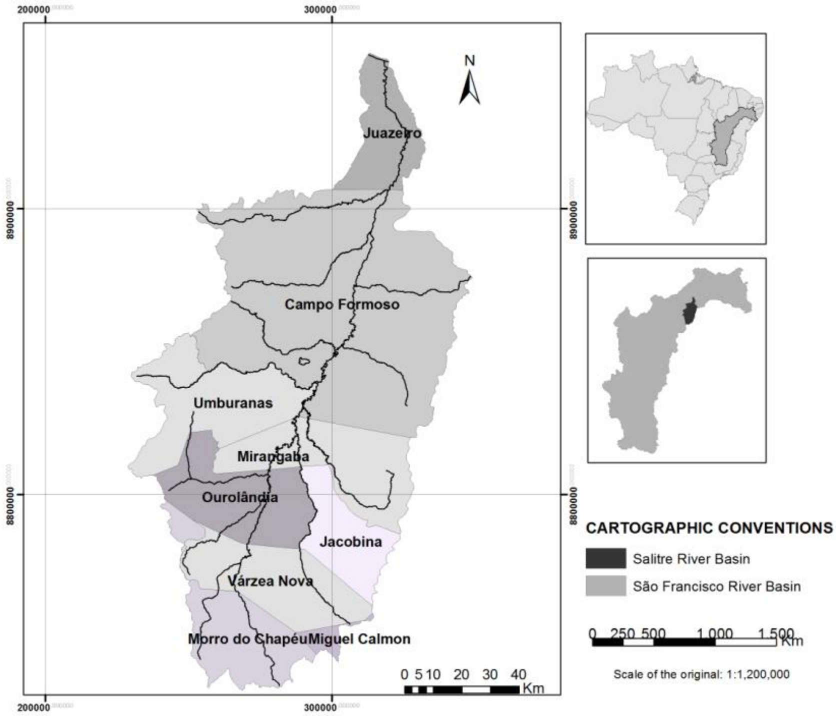


Figure 5.1 – The Salitre River Basin, its municipalities and location as one of the sub-basins of the São Francisco River. Source: Medeiros et al. (2015)

The occurrence of water shortage is associated with additional factors, such as: unsustainable use of water and soil; high level of salinity content; incipient treatment of wastewater; occupation of the riverbanks for agriculture and livestock (Silva, 2013) and the unsustainable operation of several daws. The soil of a significant part of the basin is of high quality for agriculture (Medeiros, 2003), and due to this, irrigated agriculture is the major activity of the region, especially at the medium and lower parts of the basin. Furthermore, mining of ornamental stones, particularly marbles, is also significant for the economy, mainly at the medium segment of the basin, increasing the pressure on the already scarce water resources (Silva, 2013). Another element that needs to be highlighted is the existence of several dams, in the course of the main rivers that have no spillways, nor are they managed correctly (Medeiros, 2003). They do not allow any water to pass from the upstream side of the dam to the downstream side, contributing significantly to water conflicts downstream.

Medeiros et al. (2015) mention *"water scarcity and the occurrence of several conflicts arising from indiscriminate water uses"* as two of the major problems of the Salitre. Scarcity and conflict over water are closely related. The disagreement over water withdrawal for irrigation between upstream and downstream farmers on the lower part of the Salitre has been recognized as the main cause of at least three murders and several criminal actions of property damage, especially sabotage of water pumps and their electrical supply (Silva, 2013). This severe situation puts in evidence that water use and management is one of the most pressing issues on the social and political agendas in this region, also strongly impacting the economy and the environment. This called the attention of the general public and helped bring water related stakeholders together to search for conflicts' solutions.

This basin also presents outstanding features in terms of the interest, organization and diversity of the major stakeholders related to water resources. These were also important criteria for the selection of this River Basin. Informal consultations with key stakeholders indicated their interest in the research; this interest was further confirmed by the opinion survey conducted in the first formal meeting with stakeholders (see next section of this chapter). The interest in the use of indicators was reinforced by their will to incorporate a set of indicators for sustainable water use and management in the new Salitre River Water Management Plan. The revision process of this plan was ongoing during the research, giving a very promising window of opportunity to the development of this participative study.

The stakeholders of the Salitre River Basin are well organized, strongly mobilized to discuss solutions for the critical water issues and, in general, have adequate capacity to carry out substantial debates about water related topics such as the one proposed by this study.

Furthermore, in discussions with the major stakeholders it became evident that they demonstrate very close roots with the river bodies of the Salitre basin (mainly because of the economic, historic and cultural linkages with the rivers and the territory). It should also be noted that the stakeholders presented a collective spirit for fighting against the degradation process that has been affecting the River Basin in the last decades, by looking for solutions for the revitalization of the watercourses and the sustainable use of water.

The Salitre River Basin Committee was created in 2006, as an advisory and deliberative formal organ of the federative Brazilian Water Management System (Resolução CONERH No 16, 2006). It is composed of 36 members with an even tri-parted representation: one third of government representatives (public administrations, water management agency, etc), one third of water user representatives (agriculture sector, water supply sector, industrial sector, etc) and one third of societal representatives (non-governmental organizations, associations, universities, etc). Regarding the geographical coverage, these members cover the upper, medium and lower regions of the Salitre River basin.

Furthermore, this basin has already been the subject of several studies by other academic researchers (Medeiros et al., 2015; Silva, 2013; De Oliveira et al., 2010, among others), international organization projects (GEF, UNEP, OAS & ANA, 2003) and therefore, offers an abundant amount of knowledge and structured information. Nevertheless, indicators of sustainable water use and management have not been addressed in sufficient detail at this River Basin. Therefore, this research adds to the discussions on the topic that have not yet been thoroughly explored and that are of interest to the Salitre River Basin stakeholders.

As part of this research, an expedition was undertaken to provide a direct contact with the river basin situation and broader the knowledge about the object of study. This expedition took three days, covered over 800km from the springs of the Salitre River, passing thought all the nine municipalities that constitute the river basin and ended at the river mouth at São Francisco River (see picture report annex).

5.3 METHODOLOGY

This section begins with the identification of the key stakeholders of the Salitre River Basin. They were invited to engage in the development of the research, and participated in the application of the eDSPIR framework for the selection of the most adequate set of indicators for sustainable water use and management at the Salitre River Basin. The sections below also describe the methods adopted in this study for the application of the multi-stakeholder participatory approach and the enhanced DPSIR framework.

5.3.1 Multi-stakeholder participatory approach

Once the pilot river basin was selected, the next step was to identify the major stakeholders related to water management and use at watershed level. The members of the River Basin Committee were the starting point of this process. Nevertheless, this study considered, similarly to Cloquell-Ballester et al (2006), the following principles to identify the major stakeholders:

a) Knowledge about the water resources situation;
b) Knowledge of the river basin territory and the interactions of its elements;
c) Social representation.

Complementary to the 36 members of the Salitre River Basin Committee, this study identified other 21 stakeholders that fulfil the criteria listed above and demonstrated genuine interest in the sustainability of the water resource management and use at the Salitre River Basin. In total, 57 people with broad social representation and deep understanding of the river basin territory have been short-listed as key stakeholders. In order to map these stakeholders, this research has followed the main recommendations presented by Voinov & Bousquet (2010), Rosso et al. (2014) and deReynier et al. (2010). Voinov & Bousquet (2010) note the importance of engaging many different groups with a wide-ranging set of interests to increase the diversity of opinions. Care was also taken to identify those stakeholders whose demands may contribute to the success of our study or its application (Rosso et al., 2014). The approach adopted by deReynier et al. (2010) and by our research identified stakeholders with knowledge of the topic, ranging from formal groups involved in management, to those that profit indirectly from the resource, to those that directly use the resource.

The involvement of these stakeholders aimed, as a primary goal, to assess their interest in the research and to confirm whether they were willing to collaborate with this participative study or not. In order to do this, the stakeholders were invited formally by the president of the River Basin Committee and the UNESCO Chair on Sustainability to participate in a one-day meeting. Stakeholders were encouraged to participate in the meeting where they, on one hand, would contribute with their time and expertise, on the other hand, would learn more about the science of indicators and its application at the river basin level. The stakeholders that participated in the meeting received formal acknowledgments for their contribution and will receive a copy of the results of this study.

Together with the invitation letter they received an explanatory summary about the research. This brief document presented background information about indicators and explained how the outcomes of this study could contribute to the better management and use of water at the Salitre River Basin. At this meeting, the research team presented the scope of the study, its relevance, the methods applied, the results obtained so far and the expected outcomes.

In order to make this meeting as participative as possible, all materials were adapted to the target audience. The materials produced were easy to understand, communicating in a direct and simple way, so as to avoid misunderstandings and misinterpretation. Information about each indicator (originally presented in the IPSs) was converted into power point presentations delivered by the research team at the meeting.

Furthermore, during the meeting a significant amount of time was spent on discussions and debates. The stakeholders provided their inputs about the selection process (including the step-by-step eDPSIR process – see sections below) and the indicators short-listed by this research. An opinion survey was undertaken at the end of the meeting, where participants were invited to answer the following questions in a structured survey form:

1. How relevant is this research for the Salitre River Basin, on a scale of 0 to10?
2. How relevant were the outcomes of this first meeting, on a scale of 0 to10?
3. In your view which were the most important issues addressed in this meeting?
4. Do you have any suggestions that might help planning the next meetings?

In this scale, 0 is the worst result, 5 means neutrality and 10 excellent. This scale was used because it was easily applied by the stakeholders; and it is a general and largely used scale for rating (Wimmer and Dominick, 2010).

This first meeting with the stakeholders took place in the city of Juazeiro – Bahia, located in the lower part of the river basin, on the 24th of October 2013 (see picture report annex). It is worth mentioning that a series of three meetings with the stakeholders were agreed upon with the head of the River Basin Committee. During the first meeting the stakeholders were invited to validate (or not) this agreement.

These three meetings would be co-organized with the River Basin Committee and they would take place each in a sub-region of the pilot river basin (the upper, medium and lower sections). The main objective of the second meeting was to validate the set of indicators selected by the eDPSIR, using end-user criteria in a multistage and multi-stakeholder validation process. The methods adopted and the results obtained are presented in detail in the next chapter.

The third meeting will be held after the closure of the research. It aims to present the final results and to transfer the knowledge to the stakeholders in order to promote the use of these outcomes, to improve the sustainability of water use and management at the Salitre River Basin.

5.3.2 The enhanced DPSIR framework

At this stage of the research the enhanced DPSIR framework (eDPSIR), proposed by Niemeijer & Groot (2008a), was adopted to select from the 11 short-listed indicators (see previous chapters), the ones that are most relevant for the specific research domain, problem and location. For this selection, the indicator's systematic usefulness was examined within the entire set of the short-listed indicators. The systematic usefulness, as mentioned by those authors, analyses the particular function that each indicator in the set has to address the problem under consideration (in the case of this research sustainable water use and management). The eDPSIR approach provided enhanced conceptual assistance for indicator selection, while building upon three major concepts: the DPSIR framework, causal networks and cognitive mapping.

The DPSIR framework has been applied from the very beginning of this research in order to analyze, classify and organize the indicators (see previous chapters). The causal network is a probabilistic graphical model, rooted in the system thinking approach to problem solving, which examines the links and interactions between elements of a system (Boardman & Sauser, 2008). Cognitive mapping is a causality based mapping technique where *"concepts representing elements of a complex problem are organized and structured using arrow diagrams"* (Mendoza & Prabhu, 2003). The eDPSIR approach combines these powerful concepts in a method that is easy to use and transparent, based on eight steps described below.

The eight steps of the eDPSIR

This research adopted the eight steps of the eDPSIR approach proposed by Niemeijer & Groot (2008a). The first five steps are related to the creation of the causal network, followed by three steps to select the indicator set using the causal network (figure 5.1).

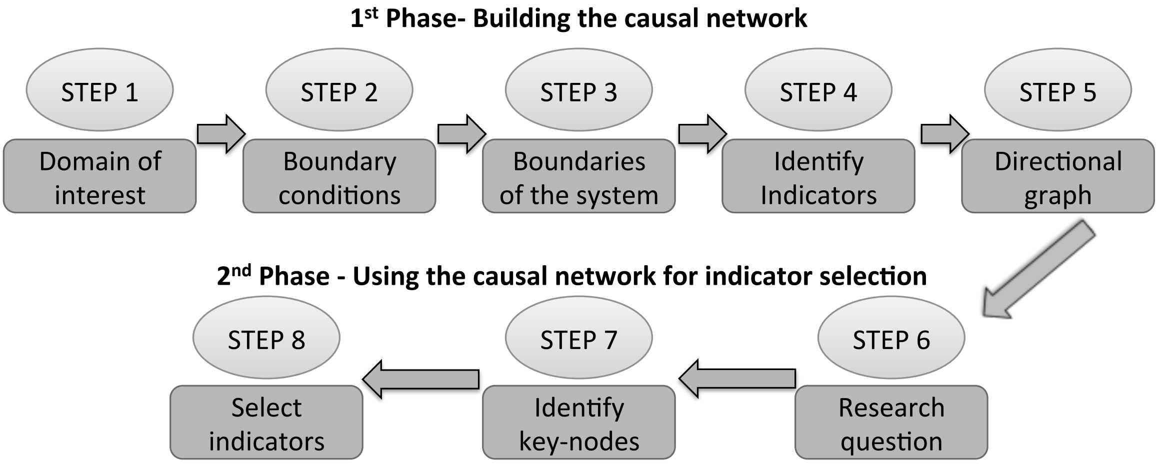


Figure 5.2 – The 8 steps of the eDPSIR approach adopted by this research.

The 1st phase of the eDPSIR consists in building the causal network and comprises the following five steps, adapted from Niemeijer & Groot (2008a):

1st Step – Define the domain of interest: *"to define a particular issue or problem to look at. The domain of interest may be very broad, but if a clearly outlined specific issue is already identified, that certainly helps in keeping the causal network small and manageable."*

2nd Step – Determine boundary conditions: *"to determine boundary conditions that can help determine which aspects to cover and which to omit. Boundary conditions, such as whether a specific ecological system, climate, socio-economic context, etc. need to be considered."*

3rd Step – Determine the boundaries of the system: *"to determine what will be included and what will be considered just in terms of outputs and inputs. I.e. limit ourselves to the in situ situation and not extend the causal network to processes occurring outside the research area."*

4th Step – Identify the indicators of interest: *"to identify indicators for the main factors and processes"*, considering the domain of interest and boundaries established in the previous steps.

5th Step – Iteratively map the indicators in a directional graph: *"to put together the actual causal network - draw the causal network with nodes connected with arrowed arcs showing the cause-effect pathways."*

Once the causal network is built, Niemeijer & Groot (2008a) propose three last steps to use it for the indicator selection process (the 2nd Phase the eDPSIR):

6th Step – Define the research question: *"to define an actual concrete research question. This research question may be a broad-brush question or a very specific question. The key point is that the better the questions or objectives are defined, the better the indicators can be selected."*

7th Step – Identify key-nodes: *"to identify key-nodes in the causal network and explore relevant sections of the causal network."*

8th Step – Select the best indicators for the key-nodes: It is at this point that the conventional indicator selection process based on individual criteria can be applied."

The steps 1, 2, 3 and 6 are related to the definition of the domain of interest, boundaries and the research question. These issues were already identified in the scope of this research and are stated in Chapter 1. Nevertheless, they are presented here again in a summarized and easy to understand way, as responses for each corresponding step of the eDSPIR (see the Results' section below). Step 4 corresponds with the search for the indicators of interest. This research has already identified them: the 11 indicators short-listed from an initial list of 245 as described in Chapters 3 and 4.

Step 5, nevertheless, was an entirely new task for this study consisting of creating the causal network of the 11 short-listed indicators. In order to build it, the detailed review of the direct cause-effect relation between the indicators were analysed in a pairwise process. Fifty-five pairs of indicators were examined in detail. During this process, the direct causal dependencies among the indicators were identified and represented in a graphic by an arc, where the arrow represents the direction of the relation (from cause to consequence).

In order to distinguish the direct cause-effect relation of possible indirect connections among the indicators, the following questions were proposed and used as guidelines:

- If indicator A changes (increases/reduces/goes to zero) will indicator B be affected (changes/increases/reduces) too? How?
- Does indicator A influence or impact indicator B? How?

The direct cause-effect relations could be unidirectional or bi-directional. Unidirectional relations occur where an indicator affects the other, but the latter does not directly affect the former. Bi-directional are those relations where one indicator affects and is simultaneously affected by the other. Double arrowed arcs were used to represent bi-directional relationships. The unidirectional relations were represented by single arrowed arcs, showing the direction from cause to effect. Lucidchart (Lucid Software Inc.), an intuitive and collaborative computer aid diagramming tool, was the software used to create the causal network.

Step 7 consists of locating key-nodes in the causal network. These nodes are in fact the most relevant indicators according to the eDPSIR approach. According to Niemeijer & Groot (2008a), step 7 leads to the identification of three types of key nodes: root-nodes, central nodes and end-of-chain nodes. They are the nodes that "*have a higher than average number of incoming or outgoing arcs or both*" (table 5.2).

According to the method proposed by Niemeijer & Groot (2008a), these key-indicators (the ones that are the key-nodes of the eDPSIR causal network) should be then analysed based on individual criteria assessments (this is the step eight of eDPSIR process). These assessments were performed as a comprehensive evaluation aiming to validate (or not) the key-indicators. Due to the far-reaching nature of this assessment it is presented in the next chapter (chapter 6).

Table 5.2 – Key Nodes of the eDPSIR causal-network.

Node	How to identify	Description
Root nodes	Have many outgoing arcs (diverging arcs)	Their associated indicators typically provide information on the source of multiple issues or environmental problems.
Central nodes	Have many incoming and outgoing arcs (converging and diverging arcs)	Their associated indicators: - allow gauging the impact of multiple processes or issues at once; - are at the core of multiple processes.
End-of-chain nodes	Have multiple incoming arcs (converging arcs)	Their associated indicators: - also, allow gauging the impact of multiple processes or issues at once; - are likely to have a bearing on a large number of issues and research questions; - are located at the end of a series of cause-effect chains, where the effects of multiple pressures become more visible.

Source: Adapted from Niemeijer & Groot, 2008a

5.4 RESULTS

5.4.1 The Stakeholder's Response

Thirty-one people responded positively to the invitation and participated in the first stakeholder meeting of this research, representing a 54% answering rate. Based on Nulty (2008), this can be considered an adequate answering rate. This result could be largely attributed to the intense follow-up and motivational process adopted by the researchers after the initial invitation. The members formed a diverse panel: 11 females and 20 males, from different age ranges and cultural backgrounds. The group included representatives from government (at local, sub-national and national levels – including the environmental agency responsible for the water management of the Salitre River Basin), research institutions, youth associations, environmental associations, farmers (including both small scale farmers and agribusiness), afro-descendant groups, public heath institutions, public prosecutors, water supply sector, labour associations, educational institutions, mining sector, among other representatives of civil society.

The stakeholders participated actively in the discussions and provided important feedback for the study. They considered the research to be very relevant for the Salitre River Basin: 94.5% of them gave grades between 6 and 10 to the first survey question (How relevant is this research for the Salitre River Basin?). As a matter of fact, 39% of them gave the maximum grade, confirming that indicators for sustainable water use and management are a subject of great interest to them.

The majority of the participants also considered the outcomes of this meeting as extremely important: 52.9% of them gave the maximum grade for the second question (How do you evaluate the outcomes of this first meeting?). The positive answers for this question (grades between 6 and 10) represented 88.3% of the total, indicating that the results achieved in the meeting satisfied them. The stakeholders considered that several issues addressed in this meeting (the 3rd question of the survey) were especially important. Table 5.3 summarizes the most frequent answers given. This table also presents the most recurrent suggestions proposed by the stakeholders for the next meetings of the research (the last question of the survey). It is also noteworthy to mention that all the participants of this meeting welcomed the proposal of having a series of three meetings and agreed to join the next meetings of the project (see section 5.3.1).

Table 5.3 – Summary of the stakeholders' response for the third and fourth survey questions.

Most important issues addressed in this meeting (3rd question)	Suggestions for the next meetings (4th question)
- **The overall discussions about the subject** - **The quality of the presentations delivered** - **Sharing information and knowledge, especially the academic knowledge that was converted into comprehendible information** - **The diversity of institutions and people working together with the same goal** - **The methods adopted by this research** - **The relevance of the issues addressed by the study** - **The suitability of the research for the local situation and needs** - **The usefulness of the expected outcomes of this research for the activities and projects currently undergoing at the Salitre River Basin, especially the update of its Water Management Plan** - **The fact that the discussions would not end at this meeting (two other meetings have been scheduled)**	- Some logistical adjustments such as changes of the distribution of the time for presentations and discussions, in order to promote more debates - To send the invitation letters at least one month before the meeting - To broader the invitations, especially to mayor of the municipalities of the Salitre - To better spread the outcomes of the research outside the Salitre River Basin - To send more written information about indicators before the next meeting - To organize a capacity-building workshop specifically about indicator aiming to increase their ability to address this subject

Note: The responses listed above correspond to summary of 88.2% of the answers received for the 3rd question and 94.4% of the answers received for the 4th.

5.4.2 The eDPSIR Assessment

The eDPSIR assessment begins with the definition of the domain of interest. In the case of this research, it has been clearly defined in the previous stages of the study and it corresponds with the field of indicators of water use and management (see chapters 1 and 2 for detailed information about the domain of interest of this research). The boundary conditions of the study were brought to evidence by the second step of the eDPSIR assessment. The previous stages of this research identified indicators of water use and management that fullfil the criteria of social, economic, environmental and institutional sustainability (see chapter 3) and that are suitable for application at the river basin scale (see chapter 4). Therefore, sustainability criteria and the river basin scale were considered as the main boundary conditions of the study (step 2 of the eDSPIR approach). Figure 5.3 summarizes the results obtained in each step of the eDPSIR.

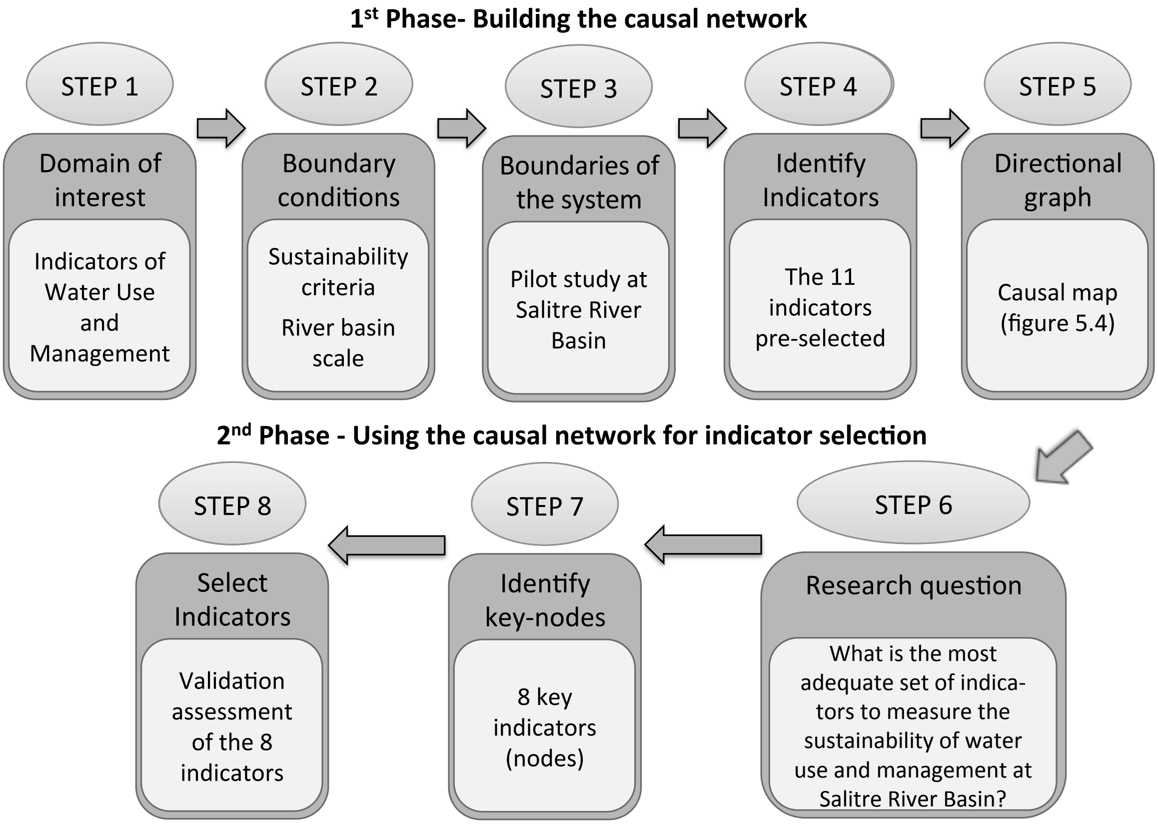


Figure 5.3 – Summary of the results obtained in each step of the eDPSIR.

The third step of the eDPSIR, which corresponds with the determination of the boundaries of the research area, was defined by the selection of the pilot river basin - the Salitre River Basin (see previous section). The delimitation of this geographic scope contributed to focusing the application of the eDPSIR approach to the actual situation of the River Basin and not extending the causal network to processes occurring outside of these boundaries.

The next step, the identification of the indicators of interest, has also been addressed in previous stages of this research (see chapters 3 and 4). It corresponded with the 11 indicators pre-selected by this study to assess the sustainability of water use and management at river basin scale listed below:

- Water Poverty Index (WPI);
- Climate Vulnerability Index (CVI);
- Water Footprint (WF);
- Water Reuse Index (WRI);
- Relative Water Stress Index (RWSI);
- Index of Non-sustainable Water Use (INSWU);
- Social and Economic Impacts from Drought (SEID);
- Total Water Storage Capacity (TWSC);

- Access to Improved Sanitation (AIS);
- Proportion of Urban Population Living in Slums (PUPLS) and
- Incidence of Cholera (IC)

These 11 indicators were selected from an initial list of 245 indicators, based on individual criteria of social, economic, environmental and institutional sustainability (chapter 3) and scientific foundation, individuality and geographic scale of interest (chapter 4).

Building the actual causal network around the 11 indicators (step 5 of the eDPSIR) was an outcome of an in-depth analysis of their cause-effect relation. As a result, 22 unidirectional relations, 20 bi-directional relations and 13 pairs of indicators that do not present a direct cause-effect relation between them (table 5.4) have been identified. The eDPSIR diagram of the 11 indicators is presented in Figure 5.4. In this diagram, the indicators are positioned according to their DPSIR classification (see chapter 3) and are connected with arcs showing the cause-effect pathways.

Table 5.4 - Matrix of Cause-Effect relations among the indicators.

		Indicator B									
		IC	**PUPLS**	**AIS**	**SEID**	**TWSC**	**INSWU**	**RWSI**	**WRI**	**WF**	**CVI**
Indicator A	**WPI**	→	←→	←→	→	←	←→	←→	←→	←→	←→
	CVI	→	←→	←→	→	←	←→	←→	←→	←→	
	WF	No	No	No	No	←	→	→	→		
	WRI	No	←	No	→	←	←→	←→			
	RWSI	No	←	No	→	←	←→				
	INSWU	No	←	No	→	←					
	TWSC	No	No	No	←→						
	SEID	←→	←→	←							
	AIS	→	←→								
	PULPS	→									

Legend: Relations between indicators A and B
→ Unidirectional (from A to B)
← Unidirectional (from B to A)
←→ Bidirectional
No – no direct relation

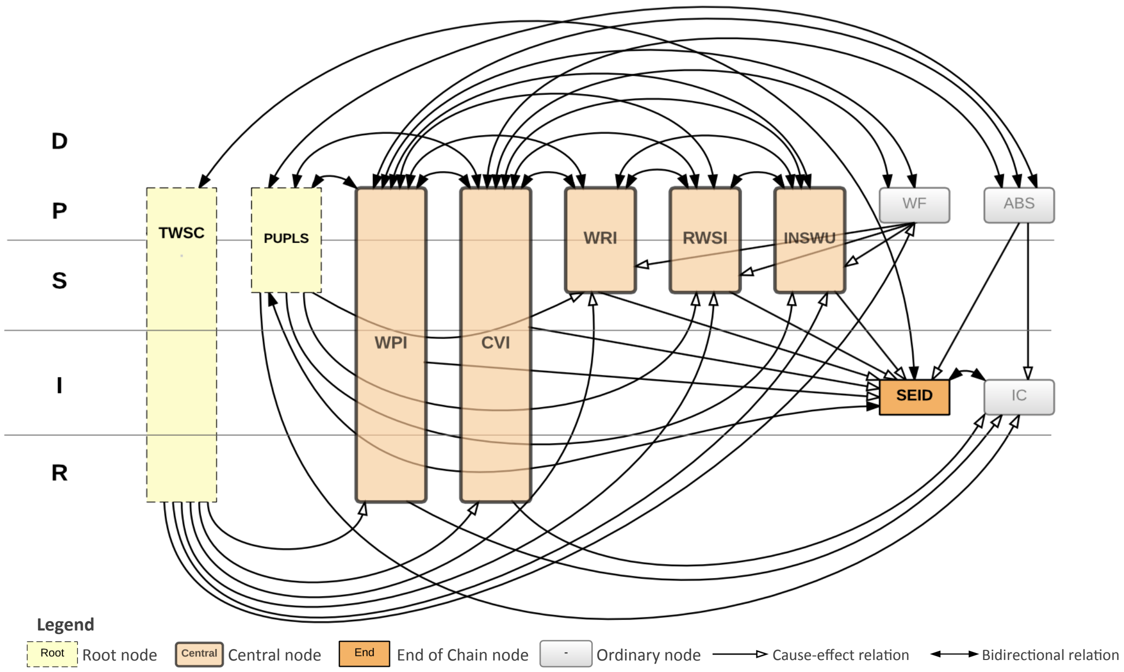


Figure 5.4 – The eDPSIR diagram of the 11 indicators

The research question (step 6 of the eDPSIR) was then formulated in a clear and precise way: *"What is the most adequate set of indicators to measure the social, economic, environmental and institutional sustainability of water use and management at the Salitre River Basin?"*.

The results obtained by the seventh step of the eDPSIR demonstrated that eight indicators are the key-nodes of the causal network (see Table 5.5). PUPLS and TWSC are root-nodes, with eight and seven outgoing arcs, respectively. WPI, CVI, WRI, RWSI and INSWU are the central-nodes of the system. They have a significant number of converging and, at the same time, diverging arcs (in total, over 12). SEID is the end-of-chain node of this causal network, where eight incoming arcs rest. Nevertheless, WF, AIS and IC presented a number of arcs below the average and were not considered by the eDPSIR assessment as key-nodes for the specific domain, problem and location of the research.

The last step of the eDPSIR, as proposed by Niemeijer & Groot (2008a), corresponds to the validation of the indicators, where they are assessed based on individual criteria. The detailed methodology adopted to assess the validation of the eight indicators and the results obtained are presented in the next chapter. In order to do this, the indicators were then assessed against a set of scientific and end-user criteria in a participatory process, with the involvement of the major stakeholders related to the research (see chapter six for detailed information).

Table 5.5 – Key-nodes of the eDSPIR assessment.

Type of Node	Indicator	Number of arcs		
		Incoming	Outgoing	Total
Central	WPI	8	9	**17**
	CVI	8	9	**17**
	WRI	7	5	**12**
	RWSI	7	5	**12**
	INSWU	7	5	**12**
Root	PUPLS	4	**8**	12
	TWSC	1	**7**	8
End-of-Chain	SEID	**8**	3	11
Others	WF	3	5	8
	AIS	3	5	8
	IC	5	1	6
	Average	*5.5*	*5.6*	*11.2*

5.5 Discussions

The application of the eight steps of the eDPSIR approach in a participatory way with the engagement of the stakeholders, contributed significantly to visualize the relevant cause-effect relations between the indicators. It lead to the selection of a set composed of eight key-indicators that are very important for the specific domain, problem and location of the research: measure the social, economic, environmental and institutional sustainability of water use and management at the Salitre River Basin.

5.5.1 The eight steps process

The eight steps process of the eDPSIR proved to be an efficient tool for the selection of the most relevant indicators. Furthermore, this approach contributed to better organising and communicating the main issues related to the object of the research. The eight steps process is clearly defined, transparent and easy to understand and/or use. This step-by-step approach facilitated the engagement of the River Basin stakeholders contributing to the participative nature of this research.

Steps one, two, three and six, are related to defining components, limits, boundaries and questions of research that are the major guidelines for the eDPSIR analysis. Step one provided a clear definition of the specific issue addressed by the research and step six outlined the concrete research question.

By doing so, they undoubtedly contributed to the reduction of the size and complexity of the causal network, keeping it manageable and effective. As mentioned by Niemeijer & Groot (2008a), *"the better the questions or objectives are defined, the better the indicators can be selected"*, pointing out that a more precise definition of the research question leads to more accurate results of the eDPSIR.

Step three of the method narrowed the area of interest to be pilot tested (in this case, the Salitre River Basin), so that the causal network would not have a spill over effect to processes happening outside this area. The definition of these frontiers brought an objective view and more pragmatism to the process of selecting the indicators. It also contributed to avoiding unnecessary discussions outside the boundaries of the research objective, particularly during the meetings with the stakeholders. At these meetings, people with different views and interests were invited to discuss the research. Time management was crucial to achieve the expected results of the meetings. The eDPSIR step-by-step approach provided a clear definition of which aspects to consider and which to overlook and contributed to making these discussions more productive, focused and pragmatic.

5.5.2 Cause-Effect Relations

The analysis of the cause-effect relations among the indicators proved to be challenging, mainly because it is not trivial to distinguish between direct and indirect relations. In a broader perspective, all 11 indicators have some level of relation to each other. They address the same subject (water use and management), all of them fulfil the sustainability criteria (see Chapter 3), are suitable for the river basin scale and present solid scientific foundations (see Chapter 4).

However, the eDPSIR method aims at identifying the direct cause-effect relations among indicators. It was not an easy task to clearly identify these straight relations, distinguishing them from possible indirect connections between the indicators. In order to do this, the guideline questions proposed by the research (presented in section 5.3.3) can be considered as a useful tool to help in the identification of the direct relations among the indicators.

Answering these questions helps to map how these relations come about and how to better understand the complex interaction between the indicators (Niemeijer & Groot, 2008a). By better understanding these connections, one can have a more accurate comprehension of the multifaceted relations of the indicators with the problem under consideration. It also contributes to better explaining to the stakeholders the relevance of the indicator set, once the cause-effect relations between indicators are clearly demonstrated by a valid scientific method. It is also worth noting that, as mentioned by Wolfslehner & Vacik (2011), *"in performing network analysis, an exact definition of the term "linkage" is strictly required"*. The guideline questions presented above provide a clear definition of what linkages are relevant for the eDPSIR.

The findings of this research (see table 5.4 and figure 5.4) demonstrate that the majority of the indicators (76% of the 55 pairs) presented some direct cause-effect relations. The most frequent type of relation presented by the indicator set was unidirectional (where the first indicator affects the second, but the latter does not directly affect the former). They represent 40% of the results. The presence of bi-directional relationships (where the first indicator affects the second, and simultaneously the latter affects the former) was also significant, representing 36% of the total. Only, 24% of the pairs did not present a direct cause-effect relation between the indicators.

In order to illustrate the above relations, one may take a look at three relations of the indicator SEID (Social and Economic Impacts from Drought): the unidirectional relation with AIS, the bidirectional relation with TWSC, and its indirect relation with WF. SEID measures the socio-economic impacts caused by drought, in a given area and in a given period of time, using a valid methodology, considering aspects such as deaths (human/livestock), people affected, economic losses and property damage (Jenkins, 2011)[**].

This indicator showed a unidirectional cause-effect relation with the indicator AIS (Access to Improve Sanitation), pointing out that changes in the AIS affect SEID. For example, improving the access to sanitation facilities in a given region reduces the social impacts of drought that this population would suffer, especially the ones related to human health, i.e. illness, deaths, etc. (WWAP, 2012). Nevertheless, changes on the SEID do not directly affect the number of people with access to toilets or other improved sanitation facilities.

SEID presents bi-directional relations with the indicator TWSC. It represents the total cumulative water storage capacity of all large reservoirs, in a given area (Cap-Net UNDP, 2008; United Nations, 2009). On one hand, improving the TWSC is one of the major responses to reducing the social and economic impacts of drought (Wilhite, et al., 2014). On the other hand, these impacts of drought, usually signal that the total water storage capacity of a system should be adjusted to aim at mitigating the impact of the next drought event (Shiferaw et al., 2014; Sena et al., 2014).

Regarding the indicator WF (Water Footprint), no direct cause-effect relation could be clearly established between it and SEID. The water footprint of a river basin indicates the water that is used to produce the goods and services within that geographical area (Hoekstra et al, 2011). The social and economic impacts of drought do not automatically affect the Water Footprint of a given area. Certainly the water shortage, that characterizes drought events, affects the WF of a given area in a direct way, by modifying (usually reducing) the production of goods and services in a given region.

[**] See IPS (Indicator Profile Sheet) annex to the previous Chapter, for detailed information about all 11 indicators, including their underlying definitions and concepts, position in DPSIR chain, etc.

Nevertheless, the indicator SEID does not measure water scarcity; it measures social and economic impacts from droughts. Furthermore, changes on the WF of a given river basin will not necessarily directly increase nor reduce the social and economic impacts from droughts. Finally, it is worth mentioning that there are indirect relations between WF and SEID. These indirect relations pass through indicators that are related to the use of water in a more efficient way or the ones that point towards increasing the capacity of adaptation to droughts. WPI is an example that illustrates this: both indicators, WF and SEID, are linked with it (see figure 5.4).

5.5.3 Key Indicators

The identification of the key nodes at the eDPSIR causal chain (see Figure 5.4) allowed the recognition of the most relevant indicators related to the research question. According to Niemeijer & Groot (2008b), indicators associated with key nodes are usually the most useful indicators because they are likely to be connected with a large number of important cause-effect relations. The eight key-indicators (PUPLS, TWSC, WPI, CVI, WRI, RWSI, INSWU and SEID) are from different categories (root, central and end-of-chain nodes) and therefore each has a specific kind of utility to address the research question.

The root nodes, PUPLS and TWSC, are indicators that provide information on the source of multiple issues. In the causal network, they are in a position where they affect a significant number of indicators but are not affected by as many. For example, TWSC influences seven other indicators (WPI, CVI, WF, WRI, RWSI, INSWU and SEID), but is directly affected only by SEID (see table 5.4). The amount of urban population living in slums is also considered as a relevant cause of several problems related to the sustainability and the use of water due to their direct impact on the environmental condition (Chowdhury & Amin, 2006). Its eight outgoing arcs signal this. But it is also noticeable that the total number of arcs, incoming and outgoing, is also high (12), yet the amount of outgoing relations is double of the incomings ones. This feature also points towards its classification as a root note, albeit with a higher number of connections than TWSC. This comparison shows that, with regard to the research problem, the living conditions of the population are somewhat seen as a more central issue than the capacity to storage water.

The central nodes (WPI, CVI, WRI, RWSI and INSWU) are at the heart of multiple important processes and play relevant roles in the cause-effect network. These indicators are, at the same time, affected by a number of indicators and influence a series of others. The indicator WPI is an interesting example demonstrating the former. It is linked in the causal network with all other indicators, presenting a total of 17 connections (eight incoming and nine outgoing). WPI integrates physical, social, economic and environmental factors, and links water and poverty issues (Sullivan et al, 2002).

WPI and the other four indicators associated with the central nodes are in fact composite indexes, constructed by multiple sub-components. WPI, for instance, is composed of five components: available water resources, access to water, effective water use, water management capacity and environmental impacts (Sullivan & Lawrence, 2006). The numerous topics addressed by these five indicators allow them to be in a central position of multiple processes or issues at once.

An end-of-chain node represents an indicator positioned at the end of a sequence of cause-effect relations where the impacts of multiple pressures become more noticeable (Niemeijer & Groot, 2008b). SEID was the only end-of-chain node identified by the current research. The social and economic impacts from droughts are affected by the majority of the indicators (eight), but only cause influence in three (see figure 5.4). This indicator makes the direct and indirect social-economic impacts caused by drought visible, positioning it at the end of the causal network.

5.5.4 The eDPSIR Approach

The eDPSIR approach helped to visualize and to better understand the complexity of the **inter-connections** of the set of indicators. The findings of this research showed that all indicators are **interconnected** in an intricate network of cause-effect relations. Similarly to what was mentioned by Niemi and McDonald (2004), the results obtained by the eDPSIR approach made explicit that the relevance of the key indicators is much more evident in conjunction with other indicators and within the context of a specific research question and location. The network of cause-effect relations connecting the key indicators resulted in a comprehensive set, allowing indicator developers and end-users to better interpret them and providing the visualization of cause and effect patterns among the indicators.

The application of the eDPSIR approach helped to build this causal network and, by doing so, it identified the eight key-indicators related to the research question. These eight indicators, according to the eDPSIR method, should not only be considered as "stand-alone" indicators, but as a consistent set of indicators, where each and every indicator has a particular function in addressing the problem at hand. PULPS and TWSC address important causes, SEID is a very important indicator of impacts and the five indexes (WPI, CVI, WRI, RWSI and INSWU) are in a central position to assess the sustainability of water use and management at the Salitre River Basin.

The function of each indicator in the causal network became a crucial part of the indicator selection process. In this stage of the research, the 11 indicators were evaluated based not only on their individual features, as was the case in the previous stages (Chapters 3 and 4). The eDPSIR proved to be an effective framework that conducts the selection of indicators based on an analytical logic of the whole set of indicators rather than individual features.

Furthermore, the selection of the indicator set followed clearly outlined procedures that are replicable and scientifically robust.

It is worth mentioning that the conventional procedure to validate indicators based on individual criteria continues to be an important step in the assessment of indicators. In fact, it corresponds to the last step of the eDPSIR process and is addressed in detail in the next chapter. However, only eight indicators (key-nodes) were assessed, putting aside the other three that are not essential to the research problem.

The findings of this study confirmed, as mentioned by Niemeijer & Groot (2008a), that the eDPSIR framework lead to an approach in which more insight about the research question was gained with fewer indicators. This reduced number of indicators allowed the optimization of the operational efforts of the research team (less time and resources were invested in the next stage of the study by assessing eight instead of 11 indicators), the achievement of an even better result (the relations between indicators are clear) and lead to more efficient decision-making (a concise number of indicators is easier to be managed by end-users). It is also worthy to note that more accurate decisions are made when one has a deeper knowledge about the interactions between the indicators (Wolfslehner & Vacik, 2011).

5.5.5 Participatory process

The effective participation and engagement of stakeholders in the process was of great relevance to this study. Their view, that the current research about indicators for the sustainable water use and management is a subject of major relevance for the Salitre River Basin was also very important in fostering their interest in this study. Furthermore, this interest in collaborating with the research was crucial in order to move to the next phase, during which they were invited to, in a participative way, evaluate the indicators based on end-user criteria (see next Chapter). It is also worth mentioning that the suggestions presented by them (see section 5.4.1), were welcomed by the research team and most of them were implemented, as laid out in chapter 6.

According to Mendoza & Prabhu (2005), Rosso et al. (2014), among others, it is expected that the involvement of the stakeholders with the development of the research will contribute to the better application of the results of this study. One of the goals of this research is to produce knowledge that could be used to better addressing the challenges of society related to sustainable water use and management (see chapter one). The adoption of the outcomes by the stakeholders engaged as active collaborators of this research would, undoubtedly, contribute to achieving this goal.

5.5.6 Further Discussions

Scientific and/or operational approaches that use network frameworks for the selection of indicators are still rare in the field of natural resource management, in general, and in the field of water resources management, in particular. This document presents some previous application of this approach to indicators related to forest (Wolfslehner & Vacik, 2011; Mendoza & Prabhu, 2005), ecological systems (Lin et al., 2012), environmental aspects of pork production (Neimeijer & Groot, 2008b), water shortage mitigation (Azarnivand & Chitsaz, 2015), wetland management (Zsuffa et al, 2014; Van Dam et al, 2013), among others. Nevertheless, no previous work addressing the use of causal networks for the selection of indicators of water use and management could be found, highlighting the originality and relevance of the current research.

Another issue that should be considered when applying the eDPSIR approach to water resource indicators related to sustainability, is that some of these indicators are in fact indexes, made up of several sub-components (as it was the case of the majority of the 11 short-listed indicators of this research). Considering the multidimensional nature of sustainability (social, economic, environmental and institutional issues are linked together), it is expected that an index to measure sustainability would be classified in more than one position of the DPSIR framework. For example, the Climate Vulnerability Index (CVI) is an index that considers six 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 & Huntingford, 2009).

Nevertheless, the majority of previous works that have applied the eDPSIR approach considered indicators that are positioned only in one category at the DPSIR framework (Azarnivand & Chitsaz, 2015; Neimeijer & Groot, 2008; Wolfslehner & Vacik, 2011) or did not inform the classification of the indicators under the conventional DPSIR framework (Lin et al., 2009; Lin et al., 2012). The current research demonstrates that it is feasible to apply the eDPSIR approach, regardless of whether the indicators or indexes are classified into one single DPSIR position (it was the case of IC and SEID that are Impact indicators, as well as WF and AIS that measures Pressures) or more than one DSPIR position (for example, WRI, RWSI, INSWU and PUPLS are classified under two DPSIR positions, namely Pressure and State).

As mentioned by Neimeijer & Groot (2008a); Wolfslehner & Vacik (2011) and Mendoza & Prabhu (2005), a causal network can also be mathematically analyzed as a probabilistic model in which the indicators are “variables of interest” and the links represent “causal dependencies among the variables”. This mathematical exploration of the results goes beyond the scope and the interest of the current research.

Nevertheless, further studies could investigate the probabilistic model considering the causal network presented in Figure 5.4. Within this mathematical theory it is worth highlighting the analysis of domain, centrality and criticality (Mendoza & Prabhu, 2005). They measure the effects of direct and indirect linkages between the indicators. As suggested by Wolfslehner & Vacik (2011), "*the complexity of a network (i.e., the ratio of nodes and arrows), the identification of positive and negative loops within the system, the discovery of thematic clusters, and the possibilities for simplification and removing redundancies*" could also be further explored by other studies.

5.6 Conclusions

Water resources indicators are often interrelated and, consequently, it is conceivable that although assessing indicators individually appears to be enough, sustainability requires evaluating cross-indicator interactions. Furthermore, the involvement of the stakeholders in the decision-making process is a key element in sustainable water use and management. The aim of this research was to select, out of the 11 short-listed indicators, the most relevant ones using the interconnectedness of the indicators as a key component in the selection process.

This goal was reached by adopting a selection process using the eDPSIR framework in a participatory approach. The eDPSIR is an innovative method that considers the systematic function of the cause-effect relations between the indicators as an essential part of the indicator selection process. To effectively use this method it is recommended to define a specific location for its application. The definition of a pilot river basin gave an objective perspective and more pragmatism to the process of selecting the indicators.

The Salitre River basin was selected as the pilot river basin where to apply this method. The process adopted to identify and choose the river basin was transparent and based on clear selection criteria, focusing on its geographic characteristics and stakeholder features. The main social, economic, environmental and institutional aspects of the Salitre river basin are described here pointing out the need for tools, such as those developed in this research, that would promote sustainable water use and management at this basin. The usefulness of the indicators was confirmed by the surveys that were carried out as part of the multi-stakeholder participatory approach implemented during the research.

The findings of the study confirmed that indicators are more useful if they are selected based on their interconnection in relation to the problem at hand instead of selected individually as a simple collection of elements. The eight steps of the eDPSIR framework guided the identification of the most relevant set of indicators (eight in total - PUPLS, TWSC, WPI, CVI, WRI, RWSI, INSWU and SEID) that allows the stakeholders and water managers to assess the sustainable water use and management at the Salitre River Basin in a clear, well-organized and effective manner. The eDPSIR contributed to the participative nature of this research making the participatory process more productive, focused and pragmatic.

The effective participation and engagement of stakeholders in the process was of great relevance to this study. They contributed to improving the adjustment of the research to local conditions, enhanced the use of local knowledge and confirmed that the research about indicators for sustainable water use and management is a subject of major relevance for the Salitre River Basin. This research aims to produce knowledge that could be used to better address the challenges of society related to sustainable water use and management. It is expected that the involvement of stakeholders will contribute to the practical application of the results.

Finally, it is relevant to mention that the methods adopted here are clearly defined, transparent and easy to understand and/or use. This methodology can be replicated in other river basins. Furthermore, it is worth mentioning that the conventional procedure to validate indicators based on individual criteria continues to be an important stage in the assessment of indicators. In fact, it corresponds to the last step of the eDPSIR process and is addressed in detail in the next chapter (Chapter 6), where the eight key-indicators were assessed against a set of scientific and end-user criteria in a participatory process.

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5.8 ANNEX

SALITRE RIVER BASIN (2013-2014)

Picture 1. Rio Sao Francisco, Bahia-Brasil.

Picture 2. Semiarid territory at Bahia, Brasil.

Picture 3. Program "1 milhao de cisternas", reservoirs for rainwater harvesting and goats, at the Salitre River Basin in Bahia, Brasil.

Picture 4. Upper part of the Salitre river basin – one of the main springs of the Salitre River at Morro do Chapeu, in Bahia Brazil.

Picture 5. Medium part of the Salitre River Basin – showing the contrast between the polluted river in the picture below and the beautiful natural reservoir above.

Picture 6. Lower part of the Salitre River Basin – the picture below shows a five meters high bridge on the Salitre river completely silted up.

Picture 7. Lower part of the Salitre river basin – water supply is also a critical issue for several areas of the Salitre River Basin.

MEETINGS WITH STAKEHOLDERS

Picture 8. First meeting with stakeholders at Juazeiro (24th of October 2013).

Picture 9. Second meeting with stakeholders at Caatinga do Moura – Jacobina (4th September 2014)

CHAPTER 6 – VALIDATION OF THE INDICATORS FOR SUSTAINABLE WATER USE AND MANAGEMENT

ABSTRACT

Validation of indicators is an essential step in the identification of an accurate and credible indicator set. This study used transparent and replicable methodology to implement a multistage and multistakeholder validation process of indicators for the use and management of water resources, selected by previous stages of the research. A pilot study served to test and approve the research methodology and data analysis before carrying out the full implementation. Indicators were then evaluated against a set of scientific and end-use criteria. A scientific panel composed of experts from the Ibero-american scientific community assessed the validation of the indicators using an evaluation matrix. An end-use panel composed of stakeholders from the Salitre river basin in Bahia-Brazil examined the indicator set using the end-use criteria through a structured survey. Based on the results obtained, all 8 indicators were validated under this methodology.

6.1 INTRODUCTION

An indicator can be a "pragmatic tool" for measuring and describing complex issues (Bélanger et al., 2012). However, in order to rely on the guidance provided by these tools, critical review and validation of indicators is necessary to ensure their relevance and credibility (Meul, Nevens & Reheul, 2009). Validation is crucial to the scientific process and to the creation of an indicator that is "useful and used by the end users" (Bockstaller & Girardin, 2003).

Hak, Kovanda & Weinzettel (2012) describe the validation of indicators as a *"multicriteria multiexpert decision problem"*. However, **restricting the validation process to only scientists and academic experts removes an important social dimension from the process**. The use and management of water resources have multiple effects (i.e. social, economic and environmental), therefore the stakeholders "*...who are going to be potentially affected by them must be given the possibility to express their opinion on them*" (Cloquell-Ballester, Monterde-Díaz & Santamarina-Siurana, 2006). Involving individuals that represent the society and territory can help to improve the success of an indicator set as an effective water management tool (Bosch et al., 2012). They are usually the persons who, despite not been considered as academic experts, possess basic knowledge of the intrinsic interconnections between the environmental, social, cultural and economic processes that influence water use at the local level (Yavuz & Baycan, 2015).

Therefore, validation is applied by our research as a multicriteria, multistakeholder process. Not only is the involvement of both scientific and end user perspectives important, but the criteria used by these groups to evaluate indicators should reflect these two perspectives. Expert involvement should focus on ensuring that indicators provide accurate and relevant output. Stakeholders should help ensure ease and utility.

In the initial stage of this study 170 indicators linked to water resources were identified through an extensive literature review. Subsequently, an international panel of experts selected from these the 24 indicators which best fulfilled the criteria of social, economic, environmental and institutional sustainability (Chapter 3). Then, it was identified that 11 of the 24 indicators have the appropriate characteristics to assess water use and management in an actual watershed (Chapter 4). In the next step, the Salitre River Basin (in semiarid region of Bahia-Brazil) was selected for pilot implementation of this project. At that point, the indicators were assessed based on the innovative eDPSIR methodology. The application of this method showed that 8 of the 11 indicators are of great relevance to address the complex issue of sustainable use and management of water in a river basin (Chapter 5). These eight indicators are the following:

- Water Poverty Index (WPI);
- Climate Vulnerability Index (CVI);
- Water Reuse Index (WRI);
- Relative Water Stress Index (RWSI);
- Index of Non-sustainable Water Use (INSWU);
- Social and Economic Impacts from Drought (SEID);
- Total Water Storage Capacity (TWSC) and
- Proportion of Urban Population Living in Slums (PUPLS).

The main objective of this last stage of the research was to determine the validity of these eight indicators. The indicators were then evaluated against a set of scientific and end use criteria (see chapter 3 for detailed information about selection of the criteria) in a participatory process, involving the major stakeholders related to the subject. This evaluation applied transparent, solid and replicable methodological tools – such as the Likert Scale and multistage validation process.

6.2 METHODOLOGY

This study adopted a multistage and multistakeholder validation process using evaluation matrixes and structured surveys based on pre-defined assessment criteria. A participatory process was used to examine the validity of the indicators. A pilot validation test was carried out in order to test the methodology and statistical techniques employed in this research, prior to full-scale implementation of the study.

6.2.1 Criteria for Indicators Assessment

As presented in detail in chapter 3, selection of the assessment criteria was one of the first steps of this research. An extensive revision of criteria for evaluating indicators was carried out through an in-depth meta-analysis of 74 relevant sources, which identified 346 mentions of criteria. An evaluation matrix was then constructed in order to determine the most relevant criteria for assessing indicators.

The number of criteria used to assess indicators is important both from a scientific standpoint, and from an appraiser standpoint (Cloquell-Ballester et al., 2006). Using a greater number of criteria can increase the quality of the assessment by considering validity from a greater number of angles (Niemeijer & de Groot, 2008). However, the quality of the validation process also depends on the engagement and interest of participants. Too many criteria would take longer time and concentration, and therefore increase the chance of respondent fatigue, deteriorating the attention and motivation of respondents (Ben-Nun, 2008).

Eight criteria were originally used in the pilot validation test of the indicators (see section 6.2.4 below), but experts' feedback pointed to the need to reduce the number of criteria. Accordingly the number of criteria was reduced to 6, thus adjusting to the recommendations while still fulfilling the requirements of this study.

This number of criteria was further supported by the review of the literature. An average of 5 criteria was mentioned in each of the 74 papers reviewed our study. This research increased it to 6 in order to have an equal number and balance of scientific and end-use criteria.

An in-depth review of the most relevant criteria to assess indicators was done using an assessment matrix of the 346 criteria. These criteria were identified by several electronic searches using databases and academic search engines (including Web of Science, SCOPUS, ScienceDirect, Google Scholar and others), complemented by relevant grey literature (mainly international institutions). This comprehensive examination revealed that the 346 criteria were in fact 60 different criteria (some had the same name but different definitions; some had different names but their definitions indicated that they were, in fact, the same criterion). The next step was to count the number of sources that consider each criterion in question as relevant. Similarly to WWAP (2006), our research organized the criteria into two major groups: scientific criteria and end-use criteria.

For the assessment of the validation of the indicators there has been selected the most important criteria based on the assessment described above that have not been assessed in previous stages of the current study. Consequently the six criteria adopted to assess indicator validity were: Reliability, Measurability and Sensitivity, from the scientific perspective; and Data availability, Relevance and Comprehensibility, for the end-use assessment (Table 6.1).

Table 6.1 – The scientific and end-use criteria adopted in this validation assessment.

	Name	Definition	Citations*
Scientific Criteria	**Reliability**	The extent to which an experiment, test, or measuring procedure yields the same results on repeated trials.	18
	Measurability	The extent to which the proposed measurement procedures to obtain the indicator use standardized methods.	15
	Sensitivity	The extent to which a small change in the factor measured should result in a measurable change in the indicator.	13
End-use Criteria	**Data availability**	The extent to which the data required for the indicator is easy or possible to get at a reasonable cost.	31
	Relevance	The extent to which an indicator is related or connected to the matter at hand.	25
	Comprehensibility	The extent to which the indicator can be understood by the target audience.	21

*Number of sources that mention the criteria. Aveline et al, 2009; Baker et al, 2002; Bélanger et al, 2012; BNIA, 2006; Bockstaller et al 2008; Bringhenti et al., 2011; Buchholz et al, 2009; Butler et al, 2003; Clark and Dickson, 1999; Cloquell-Ballester et al. 2006; Doukas et al, 2007; FAO, 1999; Fraser et al, 2006; Gilmour et al, 2007; Graymore et al, 2009; Gudmundsson, 2010; IISD, 2008; ITFM, 1995; Kurka and Blackwood, 2013; Lattimore et al, 2009; Niemeijer & de Groot, 2008; OECD, 2003; Olsthoorn et al, 2001; Parris and Kates, 2003; Prescott-Allen, 2001; Rovere et al, 2010; Segnestam, 2002; Shmelev & Rodríguez-Labajos, 2009; Singh et al, 2008; SNZ, 2002; UN, 2007; UNEP, 2006; US EPA, 2000; Vera & Langlois, 2007; Wang et al, 2009; WHO, 2002; World Bank, 2000; WWAP, 2006.

6.2.2 Likert Scale

This study adopted a five-level Likert Scale to assess the validity of the indicators (Table 6.2). The Likert scale is a symmetric agree-disagree rating scale to measure either negative or positive responses to research that employs questionnaires (Allen & Seaman, 2007).

This scale, originally introduced by Likert (1932), is the most widely used scale in social research for the measurement of attitudes (Li, 2013). Likert scales have been widely used to measure opinion or belief of appraisers, indicating their levels of agreement with a declarative statement in various areas, such as: social sciences (Brody & Dietz, 1997), marketing (Weijters, Cabooter & Schillewaert, 2010), psychology (Camparo, 2013), pharmacology (Ried, 2014), experts systems (Li, 2013), medicine (Chachamovich, Fleck & Power, 2009; Falk & Anderson, 2012), health care (Harland, Dawkin & Martin, 2014), quality control (Allen & Seaman, 2007), engineering education (Li, McCoach, Swaminathan & Tang, 2008) and construction (Acharya, Lee & Im, 2006).

Furthermore, some authors have applied this scale in the field of indicator validation and sustainability assessment (Cloquell-Ballester et al., 2006; Hajkowicz & Young, 2000; Macharis, Witte & Turcksin, 2010).

Table 6.2 - Five-level Likert Scale adopted by this study.

Numeric Value	Likert Item
5	Strongly agree
4	Agree
3	Neither agree nor disagree
2	Disagree
1	Strongly disagree

In this study the Likert scale is treated as an ordinal scale (Blaikie, 2003; Babbie, 2005), meaning that the responses have a rank order (from 1 to 5), but the intervals between values cannot be presumed equal. The nature of the Likert scale as ordinal or interval is the subject of ongoing debate in the scientific literature (Norman, 2010; Jamieson, 2004; Hodge & Gillespie, 2003). Li (2013) points out that it cannot be assumed that the intensity of feeling between consecutive items on a Likert scale is equivalent. Edmonson (2005) also notes that this assumption of the scale as interval, is not mentioned in the original report by Rensis Likert. Norman (2010) argues that despite the ordinal nature of the Likert scale, the data can still be described using the mean and standard deviation due to the robustness of these calculations.

However, this study chosen to engage with the scale as ordinal and analyse the data using statistical methods that do not rely on interval data. Therefore the results are presented as frequency responses (using boxplots and bar charts), the central tendency is summarized by the median (not the mean) and dispersion is represented by the interquartile range (not the standard deviation). The interquartile range (IQR) is a useful measure of variation that is much less susceptible to extreme values, measuring the spread between the 1st and 3rd quartile (Groebner, Shannon, Fry & Smith, 2011). Tukey boxplots are used to visually represent non-parametric data. For this study, box whiskers represent the highest datum within 1.5 IQR of the upper quartile, and the lowest datum within 1.5 IQR of the lower quartile. Data not included within the whiskers are represented with open circles as outliers; lower and upper hinges (top and bottom of the box) represent the 1st and 3rd quartiles, respectively. Diverging stacked bar charts are useful for visualizing the distribution of responses along the Likert scale. Heiberger & Robbins (2014) recommend them above other methods *"as the primary graphical display technique for Likert and related scales"*.

6.2.3 Multistage and Multistakeholder Validation Process

The quality of indicators was assessed using a participatory double validation process: 1) the scientific community and indicators' developers determined whether the indicators fulfil the scientific criteria; 2) the major stakeholders at river basin level checked if the indicators fulfil the end-use criteria. The multistakeholder validation process has been adopted successfully by other authors (Cloquell-Ballester et al., 2006; Gain & Giupponi, 2015; Meul et al., 2009). A multistakeholder approach is important for its ability to connect abstract models of measurement "*with real needs, and can feed and invigorate*" the process of indicator development and validation (Voinov & Busquet, 2010). Involving stakeholders recognizes the complexity inherent in natural resource management, and increases the chance of indicator credibility and success (Voinov & Gaddis, 2008).

Two survey forms were created to guide the task of validating the indicators: an evaluation matrix was used for the scientific validation and a structured survey questionnaire was used for the end-use validation. In both forms the research question posed to appraisers was: *"In your opinion, does the indicator X fulfil the criteria Y?"* (Where X is one of the 8 short-listed indicators and Y, is one of the 6 assessment criteria).

Scientific Validation

Scientific panels have been used by other authors to supply independent, expert judgement to the validation process (Aveline, Rousseau, Guichard, Laurent & Bockstaller, 2009; Meul et al., 2009; Van der Werf & Zimmer, 1998). Scientific validation is often integrated into the design and output validation of an indicator. This helps to determine, respectively, if the indicator is scientifically accepted, and if it provides relevant and accurate information based on the judgement of a party *"independent of both the model developers and the model users"* (Meul et al., 2009).

The scientific validation was achieved by the formation of a scientific panel. This panel assessed the quality of the eight indicators selected in the previous stage of the research based on the three scientific criteria listed on Table 6.1. In order to select the members of this panel, 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) Motivation to participate in the process;

In order to identify these experts, this study adopted approaches similar to those used by Orsi, Geneletti & Newton (2011), Gain & Giupponi (2015), and Bélanger et al. (2012). Orsi et al. (2011) identified experts based on the researchers' personal knowledge of appropriate individuals, a review of the literature, and by using project databases to identify individuals with relevant experience. Researchers should thus obtain a list of individuals that are knowledgeable in the study area, have been involved with similar projects and therefore are considered to have expertise (Gain & Giupponi, 2015). Bélanger et al. (2012) state that the use of volunteer experts can result in a high dropout rate, particularly throughout a multistage process. Therefore the motivation of experts to participate, and consistent communication with participants by the researcher is important for a successful interaction.

At this stage of the study, 68 experts from the Ibero-american scientific community were invited for the formation of the scientific panel. These individuals have proven experience in the water resources field, familiarity with I&C (Indicators and Criteria), and knowledge of the water resources sector of two or more Ibero-american countries. These scientists were selected from international networks related to the field of this research, namely RECNET (Recycling City Network - Rethinking the Transformation of Cities), CYTED (Ibero-American Programme for Science, Technology and Development), and UNESCOSOST, among other networks.

Communication with the invitees was based on the fundamentals of trust and reciprocity: participants would dedicate their time and expertise; in return, they would receive a copy of the results and formal acknowledgments of their contribution. In order to facilitate the work as much as possible: a webcast tutorial was produced and broadcasted; and all materials sent to them were as user friendly as possible. The evaluation matrix was colour-coded and self-explanatory. Using the Likert Scale, participants described how strongly they felt each indicator fulfilled each scientific criterion. The participants performed remote and independent evaluations. Participants were also invited to write their comments or observations about the indicator.

New versions of the IPSs (Indicator Profile Sheets) were produced, providing in a summarized and organized way the information participants would need to evaluate the indicators (Annex 6.1). The original IPSs present brief information, such as a description of each indicator, its classification based on sustainability criteria and some references to further resources (Chapter 4). The new version of the IPSs created for the 8 indicators selected for validation includes more detailed and comprehensive information, such as a description of how to compute the indicator, its unit of expression, the specification of determinants and data needed, and other relevant information.

Forty appraisers collaborated with this work, representing a response rate of 59%. According to Nulty (2008), this can be considered a good answering rate. The majority of the members were pursuing or possessed a PhD, 12 participants were females and 29 were males. Appraisers came from a wide range of fields of knowledge such as economy, hydrology, agronomy, engineering, environmental science, water and sanitation, sociology, biology, climatology, geography, geology, sustainability, energy, desertification, natural resource management, international cooperation, and health science, among other fields. Their professional profile ranged from staff in international institutions (such as World Bank, UNCCD, UNEP, UNESCO and WHO) to water resources managers with leading positions, and from research fellows to professors.

End-use Validation

The involvement of end users in the validation of indicators is a very important step of the evaluation process. They are the people and institutions that will use the indicator in order to better allocate and manage the water resources. In order to be truly participatory and reliable, any validation process should take into consideration the knowledge and needs of these stakeholders (Aveline et al., 2009; Bockstaller & Girardin, 2003)

An end users panel was formed in order to validate the eight indicators selected in the previous stage of the research. Validation was based on the three end-use criteria listed in Table 6.1. Similarly to Cloquell-Ballester et al. (2006), the principles considered to select panel members were the following:

a) Knowledge about the water resources situation at river basin level;

b) Knowledge of the river basin territory and the interactions among its elements;

c) Social representation;

Committee members for the Salitre River, the pilot river basin for this research (see previous chapter), were the major target group for involvement in the end users panel. The

Salitre River Basin Committee is composed of three types of representatives: one third government representatives (public administrations, water management agency, etc), one third water users representatives (agriculture sector, water supply sector, industrial sector, etc) and one third societal representatives (non-governmental organizations, associations, universities, etc). Additional individuals that fulfil the criteria listed above were also invited. In total, 66 people were invited to join the end users panel.

In order to map these stakeholders, this research has followed the main recommendations presented by Voinov & Bousquet (2010), Rosso, Bottero, Pomarico, La Ferlita & Comino (2014) and deReynier, Levin & Shoji (2010). Voinov & Bousquet (2010) note the importance of engaging as diverse a panel as possible. Individuals from many different groups with a wide-ranging set of interests should be invited. According to them, doing so increases diversity of opinions, which can often increase the external credibility of the process and can help to ensure a smoother implementation of any management recommendations after the study.

Care should also be taken to identify those stakeholders whose demands may affect the success of a study or its recommendations (Rosso et al., 2014). The approach adopted by deReynier et al. (2010) identified stakeholders with knowledge of the topic, ranging from formal groups involved in management, to those that profit indirectly from the resource, to those that directly use the resource.

In order to perform the end-use validation, the stakeholders were invited to participate in a one-day meeting. Communication with the invitees was based on the fundaments of trust, reciprocity and mutual interest. The president of the River Basin Committee (a person trusted by his peers) and the UNESCO Chair on Sustainability (an international and reliable institution) formally invited the members. Invitees were encouraged to participate in a meeting where they would dedicate their time and expertise to evaluate the indicators, but in return they would receive a copy of the results, formal acknowledgments for their contribution and learn more about indicators science.

As proposed by Voinov & Bousquet (2010), the invitations emphasized the important role of stakeholder input in the process, and the potential value of the study results. The mutual interests of the invitees and the research team converge on the use of indicators as a management tool to promote better use of the water resources at river basin level. The research objectives proved to be of interest to the participants, which is evident from the survey performed in the previous chapter of this research (see Chapter 5).

Together with the invitation letter, participants received explanatory summaries about the research and about water resources indicators. These brief documents presented background information about indicators and pointed to how the outcomes of this study could contribute to the better management and use of water at the Salitre river basin.

Forty-eight people were part of the end users panel, representing a response rate of 73% (Table 6.3). This high answering rate is largely attributed to the intense follow-up and motivational process adopted by the researchers following the initial invitation. The success of the previous meeting held with the Committee (see previous chapter) and the high expectation generated also contributed to reaching this high answering rate. The members formed a diverse panel: 11 females and 37 males, from different age ranges and cultural backgrounds. The panel included representatives from government (at local, sub-national and national levels – including the environmental agency responsible for the water management of the Salitre river basin), research institutions, youth associations, environmental associations, farmers (including both small scale farmers and agribusiness), afro-descendants groups, public heath institutions, public prosecutors, water supply sector, trade associations, labour associations, legislative representatives, educational institutions, mining sector, among other representatives of the civil society.

Table 6.3 - Information about the meetings with stakeholders on the Salitre River Basin in the state of Bahia- Brazil.

	First Meeting	Second Meeting
Date	24/10/2013	04/09/2014
Location	Juazeiro	Jacobina
Number of Invited Stakeholders	57	66
Number of Participants at the meeting	31	48
Answering Rate	54%	73%

At the meeting, the research team presented the scope of the study, its relevance, the methods applied, the results obtained so far and the expected outcomes. Furthermore, during the meeting a significant amount of time was spent on discussions and debates. In order to make this evaluation process as participative as possible all materials were adapted to the target audience. Structured survey questionnaires, with clear statements and decoded information, were adopted instead of the evaluation matrix used by the scientific panel. Questionnaire answers were not numerical, but nominal, converting the Likert scale into a simple visual analogue scale: a horizontal line, on which each appraiser indicates his or her response by checking tick-marks. Participants were also invited to write their comments or observations about the indicator on the survey form. The materials produced were easy to understand, communicating in direct and simple way, so as to avoid misunderstandings and misinterpretation. Information about each indicator (originally presented in the IPS format) was converted into PowerPoint presentations delivered by the research team at the meeting.

The meeting with the stakeholders took place at Caatinga do Moura, a district of the city of Jacobina – Bahia, located in the upper part of the river basin, on the 4th of September 2014. It is worthy to mention that this meeting was the second of a series of 3 meetings arranged with the River Basin committee (see previous chapter for detailed information). The first meeting with the stakeholders took place at the city of Juazeiro – Bahia, located in the lower part of the river basin, on the 24th of October 2013. At this first meeting, the stakeholders confirmed their interest in the research and agreed to collaborate with this participatory study. The stakeholders participated actively in the discussions and provided important feedback for the study that was incorporated in this phase of the study (i.e. more time for debates, communicate research results to a broader audience, broaden the list of invitees, etc.). The third meeting will be done after the closure of the research. It aims to present the final results and to transfer this knowledge to them in order to promote the use of these outcomes to improve the sustainability of the water use and management at the Salitre River Basin.

6.2.4 Pilot Validation Test

Pilot tests, like the one done in this stage of the study, are very important in qualitative research for their ability to reveal any methodological limitations and flaws, or areas for design improvement (Van Teijlingen & Hundley, 2001). Pilot tests give researchers the opportunity to make any necessary revisions prior to full implementation in order to increase the likelihood of success (Turner, 2010).

A pilot test of the validation assessment was performed in order to check if the scale and the criteria selected in the previous stages, as well as the survey design and settings, would work as expected. This test simulated the application of the evaluation matrix to a group of 7 experts from the network of the UNESCO Chair on Sustainability. Indicators were evaluated against both the scientific and the end-user criteria. The test participants were limited in number but diverse in their representation, including professors and PhD/Master students, males and females as well as people from diverse age ranges with different backgrounds from several Ibero-american countries.

The results were statistically treated in the same way that the final results would be. The volunteers welcomed the design and the material produced. Nevertheless, they provided relevant feedback and suggestions to further improve them, such as, presenting the support material in a different format, organizing the IPS structure in a different way and reducing the number of criteria.

Furthermore, in order to better adapt the survey material for the target group of the end-use validation (the stakeholders of the Salitre River Basin), the research team consulted with the president of the River Basin Committee, as well as experts that have a proven record of working with surveys of this nature in the Salitre River Basin. They approved the material and the methodology proposed. Nevertheless, they recommended that the surveys use simple and direct language, and maximize the use of visual elements in order to make the survey as straightforward and "enjoyable" as possible.

The methodology was approved through the pilot validation test, and the main recommendations from the participants were incorporated into the research design.

6.2.5 Validation Assessment

The data obtained by the scientific and end-use assessments was categorized, processed and analysed using the fundamentals of descriptive statistics. The R, a free software environment for statistical computing and graphics (Kabacoff, 2011), was used for data manipulation, calculation and graphical display. The validation assessment aimed to determine if each one of the eight indicators is valid or not based on each and every one of the six criteria considered by this study. In order to process the validation assessment, the results obtained were organized in three groups (called validation groups), based on the Likert Scale (Hartley, 2014; Lowell, 2007):

- Group A (positive responses) represents the results where the appraisers agree or strongly agree that the indicator fulfils the validation criterion in question (values 4 and 5 of the Likert scale).
- Group B (neutral responses) represents the results where the appraisers are unsure or undecided if the indicator fulfils the criterion or not (value 3 of the Likert scale).
- Group C (negative responses) represents the results where the appraisers disagree or strongly disagree with that the indicator fulfils the specific criterion (values 1 and 2 of the Likert scale).

These validation groups were used to examine appraisers' levels of agreement with the validation statement and can be considered an intermediary analysis necessary to classify the indicators into validation categories. Finally, the results were classified into four validation categories – valid, needs a brief review, needs thorough review, or unacceptable – as proposed by Cloquell-Ballester et al. (2006). The classification into these categories is based on the validation groups described above (Table 6.4). The validation categories point to positive or negative answers/tendencies of the majority of appraisers' responses. This research used the simple majority – when a subset of a set consists of more than half of the set's elements; or the relative majority, when a subset is larger than any other subset considered.

Table 6.4 – Categories of the Validation Assessment.

Category	Meaning	Mathematical representation
Validated	The majority of results are under Group A – simple majority **(positive answers)**	If Group A > 50%
A **brief review** is required	The results under Group A are not the simple majority but they are higher then the ones under Group C – relative majority **(positive tendency)**	If Group A $\leq$ 50% and Group A > Group C
A **thorough review** is required	The results under Group C are not the majority but they are higher then the ones under Group A – relative majority **(negative tendency)**	If Group C $\leq$ 50% and Group C $\geq$ Group A
Unacceptable	The majority of results are under Group C – simple majority **(negative answers)**	If Group C>50%

Source: adapted from Cloquell-Ballester et al. (2006)

6.3 RESULTS

In total, the 98 appraisers provided 1893 results; 960 came from the scientific validation and 933 from the end users validation. The frequency distribution of the results was analysed and summarized in the tables and figures below.

Median and Interquartile Range (IQR)

The majority of the results (35 out of 48) showed a median of 4, demonstrating that, in general, appraisers agree with the validation statement (Table 6.5). The prevalent IQR was 1 (33 out of 48 results), showing that the responses were consistent (most values lie not far from each other).

Data Availability was the criterion that presented the lowest median of the results (5 of the 8 indicators reached median 3 and TWSC reached just 2.5) denoting that appraisers were not sure about the validation of these indicators under this criterion. Nevertheless, SEID and PUPLS scored a median of 4 in this criterion, showing agreement with the validation statement. IQR was high (2) for all indicators (except PUPLS) assessed the Data Availability criterion, suggesting that the results were more disperse and divergent in comparison with the other results obtained in this study.

PUPLS presented a couple of interesting features regarding its IQR. On the one hand it was the only indicator with a low IQR (1) for Data Availability. On the other hand, it was the only indicator to have an IQR of 2 for all three Scientific Criteria, pointing to greater dispersion of the results regarding its reliability, measurability and sensitivity.

TWSC had an outstanding performance with regard to the Measurability and Relevance criteria, reaching a median of 5 and 4.5, respectively. Similar performance was also achieved by SEID under the criterion Relevance (median 5), demonstrating that appraisers very strongly agree that it is an important indicator. WPI and CVI also performed remarkably under the Measurability criterion, presenting a median of 4 with an IQR of only 0.25, indicating a very high consistency of responses in this assessment.

Table 6.5 - Median and IQR of the validation assessments.

		Scientific Criteria						End-Use Criteria					
		Reliability		Measurability		Sensitivity		Data Availability		Relevance		Comprehensib.	
		Median	IQR	**Median**	IQR	**Median**	IQR	**Median**	IQR	**Median**	IQR	**Median**	IQR
INDICATOR	WPI	**4.0**	1.00	**4.0**	0.25	**3.0**	1.00	**3.0**	2.00	**4.0**	1.00	**4.0**	1.00
	CVI	**4.0**	1.00	**4.0**	0.25	**4.0**	1.00	**3.0**	2.00	**4.0**	1.00	**4.0**	1.00
	WRI	**4.0**	1.25	**4.0**	1.00	**4.0**	1.00	**3.0**	2.00	**4.0**	1.00	**4.0**	1.25
	RWSI	**4.0**	1.00	**4.0**	1.00	**4.0**	1.00	**3.0**	2.00	**4.0**	1.00	**4.0**	1.25
	INSWU	**4.0**	1.00	**4.0**	1.00	**4.0**	1.00	**3.0**	2.00	**4.0**	1.00	**4.0**	1.00
	SEID	**4.0**	1.00	**3.0**	1.00	**3.0**	1.00	**4.0**	2.00	**5.0**	1.00	**4.0**	1.00
	TWSC	**4.0**	1.00	**5.0**	1.00	**4.0**	1.00	**2.5**	2.00	**4.5**	1.00	**4.0**	1.00
	PUPLS	**4.0**	2.00	**4.0**	2.00	**3.0**	2.00	**4.0**	1.00	**4.0**	1.00	**4.0**	1.00

The results presented above were further analysed by studying the distribution of the medians using boxplots of the combined results (merging all data obtained by this research) for each criterion, and for each indicator, as described below.

Boxplot of the Criteria

Data Availability was the only criterion presenting a median of 3, indicating that the Likert item "neither agree nor disagree" was the middle value of the results (Figure 6.1). All other criteria presented a median of 4, showing that appraisers agree with the validation statement.

A perfect **symmetry** is observed for Data Availability with upper and lower fences reaching the extreme values (1 and 5) and an IQR of 2. These properties demonstrate that appraisers were more undecided, in comparison with the other criteria, as to whether the indicators fulfil this criterion. The criterion Sensitivity presented with symmetry in relation to its extreme values but with asymmetry in relation to its quartiles. Asymmetry, with clear tendencies toward positive answers (scores of 4 and 5), is noticed in all other criteria (Reliability, Measurability, Relevance and Comprehensibility). These asymmetries point towards decisions and the symmetries towards indecisions.

The **box** of the criteria Reliability and Measurability ranged from 3 (lower hinge) to 5 (higher hinge) and the whiskers reached 1. This points to a generally positive perception by appraisers regarding the validation of the indicators based on these two criteria, with the exception of a few appraisers who disagree or strongly disagree.

The boxes of the Relevance and the Comprehensibility criteria went only from 4 to 5 and their whiskers only reached grade 3. Furthermore, their low hinges were equal to the median (4). These results mean that the vast majority of appraisers agree or strongly agree that the indicators fulfil these criteria.

The Sensitivity criterion box has its upper hinge equal to the median (4), showing that it received less scores of 5 than the other criteria (such as Reliability or Measurability). On the other hand, its lower whiskers only reach 2, meaning that just a few appraiser disagree that the indicators fulfil this criterion.

Outliers were found for Sensitivity, Relevance and Comprehensibility, indicating that a few results (just 38 out of 944) were further away from the median than the extremes. These marginal results, grades 1 or 2, point to a discrepancy of only a minor number of appraisers.

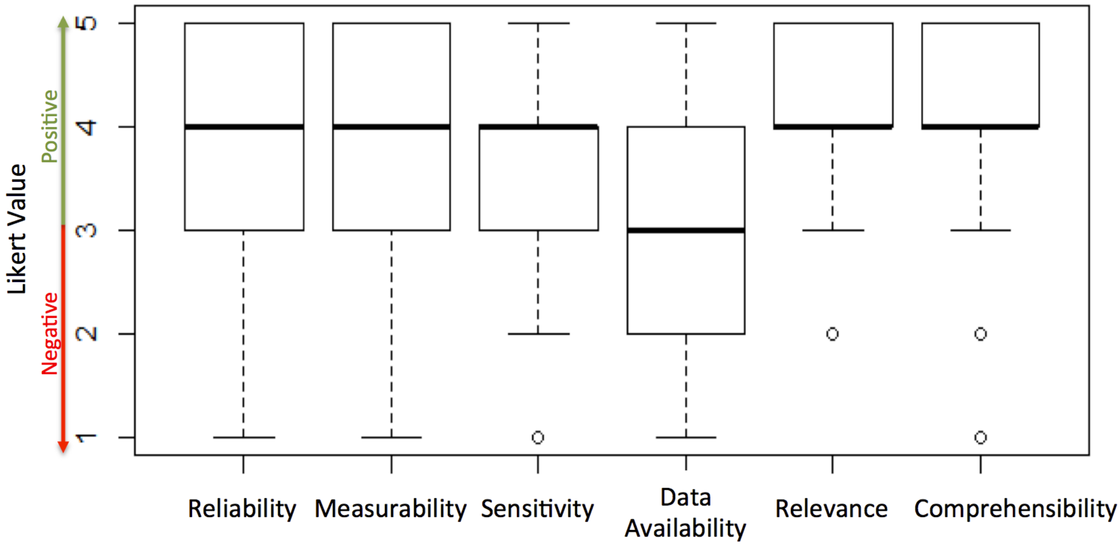

Figure 6.1 – Tukey Boxplots of the Criteria (combined results).

Boxplot of the Indicators

All indicators presented a median of 4, showing that, overall, the appraisers agree that the indicators fulfilled the criteria (Figure 6.2). All boxes range from 3 to 5, meaning that positive answers were predominant.

All indicators received at least one grade 1. In the cases of WPI and CVI, this grade was only reached by outliers and for the other indicators represented the lower extreme. This points to the diversity of results, but a low frequency of negative answers.

Six indicators (WRI, RWSI, INSWU, SEID, TWSC and PUPLS) presented similar boxplots, covering the whole grade range (from 1 for their low extreme to 5 for their upper hinge and extreme). These indicators presented asymmetry, with clear tendencies toward positive answers (grades 4 and 5), signalling decision by the appraisers regarding their fulfilment of the criteria.

The other two indicators, WPI and CVI, each showed symmetry in relation to its extreme values but with asymmetry in relation to its quartiles. Their 3rd quartiles are equal to the median (4), meaning that they received less grades of 5 than the other indicators. However, their whiskers only reach a grade of 2, thus fewer appraisers disagreed with the validation of these indicators.

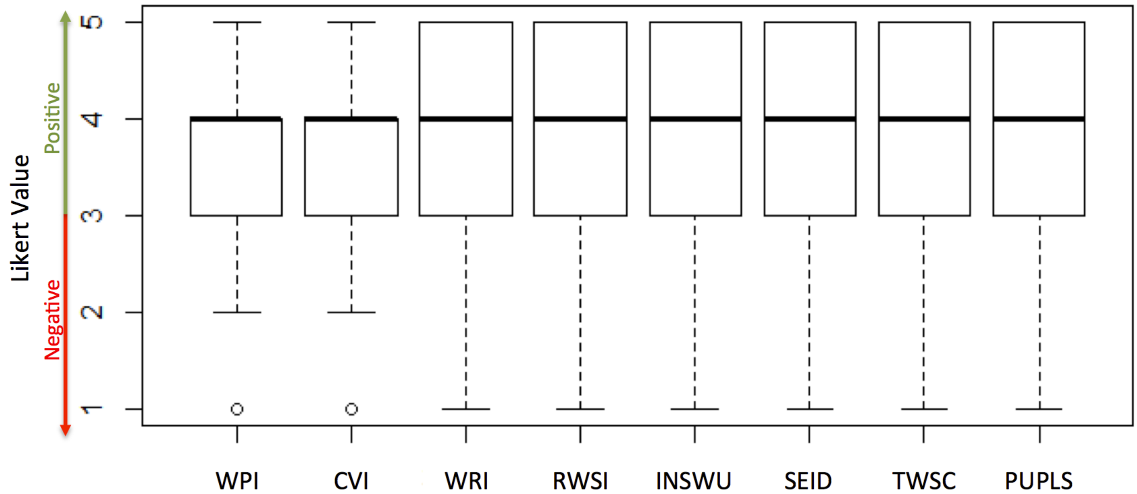

Figure 6.2 – Tukey Boxplots of the Indicators (combined results).

Frequency distribution: Scientific Criteria

All Indicators assessed by this study presented positive responses for all three scientific criteria (Figure 6.3). The most frequent grade was 4, showing that appraisers agree with the scientific validation of the indicators.

Besides these overall positive results, **Sensitivity** presented the lowest number of positive results out of the three scientific criteria. Furthermore, several indicators received a significant number of results under grade 3 for this criterion; for example 38% of WPI and 35% of WRI.

RWSI, INSWU and TWSC presented the **best results** of all the indicators. TWSC had an outstanding performance under the criteria Measurability and Reliability: respectively, 53% and 40% of the appraisers strongly agree that TWSC fulfils these criteria.

SEID and PUPLS presented the **lowest grades** for the scientific criteria. SEID received a significant number of grades of 3, especially under Measurability and Sensitivity (equally 43% for both), indicating that several members of the scientific panel were not sure if the indicators fulfil these criteria. On the other hand, PUPLS received a significant number of grades of 5 for the Reliability and Measurability criteria (38% and 25% respectively). Furthermore, PUPLS, together with WPI, were the only indicators to present results of grade 1 for all three scientific criteria. Nevertheless, these results were only given by a very small amount of appraisers (less then 5%).

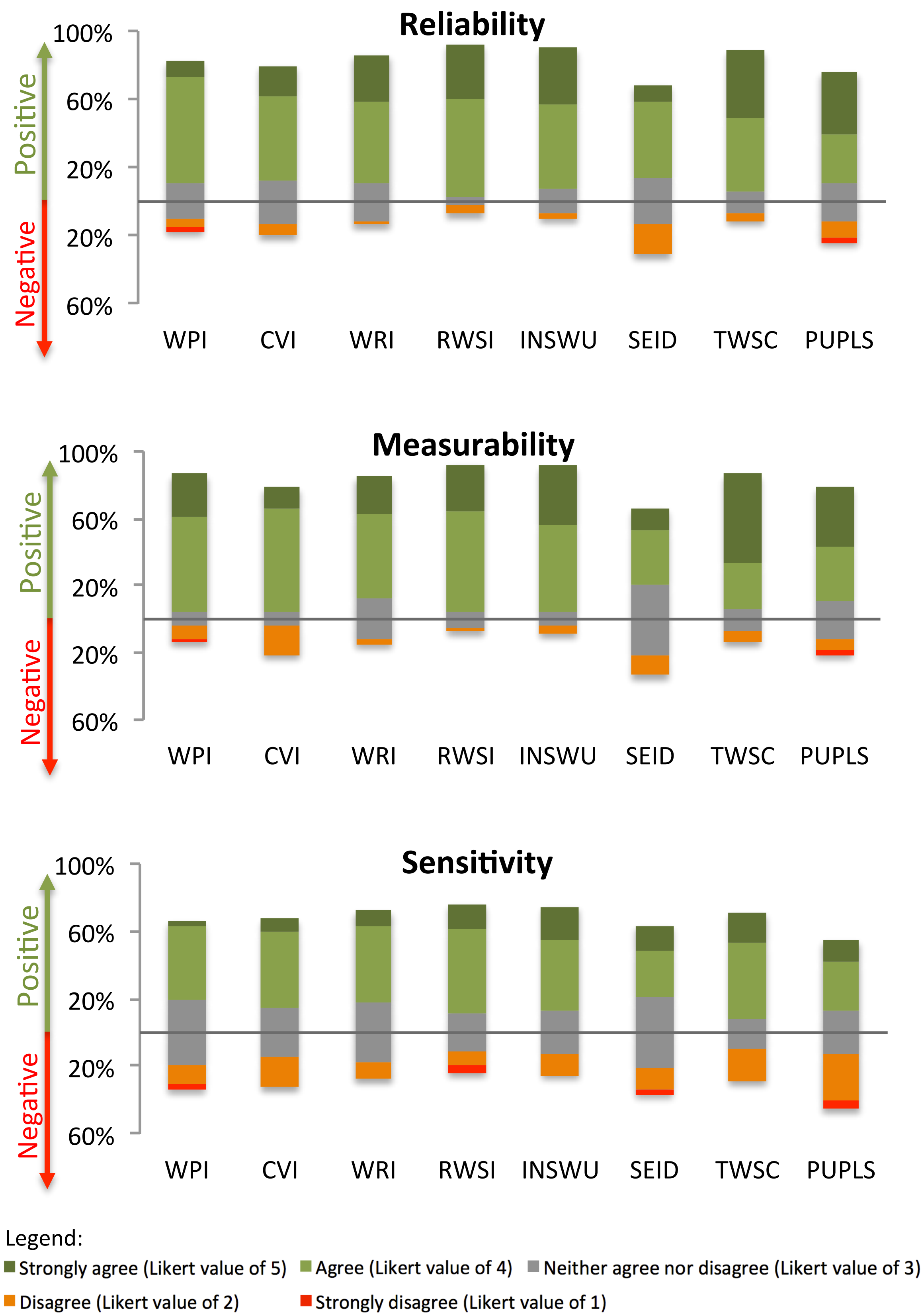

Figure 6.3 – Diverging Stacked Bar Charts of the results for the Scientific Criteria.

Frequency distribution: End-use Criteria

The Relevance and Comprehensibility criteria were valid for all indicators (Figure 6.4) and received the highest overall scores of the six criteria assessed by this study.

Of all the six criteria, **Relevance** presented the best results. No indicator received grade 1 under this criteria and the indicators WRI, RWSI and INSWU showed no negative results at all, demonstrating that appraisers considered them to be very important indicators.

The criterion **Comprehensibility** also received a majority of positive results. SEID was the indicator that was easiest to be understood –90% of grades 4 and 5. Nevertheless, CVI, WRI, RWSI and TWSC were the indicators that had at least 10% of the appraisers grading 1 or 2 for this criterion, signing that the majority of appraisers had a good comprehensibility of these indicators, but some end users could not fully understand these four indicators.

Data Availability had the worst evaluation of the six criteria assessed by this research. Six of the eight indicators showed negative trends under this criterion. Just SEID and PUPLS presented positive responses (55% of grade 4 and 5 for SEID and 60% for PUPLS).

When looking at the **performance of particular indicators**, SEID and PUPLS were the indicators with the highest scores, not only for the criterion Data Availability (as mentioned above), but also for the criterion Comprehensibility (no appraisers at all gave negative scores for SEID and just one end user gave a grade 2 for PUPLS). However, RWSI and TWSC showed slightly lower grades than the other indicators for the three end-use criteria. TWSC, when evaluated under Data Availability, clearly presented the highest number of negative responses of the results of this study (half of the appraisers gave it a grade of 1 or 2).

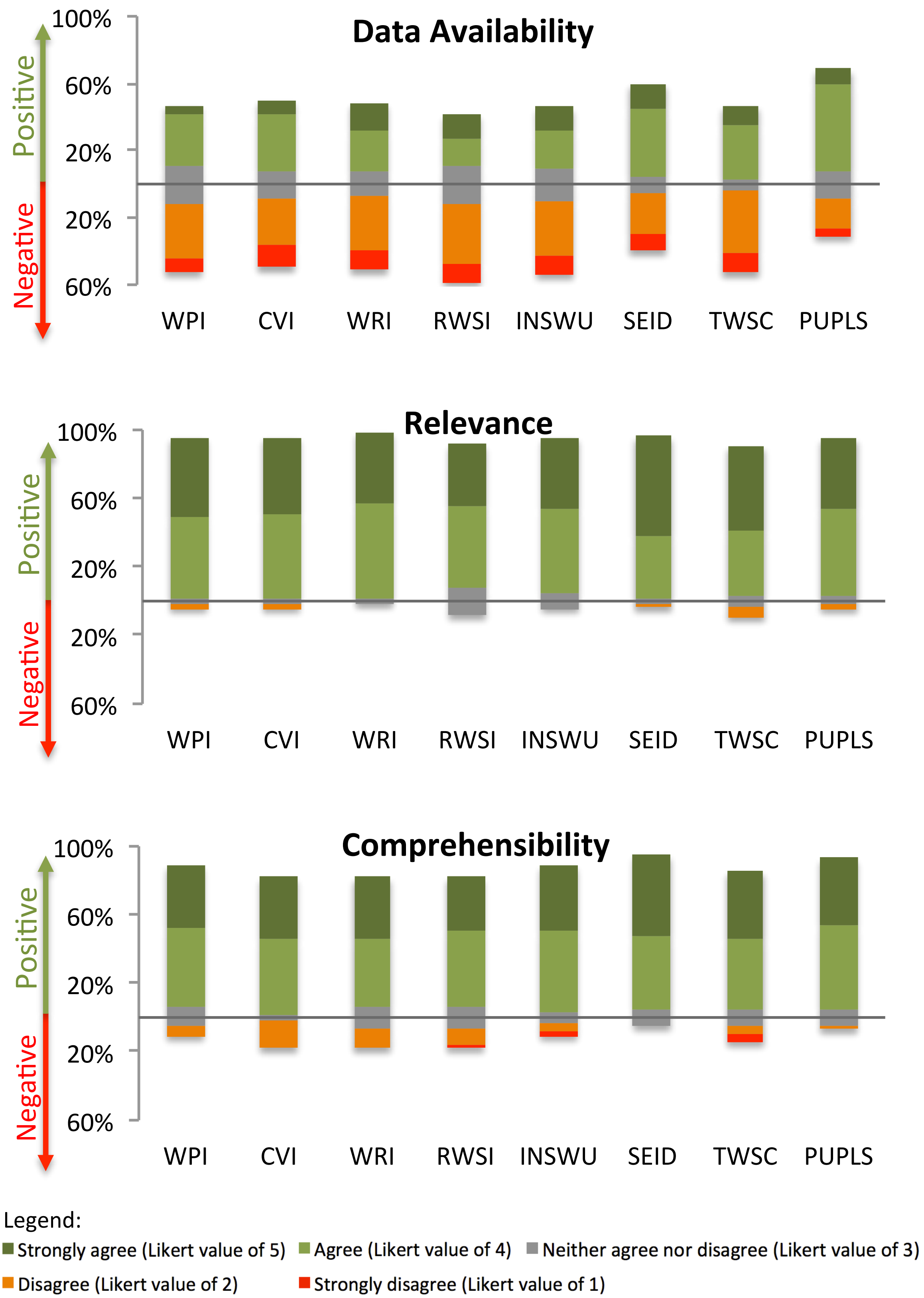

Figure 6.4 – Diverging Stacked Bar Charts of the results for the End-use Criteria.

Validation Matrix

Thirty-eight assessments out of 48 done by this study considered the indicator valid for the criterion under consideration (Table 6.6). Six assessments pointed to the need for thorough reviews, all of them related to the criterion Data Availability. Four evaluations indicated a need for brief reviews, three of them for the criterion Sensitivity and one for Measurability.

All indicators were validated regarding their Reliability, Relevance and Comprehensibility. The indicators performed better under the scientific criteria: no one needed thorough review nor was unacceptable. Measurability was a valid criterion for all indicators, except SEID, which needs a brief review regarding this criterion. Sensitivity was the scientific criterion that needs the most attention: the validation assessment showed that three of the eight indicators need brief reviews. Data Availability was perceived by the end users panel as being problematic for the majority of the indicators. There was a clear tendency toward negative answers for six of the eight indicators under Data Availability, pointing to their need for thorough reviews related to this criterion.

Table 6.6 – Validation Matrix presenting the result of the assessment.

		Indicators							
		WPI	CVI	WRI	RWSI	INSWU	SEID	TWSC	PUPLS
Scientific Criteria	Reliability	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid
	Measurability	Valid	Valid	Valid	Valid	Valid	Needs brief review	Valid	Valid
	Sensitivity	Needs brief review	Valid	Valid	Valid	Valid	Needs brief review	Valid	Needs brief review
End use Criteria	Data Availability	Needs thorough review	Needs thorough review	Needs thorough review	Needs thorough review	Needs thorough review	Valid	Needs thorough review	Valid
	Relevance	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid
	Comprehensibility	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid

In an overall analysis, all eight indicators assessed by this research can be considered valid based on the scientific and end user criteria. All of the indicators are valid for the majority of the criteria evaluated by this research, nevertheless, all of them need to be reviewed regarding one or two criteria, as listed below:

- WPI needs a brief review related to its sensitivity and a thorough review related to data availability issues.
- CVI, WRI, RWSI, INSWU and TWSC need thorough review related to the Data Availability criterion.
- SEID needs brief reviews for two scientific criteria: Measurability and Sensitivity
- PUPLS needs a brief review regarding its sensitivity.

6.4 DISCUSSION

6.4.1 Likert Scale

The results obtained in the validation process and the feedback provided by the appraisers demonstrated that use of the Likert scale simplified the process of constructing and administering surveys, as well as coding and analysis of data. The Likert scale is one of the most widely used scales in survey research for a number of reasons (Hodge & Gillespie, 2003). As noticed by this research, the scale is easy to construct, intuitive to use and adaptable. Its use in surveys allows researchers to collect large amounts of data relatively easily, and the numbered scale format lends itself directly to statistical analysis (Li, 2013). We therefore recommend the use of this scale to measure observable attributes in survey research.

Nevertheless, there are a couple of issues that deserves to be brought to attention:

1) there is an on-going debate among the scientific community about whether a Likert scale is ordinal or interval (Norman, 2010; Jamieson, 2004; Harwell & Gatti, 2001; Clason & Dormody, 1984);
2) its close response format limits appraisers to make a selection from the listed options that may not represent their precise answers (Li, 2013; Russell & Bobko, 1992).

Therefore our research recommends that further studies could test the Fuzzy Likert Scale proposed by Li (2013). According to him *"the major contribution of the fuzzy Likert approach is that it permits partial agreement of a scale point"*, resulting in a promising way to overcome both issues presented above.

Last but not least, it is worth mentioning that Likert scales may be subject to distortion such as central tendency bias and acquiescence bias. Central tendency, or mid-point, bias is the tendency of respondents to avoid using extreme response categories (Furnham & Henderson, 1982). The results of this research indicated that appraisers clearly stated their preference and none of the assessments displayed central bias. Acquiescence bias, or "yea-saying" as it is sometimes referred to, is the tendency of respondents to agree with a statement as written without regard to its content (Furnham, 1986), a phenomenon *"most pronounced with Likert-based scales containing only positively worded items"* (Friborg, Martinussen & Rosenvinge, 2006). To combat acquiescence bias, the questionnaire used in this study employed balanced keying (an equal number of positive and negative statements). According to several authors (Watson, 1992; Hodge & Gillespie, 2003), this can obviate the problem of acquiescence bias, since acquiescence on positively keyed items will balance acquiescence on negatively keyed items.

6.4.2 Validation Assessment – Part 1: the indicators

The ultimate purpose of this last stage of the research was to analyse whether the eight indicators selected in the previous stages of this study were valid for end user application or not. In order to reach this objective, a multistage and multistakeholder process was used. Findings of the current study support that all eight indicators assessed can be considered valid based on the scientific and end-use criteria adopted by this research. Nevertheless, all of them require a review regarding one or two criteria. Below, you can find discussions about each indicator including suggestions of reviews proposed by this research.

Water Poverty Index (WPI) and Climate Vulnerability Index (CVI)

Both indicators were devised in the last decade by Dr Sullivan of the Centre for Ecology and Hydrology - UK (Sullivan, 2001; Sullivan and Meigh, 2005). They are indexes derived from the weighted average of several components. WPI evaluates five strategic components: water resources available, access to water, how effectively water is used, capacity to manage water and environmental impacts (Sullivan et al., 2003). CVI considers six components: five that are similar to WPI (resource, access, uses, capacity and environment) plus the geographical vulnerability of the location. The CVI can be considered an extension of WPI that includes geographical aspects specific to the site under consideration, related to climate and global change (Sullivan & Huntingford, 2009).

The validation assessment pointed a need to review both indicators regarding the Data Availability criterion. Nevertheless, WPI and CVI are based on a rational framework, where the final user can select the data that will be deployed to calculate each component (see their IPS at Annex 6.1). This flexibility allows the use of the indicators in situations where certain data may be limited or lacking; in this event, estimates or proxy data can be used (Sullivan et al., 2003; Pandey & Jha, 2012). One way or another, however, data is necessary to compute each of their components. Based on the open and transparent framework adopted by these indicators, the end users should carefully select the data they will deploy to compute the WPI or CVI (Sullivan & Huntingford, 2009; Sullivan & Meigh, 2007). Regarding this WWAP (2012) stresses that *"for the purposes of any comparison of areas (i.e. river basin) or track progress over time in the same area, the data used for the assessment must be the same"*.

The validation assessment also indicated that WPI needs a brief review regarding the Sensitivity criterion. This result points to a need to improve the indicator's ability to better reflect small changes in the factor measured. This limitation regarding its sensitivity can be understood by the nature of the indicator: it is a composite indicator, where five components are aggregated into a single index. According to Sullivan et al. (2002), the simplicity of the results – a single number can be used to represent the situation at a particular location – means it has appeal for policy-makers. At the same time, however, a change of one component (for example, an increase in the "capacity component") can be hidden in the final result by some other change in another component (for example, a reduction in the "resource component").

It is worth noting that CVI is also a composite indicator, where six components (one more then the WPI) are aggregated into a single index. Nevertheless, the assessment indicated that CVI is valid under the sensitivity criteria. This result can be considered unexpected and requires further investigation. Looking at Figure 6.3, one can see that the behaviour of WPI for the sensitivity criteria is only slightly inferior to CVI.

WPI received 48% positive responses, 38% neutral answers and just 15% of negative ones; CVI obtained 53% of positive, 30% of neutral and 18% of negative responses. Still, this small difference was enough to classify WPI under the category of "a brief review is required" and leave CVI under the category "validated" (see Table 6.4).

The findings presented in this study showed that the Relevance of WPI and CVI are similar, and WPI is slightly easier to be understood (Comprehensibility criterion) by end users, in comparison with CVI (Figure 6.4). Further studies can explore in detail the main advantages and limitations for the end users of applying both WPI and CVI, especially for river basins with water scarcity and high vulnerability.

It is also worth mentioning that composite indicators, such as WPI or CVI, could be susceptible to some level of misinterpretation due to the aggregation of various sub-components to form the indicator. Aggregating a number of sub-components to one indicator includes among other activities the definition of weights and the transformation of the sub-components into dimensionless measures that can be combined. In order to avoid problems of misinterpretation, WWAP (2003) recommends that *"a clear description of the subjective elements in the indicators should be given, such as the reference condition, the measuring rod, the weighting factors and the aggregation method".*

Water Reuse Index (WRI), Relative Water Stress Index (RWSI) and Index of Non-sustainable Water Use (INSWU)

These three indicators were devised by the same institution (Water Systems Analysis Group of the University of New Hampshire) and use the same row data, but each is computed in a different way (see their IPS at Annex 6.1). They address the sustainability of use of water, considering the domestic, agricultural and industry demand in comparison to available water supplies in a given region. The data used for their computation is generally based on estimates of water demand / supply. Nevertheless, the validation assessment showed that they need thorough review related to the Data Availability criterion.

This finding indicates that data about the volume of water available and how much water is needed for domestic use, agriculture and industry is not easily available at river basin level (in this case the Salitre River). These data are crucial for water resources management and should be gathered / estimated by the river basin management institutions. The use of estimation to measure demand /supply is accepted but does not transmit the level of confidence necessary to generate major decision and changes. These estimates can be improved by using water demand statistics and hydro-meteorological data, but there is a cost associated with these (WWAP, 2006).

WRI, RWSI and INSWU showed outstanding results for the three scientific criteria assessed by this study (see Figure 6.3) and were the only indicators among the whole set to show all positive or neutral results (no negative answers at all) in the Relevance criteria. These findings point to the importance and the scientific credibility of these indicators. Nevertheless, end users considered that WRI and RWSI are not as easily understood as INSWU (see Figure 6.4) – over 10% of appraisers grading them gave negative responses for the Comprehensibility criterion.

Social and Economic Impacts from Drought (SEID) and Proportion of Urban Population Living in Slums (PUPLS)

The SEID and PUPLS indicators, on the one hand, had the best performance within the end-use criteria, but on the other hand, showed the worst results in the scientific criteria. As a matter of a fact, SEID and PUPLS scored less than all other indicators for all three scientific criteria. However, they were the only indicators to fulfil the Data Availability criterion. Furthermore, these indicators were considered by the appraisers to be the easiest to understand (highest scores under the Comprehensibility criterion).

SEID has been used for a long time to inform decision makers and the general public about the impacts of drought (Ding et al., 2010). Several valid methodologies for its computation are available in the literature (i.e. Low, 2013; Jenkins, 2011). The final user should select the methodology most suitable for the local situation, based on the information available, which impacts are more relevant, and other aspects. An interdisciplinary approach is needed for the quantitative measurement of social and economic impacts from droughts, including even the loss of ecosystem and biodiversity. Economists, sociologists, meteorologists, biologists, hydrologists and water managers must work together to obtain comprehensive assessments (Ding et al, 2010). The lack of a standardized methodology for its computation and the complexity of measuring social-economic impacts seem to be among the reasons why 43% of appraisers were unsure (grade 3 on Likert scale) whether SEID fulfils the Measurability criterion. The validation assessment recommended a brief review of SEID for the Measurability criterion as well as for the Sensitivity criterion. This research recommends the development of studies aiming to further explore the advantages and disadvantages, as well as the possibilities for and the limitations, of adopting a standardized methodology for the measurement of the social and economic impacts from drought.

The validation assessment also indicated that PUPLS needs a brief review regarding the Sensitivity criterion. According to WWAP (2012), PUPLS measures the proportion of population **lacking at least one** of the following five housing conditions: access to improved water; access to improved sanitation facilities; sufficient living area; structural quality; and security of tenure. PUPLS was developed as part of the UN Millenium Development Goals as a *"key indicator measuring the adequacy of the basic human need for shelter"* (UN HABITAT, 2009). The purpose of the indicator is to identify the presence of households in slums in order to provoke action to address the principal problems faced by slum dwellers. The developers, however, recognized the inherent balancing act between effectiveness and sensitivity of the indicator. Its computation method generates a reduction in its sensitivity, because it considers that the situation of one of the five housing conditions is required to calculate the indicator independent of the state of the other four conditions. For example, if the qualifying condition is satisfactory for all categories except one, the indicators will present the same results as if all five conditions were not satisfied.

While PUPLS is useful for its ability to clearly and simply communicate the presence of slums with readily available data, it cannot speak to the severity and spatial extent of slum conditions (WWAP, 2012). Therefore, it is clear that the sensitivity of the indicator could be improved. This study recommends further investigation into alternatives to overcome this limitation. One option could be to adjust the computation method in order to convert PUPLS into a composite indicator that considers the proportion of the population that satisfies each of the five original housing qualifying conditions.

Currently, the international community is building the Sustainable Development Goals (SDGs), the post-2015 development agenda for the world (UN, 2014). One of the proposed goals is to "*Make cities and human settlements inclusive, safe, resilient and sustainable*". This could be an interesting opportunity to up-grade the indicator aiming to address the problems of sensitivity presented above.

Indicators whose calculations are dependent upon environmental variables, such as those indicators that measure and monitor water resources, are likely to find large gaps in the data due to the challenge, cost and complexity of gathering this type of information (WWAP, 2012). On the other hand, indicators such as PUPLS and SEID require mostly socio-economic data, which is often collected on regular basis using household surveys or censuses (UNU, 2002; WWAP, 2012). The flow of this data may thus be more consistent and less sophisticated to obtain. These facts may be among the reasons that a majority of appraisers considered PUPLS and SEID to be the only indicators that fulfil the data availability criterion.

Total Water Storage Capacity (TWSC)

TWSC scored high grades on the scientific criteria but presented somewhat low results for end-use criteria, in comparison with the other indicators. TWSC had the best performance in relation to the criterion Measurability, reaching a median of 5 and also presented an outstanding result under the criterion Reliability: 40% of the appraisers strongly agreed (grade 5 of Likert scale) that the TWSC fulfils this criterion. But under the criterion Data Availability this indicator obtained the lowest median of all: just 2.5. The validation assessment recommends a thorough review for TWSC under this criterion.

When analysing the issue of data availability it is relevant to look at the definition of the TWSC indicator: *"total cumulative water storage capacity of all large surface reservoirs and groundwater, in a given area"* (adapted from Cap-Net UNDP, 2008; UN, 2009). According to UN (2010), data on large surface storage is usually available. The International Commission on Large Dams (ICOLD) gathers data on large surface reservoirs at global level. But less often can one find information gathered on small and middle storages (UN, 2010). The groundwater storage capacity depends on very specific hydro-geological features and good historical information that usually is not available at a detailed enough scale to provide consistent data (Brutsaert, Crosbie, & Potter, 2014; Vouillamoz, Lawson, Yalo & Descloitres, 2015; Zhang,).

TWSC is widely used for water management planning and operation (WWAP, 2012). However, TWSC is only one of the elements for water management that links hydraulic infrastructure and human vulnerability: it is necessary to consider other issues such as accessibility (water distribution and rights), multiples uses, among other aspects. The operation of the reservoir and its maintenance are also key issues that are not addressed by TWSC. The end user should also take note that there are alternative ways to communicate the results of this indicator, including: a) as a percentage (%) comparing the level of water available at reservoirs at a particular date with the total water storage capacity or, b) as per capita water storage capacity (i.e. m^3 per person) considering the population supplied by those reservoirs. In consequence, the results clearly indicate that TWSC is relevant, measurable and reliable

6.4.3 Validation Assessment – Part 2: the criteria

Based on the assessment carried out by this research, the criteria of Reliability, Relevance and Comprehensibility have been validated for all indicators. This shows that all of the indicators are consistent, important and easily understood. Measurability and Sensitivity are also features of the majority of the indicators, nevertheless briefs reviews were recommended for a few of them (WPI, SEID and PUPLS - look previous section). This study showed that Data Availability was the criterion that deserves the most attention among the six criteria adopted by this research (this criterion had the worst overall performance of the assessment).

Data availability

Data availability was considered to be the most relevant criterion, according to the sources analysed by this study (as detailed in chapter 3). It was mentioned by 31 different publications and its inclusion as one of the validation criteria is crucial, mainly because if data is not available it is likely that the indicators will not be used. The accurate calculation of indicators requires the availability of regular and reliable data sources. Data availability was the most problematic criterion for the indicators outlined in this study. However, this issue goes far beyond the boundaries of this research.

The past 10-15 years have seen significant losses of hydrological monitoring networks at a global level, deteriorating the quality and availability of water resources data (Shiklomanov, Lammers, & Vörösmarty, 2002; UN, 2010). While indicators are important to successful management of water resources, UN (2009) consider that the primary challenge facing water management is "…*the systematic generation of a set of core data items that will allow a wide range of such indicators to be calculated to meet the many different needs of the potential audiences."*

Where actual data is lacking, indirect measures and imputation from available data are sometimes used to fill in the gaps. While practically useful, these can be unsatisfactory because of the inherent assumptions made about the data, which may be unjustified at times. Even where data is available, that information may be either unreliable or out of date (UN, 2009). These problems relate to data quality. According to several authors (Cloquell-Ballester et al., 2006; FAO, 1999; OECD, 2003; Segnestam, 2002; US EPA, 2000; World Bank, 2000;), "data quality" is another important criterion with which indicators should comply. This criterion was not assessed explicitly in this research, but it is tied to the issue of data availability. The management of water resources requires reliable, regular and systematic data monitoring and reporting.

It is worthy to mention that remote sensing, or the extraction of information from satellite images, is a promising and under-utilized approach to address these issues of data availability. Often, satellite images are collected routinely for different purposes, and could be used to fill in information gaps. Van Eekelen et al. (2015) looked at the possibility of using satellite images to monitor direct and indirect water withdrawals and found that remotely sensed measurements have the potential to be used more widely in cases where basins lack sufficient available data. This independently collected information may also be viewed as more transparent and reliable (Van Eekelen et al., 2015). However, WWAP (2012) note that the collection of "ground truth," or field information, data would still be necessary to increase the accuracy and reliability of the remotely sensed data.

6.4.4 Further discussions

The multistakeholder validation process adopted by this research clearly shows that the development and validation of indicators is not solely the insular work of scientists and experts. Today there is greater recognition of the participation of end-users *"as being complementary to traditional scientific knowledge"* (Bélanger et al., 2012). Water management in a river basin is a complex issue, involving many stakeholders and competing uses of water. If not addressed, competing motivations can detract from the success of a water management plan. By engaging in consistent and productive contact with the stakeholders of the Salitre River Basin, the selection and validation of the indicator set can better reflect the real needs of the individuals who bear the consequences of the decision-making.

Indicators are, ultimately, a communicative tool, whose development and validation should involve collaboration between experts and end users, facilitated by the researcher (Thivierge et al., 2014). The use of multiple, complementary stages also contributed to the success of this approach.

The utilization of a pilot validation test was a relevant stage of research prior to engaging in the full study. As mentioned by Van Teijlingen & Hundley (2001), some methodological issues may only become clear when put into practice. The pilot validation test provided an invaluable opportunity to assess the methodology and to identify and make necessary changes prior to implementing the full-scale study. The methodology and data analysis were largely approved through this exercise. Participants provided feedback on the evaluation matrix and scientific validation methodology, leading to a decrease in the number of criteria and improvements in the design of the questionnaire materials. Communication with the River Basin Committee president and survey experts also served to approve the end-use methodology and improve the clarity and design of the survey for the end-user panel questionnaire. This research recommends the use of pilot tests in studies of this nature.

It is worthy to mention that several criteria were assessed by previous stages of the research:

- Chapter 3 presents the evaluation of 170 indicators under the sustainability criterion, considering the underlying social, economic, institutional and environmental systems*;*
- Chapter 4 addresses the assessments of the indicators based on three criteria: "scientific foundation", "individuality", "spatial scale" and "specificity";
- Chapter 5 was where the criterion "causal links" was evaluated using eDPSIR as the framework to identify the cause-effect chain of the selected indicators.

The eight indicators short-listed by this study fulfil not only the six criteria assessed in this stage of the research, but also the six criteria mention above (sustainability, scientific foundation, individuality, spatial scale, specificity and causal links). Further studies could continue this in-depth assessment of these eight indicators by evaluating their performance under other criteria.

It is recommended that the development and validation of an indicator set go beyond theoretical calculations, to take into consideration an actual river basin. What works for one river basin will not necessarily apply directly to another because indicators depend on context, purpose, and scale (GWP & INBO, 2009). Developing indicator sets using only a theoretical approach excludes the potentially valuable contribution of stakeholders, and ignores the situational realities of a specific location. This highlights the relevance of working with river basin organizations and managers during the development and validation of indicators.

Based on the positive results obtained by the validation assessment, this study recommends the application of the eight indicators (WPI, CVI, WRI, RWSI, INSWU, SEID, TWSC and PUPLS) at the Salitre river basin. These eight indicators have been validated by a scientific panel and by the major stakeholders of the Salitre river basin, demonstrating that they are adequate for this river basin.

Further studies could calculate the actual value of the indicators for the Salitre basin and investigate in greater detail, the issues of data availability and quality at the local level. The selected indicators could be integrated into the next update of the Salitre river basin Water Management Plan and into the Water Management Information System as key indicators for the basin. They could also be used by the water management authority to support their decisions related to the concessions of water permits, aiming for sustainable use of water.

In order to feed the real needs and ideas of stakeholders into the validation process of this indicator set, it was important to engage with the end-users from the Salitre river basin. In doing so, however, the specific results of the end use validation are considered limited to that the Salitre basin, and cannot be directly extrapolated or generalized to all river basins. The particular geographical, social, economic and environmental issues of the Salitre basin affect the response of stakeholders towards indicators for assessing the sustainability of water use. Different water use constraints at a different river basin could result in the selection or validation of different indicators.

Future studies might investigate how these indicators perform when assessed using the same criteria, but by other end users, i.e. at a different river basin. The replication of this validation assessment in different river basins 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 from different river basins and, by doing so, broaden the scope of this current study. Last but not least, the assessment of the scientific criteria done by this study focused on experts from Ibero-american countries; therefore it would be desirable to perform a broader evaluation including experts from other parts of the world.

6.5 CONCLUSIONS

Indicators are key tools that help the society to monitor progress and trends on the path towards the sustainable use and management of water natural resources. Validation of indicators is an essential step in the identification of an accurate and credible indicator set. The adoption of both scientific and end user perspectives is very important in the validation process. The criteria used by these groups to evaluate indicators should reflect these two perspectives.

This chapter demonstrates the importance of a multicriteria, multistakeholder process for validating indicators for sustainable water use and management. These indicators were evaluated against a set of well-defined and balanced criteria to assess the validity of their design and applicability for a specific river basin. The use of a pilot validation test is recommended by this study as an important tool to test validation methodology before full implementation of the study. Methodology and materials were better adapted for participant use as a result of the pilot validation test. Transparent and replicable methods were used, which resulted in the validation of all eight indicators of interest for the sustainable use and management of water resources.

The management and sustainable allocation of water resources is a complex issue. The balance of scientific and end-use criteria employed in this research mirrors the recognition of a balance role of experts and stakeholders in indicator validation, and solutions for sustainable resource management. Expert opinion helps to ensure that an indicator measures the intended variables, and does so accurately. Their involvement increases the credibility of an indicator among the scientific community. However, validation that ignores the stakeholder and focuses only on scientific accuracy and credibility excludes a valuable resource from the process. Indicators are a tool for not just measurement, but communication also, in the hopes that effective communication will spur action. An indicator is only effective if it is both useful, and used by stakeholders, so it is important to understand end user needs and perspectives.

The results of the end use assessment outlined in this chapter are specific to the Salitre river basin, and cannot be directly generalized beyond this territory. What is more, experts who participated in the study are from the Ibero-american region. Future studies may involve the use of a more global panel, or compare the perspectives with panels from different regions. Studies that use this methodology for other rivers, or using further criteria could act to expand the applicability of the results obtained by this study.

The 8 indicators evaluated by this research have been shown to be appropriate tools to address the complex set of water resource issues faced at the river basin level. This indicator set may be used to assess the state of river basin management and use and inform decision-making that strives for greater sustainability. One way to do this would be by incorporating the indicators directly into river management plans. This research has also shown that the involvement of both scientific and stakeholder perspectives addresses the two key concepts of accuracy and usability, and is a successful approach to the validation of indicators.

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6.7 ANNEXES - INDICATOR PROFILE SHEETS (IPSS) – 8 INDICATORS

Water Poverty Index (WPI)

Climate Vulnerability Index (CVI)

Water Reuse Index (WRI)

Relative Water Stress Index (RWSI)

Index of Non-sustainable Water Use (INSWU)

Social and Economic Impacts from Drought (SEID);

Total Water Storage Capacity (TWSC)

Proportion of Urban Population Living in Slums (PUPLS)

Indicator Profile Sheet

<table>
<tr><th></th><th>Water Poverty Index (WPI)</th><th>Climate Vulnerability Index (CVI)</th></tr>
<tr><td>Definition</td><td>Integrates physical, social, economic and environmental factors, and links water and poverty issues.

Evaluates 5 strategic components: water resources available, access to water, how effectively water is used, capacity to manage water and environmental impacts.

Source: Sullivan et al, 2002.</td><td>Draws together data from the bio-physical, economic and social sciences (similar to WPI), but, in this case, combines them in order to make a holistic assessment of human vulnerability in the context of climate and global threats to water resources.

It considers 6 aspects: 5 are the same as WPI (resource, access, uses, capacity and environment) plus the geographical vulnerability of the location.

Source: adapted from WWAP (2006), WWAP (2012) and Sullivan & Huntingford (2009).</td></tr>
<tr><td>Underlying definitions and concepts</td><td>Water poverty is not only measured by the availability of water in a given location. Other components should be taken in consideration to assess if an area is rich or poor in relation to its water resources (i.e access, use, capacity, environmental impacts). The WPI is mainly designed to help improve the situation for populations facing poor water endowments and poor adaptive capacity.</td><td>The CVI does not consider all aspects of vulnerability, but it focuses on water, since water is a key component of all life and an essential element in all people's livelihoods (Sullivan & Huntingford, 2009).

It is a multidimensional vulnerability assessment acting as a "tool to identify which human communities are the most vulnerable to the combined impacts of climate and global change." (WWAP, 2012)</td></tr>
<tr><td rowspan="2">Computation</td><td>The WPI is derived from the weighted average of five components: Resource (R), Access (A), Capacity (C), Use (U) and Environment (E),

$$WPI = \frac{w_r R + w_a A + w_u U + w_c C + w_e E}{w_r + w_a + w_u + w_c + w_e}$$

where WPI is the Water Poverty Index value for a particular location and w is the weight applied to each component.

Source: Sullivan & Lawrence, 2006</td><td>The CVI is derived from the weighted average of six components: Resource (R), Access (A), Capacity (C), Use (U), Environment (E) and Geospatial variability (G),

$$CVI = \frac{w_r R + w_a A + w_u U + w_c C + w_e E + w_g G}{w_r + w_a + w_u + w_c + w_e + w_g}$$

where CVI is the Climate Vulnerability Index value for a particular location and w is the weight applied to each component.

Source: WWAP, 2012</td></tr>
<tr><td colspan="2">The components of both indicators (WPI and CVI) are standardized to fall in the range 0-100. Each component is computed as a composite index itself, constructed by a selection of sub-components, which can be identified on the basis of available data. The components are weighted according to their estimated importance (WWAP, 2006 and WAAP, 2012).</td></tr>
<tr><td>Unit of expression(s)</td><td colspan="2">Dimensionless (0-100 or 0-1)</td></tr>
<tr><td>Who devised the indicator</td><td colspan="2">Both indicators were devised by Dr. C. Sullivan, Center for Ecology and Hydrology – UK.</td></tr>
<tr><td>Main difference between WPI and CVI</td><td colspan="2">The main difference between WPI and CVI is the component geospatial vulnerability (G), used in the computation of the CVI, but not considered by the WPI. The G component addresses the geographical vulnerability of the location under analysis. The CVI is an extension of WPI, including geographical aspects specific to the site under consideration related to climate and global change. CVI also introduces the possibility to assess both current conditions and future scenarios.</td></tr>
</table>

<table>
<tr><td>Specification of determinants and data needed</td><td colspan="2">

Both, WPI and CVI, use the 5 components below:

Resources (R)– how much water is available, taking into account seasonal and inter-annual variability and water quality, both from all sources including surface and groundwater. Example of sub-components: total or per capita amount of water available, estimated water storage capacity, qualitative or quantitative assessment of water quality, etc.

Access (A) – how well provisioned the population is, including accessibility, property rights and ease of access for domestic use, irrigation and industry. Example of sub-components: access to clean water as percentage of household, access to sanitation as percentage of population, time spent on water collection, access to irrigation coverage, etc.

Use (U) – how effectively water is used, capturing its contribution to generating economic benefits. Example of sub-components: domestic water consumption rate, economic return related to water use, agricultural water use expressed as the proportion of different irrigation systems (aiming for efficient techniques), livestock water use based on standard water needs, etc.

Capacity (C) – ability of people and institutions to manage water resources, based on education, health, access to financing and on institutional arrangements in place. Example of of sub-components: IWRM (Integrated Water Resources Management) system in place and operative, educational level of the population, mortality ratio for children under 5 years in the region, total investment in water sector, etc.

Environment (E) – attempts to reflect the degree to which water use in the area has had a negative (or positive) impact on ecological status. Example of sub-components: qualitative or quantitative environment assessment related to water bodies, rate of habitat loss, percentage of protected area coverage, deforestation rates, etc.

CVI has a sixth component:

Geospatial variability (G) - captures the risks a location faces as a result of its geographical location and characteristics in relation to climate and global change. Example of sub-components: climate change risk assessment, desertification rates, erosion rates, drought and flood events, presence of mountainous slopes or low lying coasts, etc.

Adapted from: Sullivan & Lawrence, 2006 and WWAP, 2012

WWAP (2012) comments that *"at the local scale, if data gaps are identified, measures are then to be taken to remedy this, either with proxy data identified, or new data gathered."*

</td></tr>
<tr><td rowspan="2">Complementary information</td><td colspan="2">

Both indicators provide a systematic approach that is open and transparent to all. This approach is a powerful tool for prioritization of needs and/or actions as well as for monitoring progress toward goals. WPI and CVI are based on a rational framework, where the final user can select the data used to calculate each component, and the respective weight of those components. On one hand this allows the use of the indicators in situations where there is limited or even no data available (in this case estimation can be used). On the other hand, WWAP (2012) highlights that *"for the purposes of any comparison of areas (i.e. river basin, countries...) or track progress over time in the same area, the data used for the assessment must be the same"*.

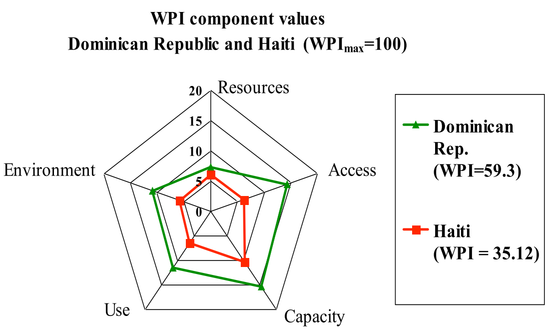
Because of the simplicity of the results – a single number can be used to represent the situation at a particular location – it has appeal for policy-makers. At the same time, the underlying complexities need not be lost. This complexity should be made understandable to policy-makers and stakeholders using graphic representations such as the 'WPI pentagram' (see example below).

Source: Adapted from Sullivan et al, 2002

</td></tr>
<tr><td>WPI was calculated for over 140 countries worldwide. According to WWAP (2012) it is now widely known.</td><td>CVI was classified by WWAP (2012) as a key indicator: *"key indicators are well defined and validated, have global coverage and are linked directly to policy goals".*</td></tr>
<tr><td>DPSIR classification</td><td>Pressure, State, Impact and Response</td><td>Pressure, State, Impact and Response</td></tr>
<tr><td>Sustainability criteria</td><td>Social, Economic, Environmental, Institutional</td><td>Social, Economic, Environmental, Institutional</td></tr>
</table>

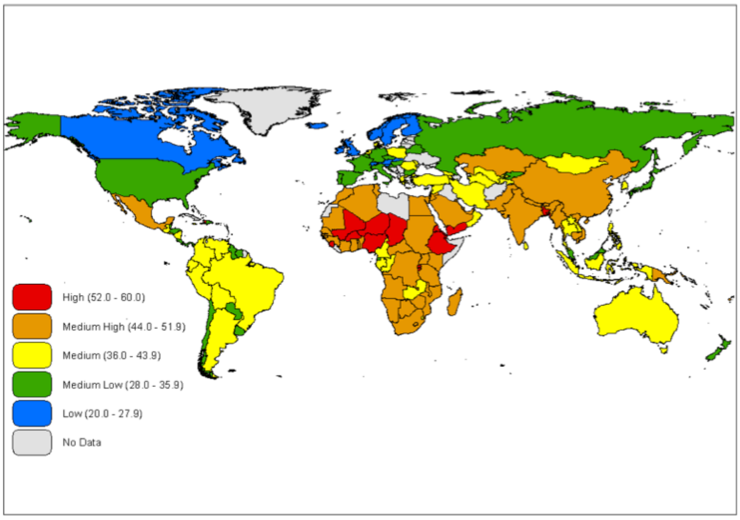
Criteria verified	Scientific foundation, Individuality, River basin scale, Specificity, Reliability, Measurability, Sensitivity (Needs brief review), Data availability (Needs thorough review), Relevance and Comprehensibility	Scientific foundation, Individuality, River basin scale, Specificity, Reliability, Measurability, Sensitivity, Data availability (Needs thorough review), Relevance and Comprehensibility
Function at causal network	Central indicator: are at the core of multiple processes …	Central indicator: are at the core of multiple processes …
Sources of further information	Jemmali, H., & Sullivan, C. a. (2012). Multidimensional Analysis of Water Poverty in MENA Region: An Empirical Comparison with Physical Indicators. *Social Indicators Research*. doi:10.1007/s11205-012-0218-2 Juwana, I., Muttil, N., & Perera, B. J. C. (2012). Indicator-based water sustainability assessment - a review. The Science of the total environment, 438, 357–71. doi:10.1016/j.scitotenv.2012.08.093 Sullivan CA (2001) The potential for calculating a meaningful Water Poverty Index.Water Int 26:471–480 Sullivan, C. (2002). Calculating a Water Poverty Index. World Development, 30(7), 1195–1210. doi:10.1016/S0305-750X(02)00035-9 Sullivan, C. (n.d.). Using the Water Poverty Index to monitor progress in the water sector. Wallingford: CEH Wallingford. Retrieved from http://www.managingforimpact.org/sites/default/files/resource/water_poverty_index.pdf Sullivan, C., Meigh, J. ., & Fediw, T. (2002). *Derivation and Testing of the Water Poverty Index Phase 1. Center for Ecology and Hydrology CEH. Natural …* (Vol. 1, p. 53). Wallingford. Retrieved from http://www.soas.ac.uk/water/publications/papers/file38386.pdf Sullivan, C., Meigh, J., Ecology, C., & Lawrence, P. (2006). Application of the Water Poverty Index at Different Scales: A Cautionary Tale, *31*(3), 412–426.	Sullivan, C., & Huntingford, C. (2009). Water resources, climate change and human vulnerability. *18th World IMACS/MODSIM Congress, …*, (July), 3984–3990. Retrieved from http://www.kmafrica.com/files/sullivan_ca.pdf Sullivan C.A. & Meigh, J.R. (2005) Targeting attention on local vulnerabilities using an integrated indicator approach: the example of the Climate Vulnerability Index. Water Science and Technology, Special Issue on Climate Change Vol 51 No 5 pp 69–78, 30, 1195-1210. WWAP (World Water Assessment Programme). 2006. The United Nations World Water Development Report 2: Water a shared responsibility. Paris, UNESCO WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

Example of "Water Poverty Index" (WPI):



Source: Sullivan & Lawrence, 2006

Example of "Climate Vulnerability index" CVI:



Source: WWAP, 2012

Indicator Profile Sheet

	Water Reuse Index (WRI)	Relative Water Stress Index (RWSI)	Index of Non-sustainable Water Use (INSWU)
Definition	Aggregate upstream water demand/use per available water supply along river network. It measures consecutive water withdrawals for domestic, industrial and agricultural water use along a river network relative to available water supplies. Source: WWAP, 2012	Water demand pressures from the domestic, industrial and agricultural sectors relative to the local water supplies. The Domestic, Industrial and Agricultural water demand are compared with the available water supply in a given area/point. Sources: Vörösmarty et al. 2000 and WWAP, 2012	Renewable freshwater resources (streamflow) minus geospatially distributed human water demand. This indicator provides a measure of the human water demand in excess of natural water supply in a given area/point. Source: WWAP, 2012
Underlying definitions and concepts	Represents the extent to which runoff is recycled or reused as it accumulates and flows toward the basin mouth (Vörösmarty et al 2005). It is a measure of upstream competition for water, its reuse and potential ecosystem and human health impacts (Vörösmarty et al, 2000).	Also known as Relative Water Demand (RWD), it indicates water shortage or abundance in a given region in relation to the water demand (adapted from WWAP, 2012).	Comparison of water demands to renewable water supply, indicating areas where non-sustainable practices may be occurring (WWAP, 2012).
Computation	$WRI = \frac{\sum D + \sum I + \sum A}{Q}$ Where: ΣD = aggregate upstream domestic water demand (km3/year); ΣI = aggregate upstream industrial water demand (km3/year); ΣA = aggregate upstream agricultural water demand (km3/yr); Q = water supply (km3/year) Source: WWAP, 2012	$RWSI = \frac{D + I + A}{Q}$ Where: D = domestic water demand (km3/year); I = industrial water demand (km3/year); A = agricultural water demand (km3/year); Q = water supply (km3/year) Source: WWAP, 2012	$INSWU = Q - (D+I+A)$ Where: D = domestic water demand (km3/year); I = industrial water demand (km3/year); A = agricultural water demand (km3/year); Q = water supply (km3/year) Source: WWAP, 2012
Unit of expression(s)	Dimensionless. It can be expressed as a percentage (0-100) or as an absolute value (0 - ∞).	Dimensionless. It can be expressed as a percentage (0-100) or as an absolute value (0 - ∞).	Volume per time (i.e., cubic kilometres per year)

<table>
<tr><td>Who improved the indicator</td><td colspan="3">Water Systems Analysis Group, University of New Hampshire (UNH) and Environmental CrossRoads Initiative, The City University of New York (CUNY)</td></tr>
<tr><td>Main difference among WRI, RWSI and INSWU</td><td colspan="3">All three indicators use the same variables but they are computed in different ways. They apply the same row data in their computation (D, I, A and Q), but result in different indicators: WRI aggregates the upstream water demand along river network (ΣDIA), RWSI measures the water demand pressures to the local water supplies at a given area (DIA/Q) and INSWU measures the human water demand in excess of natural water supply in a given area (Q-DIA).</td></tr>
<tr><td>Specification of determinants and data needed</td><td colspan="3">All three indicators are based on the following data:
• Domestic Water Demand: Volume of water required for domestic use.
• Industrial Water Demand: Volume of water required for industrial use.
• Agricultural Water Demand: Volume of water required for agricultural use.
• Water Supply: Volume of renewable water supply available

These three indicators are usually based on estimates of water demand / supply and can be improved by using water demand statistics and hydro-meteorological data. Higher quality data on the extent of irrigated areas would also increase the quality of this indicator.

The three indicators are customarily supported by GIS (geographic information systems). Therefore a digitized, topological river network is a useful tool to display the indicator in a map (i.e. river basin map).

Source: adapted from WWAP, 2006 and WWAP, 2012</td></tr>
<tr><td rowspan="2">Complementary information</td><td colspan="3">These three indicators are classified by WWAP, 2012 as key indicators: “key indicators are well defined and validated, have global coverage and are linked directly to policy goals.”</td></tr>
<tr><td>The water reuse index is a measure of the number of times water is withdrawn consecutively during its passage downstream. Several of the world’s river systems bearing large populations, industrial development, and irrigated water use, show water use by society in excess of natural river flow (i.e. >100%). With high values for this index, we can expect increasing competition for water between users, nature and society, as well as pollution and potential public health problems (WWAP, 2012).

The water reuse index typically increases in a downstream direction, indicating reuse and</td><td>Areas experiencing water stress and water scarcity can be identified by relative water demand ratios exceeding 0.2 and 0.4, respectively (Vörösmarty et al. 2000).

Population exposure to water stress is computed by setting a water stress threshold and then summing the number of people in the area that is above or below this threshold (adapted from WWAP, 2012).

The combination of a water stress threshold and gridded population data allow for identification of water stress “hot spots”, areas where large</td><td>Adequate supply is where the water supply is higher that the demand (INSWU > 0). Non-sustainable water use can be classified as low, moderate and high:

Low: ISNWU = 0 to -0.1;

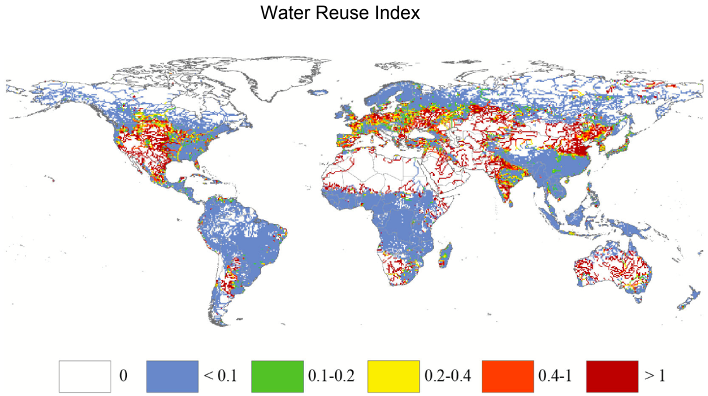
Moderate: INSWU = -0.1 to -1;

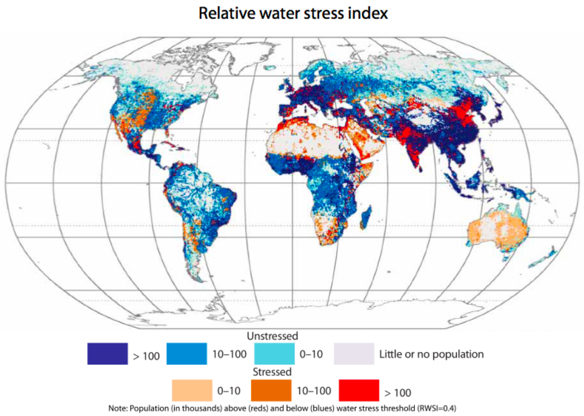
High: INSWU < -1.

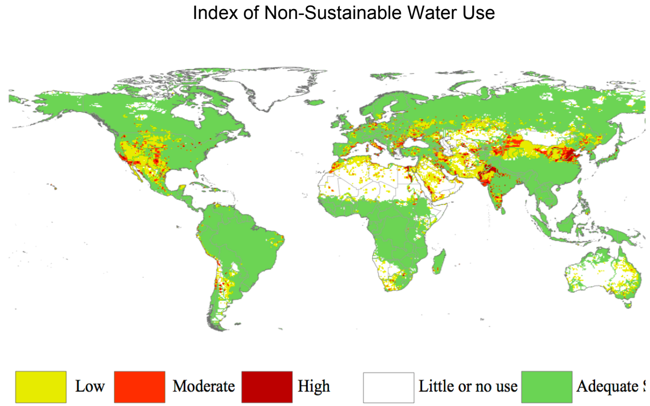
Areas with high water overuse tend to occur in regions that are highly dependent on irrigated agriculture and/or a low supply of water (especially in arid and semi-arid areas). Urban</td></tr>
</table>

	recycling of river corridor water. This index can, however, decrease when mainstream flow is diluted by more pristine (less recycled) tributary waters. The Water Reuse Index can vary greatly in response to climate variations (Vörösmarty et al 2005).	numbers of people may be suffering from the effects of water stress and its consequent impacts (WWAP, 2006).	concentration of water demands adds a highly localized dimension to these broader geographic trends. These areas are often dependent on infrastructure that transports water over long distances (i.e., pipelines and canals) or on the mining of groundwater reserves, practices that are not sustainable over the long-term. Source: adapted from WWAP, 2012
DPSIR classification	Pressure, State	Pressure, State	Pressure, State
Sustainability criteria	Social, Economic, Environmental	Social, Economic, Environmental	Social, Economic, Environmental
Criteria verified	Scientific foundation, Individuality, River basin scale, Specificity, Reliability, Measurability, Sensitivity, Data availability (Needs thorough review), Relevance and Comprehensibility	Scientific foundation, Individuality, River basin scale, Specificity, Reliability, Measurability, Sensitivity, Data availability (Needs thorough review), Relevance and Comprehensibility	Scientific foundation, Individuality, River basin scale, Specificity, Reliability, Measurability, Sensitivity, Data availability (Needs thorough review), Relevance and Comprehensibility
Function at causal network	Central indicator: are at the core of multiple processes	Central indicator: are at the core of multiple processes	Central indicator: are at the core of multiple processes .
Sources of further information	Vörösmarty, C. J., Douglas, E. M., Green, P. A., & Revenga, C. (2005). Geospatial indicators of emerging water stress: an application to Africa. Ambio, 34(3), 230–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16042282 Vörösmarty, C. J., Green, P., Salibury, J., & Lammers, R. (2000). Global Water Resources: Vulnerability from Climate Change and Population Growth. Science, 289(5477), 284–288. doi:10.1126/science.289.5477.284 WWAP (World Water Assessment Programme). 2006. The United Nations World Water Development Report 2: Water a shared responsibility. Paris, UNESCO WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.	Vorosmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2000). Global Water Resources: Vulnerability from Climate Change and Population Growth. *Science*, *289*(5477), 284–288. doi:10.1126/science.289.5477.284 Vörösmarty, C. J., Douglas, E. M., Green, P. A., & Revenga, C. (2005). Geospatial indicators of emerging water stress: an application to Africa. *Ambio*, *34*(3), 230–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16042282 WBCSD & IUCN. (2010). *Water for Business: Initiatives guiding sustainable water management in the private sector* (Geneva and., p. 40). Retrieved from http://www.wbcsd.org/web/water4business.pdf WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.	Falkenmark, M. and Lindh, G. (1974). Impact of Water Resources on Population. *Submitted by the Swedish Delegation to the UN World Population Conference*, Bucharest Vörösmarty, C. J., Revenga, C., Le, C., Authors, L., Bos, R., Caudill, C., Chilton, J., et al. (2005). Fresh Water. *Millennium Ecosystem Assessment*. Island Press. WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

Examples of the indicators (WWAP, 2012)







Indicator Profile Sheet

Social and Economic Impacts from Drought (SEID)	
Definition	The direct and indirect socio-economic impacts caused by drought, in a given area and given period of time, are converted, using a valid methodology, considering aspects such as deaths (human/livestock), people affected, economic losses, property damage, etc. Source: adapted from Jenkins, 2011
Underlying definitions and concepts	Drought events and their impacts generate considerable consequences for the society and individuals. Economic damages from drought can be severe and their social impacts can affect millions of people changing their life style definitively, generating mass migration, increasing poverty, and even causing significant loss of lives. Drought events can happen in practically any part of the world, regardless of its climate regime. Drought is a weather-related phenomenon influenced by anthropogenic aspects. Drought develops slowly and quietly, is spatially extensive and can affect regions for months or years. Furthermore, because of its slow and progressive development, the impacts of drought are not as visible as the ones from other weather-related events (i.e. floods, hurricanes, etc.). Therefore, it is crucial to measure the social-economic impacts of drought in order to take action to mitigate and prevent them, influencing policy decision and public response to the crises. Source: adapted from Jenkins, 2011; Ding et al., 2010; and Wilhite et al., 2007
Computation	Several valid methodologies are available in the literature to calculate the socio-economic impacts of drought (i.e. Low, 2013, Jenkins, 2011). They are scientifically robust and have been used in previous drought events. In order to compute this indicator it is recommended to select the methodology most suitable for the local situation, based on the information available, which impacts are more relevant, and other aspects. The most advanced methodologies to compute the indicator consider one or more of the following impacts: • Economic impacts are divided into three main categories: direct impacts, which affect the land users that cause degradation; indirect impacts, which can affect people far away from where the degradation occurs; and economy-wide impacts, in which the sum of these initial costs is increased by the "multiplier effect" owing to complex links with other economic sectors. • Social impacts from drought affect communities and the many individuals within them. These social impacts can be measured by the number of people affected, the influence on the poverty of a community, the reduction of food security, the increase of conflicts for water, the decrease of human health, among other gross social impacts. Source: adapted from Low, 2013
Unit of expression(s)	Depends on the socio-economic variables selected to present this indicator (i.e. currency for economic losses, number of people affected, etc).
Specification of determinants and data needed	This indicator requires information from: duration and magnitude of drought events, precipitation data (current and historical), population affected, and the associated socioeconomic losses (i.e. deaths of livestock, agriculture lost, abandoned farmland, influence of the impacts

	on the community's poverty status, food security and human health, etc). Source: adapted from Jenkins, 2011 and Low, 2013
Complementary information	This indicator is easy to understand and has been used for a long time to inform decision makers and the general public about the impacts of drought. Interdisciplinary approach is needed on the quantitative measurement of drought impacts: economists, sociologists, meteorologists, hydrologists and water managers need to work together to obtain a comprehensive assessment of socio-economic impacts of drought. Source: adapted from Ding et al., 2010
DPSIR classification	Impact
Sustainability criteria	Social, Economic, Environmental
Criteria verified	Scientific foundation, Individuality, River basin scale, Specificity, Reliability, Measurability (Needs brief review), Sensitivity, (Needs brief review), Data availability, Relevance and Comprehensibility
Function at causal network	End of node indicator: allow gauging the impact of multiple issues at once
Sources of further information	Jenkins, K. L. (2011). *Modelling the Economic and Social Consequences of Drought under Future Projections of Climate Change*. University of Cambridge. Retrieved from http://www.dspace.cam.ac.uk/bitstream/1810/242439/1/KJenkins_PhD_Thesis.pdf Low, P. S. (ed). (2013). *Economic and Social impacts of desertification, land degradation and drought*. (UNCCC, Ed.) (UNCCD 2nd., p. 79). Retrieved from http://2sc.unccd.int Ding, Y., Widhalm, M., & Hayes, M. J. (2010). Measuring Economic Impacts of Drought: A Review and Discussion. *Papers in Natural Resources. Paper 196.*, 26. Retrieved from http://digitalcommons.unl.edu/natrespapers/196 Wilhite, D. (2005). *Drought and Water Crises: Science, Technology, and Management Issues*. (T. & Francis, Ed.) (p. 406). London: CRC Press. Wilhite, D. a., Svoboda, M. D., & Hayes, M. J. (2007). Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness. *Water Resources Management*, *21*(5), 763–774. doi:10.1007/s11269-006-9076-5

Examples of indicator “Social and Economic Impacts of Drought” (SEID)

(a)

Country	Date	Damage (000 US$)
China P Rep	1994	13,755,200
Australia	1981	6,000,000
Spain	1990	4,500,000
Iran Islam Rep	1999	3,300,000
United States	2002	3,300,000
Spain	1999	3,200,000
Canada	1977	3,000,000
China P Rep	2006	2,910,000
Zimbabwe	1982	2,500,000
Brazil	1978	2,300,000

(b)

Country	Date	People Killed
China P Rep	1928	3,000,000
Bangladesh	1943	1,900,000
India	1942	1,500,000
India	1965	1,500,000
India	1900	1,250,000
Soviet Union	1921	1,200,000
China P Rep	1920	500,000
Ethiopia	1983	300,000
Sudan	1983	150,000
Ethiopia	1973	100,000

Table 1.1: Top ten drought disasters during 1900 to 2010 defined by (a) economic damage (000 US$ in year of event), and (b) number of people killed at a country level. Source: EM-DAT, 2010

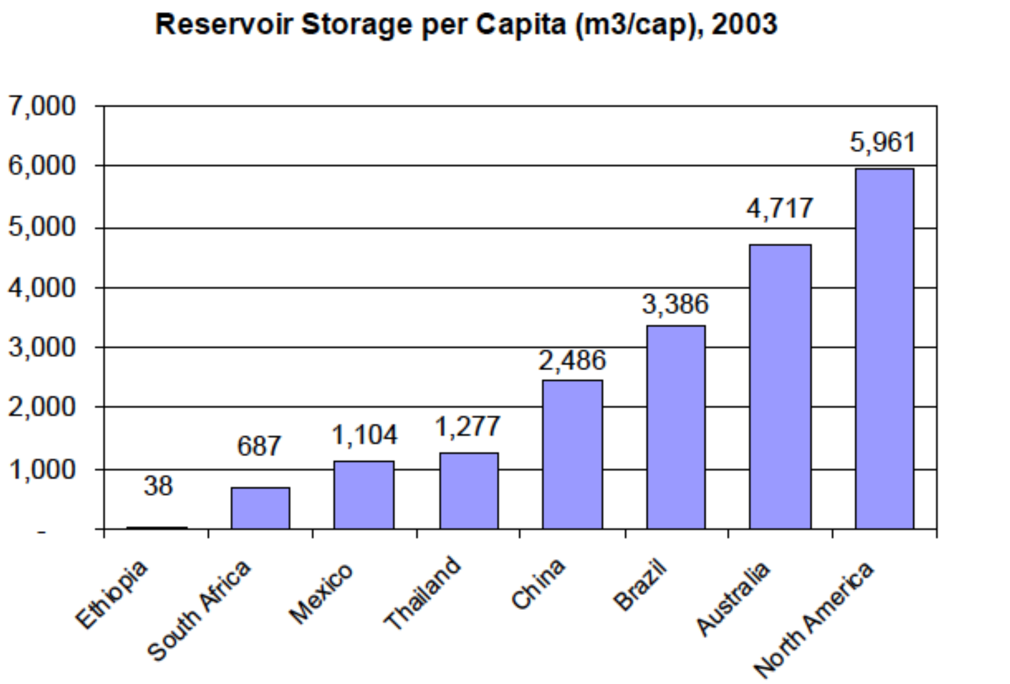
From: Jenkins, 2011

Indicator Profile Sheet

Total Water Storage Capacity (TWSC)	
Definition	Total cumulative water storage capacity of all large surface reservoirs and groundwater, in a given area. Surface water storages include natural and man-made ponds, lakes, reservoirs, dams and lagoons. Source: adapted from Cap-Net UNDP, 2008 and United Nations, 2009
Underlying definitions and concepts	This indicator can point to the capacity to face a water shortage, by measuring the presence of adequate natural or built infrastructure to store water. It can also indicate the depletion of water reservoirs on an annual and long-term basis (when comparing water storage capacity with current water level of reservoirs).
Computation	$TWSC = \sum Sc$ Where: Sc is the storage capacity of all large surface reservoirs and groundwater, in a given area. This indicator can be presented also as the per capita water storage capacity, or can compare the current level of water available at reservoirs with the total water storage capacity. Source: adapted from Cap-Net UNDP, 2008 and United Nations, 2009
Unit of expression(s)	The main unit of expression is volume (i.e. hm^3), but often it is presented as percentage (%) when comparing the level of water available at reservoirs in a particular date with the total water storage capacity or as per capita water storage capacity (i.e. m^3 per person).
Specification of determinants and data needed	• Storage capacity of all large surface reservoirs and groundwater, in a given area; • Amount of water available at reservoirs at a particular date; • Population supplied by those reservoirs.
Complementary information	This is an indicator widely used for water management plan and operation. However, TWSC is only one guide to the linkage between infrastructure and vulnerability: it is necessary to consider other issues such as accessibility (water distribution and rights), prioritized uses such as generation of energy, among other aspects. This indicator is easy to understand even by non-specialized public and helps to build public opinion, especially in situations of water shortage. Cap-Net UNDP (the International Network for Capacity Building in IWRM hosted by the United Nations Development Programme) points to TWSC as one of the Minimum Indicator Set for Water Resources Management Function that should be considered by decision makers for monitoring functions (Cap-Net UNDP, 2008). It was selected, among a set of 15 indicators by the Expert Group on Indicators, Monitoring, and Data Bases (EG-IMD, also hosted by UN-WWAP) as a key global indicator of the state of water resources to meet the needs of policy- and decision-makers at all levels (UN, 2009). Furthermore, the UN-Water Task Force on Indicators, Monitoring and Reporting (TF-IMR, coordinated by UN-WWAP) consider it to be one of a core set of indicators used to monitor and communicate the status of water resources and progress in the water sector (UN, 2010). The definition of “large dams” may vary, depending on the source. The

	ICOLD defines Large Dams as any dam with the maximum height (H), measured from deepest foundation level to highest structure crest level: - more than 15m, or - 5m < H < 15 and reservoir storage capacity more than 3 million m^3. Source: Scudder (2005)
DPSIR classification	Pressure, State, Response
Sustainability criteria	Economic, Environmental, Institutional
Criteria verified	Scientific foundation, Individuality, River basin scale, Specificity, Reliability, Measurability, Sensitivity, Data availability (Needs thorough review), Relevance and Comprehensibility
Function at causal network	Root indicator: provide information on the source of multiple issues
Sources of further information	Cap-Net UNDP. (2008). Integrated Water Resources Management for River Basin Organisations. Pretoria. Grey, D. And Sadoff, C. (2006) *Water for Growth and Development. Thematic Documents of the IV World Water Forum. Comision Nacional del Agua: Mexico City*. Scudder, Thayer (2005) *The Future of Large Dams: Dealing with Social, Environmental, Institutional and political costs. London.* United Nations. (2009). *Final Report of the Expert Group on Indicators, Monitoring, and Data Bases (EG-IMD)* (p. 26). Colombella. United Nations. (2010). *UN-Water Task Force on Indicators, Monitoring and Reporting - Final Report - Monitoring progress in the water sector: A selected set of indicators - Annexes: Indicators in use* (p. 47).

Example of indicator “Total Water Storage Capacity” (TWSC)



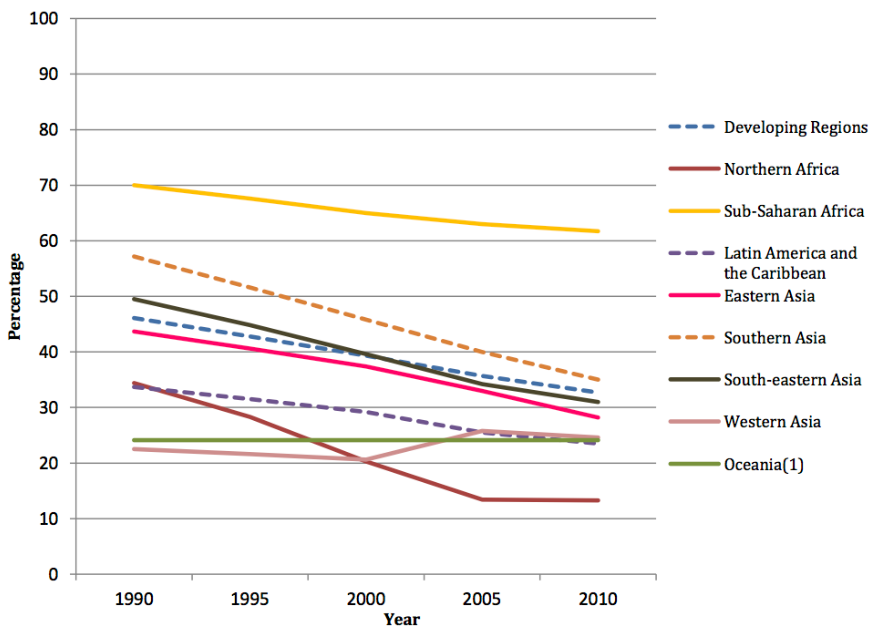
Source: Grey and Sadoff, 2010 based on World Bank analisys of data from ICOLD World Register of Dams

Indicator Profile Sheet

Proportion of Urban Population Living in Slums (PUPLS)	
Definition	The proportion of urban population lacking at least one of the following five housing qualifying conditions: access to improved water; access to improved sanitation facilities; sufficient-living area - not overcrowded; structural quality/durability of dwellings; and security of tenure. Source: WWAP, 2012
Underlying definitions and concepts	This indicator measures the proportion of urban dwellers living in deprived housing conditions. It is a key indicator measuring the adequacy of the basic human need for shelter. An increase in this indicator is sign of deteriorating living conditions in urban areas. Source: WWAP, 2012
Computation	$PULPS = 100\times\left(\frac{Pa}{Pt}\right)$ Where: • Pa is the number of people lacking one or more of the qualifying conditions. • Pt is the total urban population. Source: WWAP, 2012
Unit of expression(s)	Percentage
Who devised the indicator	UN-HABITAT (United Nations Human Settlements Programme)
Specification of determinants and data needed	Urban population Qualifying conditions: • Urban population with **access to safe drinking water** in sufficient amounts at an affordable price • Urban population with **access to improved sanitation** in the form of a private or public toilet shared by a reasonable number of people • Urban population with **secure tenure** that prevents forced evictions • Urban population with **durable housing** of a permanent nature that protects against extreme climate conditions • Urban population with **sufficient living area** which means not more than three people sharing the same room Source: WWAP, 2012
Complementary information	Slums are a global phenomenon: it has been reported that 43% of the urban population live in slums. The lack of basic services and the unstructured growth of slums is also a major a major cause of pollution leading to environmental degradation of urban water courses - ground and surface water (WWDR2, 2006). According to WWAP (2012) PUPLS is a key indicator *“well defined and validated indicator that has global coverage and is linked directly to policy goals”.* This indicator is linked with Target 11 of the MDG (millennium Development Goal) *“By 2020, to have achieved a significant improvement in the lives of at least 100 millions slum dwellers”.*
DPSIR classification	Pressure, State

Sustainability criteria	Social, Economic, Institutional
Criteria verified	Scientific foundation, Individuality, River basin scale, Specificity, Reliability, Measurability, Sensitivity (needs brief review), Data availability, Relevance and Comprehensibility
Function at causal network	Root indicator: provide information on the source of multiple issues
Sources of further information	UN-HABITAT. (2003). *Guide to Monitoring Target 11: Improving the lives of 100 million slum dwellers* (p. 15). NAIROBI. Retrieved from http://ww2.unhabitat.org/programmes/guo/documents/mdgtarget11.pdf UN-HABITAT. (2008). *State of the World´s Cities 2010/2011: Bridging the Urban Divide*. (Earthscan, Ed.) (p. 244). London: UN-HABITAT. UN-HABITAT. (2009). *Global Urban Indicators – Selected statistics: Monitoring the Habitat Agenda and the Millennium Development Goals* (p. 123). NAIROBI. Retrieved from http://www.unhabitat.org/downloads/docs/global_urban_indicators.pdf WWAP (World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

Examples of indicator “Proportion of Urban Population Living in Slums” (PUPLS)



Proportion of urban population living in slum (%)					
Regions	1990	1995	2000	2005	2010
Developing Regions	46.1	42.8	39.3	35.7	32.7
Northern Africa	34.4	28.3	20.3	13.4	13.3
Sub-Saharan Africa	70.0	67.6	65.0	63.0	61.7
Latin America and the Caribbean	33.7	31.5	29.2	25.5	23.5
Eastern Asia	43.7	40.6	37.4	33.0	28.2
Southern Asia	57.2	51.6	45.8	40.0	35.0
South-eastern Asia	49.5	44.8	39.6	34.2	31.0
Western Asia	22.5	21.6	20.6	25.8	24.6
Oceania[(1)]	24.1	24.1	24.1	24.1	24.1

(1) Trends data are not available for Oceania. A constant figure does not mean there is no change

Source: UN-HABITAT, 2009

CHAPTER 7 – GENERAL CONCLUSIONS

7.1 GENERAL CONCLUSION

Water is essential for life on earth and it is a fundamental element for human development. Nevertheless, water is a limited resource and human activities have been exercising considerable pressures on its availability, in terms of both quality and quantity. World leaders and the scientific community agree that the unsustainable use of water and the need to improve its management are among the largest global concerns of our time. They also consider indicators to be important decision making tools and a crucial part of integrated water resources management.

Indicators are fundamental to monitoring progress and trends on the path towards sustainable water use and management. Yet, despite the efforts of the international and scientific communities to develop indicators, there remains a significant demand for research and applied knowledge on indicators for water use and management. This demand also points to the need to develop indicators using participatory methods. Furthermore, these indicators should be suitable and optimized for the scale where the governance of water takes place: the river basin scale. The main objective of this research was to identify and validate, in a participatory way, a set of indicators that allow decision makers to measure the sustainability of water use and management at river basin level.

In order to reach this objective, 60 criteria for the evaluation of indicators were assessed; an initial set of 170 indicators related to water use and management were identified and evaluated against multiple criteria (sustainability, scientific foundation, etc.); a river basin for pilot testing the method was selected (Salitre River Basin in Brazil); the major stakeholders were identified and involved in the development of the research; the eDPSIR framework was used to choose the most effective set of indicators for the specific domain and location of our research; and finally, this set of indicators was validated against scientific and end-use criteria in a multistakeholder participatory approach. This study resulted in the selection and validation of a comprehensive set of eight key indicators to measure the social, economic, environmental and institutional sustainability of water use and management at the Salitre River Basin. This research also provides a transparent, robust and reproducible set of methods that could be applied by the scientific community, indicator developers/users and decision makers to identify, select and assess indicators at other river basins of interest.

7.2 SYNTHESIS OF THE FINDINGS AND RECOMMENDATIONS

Criteria for the evaluation of indicators

The first objective of the study was to carry out a comprehensive assessment of the most relevant criteria for the evaluation of indicators. The quality and reliability of indicators depends on the application of adequate and appropriate criteria to assess them. The identification and selection of criteria to evaluate indicators is a relevant task and should be done in a solid, transparent and scientifically valid manner. An extensive bibliographical review was done, aiming to identify criteria for the assessment of indicators. In total, 74 sources were examined containing a total of 346 mentions of criteria used for indicator assessment. An in-depth analysis was done using a structured matrix to organize and identify the most relevant criteria. The findings of the study revealed that the 346 criteria were in fact 60 different criteria (some had the same name but different definitions; some had different names but their definitions indicated that they were actually the same criterion). This study also proposes a standard name and a description for each criterion, aiming to provide more clarity and reduce ambiguity. The 60 criteria were divided into two groups (scientific and end-use) and ranked according to their relevance.

It is also worth mentioning that throughout this study 12 of the most relevant criteria were adopted to assess the indicators. Six of them are scientific criteria: scientific foundation, specificity, spatial scale, reliability, measurability and sensitivity. Six are end-use criteria: sustainability, individuality, causal links, data availability, relevance and comprehensibility. They represent only 12 of the long list of criteria (60 in total), but are nonetheless the most relevant ones covering 51% of all mentions found in the bibliography (178 out of 346 mentions).

The assessment of criteria conducted here is one of the broadest and, probably, the most up-to-date reviews in the field so far. It provided a solid ground for the next research stages as well as transparency and proper foundation for the selection of criteria. These outcomes and knowledge will undoubtedly be of benefit to further works on the topic. For example, the criteria tables (Annexes 3.1 and 3.2) could be used by future studies and practical applications to identify and select criteria according to their relevance. This assessment of criteria was built in a transparent and replicable way, so that it can be further developed with the incorporation of new sources, of new criteria and/or regular updates.

Indicators of water use and management

Furthermore, the research aimed at identifying indicators related to water use and management used by international institutions, key national governments and the scientific community. Despite the scientific and practical knowledge generated on the subject, so far no comprehensive list of the available indicators to assess the sustainable use and management of water exists. This research has performed a comprehensive bibliographical search to identify indicators related to water use and management presented by international institutions and national governments, as well as the ones addressed by the scientific community in peer reviewed international journals.

One hundred and seventy (170) indicators related to water use and management were identified. They were organized in comprehensive lists (Annexes 3.3, 3.4 and 3.5), were briefly described, and their classifications under two relevant frameworks (DPSIR and system approach) were presented. These deliverables can be considered as useful contributions for water resources management and sustainability science. So far, no other scientific publication has done a similar assessment. Nevertheless, it should be taken into consideration that indicator development is a continuous process and therefore these lists, despite their relevance, cannot be considered "complete", and other indicators may be included as a result of future studies.

Indicators that fulfil the sustainability criteria

It has been clearly demonstrated that the application of indicators of water use and management can contribute to better allocation of water, a limited and valuable resource. Nevertheless, formulating indicators should not only take into account technological issues, but should also include the environmental, social, institutional, and economic dimensions of sustainability. Our study aimed to evaluate the sustainability criteria of the 170 indicators of water use and management identified previously.

An international panel of experts assessed whether each of the 170 indicators fulfil the four sustainability criteria: social, economic, environmental and institutional. Our research employed an evaluation matrix and a pilot study served to test and approve the methodology before carrying out the full implementation. The findings 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) and 86 are one-dimensional indicators (fulfilling just one of the four sustainability criteria).

These findings demonstrated that 86% of the indicators of water use and management available in the literature do not fulfil the majority of sustainability criteria, suggesting that they do not provide the holistic and multi-dimensional perspectives of sustainability.

Nevertheless, 146 indicators did adequately address one or two of the four components of sustainability, meaning that they are interesting tools that reveal specific angles and some of the multiple aspects of water use and management.

This assessment also found that 24 key indicators of water use and management fulfil the majority of the sustainability criteria. These indicators provide critical information for water governance. The identification of these indicators can be considered to be a relevant contribution to promote sustainability practices in the water resources sector.

Indicators for sustainable water use and management at river basin level

Following the results presented so far, this research had a broader objective beyond the identification of sustainability indicators: to identify and validate a set of indicators that would allow decision makers to evaluate the sustainability of water use and management at river basin level. In order to address the key concerns of water managers and other decision makers, these tools should meet other criteria beyond sustainability. Specifically, indicators:

- should be consolidated by current scientific standards and principles (scientific foundation),
- should not duplicate each other (individuality),
- should be appropriate for the geographic scale of interest (river basin scale) and
- should be clearly and unambiguously defined (specificity).

This study adopted a multi-criteria and sequential process to select out of the 24 indicators, those that fulfil these four criteria. These criteria were of highest importance, mainly because they address strategic aspects and key attributes of the indicators related to consolidation, application and distinctiveness closely linked to the broader research objective.

The findings show that 11 indicators (see Table 4.2), out of the initial 24, fulfil all four selection criteria and were classified as indicators of interest to the research. These indicators are relevant tools that could support decision makers to measure sustainability of` water use and management at river basin level.

The findings showed that the majority of the indicators (13 out of 24) did not comply with at least one of the selection criteria: nine did not comply with the “scientific foundation” criterion; three did not comply with “individuality” and one was not valid for the “river basin scale”. These indicators were classified as not being of interest to this study. Nevertheless, we recommend further studies to improve these indicators.

These studies should aim to overcome the limitations of these indicators identified by our study. Once these limitations are overcome these 13 indicators could be considered as useful tools to measure sustainability of water resources, considering that all of them fulfil the majority of the sustainability criteria. These further studies could focus on improving the methodology for use and calculation, and/or field-tests and practical validation.

The findings of our research support that the verification of the scientific foundation, the individuality, specificity and the scale of application is a crucial part of the assessment of indicators. Our research adopted clearly outlined procedures that are replicable and scientifically robust for the selection of the indicators. This study recommends the application of these criteria for the assessment of indicators related to sustainable water use and management.

The importance of applying this research at a pilot River Basin

It is recommended that the development of indicators for water resources go beyond theoretical analysis, taking into consideration a real case scenario. The intrinsic characteristics of a specific location are very important when developing indicators that aim to measure progress towards sustainability. In the context of water management, river basin is considered to be the logical unit for addressing these issues. Therefore, our research was applied to an actual river basin aiming to pilot test the methods employed here and to produce applied knowledge.

The criteria used to identify and define the pilot river basin were related to the geographic characteristics of the site, as well as to some features of the stakeholders. The Salitre River Basin, located in the Northeast region of Brazil, was selected as the pilot river basin for the development of our research. The definition of a pilot river basin brought an objective view and more pragmatism to the process of selecting the indicators in our research. It also contributed to producing applied knowledge and transferring that knowledge immediately to the end users. Our study strongly recommends the adoption of a pilot river basin to test the application of indicators for sustainable water use and management.

Understanding the complex interrelations of the set of indicators

Indicators are often interrelated and, consequently, it is conceivable that although assessing indicators individually appears to be enough, sustainability requires evaluating cross-indicator interactions. It is crucial to understand the complexity of the cause-effect relation between the indicators in order to clearly define the analytical utility of the indicator. Therefore, our study aimed to analyse the cause-effect relations of the 11 short-listed indicators, in order to identify the most comprehensive set of indicators for the specific domain, question and location of our research.

Niemeijer and Groot (2008)[1] propose a conceptual framework, called the enhanced DPSIR (eDPSIR), in which the interconnectedness of the indicators becomes a key part of the selection process. This approach has been applied in other fields but no known previous work addressing its use for the selection of indicators of water use and management exists, highlighting the relevance, originality and opportunity of applying this method.

The eDPSIR framework was applied in a participatory way at the Salitre River Basin (the target area of this research) aiming to achieve a comprehensive visualisation of the interconnections of each indicator in the causal network. The systematic function of the relations between the indicators became an essential part of the indicator selection process. The findings showed that all indicators are interconnected in an intricate network of cause-effect relations. Nevertheless, eight indicators (out of the 11 short-listed) represent the most comprehensive set of key-indicators to measure the social, economic, environmental and institutional sustainability of water use and management at the Salitre River Basin.

This framework helps in identifying the most relevant indicators in terms of a specific field, problem and location resulting in a set of indicators that help to assess the sustainability of water use and management in a clear, well-organized and effective manner.

These eight key-indicators (PUPLS, TWSC, WPI, CVI, WRI, RWSI, INSWU and SEID) were no longer considered "stand-alone" indicators, but as a consistent set of indicators, where each and every indicator has a particular function in addressing the problem at hand. More insight about the research question was gained through fewer indicators. This reduced number of indicators allowed the optimization of the operational efforts of the research team. It also led to more efficient decision-making, considering that accurate decisions are made when one has a deeper knowledge about the interactions between the indicators. Our study recommends the adoption of the eDPSIR framework to analyse the interconnectedness of the indicators as a key component of the selection process.

The relevance of a multi-stakeholder approach

This research recognizes that restricting the process of developing indicators of water use and management to only scientists and academic experts removes an important social dimension from the process. The management of water resources has multiple dimensions (i.e. social, economic and environmental); therefore, a multi-stakeholder approach is necessary. Stakeholders possess relevant knowledge of the intrinsic interconnections between these dimensions. This research adopted a combination of scientific and end-user perspectives that mirrors the recognition of a balanced role of experts and stakeholders in the development of indicators, and in finding solutions for sustainable resource management.

[1] Niemeijer, D., & de Groot, R. S. (2008a). A conceptual framework for selecting environmental indicator sets. *Ecological Indicators*, *8*(1), 14–25. doi:10.1016/j.ecolind.2006.11.012

We firmly recommend the adoption of a multi-stakeholder approach in the process of developing indicators for water resource sustainability. The effective participation and engagement of stakeholders was of great relevance to this study. The stakeholders at the Salitre River Basin confirmed their interest in the research and more than 60 people actively collaborated with this participative study. They evaluated the indicators based on end-use criteria and proposed suggestions that were incorporated into our study.

The engagement of the diverse perspectives held by stakeholders increased the diversity of opinions assessed by this study and was key to the success of our research. They contributed to the adaptation of the research to local conditions and enhanced the use of local knowledge.

One of the goals of this research is to produce knowledge that could be used to better address the challenges of society related to sustainable water use and management. It is expected that the involvement of the stakeholders in the research process will contribute to the practical application of the results achieved. This research recognizes the right of stakeholders to participate in those decisions that affect them and strongly recommends the development of a participatory approach in studies related to sustainable water use and management.

A series of three meetings with the stakeholders were scheduled. Two of them have already taken place. The third meeting will be held after the PhD thesis defence. We will present the final results and transfer the knowledge to the stakeholders in order to promote the application of these outcomes, to improve the sustainability of water use and management at the Salitre River Basin.

The indicators validated by scientists and end-users

The validation of indicators is the final step in the identification of an accurate and credible indicator set. Validation is crucial to the scientific process and to the creation of an indicator set that is “useful and used by the end users”.

This study used a transparent and replicable methodology to implement a multistage and multistakeholder validation process of indicators of sustainable water use and management that were short-listed by previous stages of the research.

Indicators were then evaluated against a set of scientific and end-use criteria. A scientific panel composed of 40 experts from the Ibero-american scientific community assessed the validity of the indicators using an evaluation matrix. An end-use panel composed of 48 stakeholders from the Salitre river basin in Bahia-Brazil examined the indicator set using the end-use criteria in a structured survey. In total, the 98 appraisers provided 1893 results that were categorized, processed and analysed. Based on the results obtained, all 8 indicators were validated under this methodology. These eight indicators are the following:

- Water Poverty Index (WPI);
- Climate Vulnerability Index (CVI);
- Water Reuse Index (WRI);
- Relative Water Stress Index (RWSI);
- Index of Non-sustainable Water Use (INSWU);
- Social and Economic Impacts from Drought (SEID);
- Total Water Storage Capacity (TWSC) and
- Proportion of Urban Population Living in Slums (PUPLS).

Nevertheless, the findings indicate that all of them require brief reviews regarding one or two criteria. Data availability was the most problematic criterion for the indicators outlined in this research. Our study pointed out the main limitations of these indicators based on the criteria assessed and recommends that further studies address these issues in order to improve the quality of the indicators.

Practical Applications and Recommendations

Based on the results obtained by this study we recommend the application of the eight indicators (WPI, CVI, WRI, RWSI, INSWU, SEID, TWSC and PUPLS) at the Salitre river basin. A scientific panel and major stakeholders of the Salitre river basin have validated these indicators and shown that they are suitable for the river basin at hand. Based on these results our recommendation is that these eight indicators should be included in the next updated version of the Salitre river basin Water Management Plan as well as the Water Management Information System. Other possibilities for applying these indicators include supporting the Water Management Authority in decision-making concerning the concessions of water permits for more sustainable water use. Further applications could calculate the actual value of the indicators for the Salitre basin and investigate in greater detail the issues of data availability and quality at the local level.

It was necessary to involve the stakeholders of the Salitre river basin in order to include their needs and ideas into the validation process of the indicator set. However, by doing so, the specific results of the end use validation process done by the stakeholders of the Salitre River Basin need to be considered as limited to this particular basin and cannot be directly extrapolated to other river basins. The particularities of the Salitre river basin in terms of geography, social, economic and environmental issues affect the way stakeholders responded to the validation process. Different circumstances at a different river basin are likely to result in the selection or validation of a different set of indicators.

We recommend that future research explore how the eight indicators selected here would perform, using the same criteria, at a different river basin with different end users.

A replication study would have the potential to identify possible generalizations of our findings as well as to point to differences and/or similarities between results from different river basins. This would naturally also broaden the scope of our research.

Nevertheless, the methods adopted here to select indicators are reproducible and transparent and can be applied to other river basins to select the indicators that fit them best. For example, the list of 170 indicators of water use and management and the list of the 60 criteria to assess indicators are important contributions of our study. They present relevant information in a format that is easy to assess (see Annexes 3.1 to 3.5). End-users, such as water management institutions, river basin committees, policy and decision makers, can consult these lists in order to identify and select criteria and indicators according to their specific needs. Our study provided transparency and a proper foundation for the selection of indicators that surely will benefit further research and application. Computer-aided decision support tools could be developed based on the vast knowledge compiled by our study, in order to provide end-users with a friendly interface for the selection of indicators.

Complementary findings and recommendations

IPSs are efficient tools to organize information - An indicator is only effective if it is used by stakeholders, thus it is important that information about the indicators are presented in an easy to use format. This research adopted Indicator Profile Sheets (IPS) to organize and provide direct access to information about the indicators (see Annexes 4.1 and 6.1). They proved to be an efficient tool and further studies, as well as other end-users, will benefit from this simple way of accessing information. We recommend that developers of indicators of water resources also adopt Indicator Profile Sheets.

Using MCA to assess indicators of water use and management - Decision-making related to water resources use and management require the analysis of diverse points of view and the use of multiple criteria. Multi-Criteria Analysis (MCA) was used in different stages of the study (see Chapters 3, 4 and 6) to point out the most appropriate solutions guided by multiple stakeholders interests. In our research, the process of selecting and validating indicators was done using simple, efficient and transparent MCA methods. MCA added organization, accountability, transparency and thoroughness to the decision-making processes. We recommend the use of MCA in evaluating alternatives against multiple criteria related to indicators of water use and management in a participatory approach.

The challenges of data for the water sector - The management of water resources requires reliable, regular and systematic data. On the one hand, our research demonstrated that data availability is, according to the sources analysed, the most relevant criterion for the assessment of indicators (see Chapter 3). On the other hand, the validation process done by our research showed that data availability was the most problematic criterion for the indicators outlined in this study (it had the worst overall performance of the assessment – see Chapter 6). However, this issue goes far beyond the boundaries of our research. The availability of reliable data about water resources at all levels is one of the primary challenges of the water resources community. We recommend that local, national and international institutions responsible for data management and/or for water resources management devote sufficient effort to collect, organize and offer the data needed to measure the sustainability of water use and management.

Improving the methodology through pilot tests - Pilot studies were employed here (see Chapter 3 and Chapter 6), to test and improve the research methodology, materials and data analysis before carrying out the full implementation. The utilization of a pilot study was a relevant stage of research prior to engaging in the full scale application. Some methodological issues, such as the ideal number of criteria to assess the indicators, only became clear when put into practice. The pilot studies provided an invaluable opportunity to identify these issues and make necessary changes prior to complete implementation. The pilot studies led to improvements in the design of our study. We recommend the use of pilot studies similar to the one adopted here, especially in research that aims to develop indicators in a participatory way, with the involvement of stakeholders and the use of a panel of experts.

The use of Panel of Experts to assess indicators - Two panels of experts have been used by our research (see Chapter 3 and Chapter 6) to provide independent, expert judgment to the assessment of indicators. In total, 47 high-level experts from the Ibero-american scientific community participated in these panels. The experts performed independent evaluations, both remotely and in person. Their involvement increases the credibility of the indicators in the scientific community. We recommend the use of a panel of experts in the process of selecting and validating indicators. We also recommend that further studies investigate how the indicators assessed by these panels of experts from Ibero-american countries would 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.

Likert Scale to conduct surveys with multi-stakeholders - The identification of an appropriate measurement scale to conduct surveys is not a trivial task and should balance the simplicity of application with solid scientific acceptance. This study adopted a 5 level Likert scale to assess the validation of the indicators in a participatory way. The results obtained confirmed that the use of the Likert scale simplified the process of constructing and administering surveys, as well as the coding and analysis of data. We noticed that this scale is intuitive to use and adaptable to different users. It allowed for the collection of large amounts of data relatively easily, and the numbered scale format lends itself directly to statistical analysis. We therefore recommend the use of this scale to measure observable attributes in survey research, similar to the ones conducted in this research.

Final Considerations

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.

In this study, we presented a solid **scientific contribution showing how to apply multi-criteria and participatory approaches to identify, select and validate indicators for sustainable water use and management at river basin level, considering their socio-economic, environmental and institutional aspects**. **This research combined relevant concepts in a holistic methodology that is scientifically robust and easy to understand**.

We expect this knowledge to be used by the scientific community, international organizations, water resources managers, policy and decision makers, practitioners, as well as other stakeholders interested in the matter, to promote changes towards sustainable use and management of water. We believe that these changes can contribute to harmonising human and ecosystem needs at the present, and that they are essential to "*building the future we want for all*".